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Ron Middleton

SSOURI COOPERATIVE HIGHWAY RESEARCH PROGRAM

FINAL REPORT

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AN INVESTIGATION OF SKID RESISTANCE IN MISSOURI

MISSOURI STATE HIGHWAY DEPARTMENT
FEDERAL HIGHWAY ADMINISTRATION

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AN INVESTIGATION OF SKID RESISTANCE IN MISSOURI

STUDY NO. 69-3

Prepared by

MISSOURI STATE HIGHWAY DEPARTMENT

Division of Materials and Research

FINAL REPORT

August 1973

in cooperation with

U. S. DEPARTMENT OF TRANSPORTATION

FEDERAL HIGHWAY ADMINISTRATION

The opinions, findings, and conclusions expressed in this publication are not necessarily those of the Federal Highway Administration.

SYNOPSIS

This study was a comprehensive investigation of skid resistance in Missouri using a two wheel skid trailer conforming to the requirements of ASTM E 274-65T (K. J. Law Engineers Model 965A) measuring both slip and skid resistance. An attempt was made to standardize test results for the many environmental effects present during a skid test. Skid resistance of surfaces containing various fine and coarse aggregates was also studied. Comparisons were made between the occurrence of wet pavement accidents and pavement skid resistance. Procedures for texturing Portland cement concrete pavements were investigated, in addition to changes in asphaltic concrete mix designs and use of special aggregate materials to improve skid resistance in bituminous mixes.

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LIST OF ABBREVIATIONS

a-c -- alternating current
AC -- asphaltic concrete
ADT -- Average Daily Traffic
ASTM-- American Society for Testing Materials
ATI -- Age - Traffic - Index
BT -- bituminous treated surfaces
C -- regression coefficient
CF -- Coefficient of Friction
CF_{40}-- Coefficient of Friction determined at 40 mph
d-c -- direct current
df -- degrees of freedom
$D_{\bar{r}}$ -- average difference between replicates
F -- degrees Fahrenheit
G -- CF speed gradient
G_{30-50} CF speed gradient determined between speeds of 30 and 50 mph
gpm -- gallons per minute
k -- Wear Factor
k_{cf} -- Wear Factor based on CF
k_{slc}-- Wear Factor based on SLC
K -- regression coefficient
LBS -- pounds
LC -- plant mix bituminous leveling course
$\log_e$-- natural logarithim
mph -- miles per hour
Mo. -- Missouri
Mo -- month
N -- number of tests
NCHRP- National Cooperative Highway Research Project
N_m -- number of tests per mile
psi -- pounds per square inch
PCC -- Portland cement concrete pavement
PM -- plant mix bituminous pavement
R -- multiple correlation coefficient
R^2 -- coefficient of determination
S -- sample standard deviation
SC -- seal coat surface
SLC -- Slip Coefficient
SLC_{40}- Slip Coefficient determined at 40 mph
SN -- Skid Number
SN_v -- Skid Number determined at mean traffic speed
SN_{40}-- Skid Number determined at 40 mph
S_t -- standard deviation of tests
$S_{\bar{x}}$ -- standard deviation of sample mean
V -- mean traffic speed, mph
Y -- dependent variable
Y_c -- standard error of regression
YR -- year

LIST OF DEFINITIONS

1. AGE-TRAFFIC-INDEX (ATI) -- An index combining surface age and traffic volumes, representing accumulated volumes of traffic.

2. Coefficient of Friction (CF) -- The ratio of the dynamic horizontal friction force to the dynamic vertical wheel load when a locked wheel is pulled over a pavement surface at constant speed.

3. Slip Coefficient (SLC) -- The ratio of the maximum dynamic horizontal friction force to the dynamic vertical wheel load when a partially braked wheel is pulled over a pavement surface at constant speed.

4. Speed Gradient (G) -- The unit change in skid resistance with unit change in test speed.

5. Wear Factor (k) -- The rate of change in Coefficient of Friction with accumulated vehicle passes, as determined by the slope of the straight line relationship between Coefficient of Friction and accumulated vehicle passes plotted on log-log coordinates.

INTRODUCTION

The friction developed between an automobile tire and pavement surface has been considered to rank high among the causes and prevention of wet pavement accidents. However, low friction between a vehicle's tire and pavement surface is not necessarily the entire cause as driver negligence, mechanical failure, and tire deficiencies also can contribute to accident occurrence.

Numerous research efforts have studied pavement friction since the 1950's. The First International Skid Prevention Conference (1)* held in 1958 opened new avenues of research in friction theory, testing procedures, and equipment. The results of the Tappahannock Study (2) in 1962 and the Florida Skid Correlation Study (3) of 1967 answered many of the questions relating to techniques and equipment. Standard specifications for equipment have been adopted by ASTM. NCHRP Report 37 (4) presented information pertaining to the mechanics of friction forces developed between a pavement and automobile tire. Slip (incipient) resistance measurements were proposed as possible substitutes for skid resistance measurements, as this measurement is more realistic of conditions encountered during normal braking. Friction values, expressed as Skid Numbers based on mean traffic speed, also were recommended as tentative minimum requirements for use

* Number in parenthesis refers to list of references at the end of this report.

as guides to determine when adequate pavement skid resistance was being provided. Report 37 recommended additional research to further define specific frictional requirements; to improve testing methods and equipment; and to improve the design, construction and maintenance of pavements in order to produce higher frictional levels. National highway safety programs began to emphasize more specifically the need for providing safer highways for today's vehicular traffic.

The Missouri State Highway Department began in 1968 an extensive statewide investigation of the skid resistance of pavement surfaces. Prior to this time, no formal skid resistance testing had been conducted in the state. The study used commercially available equipment, built to ASTM standards which functioned so that slip, as well as locked wheel skid resistance could be studied. Testing procedures and certain constituents or characteristics of pavement surfaces were studied in addition to wet pavement accidents. The results of this investigation are presented in this report.

CONCLUSIONS

The following conclusions are based on the results of this investigation, as they pertain to wet pavement conditions.

1. A limited comparison of Coefficient of Friction with the Wet/Dry Accident ratio for single vehicle accidents was made for Missouri road systems with mean traffic speeds between 60 and 70 mph. Results of this limited comparison for Missouri roads and conditions do not indicate the necessity for skid numbers as high as the recommended minimum interim skid numbers given in NCHRP Report 37.
2. Anti-lock braking systems for automobiles would result in tire-pavement friction forces 1.50 to 2.00 times the friction forces developed during locked wheel braking.
3. Generally, a greater percentage of the average maximum available friction, developed between tire and pavement, is utilized during locked wheel braking on open-graded or large scale textured surfaces.
4. Large scale textured surfaces generally produced lower speed gradients (less rate of change in friction with unit change in test speed).
5. Generally, aggregates in Missouri, classified as dolomites or gravels when used in asphaltic concrete and plant mix bituminous pavement mixtures, produce surfaces with higher average slip and locked wheel friction than aggregates classified as limestones.

6. A comparison of pavement surface types using coarse aggregates of the same formation, indicated surface type to be a major factor contributing to a pavement's coefficient of friction.
7. The rate of wear for Portland cement concrete pavements, measured by decrease in friction with accumulated vehicle passes, was much greater in regions of the state where widespread use of studded tires is most likely to occur.
8. Asphaltic concrete surfaces constructed using aggregates classified as limestones apparently require fewer estimated vehicle passes than surfaces constructed using aggregates classified as dolomites, to reach a predetermined friction value.
9. A plastic, Portland cement concrete pavement textured with a transverse wire comb produced a significantly greater skid resistance than four other texturing procedures including a longitudinal burlap drag, on one construction project.
10. A reduction in percentage of fine aggregate in asphaltic concrete surface mixtures generally produces surfaces with larger scale textures and higher coefficient of friction.
11. Porphyry (Trap Rock), blast furnace slag, flint chat (Joplin chat), and a lightweight aggregate

(expanded shale) were found to generally increase skid resistance when incorporated into flexible pavement surface mixes.

12. Based on one installation with high traffic volumes, asphaltic concrete using expanded shale appears to be more resistant to wear (less rate of change in friction with accumulated vehicle passes) than surfaces with other special aggregates but it may not provide a satisfactory service life.

13. Correction of deficient geometric conditions alone may be sufficient to reduce wet pavement accidents.

14. The average Coefficient of Friction testing error, throughout the study, was found to be 0.013 and the Slip (incipient) Coefficient error was 0.032.

15. Complete standardization of friction measurements (correction for temperature, season, etc.) is apparently not possible because of the apparent interaction effects with pavement surface texture.

16. A change of 23 degrees in air temperature above 69 degrees Fahrenheit during one day's testing did not significantly affect friction measurements.

17. A more thorough break-in period should be used for the standard ASTM E-17 tire.

18. The K. J. Law Model 965A Pavement Friction Tester's force transducers apparently were sensitive to wheel load shift changes.

19. Three tests per mile per direction of travel for inventory testing at 40 mph should give an average Coefficient of Friction:

(a) within ± 0.03 of the true average when tests are primarily on Portland cement concrete and asphaltic concrete surfaces as constructed on the state Primary System;

(b) within ± 0.04 of the true average when tests are primarily on plant mix bituminous surfaces and seal coats as constructed on the state Supplementary System.

IMPLEMENTATION

Based on data obtained in this investigation, it appeared that various pavement surface treatments should be studied. A transverse wire comb texture was adopted on Portland cement concrete pavements in lieu of a longitudinal burlap drag for texturing. The percent fine aggregate was reduced for asphaltic concrete surface mix designs for normal state-wide use. Both of these changes have generally resulted in surfaces with improved skid resistance.

Special localized materials (Trap Rock, blast furnace slag, expanded shale and Joplin chat) were found to generally improve skid resistance when used in asphaltic or bituminous surface mixtures. These materials have been used to a limited extent due to increased costs and availability. The basis of their continued use should be at locations requiring increased skid resistance with economic justification.

These changes in the standard procedures for Missouri have primarily been made during the past two years. Sufficient time was not available in this investigation to adequately study the long range durability of the surfaces produced. Therefore, it is proposed that additional research be made to determine the ability of these surfaces to maintain the improved skid resistance.

SCOPE

The study was designed to sample the skid resistance of roadway surfaces in Missouri. The friction test equipment used was selected so that it met or exceeded the ASTM E274-65T requirements to make the data collected more useful for comparison to other agencies. Many users of skid test equipment felt that the ASTM method was basically equipment-oriented and too general regarding specific test procedures. However, past studies (2,3) have shown that equipment requirements were very critical regarding accuracy of test speed, test water placement, and data acquisition and recording.

The ASTM method does not standardize skid resistance measurements for temperature effects, seasonal effects, the effect of the amount of rainfall preceding skid tests, or the effect of roadway geometrics. A study of these effects was made in addition to investigating a procedure for sampling test sections of pavement.

Kummer and Meyer (5) have shown that slip resistance is, in most cases, greater than skid resistance and may be the most important friction measurements to make. The slip resistance occurs before the brake completely locks and may become important due to recent anti-lock braking system innovations for automobiles, a technique which has been utilized on air-craft for several years. The test equipment used in this study was selected in order that the slip and skid resistance could be determined on a large sample of surfaces. Pavements were selected to study the effect of

aggregates, mix designs, roadway geometrics, age, climate, season, and traffic.

Wet pavement accident frequencies were studied at several locations and compared with locked wheel skid resistance. This comparison was made because of wide variations in published recommended minimum friction requirements.

Several methods were investigated for altering the frictional characteristics of new construction or resurfacing projects. These methods have included changes in flexible pavement mix designs in addition to transverse texturing of plastic Portland cement concrete by mechanical brooms or combs and longitudinal grooving of hardened Portland cement concrete.

EQUIPMENT

The equipment selected to be used in this investigation was the K. J. Law Engineers Model 965A Pavement Friction Tester (the General Motors Proving Ground Model 2 Coefficient of Friction Vehicle) as shown in Figure 1. All figures are included in Appendix A. The Pavement Friction Tester was comprised of a 3/4 ton pickup truck and a towed two-wheeled trailer. Each wheel of the trailer is coupled by a disc brake assembly to a force transducer which measures the horizontal traction force and vertical load fluctuation on the trailer tires. The ASTM E249-66 standard 5 rib test tire is used.

The resulting test tire traction force, wheel load fluctuation, vehicle speed, test wheel speed, and percent slip of the test tire are recorded on paper by a multi-channel Brush lightbeam oscillograph.

The truck is a Chevrolet Series 20 Custom Sport pick-up with automatic transmission, power steering, power brakes, and air conditioning. The 396 cubic inch, 310 horsepower engine uses premium gas. It has a Power-Lock 3.54 to 1 differential, heavy-duty suspension, a 62 amp Delcotron alternator, and a Bendix-Westinghouse Tu Flo 400 air compressor.

There are two d-c to a-c inverters in the cab of the truck which converts the truck's 12 volts to 110 volts. One inverter supplies power to the oscillograph recorder and the other inverter supplies power to a regulated d-c power system for instrumentation requiring controlled d-c voltage. The

recorder and all controls for the system are contained in a console between the driver and passenger seats. A survey type odometer (recording to 0.01 mile) is attached separately on the passenger side and is used for purposes of locating test sites.

Water is supplied to the nozzles on the trailer from an internally baffled 230 gallon aluminum water tank mounted in the truck bed just behind the cab. Two positive displacement pump assemblies, one for each wheel of the trailer, are used to move the water from the tank to the trailer. Each pump is controlled by an electric clutch and is driven off the driveshaft by timing gear belts. The system is built to permit dry or wet testing, using either or both trailer wheels.

The air cylinders, solenoid water valves, control systems in the truck console, and air-over-hydraulic trailer brake system are supplied by air pre-conditioned in an assembly mounted on the rear of the water tank. The air is pre-conditioned by passing through a filter, dryer, pressure regulator and lubricator.

The trailer braking system can be regulated to permit controlled lock-up rates. A controlled lock-up rate permits evaluation of the slip resistance of the surface being tested. All of the tests in this investigation utilized a controlled lock-up rate of 0.75 seconds which is the time required, from the initial application of hydraulic brake pressure for the brake to completely lock.

The towing hitch assembly on the truck is vertically adjustable to keep the trailer tongue level with varied truck loads.

The trailer has a perimeter type frame, constructed of two-inch by four-inch rectangular box sectional steel tubing. The tongue is a four-inch box section with a two-inch ball coupler. The trailer suspension is a trailing arm design with an upper and lower control arm on each side, coil springs, air-adjustable shock absorbers, and an anti-sway bar.

The electrical relay and solenoid components on the trailer are mounted on panels fitted to the riser section of the frame. They are protected by covers and seals. An aerodynamically designed fiberglass hood with a spring-assisted lifting arm covers all of the trailer but the tongue.

The traction force transducers on the trailer are calibrated using the K. J. Law Engineers Model 1275 Air Bearing Calibrator.

Air, pavement, and tire temperatures were determined using an AOTEK Telethermometer which is composed of a portable battery operated indicator connected to a sensor unit. The AOTEK sensor is a thermistor which responds to temperature with an electronic signal. The signal is instantly received by the indicating instrument and electronically compared with known values. The difference is read on the indicator scale directly in degrees Fahrenheit. The Telethermometer which has been used in this investigation has a temperature range of -58 to +212 F. The unit was purchased from AOTEK-FRITZSCHING, Inc. of Rochester, New York.

METHOD OF INVESTIGATION

Part A: STANDARDIZATION OF PROCEDURES AND SAMPLING PROGRAM

GENERAL TEST PROCEDURES

Skid tests were conducted according to ASTM E274-70. This method specified the test to be made in the center of the left wheelpath of a traffic lane. Additional wheelpaths were tested on both divided and undivided pavements at selected locations. The ASTM standard speed of 40 mph was used on all sections where possible.

EQUIPMENT CALIBRATION

Force Transducers--The force transducers on the trailer wheels were calibrated at monthly intervals when testing was in progress. An air bearing platform was used to calibrate the traction forces. A load cell was used with the air bearing calibrator and was calibrated periodically on a Tinius-Olsen universal testing machine. The vertical force systems were calibrated using static wheel loads.

Speed and Distance--The trailer fifth-wheel, which was used to accurately determine the test speed, was checked periodically by recording the time required to traverse a known distance at constant speed. The truck survey odometer was calibrated by comparing the measured distance with the actual distance travelled. The odometer error had to be determined as it was used to locate test spots on a particular route by the log mile system.

Water Pumps--The discharge of the water pumps was checked periodically to determine any change in quantity of water supplied to the test tire. This was done by operating each pump for a known interval of time at different speeds (20, 40, and 60 mph) and weighing the amount of water discharged.

Repeatability--Repeat tests were made initially for the skid tester as received and periodically throughout the study to determine the testing error.

TEST SECTION SAMPLING

Projects of Portland cement concrete (PCC) and asphaltic concrete (AC) surfaces with different lengths were tested at various test intervals to determine the minimum number of tests within a section of pavement in order that statistically reliable averages would be determined. Speeds of 40 and 50 mph were run at test intervals ranging from 0.10 mile to 1.40 miles. Random sample averages of those tests also were obtained in addition to averages determined using the ASTM minimum of five tests.

ENVIRONMENTAL EFFECTS

Previous reports (4,6,7) indicate that the coefficient of friction is affected by environmental factors such as temperature, season of the year, number of days with no rainfall prior to testing, and roadway geometrics. The latter was an important variable prior to development and use of transducers measuring vertical dynamic wheel loads as well as horizontal traction forces.

Special Study--A special study, conducted during one working day, was made on both an AC and PCC pavement over a range in air temperatures from 69 F to 92 F.

One test speed of 40 mph was used and tests were repeated throughout the day at identical locations. Air, dry pavement, and test tire temperatures were obtained for each series of tests. Test tire temperatures were obtained with the tire in a static condition, after conditioning for testing. Three tire pressures (20, 24, and 28 psi) also were used to determine the effect of this variable.

Multiple Regression Analysis--Special sections of AC and PCC pavements were also selected throughout the state where skid tests were to be made more than once during this study. Generally, two or more series of tests were made on these sections. A variety of climatic and seasonal conditions was sampled. Official weather records were examined for the nearest reporting weather stations and the number of days with no rainfall preceding test dates was determined.

The air, pavement, and tire temperatures were determined on the special sections of pavements at approximately one hour intervals when tests were being made. The surface textures were classified according to the degree of wear (amount of coarse aggregate exposed as shown in Figures 2 and 3), the relative smoothness or knobbiness of the surface, and the presence or absence of visible surface voids. Latest available estimates of traffic volumes were determined from Department records and made a part of the test section's records.

Multiple regression analyses were made using the above factors as independent variables and Coefficient of Friction (CF), Slip Coefficient (SLC), and the ratio SLC/CF as the dependent variables.

Geometrics--The force transducers used on the Missouri skid trailer measure both the dynamic horizontal traction and vertical load forces encountered during a skid test. The change from the torque method of friction force measurement was made in the equipment after the study was initiated. Consequently, the determination of measurement error resulting from roadway geometrics became less important as the force transducer would eliminate load-shift effects due to geometrics. However, some testing was done for confirmation purposes. Tests at 40 mph were made on PCC pavement sections with positive and negative grades ranging from less than one percent to a maximum of four percent.

EFFECT OF TEST SPEEDS

The standard test speed of 40 mph was used on all test sections where speed limits permitted. Additional test speeds were used to determine the effects of speed on a large sample of surfaces.

Sections on the Interstate system were tested at speeds of 40 and 50 mph and, in addition, selected sections were tested at 60 and 70 mph. Divided pavement sections on the Primary system were tested at speeds of 40 and 50 mph with 60 mph tests on selected sections. Test speeds on undivided Primary and Supplementary systems were 30, 40, and 50 mph

on all sections where speed limits or zones permitted, with 60 mph used for selected locations. On undivided pavement, the standard speed of 40 mph was used in each direction of traffic. The speeds of 30 and 50 mph were used in only one direction of traffic. When 60 mph tests were used, they were made for each direction of traffic. Due to speed limits and zones, some locations were tested at a minimum speed of 20 mph.

The maximum test speed was 70 mph as this is the maximum speed limit in Missouri. It became apparent that testing at speeds this high would be very difficult on many routes due to traffic volumes. In addition, the frequent grades encountered, although relatively small, presented problems of accurately maintaining a 70 mph test speed. The 70 mph tests were only made on special locations with traffic control assistance, if necessary, from the Highway Patrol.

TEST TIRE COMPARISONS

A PCC pavement was selected which had very little traffic. Seven locations were permanently established and new test tires were tested at 40 mph at these locations after the initial break-in period as specified in ASTM E249. The tires were again tested prior to their removal from testing operations.

DATA PROCESSING

The test data collected in this study were recorded on chart paper and reduced manually by office personnel. Both the horizontal traction and vertical load fluctuations were recorded on the chart. Both of these values were read

(according to ASTM E274) for each skid test and a coefficient of friction could then be computed by dividing the horizontal traction force by the vertical load. The results were reported as CF. This value can be easily converted to the ASTM Skid Number (SN) by multiplying by 100.

The SLC was computed by reading the average maximum traction force occurring during the skid test, for a time period of approximately 0.2 seconds. The vertical load was averaged for this corresponding time interval. The SLC could then be computed from the resultant traction and vertical load readings.

The percent slip trace (varying from 0 to 100 percent) of the test wheel speed was also recorded on the chart. The percent slip was read from the trace, corresponding to the occurrence of the Slip Coefficient.

The traction force and vertical load (for both locked wheel and incipient conditions) as well as the percent slip were recorded for each skid test. The test speed and speed deviation were also recorded for each test. These data were input to an IBM 360 computer system and reduced further to individual CF and SLC for each skid test, with further reduction to average values of CF and SLC for each test section. Averages were computed according to ASTM E274.

Pertinent data regarding materials, year of construction (surface age), mix designs, PCC pavement finishing procedures, and traffic counts were also input to the computer and stored on magnetic tape. This permitted retrieval of the data in several different formats.

Part B: CORRELATION OF THE SLIP COEFFICIENT AND COEFFICIENT OF FRICTION WITH MANY VARIABLES

PAVEMENT MATERIALS AND MIX DESIGNS

Materials--The records for Portland cement concrete (PCC), asphaltic concrete (AC), and plant mix bituminous (PM) pavements, constructed on the state highway system between 1952 and 1968, were extensively examined. A sample of these pavements was taken by selecting test sections with a minimum length of 0.5 mile if the section, to the best knowledge, met the following requirements:

1. Material used in the surface was from the same source;
2. Surface mix design did not change;
3. Surface age was the same; and
4. PCC pavement finishing procedures and traffic volumes were reportedly consistent.

Aggregate formations, types, and sources were identified the same as given in the pavement records and were studied according to pavement surface types.

Fine aggregate sources were studied on PCC pavements. Test sections were selected where the initial surface texture was worn away but coarse aggregate was not yet exposed. These sections were on two lane highways.

Aggregate formations were studied for PCC, AC, and PM surfaces. Test sections were selected with the coarse aggregate exposed to view over a large portion of the wheelpaths. Four lane divided highways were used for PCC pavements while two lane highways were used for AC and PM pavements.

Coarse aggregate types (limestones, dolomites, and gravels) were studied, where applicable, for the PCC, AC and PM surfaces in addition to seal coat (SC) surfaces. Sections were selected from four lane divided and two lane highways.

Mix Design--The mix designs on PCC pavements changed late in 1967, which resulted in an increase of the percent of fine aggregate in the paving mix. The AC mix designs changed in 1971 which resulted in a lower percent of fine aggregate. A sample of pavements constructed with the above changes, was selected to study the effects of these changes.

TRAFFIC VOLUMES

Traffic volumes have been shown to have an effect on the durability of the skid resistance of certain paving materials (8, 9, 10, 11). The wearing action of the tire tread rubber, in combination with surface contaminates, tends to change the friction characteristics of pavement surfaces.

The effect of traffic was studied on PCC, AC, and PM surfaces. The latest available traffic volumes were estimated on each test section for the date when skid tests were made. These traffic volumes were used to compute an AGE-TRAFFIC-INDEX (ATI), an index representing the accumulated volumes of traffic and has been used by Goodwin (12). However, on special studies in Part D an estimate was made of the actual number of vehicle passes to determine a Wear Factor(k) or the slope of the line for accumulated vehicle passes plotted versus CF (13).

ACCIDENTS

The effect on pavement-tire interface friction when the pavement is wet has been adequately demonstrated in the past (4). The overall importance of the skid resistance of pavement surfaces should be related to the occurrence of traffic accidents during periods when the pavement surface is wet, a time when the CF is at a low value compared to dry conditions.

Wet Pavement Accidents--Surface frictional characteristics were determined at four locations within the state which were reported to have a high frequency of accidents during periods when the pavement was wet. Copies of accident reports from these areas were examined and all accidents were omitted which may have been due to mechanical failures, obvious traffic violations, or snow and ice conditions. Accidents were tabulated which occurred when the pavement was wet and dry, respectively.

A random sample of 23 locations distributed within the state was selected for a study of 1970-71 accidents by type. Eighteen of these locations had 1970 and 1971 CF at 40 mph (CF_{40}) ranging from less than 0.31 to 0.48. These locations were almost entirely on the state Primary and Interstate systems where speed limits were generally 70 mph. A comparison was made between one-vehicle type accidents and CF.

Tire Tread Depths--A variable, which is present at the pavement-tire interface during rolling or sliding, is the tire tread depth. Tests have shown improved friction between the pavement and tire by comparing tests with bald tires to

those with a tread design (14). Between September and December of 1971, a study was made of the tire tread depths on automobiles involved in accidents in Greene County, on roadways of the state highway system. This area included the city of Springfield. The tread depths were reported by either the Highway Patrol or Springfield City Police, at the time of the accident investigation.

Part C: COMPARISON OF THE SLIP COEFFICIENT AND COEFFICIENT OF FRICTION AS A MEANS FOR EVALUATING PAVEMENT FRICTION

Kummer and Meyer (4, 5) posed the question that perhaps slip resistance should be measured as this may give a more realistic appraisal of the friction potential of pavements. The SLC and CF have been measured on all surfaces for the extent of this study. Comparisons of SLC and CF are shown for major areas of the study.

The percent wheel slip was determined at the point of SLC. The range of the percent wheel slip was a point of discussion since anti-lock brake systems should be designed to utilize maximum available friction.

Part D: EVALUATION OF SURFACES DESIGNED TO HAVE IMPROVED FRICTIONAL CHARACTERISTICS

PORTLAND CEMENT CONCRETE PAVEMENT

When this study began, Missouri's accepted procedure for texturing plastic PCC pavements was a burlap drag. Early skid resistance measurements on PCC surfaces indicated that consideration should be given to a change in specifications in order to provide an initial surface texture with higher friction.

A field installation on one project was made where four transverse texturing methods were compared to the longitudinal burlap drag. The four experimental texturing devices were as follows:

1. Wire Comb,
2. Heavy Nylon Bristle Broom,
3. Fine Nylon Bristle Broom, and
4. Natural Bristle Broom.

The description of these are given in Appendix C.

Sand-patch tests were made to determine the surface texture depth, as initially constructed, and annually for the following two years. The sand-patch test method (Appendix D) was patterned after the Portland Cement Association procedure. In addition, friction tests were made just after the pavement was opened to traffic and during the spring, summer, and fall of the following two years.

During the interval of this study, other locations throughout the state were grooved longitudinally to retexture hardened

PCC surfaces on new construction where the surface texture was considered to be unsatisfactory. Sufficient lengths were necessary to perform the minimum number of skid tests and as a result only three locations were tested.

ASPHALTIC CONCRETE AND BITUMINOUS PAVEMENTS

Porphyry (Trap Rock), blast furnace slag, flint chat (Joplin chat), and a lightweight aggregate (expanded shale) are available in limited quantities and localized areas in Missouri. These materials were considered to have good prospects of being utilized into flexible pavement surface mix designs to provide a surface with improved skid resistance. Installations were constructed using these materials and the skid resistance of the surfaces was evaluated.

SPECIAL SURFACES

A Missouri municipal airport constructed PCC and bituminous surfaces which were different than those which the Highway Department had placed. Arrangements were made so that friction tests could be made on these surfaces.

A PCC runway was constructed using a transverse wire comb for texturing the plastic concrete. The hardened surface was later grooved, transversely, by sawing the grooves with a configuration of 1/4 inch wide by 1/4 inch deep by 2 inch centers.

A thin (5/8 inch thick) plant mix bituminous porous friction course surface was constructed on the second runway. The coarse aggregate used was Trap Rock.

Initial slip and skid resistance measurements were made on these surfaces at a very early age. No further testing was done.

RESULTS AND DISCUSSION

Part A: STANDARDIZATION OF PROCEDURES AND SAMPLING PROGRAM

GENERAL TEST PROCEDURES

A sample of 49 test sections was taken from two-lane highways and the average CF compared between the outer and inner wheelpaths for each test section. No significant difference was found between the wheelpaths which averaged 0.413 for the outer and 0.419 for the inner.

A sample of 22 test sections was taken from four-lane divided highways distributed throughout the state. The left wheelpath of the traffic lane and the right wheelpath of the passing lane was tested at each of these locations. The average CF was 0.362 for the traffic lane and 0.474 for the passing lane. This difference shows that lower CF is generally found in the traffic lane of four-lane divided highways. This condition demonstrates the wearing effects of traffic because fewer vehicles normally use the passing lanes.

It appears that the left or inner wheelpath of two-lane pavements is sufficient for determining the minimum skid resistance of a uniform pavement surface. It is also evident that the test position on divided pavements must be adequately described or identified.

EQUIPMENT CALIBRATION

This investigation was not intended to include equipment development or evaluation. However, the K. J. Law Model 965A Pavement Friction Tester did perform satisfactorily for the

purposes of this study. Malfunctions did occur in both the tow vehicle and trailer systems but their frequency was not to be unexpected when considering the operating conditions.

Force Transducers--Calibration of the force transducers at approximately one month intervals during testing seasons resulted in satisfactory calibration factors for the strain gages, varying within a ±2 percent tolerance. This tolerance was to be expected according to the manufacturer's instructions.

Speed and Distance--The fifth wheel speed calibrations were not required unless the recorded speed trace during a test indicated a consistent variation greater than ±0.5 mph. Minor electronic adjustments were necessary if this occurred.

The survey odometer was affected by truck tire wear, therefore, frequent checks were made using milepost markers and any necessary changes were made in the correction factor for the odometer readings.

Water Pumps--The results of four calibrations of the water pumps in the three years of testing showed the output of the pumps to provide a water layer nine inches wide and a thickness ranging within the ASTM E274-65T limits of 0.015 to 0.025 inch. The typical outputs for each pump (left and right wheels) are shown in Figure 4. The pump output requirements were revised in 1970 and resulted in a smaller tolerance of water layer thickness. The output of the pumps was near the top of the tolerance of the revised ASTM method E274-70.

Repeatability--Replicate 40 mph left and right wheel friction tests were made on a PCC surface shortly after the

equipment was received in 1969. The CF and SLC are shown in Table 1. The standard deviation of the tests (S_t) and the average difference between replicates, ($\overline{D_R}$) are also shown. The $\overline{D_R}$ is computed using: $\overline{D_R} = 1.128\ (S_t)$ as found in Youden(15).

The $\overline{D_R}$ for CF ranged from 0.016 to 0.025 and for SLC ranged from 0.025 to 0.027. There appeared to be a slight difference in the repeatability of the left and right sides of the trailer when measuring CF but no difference was found when measuring SLC.

Tables 2a and 2b give results of CF and SLC tests obtained on an established location extending over the time span of July 1970 through June 1972. The $\overline{D_R}$ shown in Table 2a indicates that the CF repeatability, after decreasing initially, has not changed during the last two years of this study. The SLC did not show a similar trend. However, as the SLC is determined in the short time span of maximum friction force during braking, some error is always possible in trace interpretation. The SLC and CF were computed using the recorded test measurements as shown in Figure 5.

The S_t for CF has averaged 0.013 when testing various tires and can be considered the average throughout the study. The S_t for SLC has averaged 0.032 throughout the study. The higher value for SLC indicates more variation present in the determination of these values, as noted above.

TEST SECTION SAMPLING

The skid resistance was measured at various intervals on AC pavement surfaces to determine the minimum number of

tests per sample to obtain reliable averages. The results and the comparison of sample means using Student's t-test are shown in Table 3. The only significant difference between sample means was on new PCC pavement for five equally spaced tests versus five randomly spaced tests. The five percent level of significance was used for this analysis.

This analysis indicates there was no reason to disclaim the ASTM method of requiring a minimum of five tests to be made, for these types of surfaces. Further, the results indicated that tests at specified intervals would generally result in mean values of CF no different than if the test locations were randomly selected. Therefore, a procedure was established whereby five test locations were equally spaced within a sample of pavement to be tested. Allowances for relocating tests were made if a test occurred in areas such as bridges and bridge approaches, sharp curves, or areas of extremely rough or contaminated surfaces.

The ASTM method does not specify the maximum length of pavement which the mean of the five tests is to represent. Therefore, a maximum length of five miles was chosen to be represented with the mean of five tests, which represents a testing interval of a maximum of one mile. The results in Table 3, with the exception of Pavement C, were taken from lengths of pavement less than five miles.

The variance of contracted seal coat (SC) and bituminous treated (BT) surfaces was not consistent from pavement to pavement and was not dependent on length tested, as shown in

Table 4. The pavements shown in the table were projects tested at the established sampling procedures of five equally spaced tests within a maximum length of five miles. The sample standard deviation (S), varies between pavements which is understandable after observing the variable surface conditions found on these surface types. The SC surfaces are variable due to the intermittent loss of cover aggregate. The BT surfaces are quite variable because these surfaces include blade mix oil mat roads. These types frequently result in wide variations of surface texture, especially after some service time.

A random sample of projects tested in 1972 using the established sampling procedure on the state Primary and Supplementary Systems was used to determine the number of tests on each project which would be required to obtain an average CF to be within a certain error of a project's true mean. There were 145 test sections chosen on the Primary System and 60 test sections chosen on the Supplementary System. An average standard error of the mean ($S_{\bar{x}}$) was computed for each road system using the variance and number of tests for each test section. The $S_{\bar{x}}$ for CF samples of five tests averaged 0.016 for the Primary and 0.022 for the Supplementary Systems. This represents an average error of less than five percent.

Using the average $S_{\bar{x}}$ given in Table 5 and each test section variance, the number of tests required (N) was determined. The number of tests per mile (N_m) was then determined

by dividing the total N by the total of the test section lengths for the random sample from each system.

The best estimate of the number of tests per mile which should be used in routine inventory testing would be three per direction of travel, as given in Table 5. These would be adequate to obtain average CF within ± 0.03 of the true population mean for the Primary System and ± 0.04 for the Supplementary System, 95 percent of the time. The larger error on the Supplementary System would be accounted for by the more frequent occurrence of SC and BT surfaces. The error for the Primary System is based on the majority of tests on Portland cement concrete and asphaltic concrete surfaces.

ENVIRONMENTAL EFFECTS

Special Study--A stepwise multiple regression analysis for the special temperature-tire pressure study was made using the model

$CF_{40} = C + K_1 X_1 + K_2 X_2 + \ldots K_n X_n$, where

C, K = Regression coefficients; and

X = Independent variables, tire pressure, air temperature, pavement temperature, and tire temperature.

The results of the analysis are shown in Table 6 and do not consistently indicate any variable which is most important in its effect on CF. The air temperatures were significant for all surfaces except the AC traffic lane where pavement and tire temperatures were significant. The low Coefficient of Determination (R^2) indicates that a small percentage of

the variation in CF has been explained by the significant independent variables. Air, pavement and tire temperatures appear to explain more variation in CF on AC pavements than on PCC pavements.

An analysis of variance was made for the high (92 F) and low (69 F) ranges of air temperature on PCC and AC surfaces. The results are shown in Table 7. It was found that a difference of 23 F in air temperature during one day did not significantly affect CF.

Multiple Regression Analysis--Friction tests made on specially selected sections of PCC and AC pavement, were analyzed using the model

$Y = C + K_1 X_1 + K_2 X_2 + \ldots K_n X_n$, where

Y = Dependent variable CF, SLC, or SLC/CF;

C, K = Regression coefficients; and

X = Independent variable.

Nine independent variables were measured on each section where the friction was obtained. The range of each independent variable entered is given in Table 8 and are identified by footnote.

A stepwise multiple regression analysis was made and the results of the analysis for PCC pavement are given in Table 9. The four variables found to be most significant for explaining approximately 78 percent of the variation in CF, were Test Speed, Texture, $\log_e$ ATI and Tire Temperature. These do not include two variables which have been considered to be critical for defining observed CF fluctuations, namely Season and Days

Without Precipitation. However, Season was included for the analysis using SLC. Speed, ATI and Texture were found to be most significant in explaining variations of the ratio SLC/CF.

The variables found to be most significant for AC pavements included all but two, namely Test Tire Tread Depth and Days Without Precipitation. The results of the analysis are given in Table 10. The seven variables listed for CF explained 55 percent of its variation. A different order of entry was found for SLC. The analysis using the ratio SLC/CF indicated the ratio to be a function of Speed, Texture and Pavement or Air Temperatures. This was much the same finding as for PCC pavements. The ordering of the importance of variables found significant, using Beta coefficients, is given in Table 11.

These analyses show that CF and SLC measured on AC pavement surfaces are more dependent on environmental factors than are CF and SLC measured on PCC surfaces. The ratio, SLC/CF, was found to be generally affected by Speed and Texture.

This analysis indicates that complete standardization of friction measurements is not possible. Temperatures are critical but appear to be more important variables for measurements on AC pavements. The observed differences in surface textures between PCC and AC pavements coupled with these findings suggest that many of the environmental factors interact with surface texture in affecting friction measurements. The lack of finding significant effects does not mean

that these variables do not need to be considered as important information which should be measured when running skid tests. They help to define more completely the environment in which the test was made.

Geometrics--Test results on three profile grades are shown in Table 12. The average CF on each positive and negative grade was determined and a Student's t-test was made with no significant difference found between positive and negative grade mean CF for Groups A and B. A significant difference was found between the 4.0 percent positive and negative grades on Group C. However, the difference of 0.027 between the averages was within the 95 percent confidence limits of S_t. This would indicate the difference could be attributed to other factors rather than profile grade.

The data were averaged according to absolute value of percent grade, separated into three Groups. A comparison of Group average CF using the Student's t-test indicated no significant difference between averages shown in Table 12. Therefore, no consideration was given to correction for grades or other factors which would cause dynamic load shift on the trailer wheels. It was apparent the force transducers were adequately evaluating the dynamic wheel loads.

TEST TIRE COMPARISONS

Average results of the comparative tests made at a permanently established location on PCC pavement for each test tire used in the study are shown in Figure 6. The narrow range of test tire average CF (0.46 to 0.52) indicates no

large errors were introduced with the use of different test tires. A wider range of average SLC (0.76 to 0.89) was expected because of the relatively short section of pavement used to determine the SLC. This friction parameter also has been shown to be affected by more test environment variables than the CF.

Figure 7 shows the average and range of CF and SLC obtained for various tread depths at the time of the tire comparison tests. The data were assembled in the contingency table shown in Table 13. A Chi-square test indicated the tread depth and CF to be dependent. The lower average CF for tires with tread depth of 11/32 inch was eliminated and the data assembled in a new contingency table as shown in Table 14. A Chi-square test was used for testing the hypothesis that CF and tread depth are independent, within the range of 4/32 and 10/32 inch. The test indicated the hypothesis of independence should be accepted for this range of tread depth.

The hypothesis that SLC and tire tread depth are independent was also tested using a Chi-square test for data in Table 15. The analysis indicated that for tread depths ranging from 4/32 through 11/32 inch, SLC is independent of tread depth.

Based on the CF analysis, a more thorough break-in period should be considered for the present standard ASTM E-17 tire. The results in this investigation indicate that, on an average, new tires with 11/32 inch tread depth may give lower CF results by 0.03 than tires with 10/32 inch tread depth.

Part B: CORRELATION OF THE SLIP COEFFICIENT AND COEFFICIENT OF FRICTION WITH MANY VARIABLES

PAVEMENT MATERIALS AND MIX DESIGN

Materials--The samples of pavements used in this study approached normal distributions. Therefore, the findings, pertinent to pavement surface types, would generally be representative of a complete statewide inventory. A sufficient number of test sections were sampled throughout the study to evaluate the effect of six different fine aggregate sources used in PCC pavements. These natural sand sources are the Arkansas, Current, Grand, Mississippi, and Missouri Rivers in addition to the LaGrange glacial deposit.

Table 15 gives weighted average CF and SLC for these sources for three test speeds. Weighted averages were determined by multiplying each test section average by the length of travel way miles represented by the average. Travel way miles are defined as the portion of the roadway for the movement of vehicles, exclusive of shoulder and auxiliary lanes. An undivided pavement consists of one travel way while a divided pavement is composed of two travel ways.

The averages shown in Table 16 indicate small fluctuations between sources, with CF_{40} ranging from 0.41 to 0.47 and SLC_{40} ranging from 0.76 to 0.82. A speed gradient was determined according to ASTM E274 and is defined as the unit change in skid resistance with unit change in speed. The ideal condition

is considered to be a surface with high friction and a low speed gradient which would exhibit small changes with increase in test speed. The speed gradient formula is given in Appendix B. The ASTM method specifies the standard speed gradient to be determined between the test speeds of 30 and 50 mph. These are shown where these test speeds were used but gradients over other ranges of speeds are also shown. The speed gradients for SLC were determined in the same manner as for CF. The standard CF speed gradients ($^{G}30\text{-}50$) were consistent as they ranged from 0.0050 to 0.0075. The SLC gradients showed a wider range, 0.0015 to 0.0065.

Table 17 presents the cumulative frequency distribution of miles sampled for average CF_{40} for the sand sources. The percent of miles sampled with CF_{40} less than 0.40 reveals that of the four most extensively sampled sand sources (Arkansas, Missouri, LaGrange, and Mississippi), the Missouri River sand has the highest percentage of miles with CF less than 0.40. This is based on the assumption that for smooth PCC surfaces, without exposed coarse aggregate, the friction is determined by the fine aggregate present in the mortar.

A sufficient number of test sections were obtained to study the friction properties of five stone formations used in PCC pavements. These formations were Bethany Falls, Burlington, Kimmswick, Plattin and St. Louis limestones. The data are presented in Table 18. The average CF_{40} and SLC_{40} varied within a narrow range between stone formations. Each of the stone formations had average CF_{40} near or below 0.40.

The average CF speed gradients ($^{G}40-60$) were quite variable. The low average speed gradient for the Kimmswick limestone appears likely to be a result of the low mileage sampled at 60 mph. The St. Louis formation had the lowest speed gradient of the remaining four formations. However, based on CF alone the Burlington formation exhibits the highest friction at both 40 and 60 mph. A tabulation of the cumulative frequency distribution of miles sampled is shown in Table 19.

A total of twelve stone formations used in asphaltic concrete were studied with the data shown in Table 20. A much greater range in average CF and SLC was found on the formations which also are used in PCC, with the exceptions of the Plattin. The lowest CF and SLC for the Plattin was found when it was used in AC surfaces. The St. Louis, Plattin, Warsaw, and Kimmswick limestones all had average CF_{40} of 0.40 or below. The Winterset and Stanton limestones, and the Jefferson City dolomite had average CF_{40} above 0.50.

The standard speed gradients were very consistent between formations except the St. Louis and Plattin formations which had the lowest speed gradients. A measurement of friction properties apparently is a much better method of evaluating these aggregates than the speed gradient.

It is evident that the type of surface in which the coarse aggregate is embedded is a major factor that determines the resulting friction between tire and pavement, and not necessarily the coarse aggregate alone. A tabulation of the cumulative frequency distribution of miles sampled is shown

in Table 21. Comparison of the friction by stone formation indicates the Plattin formation produces lower average friction properties when used in asphaltic concrete mixes.

Five stone formations used in plant mix bituminous pavements (PM) were compared and the data given in Table 22. Stanton and Bethany Falls formations had highest and lowest average CF_{40}, respectively. The standard speed gradients had small variations between formations, with the exception of the Deer Creek formation which had the highest gradient. A tabulation of the cumulative frequency distribution of miles sampled is shown in Table 23.

Further analyses of the data by aggregate types (limestones , dolomites, and gravels) within surface types were made and the data are summarized in Table 24. There is no apparent difference in average friction between limestones and dolomites in PCC surfaces. The dolomites appear to have a lower speed gradient. However, the low mileage sampled compared to the mileage sampled with limestone would not be sufficient to substantiate these statements.

The dolomites and gravels used in AC surfaces produced higher average CF and SLC than did limestones. Although no apparent difference is observed for the standard speed gradients, lower speed gradients are observed for SLC for all aggregate types.

It is again apparent that the gravels used in PM surfaces produced average friction values higher than limestones. The gravel also exhibited lower CF speed gradients. The SLC speed

gradients are again found to be lower than for the CF speed gradients. The sample of dolomite was too small to make conclusions.

Low friction characteristics of limestones are also observed for seal coat (SC) surfaces. In addition, the gravels exhibited a lower average speed gradient than did the dolomites. Cumulative frequency mileage distributions of CF_{40} for surface and aggregate types are given in Table 25.

These analyses indicate that Missouri limestones used in AC, PM and SC surfaces produced, on the average, lower friction properties than did dolomites or gravels. The speed gradients for the SLC are lower for AC and PM surfaces which generally exhibit surfaces with large scale surface texture. Large scale texture can be composed of either or both the knobbiness due to the exposed aggregate and the openness of the bituminous mixtures and promotes better water drainage channels. These characteristics appear to be important in determining the magnitude of the SLC speed gradient.

Mix Design--The change in PCC pavement mix designs late in 1967, which increased the percentage of sand by approximately one-third, does not appear to have had any effect on the CF or SLC. The average values are presented in Table 26. The data for the sample of pavements constructed in 1967 are given for comparison. The pavements tested were in the early stages of wear and the increased sand content would not appear to show a beneficial effect perhaps until the wear had progressed to the point where the coarse aggregate is substantially

exposed. Cumulative frequency distributions in Table 27 indicates high uniformity in friction between years.

The change in AC mix designs are more apparent when observing the average CF and SLC in Table 28. There is a trend toward higher CF and SLC in 1971 and 1972 when the mixes were changed resulting in a reduction of the percent of fine aggregate. This change generally produced large scale textured surfaces. The average speed gradients are lower on these mixes indicating small effects or changes in CF or SLC with increasing speeds. The cumulative frequency distributions are shown in Table 29.

TRAFFIC VOLUMES

The estimate of accumulated traffic volumes for coarse aggregate formations and types used in PCC, AC, and PM pavements was plotted versus CF and SLC. The aggregates studied were selected as previously outlined and have sufficient variation of traffic volumes to establish a trend or wear characteristic. A more linear relationship between traffic and friction was apparent when the data were plotted using log-log coordinates.

The Wear Factors (k) were determined by estimating the slope of the trends for each formation, type, state region, and surface given. The CF was plotted versus the Age-Traffic-Index (ATI). The ATI, computed according to the formula in Appendix B, were converted to estimated accumulated traffic volumes by multiplying by 3,000. These values were then substituted in the formula for "k", also given in Appendix B.

The Wear Factors are shown in Table 30. The estimated vehicle passes also are shown at which the CF_{40} would be expected to decrease to an average value of 0.40. This appears to be a more appropriate means of comparing aggregate formations, types, or surfaces than friction alone.

Asphaltic concrete surfaces with limestones apparently polish or reach a predetermined CF_{40} value much sooner than AC surfaces with dolomites, as evidenced by the lower number of estimated vehicle passes required to decrease to a CF_{40} of 0.40. The PM surfaces with limestone had a positive "k" slope but this type of surface has given higher average friction than AC surfaces. Sufficient variations in traffic volumes were not available to evaluate gravels.

Surface types were studied which showed that AC pavements were quite variable when plotting friction versus ATI. Therefore, only an analysis of PCC surfaces was made. PCC surfaces were subdivided into regions of the state, Northwest, Northeast and South. These subdivisions were selected based on areas of assumed popularity of use of studded tires. The difference in estimated vehicle passes, shown in Table 30, required to produce CF_{40} of 0.40 may be associated to some degree with the occurrence of studded tire traffic. The regions of the state with lower estimated vehicle passes are those where the widespread use of studded tires are most likely to occur.

ACCIDENTS

Wet Pavement Accidents--A study of accidents was made on four locations before and after surface treatment. The

results are presented in Table 31. No correction was made for differences in the period of time the pavement was wet for before and after conditions. By having approximately equivalent "before and after" study periods, this variable would tend to normalize itself on a statewide basis for Missouri.

Location 1 demonstrates the situation where the CF remains the same after the surface alteration which consisted of an asphaltic concrete resurfacing. The area is a horizontal curve which, after a study by District personnel before resurfacing, was found to have inadequate superelevation and a general uneveness in the surface that reportedly accumulated surface water resulting in a hydroplaning potential. The reduction in wet pavement accidents while the CF remains the same indicates the problem to have been associated with the apparent inadequate surface geometrics and not necessarily due to inadequate friction.

Location 2 demonstrates the situation where the CF has apparently been increased. The "before" friction measurements were not obtained in the curve itself but were estimated from measurements obtained in adjacent areas with similar age, traffic, and surface types. The surface alteration consisted of a special asphaltic mix containing expanded shale. The large reduction in accidents following application of the special mix shows the benefits of increasing CF. The observed performance of this mix will be discussed in a later section of this report.

Location 3 demonstrates a situation where a bituminous treated surface was resurfaced with a plant mix leveling course. The surface before resurfacing was quite variable but had an average CF_{40} of 0.44. After resurfacing, severe bleeding or flushing of asphalt to the surface occurred and consequently a reduction in CF was found with a corresponding increase in frequency of wet pavement accidents. Corrective treatments involving application of seal coat aggregate did not, over a two year period following the bleeding condition, substantially improve the CF as bleeding of the excess bituminous material continued. "Slippery when Wet" signs were posted throughout the area and plans are currently in progress for upgrading the surface of this roadway.

Location 4 is another example demonstrating reduction of accidents after improving the CF. It is another area where special mixes were investigated.

Past studies (16) have indicated that the skidding type of accident is most likely to be associated with one-vehicle accidents. A study of accidents was made for 23 locations, selected to represent all areas of the state and located on roadway systems where speed limits were generally 65 or 70 mph.

The null hypothesis to be tested was that Accident Type and Road Condition were independent versus the alternate hypothesis of dependency. The statewide accident records of the Department's Division of Maintenance and Traffic were used to make this analysis. A contingency table was formed and is shown in Table 32. For the 2-year period of 1970 and

1971 the accidents were classified into two types, one-vehicle and other. The "One-Vehicle" type consisted of those accidents reported as leaving the roadway. The "Other" type accidents included all other categories. The number of accidents occurring on wet and dry pavements was tabulated. The results of the Chi-square test indicated the null hypothesis should be rejected and the alternate accepted. This would mean that the type of accident is dependent on whether the road is wet or dry. The higher Wet/Dry ratio found for the One-Vehicle Type accidents indicated that this type of accident should be studied regarding the relationship of CF and wet pavement accidents.

A study was made comparing CF with the number of wet and dry accidents. A total of 18 of the 23 locations previously selected had CF measurements during 1970 or 1971. A wide range of CF was measured over a range of geometric conditions. The analysis represents a sample of statewide conditions.

The data were classified as shown in Table 33 and the CF represents average conditions over a specific length of pavement. The number of wet and dry one-vehicle type accidents was tabulated corresponding to the pavement locations where the average CF had been determined. The data indicates that at an average CF_{40} of 0.40 or above, the Wet/Dry accident ratio drops considerably. At or below an average CF_{40} of 0.39, the Wet/Dry Ratio is much higher.

The CF_{40} of 0.40 is within the range of recommended tentative skid resistance requirements given in NCHRP Report 37, for

mean traffic speeds of 50 to 60 mph, as shown in Table 34. The locations used for the present analysis included roadways selected from the Missouri rural Interstate and Primary systems where the mean traffic speed for 1972 was 62.6 mph and the 85th percentile speed was 71 mph. The recommended skid number values given in Report 37 for mean traffic speeds ranging from 60 to 70 mph were 41 and 46, respectively. This indicates that perhaps the recommended values given in Report No. 37 are too high, at least for mean traffic speeds of 60 and 70 mph, and should be lowered if they are to be applied comprehensively to all Missouri road systems.

Tire Tread Depths--A tabulation of the tire tread depth data obtained in the Greene County accident study is shown in Table 35 and by histograms in Figure 8.

Tire tread depths were measured on a total of 607 vehicles involved in 320 separate accidents during the period September 15, 1971, to December 15, 1971, on the state highway system in Greene County Missouri. The histograms of Figure 8 illustrate that the sample can be considered to be from a normal population with an average tire tread depth of 7/32 inch. There were approximately 16 percent of the passenger vehicles with either a front or rear tire with a tread depth of 2/32 inch or less.

The main hypothesis to be tested in this study was whether accidents were associated with tire tread depths and could be established as related to CF. Studies of wet pavement accidents previously had shown the best classification of

accidents to be catagories of one-vehicle versus multi-vehicle types. The hypothesis that accident type and tread depths are independent for wet pavement accidents, was tested for the data shown in Table 36. The Chi-square test indicated the hypothesis should be accepted. However, it must be noted that the data had to be grouped into only two categories of tread depth in order to have a minimum cell frequency of five. The same hypothesis was accepted in Table 37 where road conditions was not specified.

Table 38 classifies the one-vehicle accidents by tread depth and road condition. This tabulation shows that the percent of accidents occurring on wet pavement is larger for minimum tire tread depths of 5/32 inch or less than for tread depths equal to or greater than 6/32 inch. This tends to support past claims that inadequate tread depth contributes to wet pavement accidents. However, the relatively small sample of wet pavement accidents does not allow statistical statements to be made for the data. Variations in tire tread design may have contributed too much variability.

Part C: COMPARISON OF THE SLIP COEFFICIENT AND COEFFICIENT OF FRICTION AS A MEANS FOR EVALUATING PAVEMENT FRICTION

Typical relationships between the SLC and CF measurements are shown in Figures 9 and 10, for PCC and AC pavements, respectively. A direct relationship exists between the two measurements. The range of ratios, SLC/CF, is shown on these figures and was generally between 1.50 and 2.00 with apparent averages between 1.75 and 2.00 for both surfaces. The greater number of points falling within the higher ratio bands for smaller values of CF indicates the ratio SLC/CF to be inversely related to CF.

A comparison of the ratio with test speed is shown in Figure 11, for typical PCC and AC pavements. These relationships appear to be linear which confirms previous findings in Part B and also findings by Maycock as referred to in NCHRP Report 37.

A sample of PCC and AC surfaces was used to compare the ratio with surface texture characteristics. These data are summarized in Tables 39 and 40. The average ratios for each texture classification were compared using Student's t-test for each surface type. A greater number of significant differences between averages was found for AC surfaces. This reconfirms findings in Part B using multiple regression analysis. The results in Table 40 indicate that the more open textured surfaces have lower ratios which indicates that for high friction surfaces, a greater percentage of the maximum available friction is utilized for locked wheel braking conditions.

If SLC/CF can be considered a safety factor, high ratios indicate a less efficient surface when considering the surface's ability to provide high friction for emergency braking conditions. For normal driving conditions, the demand for high friction does not occur. The friction requirements for ordinary accelerating, maneuvering and cornering are only generally defined at this time. However, Kummer and Meyer (4) indicated that a friction number of 0.40 satisfied normal frictional needs of the traffic. This value is equivalent to the friction available under normal braking (driving) conditions when the brakes are not locked. The samples of measurements in Figures 9 and 10 show that all SLC_{40} are above the value of 0.40. However, approximately 50 percent of the data points are below a CF_{40} of 0.40. It appears evident from the samples shown in Figures 9 and 10 that for a CF_{40} below 0.20 the SLC_{40} would be below 0.40. For these conditions a definite increase in wet pavement accidents should occur as the surface friction would be inadequate for normal driving conditions.

Based on these findings, low CF alone does not necessarily cause wet pavement accidents. A condition was observed in the accident study of Part B where sections of pavement with CF_{40} in the range of 0.20 to 0.25 did not have any reported wet pavement accidents. Therefore, the hypothesis could be established that friction requirements vary between roadways. Dual divided, controlled access roadways could have lower CF requirements for emergency braking conditions than two-way

roadways having a wide range of geometric conditions, because of differences in potential emergency braking conditions.

It is evident that a pavement may possess adequate friction (SLC) for normal driving conditions but be inadequate for emergency braking demands (CF). Therefore, it appears that a method must be developed to determine a roadway's specific friction requirements. Otherwise, extensive use of CF alone will cause many miles of pavement to be judged inadequate based on emergency braking conditions, but which would serve adequately for normal driving conditions.

The percent wheel slip at which the SLC occurred averaged from 5 to 20 percent on most all sections. Averages for surface types were generally in the range of 9 to 12 percent. It would appear that for anti-lock braking systems to be efficient, they should operate in the range of 5 to 20 percent wheel slip.

Part D: EVALUATION OF SURFACES DESIGNED TO HAVE IMPROVED FRICTIONAL CHARACTERISTICS

PORTLAND CEMENT CONCRETE PAVEMENT

Transverse Texturing--The results of the field performance of four experimental methods of surface texturing of plastic PCC are summarized in Table 41 and identified as Location 1B through 1E. The annual CF test results are given in addition to speed gradients and wear factors. These results have consistently shown the transverse wire comb to produce significantly greater CF than the burlap drag, at a significance level of 0.05 when analyzed by analysis of variance. Friction tests were made every three months if possible and average results for the six test sections are shown in Figure 12.

Annual sand-patch tests were made on the experimental textures at Location 1. The results are given in Table 42. The tests in 1972 were after approximately 2 million vehicle passes, each direction. The sand-patch tests have shown the wire comb to have greater texture depths after two years service than the other transverse textures being compared. This supplements the findings for CF tests.

Based on the early results of this experiment, the standard specifications for PCC surface finishing were changed in 1971 from the use of a burlap drag to the use of a wire comb or similar device with the same characteristics as used in the field trial. There have been projects constructed under this specification but sufficient test results are not available to determine wear or durability characteristics. It does

appear that this type of surface finish will wear at a fast rate under high traffic volumes, in urban areas where extensive use of studded tires occur. The next area of concern would be to provide a mortar or modified texture with greater durability or resistance to wear.

Longitudinal Grooving--Grooving of hardened PCC pavement has been used on Locations 1, 2 and 3 (Table 41). These sections of pavement were relatively short which limited the number of tests and speeds that could be run.

The initial skid resistance of these surfaces was not always significantly greater than the skid resistance of the standard finish and its wear characteristics seem to be erratic. In Location 3 the grooved section had higher CF after one year than the standard burlap drag. The sand-patch results in Table 42 for Location 1 show the grooved sections to have a texture depth comparable to the wire comb. However, the CF is less than for the wire comb. This supports the past claims that transverse texturing provides greater CF. Other studies (17) have shown lower accident rates but not necessarily improved skid resistance after longitudinal grooving. It is apparent that provisions for drainage channels for surface water from beneath the tire is a very important factor.

The results have shown that skid resistance of PCC pavements can be improved by use of a transverse wire comb instead of a burlap drag. Its durability can not be evaluated at this time except for one experimental location. However, the durability can logically be associated with exposure to traffic.

ASPHALTIC CONCRETE AND BITUMINOUS PAVEMENTS

The results of friction tests, on mixes where special aggregates were used, are shown in Table 43. Trap Rock, blast furnace slag, and expanded shale were used as major aggregates in AC mixes. Joplin chat was used in varying proportions with limestone at Location 10 in a plant mix bituminous leveling course mix. At most locations only annual tests were made which are listed in Table 43. However, tests were made at approximately three-month intervals on certain experimental sections. These are shown in Figure 13. Locations with Trap Rock, where limited tests have been made, are identified as Locations 6, 7, 8 and 9. Many of these mixes were placed in areas where speed limits prevented running tests at speeds greater than 30 mph. However, 40 mph or higher test speeds were run when possible.

Based on the 40 mph tests, the mix with blast furnace slag has maintained a higher CF than mixes with Trap Rock or expanded shale. However, the estimated total vehicle passes before the CF_{40} reduces to 0.40 is much greater for the expanded shale mix (Location 5). This is due to the small change in CF with the large increase in traffic volumes. However, the durability of the mix with expanded shale has shown indications that it may be near the end of its service life. The friction of the Trap Rock mixes is variable as shown by the wide range of CF.

The blast furnace slag (Location 1B) represents a short section of pavement. The limited tests on this material indicates it to be a more skid resistant mix than the normal AC mix.

Joplin chat was incorporated into a bituminous leveling course mix in three different proportions, as shown for Locations 10A, 10B, and 10C. The CF for these mixes show high initial values. There are differences though after some exposure to traffic. There was a wide range of traffic conditions studied. The results show that maximum CF is retained for greater accumulated traffic volumes when the coarse aggregate is totally Joplin chat material (Location 10C). Figure 14 illustrates the benefit of the use of Joplin chat in even a minimum proportion, by comparing the CF for a mix with 15 percent Joplin chat used as the fine aggregate and a mix with no chat. It is apparent that Joplin chat improves the friction properties when it is incorporated into these types of bituminous mixes.

A comparison of CF, for limestones, dolomite, gravel, and Trap Rock coarse aggregates used in AC mixes, is shown in Figure 15. It is apparent that limestone gives lower CF and that Trap Rock is a more skid resistant material along with the dolomites and gravels.

SPECIAL SURFACES

The results of tests on special runway surfaces at a Missouri municipal airport are given in Table 44. The average results are much higher than for the Missouri Specification wire comb. This is apparently a result of the large scale texture produced by the transverse grooves.

The new bituminous porous friction course with Trap Rock produced CF and speed gradients comparable to the special

Trap Rock mixes designed and placed by the Missouri Highway Department.

A comparison of the ratios SLC/CF, however, again points out the role of surfaces with large scale texture. A higher proportion of the maximum available friction (SLC) on these types of surfaces is obtained during the locked wheel test (CF).

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APPENDIX A

TABLES AND FIGURES

**Figure 1: Missouri Skid Tester--
K. J. Law Model 965A
Pavement Friction Tester.**

WEAR CODE 1

WEAR CODE 2

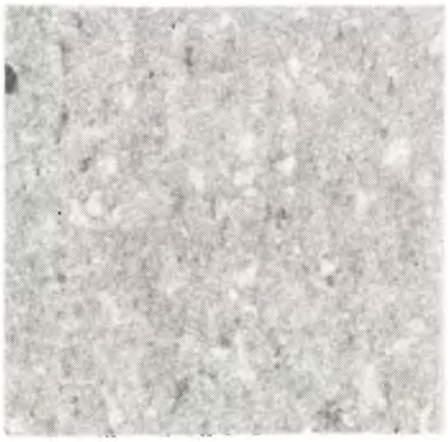
WEAR CODE 3

WEAR CODE 4

WEAR CODE 5

WEAR CODE 6

Figure 2: Surface texture classification for PCC pavements.



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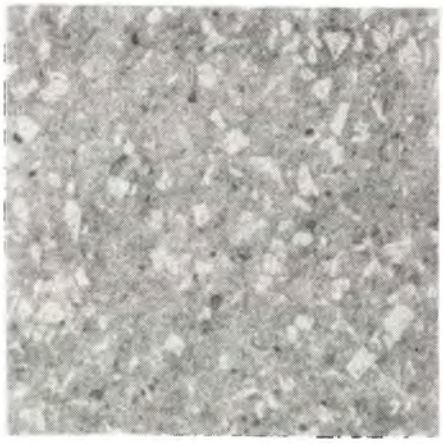

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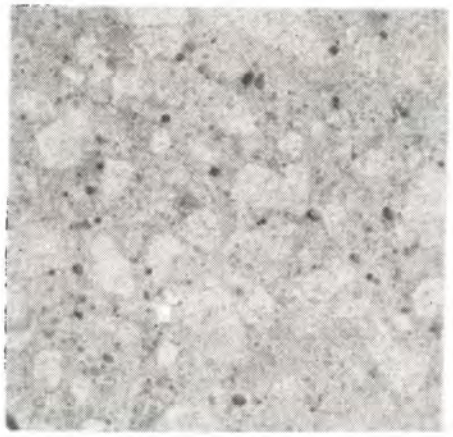

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Figure 2 (Continued)

WEAR CODE 1

WEAR CODE 2

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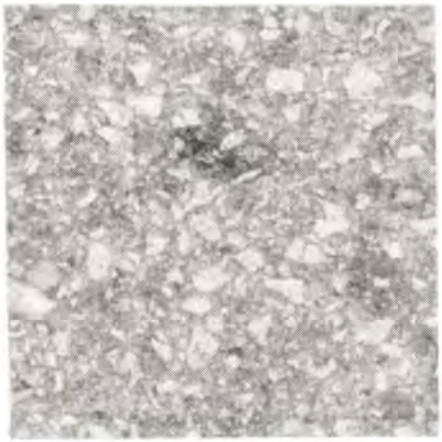

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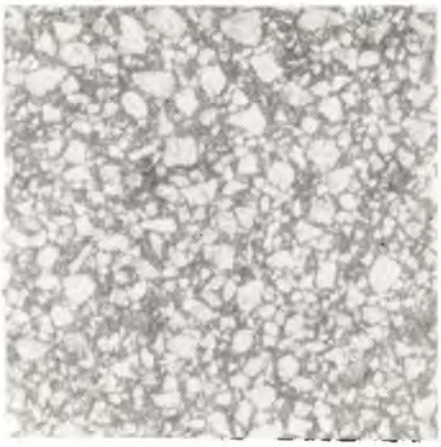

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Figure 3: Surface texture classification for flexible pavement surfaces.

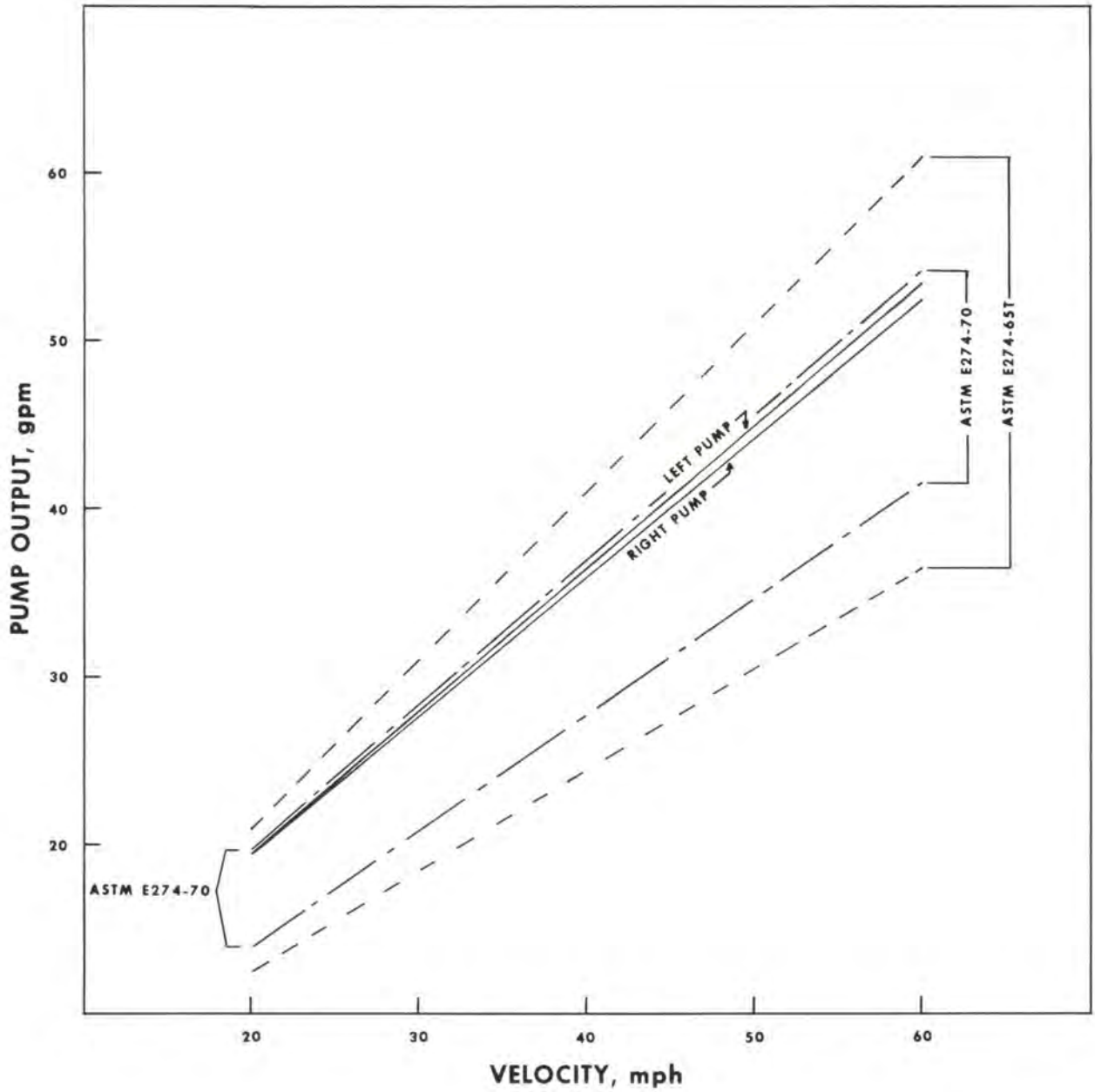


Figure 4: Average output of left and right water pumps for Missouri skid trailer.

Table 1: Replicate 40 mph Left and Right Wheel CF and SLC on PCC Surface November, 1969.

(a) Left Wheel CF - Tire No. 3

Replicate	Location 1a	2a	3a	4a	5a	S_t	$\bar{D}_R$
1	.400	.394	.358	.385	.340	.022	.025
2	.395	.405	.370	.366	.348		
3	.407	.408	.366	.366	.363		
4	.406	.421	.375	.394	.370		
5	.405	.405	.390	.396	.370		

(b) Right Wheel CF - Tire No. 4

Replicate	Location 1b	2b	3b	4b	S_t	$\bar{D}_R$
1	.398	.371	.364	.341	.014	.016
2	.416	.377	.383	.373		
3	.408	.378	.377	.350		
4	.429	.385	.388	.392		

(c) Left Wheel SLC - Tire No. 3

Replicate	Location 1a	2a	3a	4a	5a	S_t	$\bar{D}_R$
1	.794	.747	.753	.744	.720	.022	.025
2	.815	.768	.738	.756	.723		
3	.788	.770	.752	.770	.788		
4	.822	.781	.774	.799	.740		
5	.784	.809	.790	.789	.740		

(d) Right Wheel SLC - Tire No. 4

Replicate	Location 1b	2b	3b	4b	S_t	$\bar{D}_R$
1	.830	.843	.747	.711	.024	.027
2	.825	.854	.809	.735		
3	.804	.786	.781	.712		
4	.847	.844	.801	.744		

Table 2a: Replicate Left Wheel CF_{40} on a PCC Pavement For Various Test Dates and Test Tires.

Test Date	7/24/70		11/2/70		11/25/70		2/26/71		3/16/71		4/12/71		7/6/71		8/23/71		9/29/71		1/10/72		3/10/72		6/30/72		6/30/72	
Tire No.	1		13		17		17		15		20		23		23		22		25		25		27		31	
Replicate	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Location																										
1	.535	.537	.539	.518	.485	.476	.526	.515	.526	.541	.480	.490	.458	.476	.521	.505	.460	.473	.518	.518	.500	.516	.505	.484	.469	.464
2	.530	.532	.540	.531	.474	.513	.533	.523	.520	.515	.460	.463	.505	.495	.520	.495	.464	.482	.542	.519	.511	.516	.475	.505	.484	.468
3	.560	.532	.547	.510	.484	.477	--	.521	.531	.526	.485	.482	.479	.487	.505	.505	.457	.457	.537	.505	.500	.521	.500	.505	.458	.466
4	.540	.529	.539	.490	.495	.473	.500	.510	.510	.521	.469	.474	.477	.437	.490	.500	.456	.440	.521	.500	.516	.505	.482	.474	.453	.453
5	.537	.529	.508	.487	.484	.463	.510	.510	.528	.542	.479	.495	.473	.468	.500	.497	.463	.473	.526	.513	.526	.516	.490	.479	.463	.455
6	.540	.526	.528	.495	.469	.474	.535	.539	.534	.528	.484	.476	.466	.463	.500	.495	.457	.471	.505	.505	.511	.516	.465	.490	.454	.458
7	.532	.544	.529	.497	.495	.492	.540	.515	.536	.531	.477	.500	.474	.474	.505	.495	.467	.461	.529	.508	.527	.511	.489	.495	.453	.442
Average	.539	.533	.533	.504	.484	.481	.524	.519	.526	.529	.476	.483	.472	.471	.506	.499	.461	.465	.525	.510	.513	.514	.485	.490	.462	.458
S_t	.024		.022		.014		.009		.007		.008		.007		.009		.009		.014		.009		.013		.006	
$\bar{D}_R$	.027		.025		.016		.010		.008		.009		.008		.010		.010		.015		.010		.015		.007	

Table 2b: Replicate Left Wheel SLC_{40} on a PCC Pavement For Various Test Dates and Test Tires.

Test Date	7/24/70		11/2/70		11/25/70		2/26/71		3/16/71		4/21/71		7/6/71		8/23/71		9/29/71		1/10/72		3/10/72		6/30/72		6/30/72	
Tire No.	7		13		17		17		15		20		23		23		22		25		25		27		31	
Replicate	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Location																										
1	.796	.856	.885	.891	.838	.852	.841	.856	.798	.918	.776	.807	.825	.870	.848	.882	.857	.840	.930	.915	.899	.828	.842	.821	.864	.842
2	.874	.825	.842	.825	.830	.832	.782	.836	.846	.846	.821	.808	.899	.825	.860	.864	.810	.832	.849	.886	.833	.815	.787	.788	.875	.863
3	.824	- -	.848	.861	.800	.848	- -	.757	.769	.871	.771	.843	.763	.814	.886	.857	.839	.831	.911	.900	.856	.819	.857	.804	.860	.867
4	.923	.854	.858	.903	.870	.869	.806	.832	.898	.950	.880	.848	.815	.820	.824	.859	.839	.859	.870	.902	.881	.904	.802	.821	.888	.840
5	.861	.874	.815	.896	.812	.798	.867	.882	.821	.858	.752	.836	.714	.798	.851	.815	.845	.758	.908	.907	.889	.884	.842	.830	.804	.863
6	.874	.808	.880	.892	.837	.845	.769	.832	.862	.914	.828	.789	.802	.775	.838	.859	.896	.833	.877	.920	.911	.911	.851	.824	.859	.880
7	.870	.833	.857	.889	.859	.856	.871	.852	.864	.832	.819	.812	.769	.859	.745	.816	.805	.811	.918	.878	.891	.771	.760	.792	.870	.826
Average	.861	.842	.855	.880	.835	.843	.823	.835	.837	.884	.807	.820	.798	.823	.836	.850	.842	.823	.895	.901	.880	.847	.820	.816	.860	.854
S_t	.037		.027		.014		.026		.048		.034		.043		.026		.034		.021		.039		.020		.025	
$\bar{D}_R$	.042		.030		.016		.030		.054		.038		.049		.029		.038		.024		.044		.033		.028	

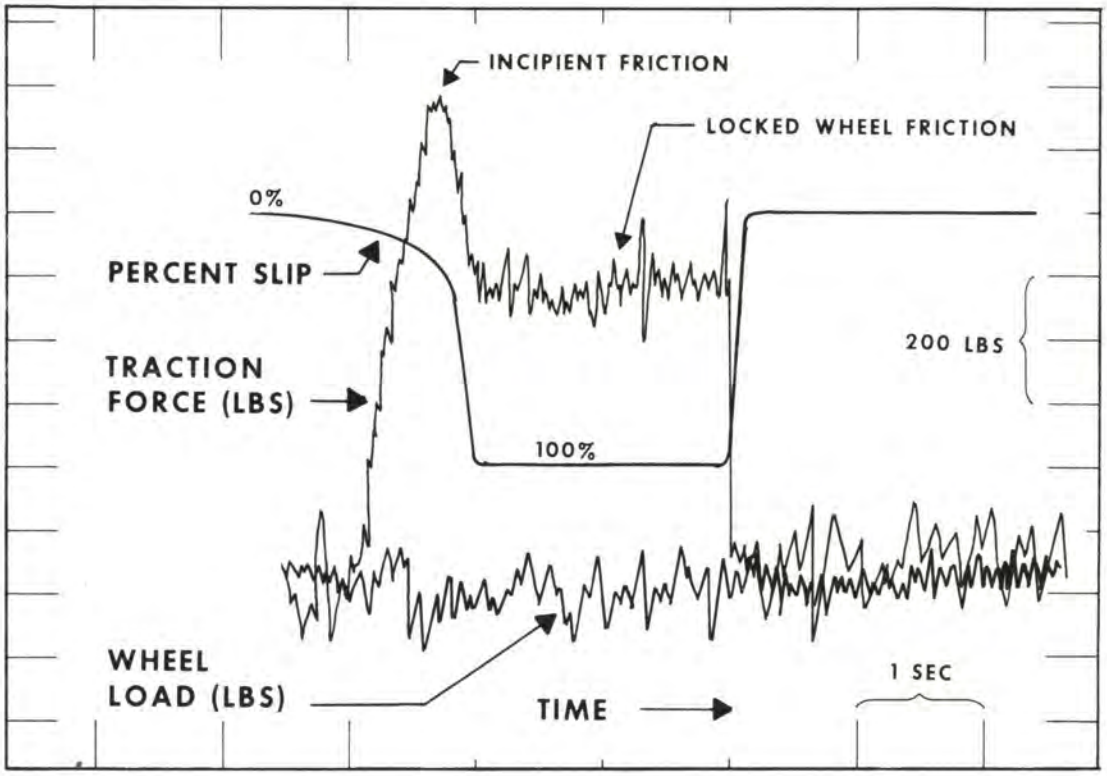


Figure 5: Typical friction test record.

Table 3: Projects Tested to Determine Sampling Procedure.

Pavement	Surface	Length (Mile)	No.of Tests	Lane	Test Interval Miles	Test Interval Group	Test Speed (mph)	Coefficient of Friction, CF Mean	Max.	Min.	Range	S	$S_{\bar{x}}$	Group	Significant Differences* For Comparison of Group Means II	III	IV
A	New PCC	3.81	14	NB	0.20	I	40	0.418	0.483	0.303	0.180	0.047	0.013	I	NO	NO	NO
			7	NB	0.40	II	40	0.427	0.466	0.388	0.078	0.028	0.010	II		NO	NO
			5	NB	0.60	III	40	0.412	0.429	0.388	0.041	0.017	0.008	III			YES
			5	NB	Random	IV	40	0.441	0.438	0.425	0.058	0.024	0.011	IV			-
			14	SB	0.20	I	40	0.410	0.459	0.349	0.110	0.033	0.009	I	NO	NO	NO
			7	SB	0.40	II	40	0.417	0.459	0.362	0.097	0.037	0.014	II		NO	NO
			5	SB	0.60	III	40	0.422	0.459	0.383	0.076	0.032	0.014	III			NO
			5	SB	Random	IV	40	0.422	0.439	0.401	0.038	0.014	0.006	IV			--
			14	NB	0.20	I	50	0.388	0.436	0.318	0.118	0.037	0.010	I	NO	NO	NO
			7	NB	0.40	II	50	0.388	0.422	0.352	0.070	0.029	0.011	II		NO	NO
			5	NB	0.60	III	50	0.377	0.400	0.352	0.048	0.020	0.009	III			YES
			5	NB	Random	IV	50	0.406	0.422	0.379	0.043	0.017	0.008	IV			--
			14	SB	0.20	I	50	0.345	0.383	0.291	0.092	0.028	0.007	I	NO	NO	NO
			7	SB	0.40	II	50	0.353	0.383	0.316	0.067	0.026	0.010	II		NO	NO
			5	SB	0.60	III	50	0.422	0.459	0.383	0.076	0.032	0.014	III			NO
			5	SB	Random	IV	50	0.422	0.439	0.401	0.038	0.014	0.006	IV			--
B	5-Year Service PCC	1.86	17	WB	0.10	I	40	0.389	0.455	0.317	0.138	0.038	0.009	I	NO	NO	NO
			9	WB	0.20	II	40	0.385	0.422	0.317	0.105	0.040	0.013	II		NO	NO
			5	WB	0.36	III	40	0.390	0.455	0.338	0.117	0.046	0.021	III			NO
			5	WB	Random	IV	40	0.400	0.422	0.324	0.098	0.043	0.019	IV			--
C	38-Year Service PCC	7.00	12	WB	0.50	I	40	0.395	0.497	0.333	0.164	0.045	0.013	I	NO	NO	NO
			6	WB	1.00	II	40	0.386	0.497	0.333	0.164	0.060	0.024	II		NO	NO
			5	WB	1.40	III	40	0.429	0.497	0.392	0.105	0.044	0.019	III			NO
			5	WB	Random	IV	40	0.411	0.497	0.333	0.164	0.065	0.029	IV			--
			13	WB	0.50	I	50	0.352	0.442	0.308	0.134	0.037	0.010	I	NO	NO	NO
			7	WB	1.00	II	50	0.346	0.442	0.308	0.134	0.045	0.017	II		NO	NO
			5	WB	1.40	III	50	0.376	0.442	0.330	0.112	0.042	0.019	III			NO
			5	WB	Random	IV	50	0.338	0.371	0.323	0.048	0.019	0.008	IV			--
D	New AC	2.10	10	EB	0.21	I	40	0.397	0.422	0.372	0.050	0.016	0.005	I		NO	NO
			5	EB	0.42	III	40	0.406	0.422	0.383	0.039	0.016	0.007	III			NO
			5	EB	Random	IV	40	0.397	0.422	0.380	0.042	0.018	0.008	IV			--
			10	EB	0.21	I	50	0.355	0.380	0.330	0.050	0.020	0.006	I		NO	NO
			5	EB	0.42	III	50	0.359	0.380	0.334	0.046	0.023	0.010	III			NO
			5	EB	Random	IV	50	0.351	0.380	0.330	0.050	0.025	0.011	IV			--
E	8-Year Service AC	2.35	21	NB	0.10	I	40	0.516	0.587	0.371	0.216	0.057	0.012	I	NO	NO	NO
			11	NB	0.20	II	40	0.503	0.566	0.371	0.195	0.060	0.018	II		NO	NO
			5	NB	0.47	III	40	0.515	0.566	0.428	0.138	0.057	0.025	III			NO
			5	NB	Random	IV	40	0.502	0.571	0.420	0.151	0.073	0.033	IV			--
			23	SB	0.10	I	40	0.498	0.574	0.377	0.197	0.055	0.011	I	NO	NO	NO
			12	SB	0.20	II	40	0.492	0.569	0.384	0.185	0.053	0.015	II		NO	NO
			5	SB	0.47	III	40	0.508	0.574	0.425	0.149	0.058	0.026	III			NO
			5	SB	Random	IV	40	0.488	0.549	0.456	0.093	0.043	0.019	IV			--
F	13-Year Service AC	3.60	14	WB	0.25	I	40	0.502	0.571	0.387	0.184	0.044	0.012	I	NO	NO	NO
			7	WB	0.50	II	40	0.484	0.527	0.387	0.140	0.047	0.018	II		NO	NO
			5	WB	0.72	III	40	0.511	0.546	0.492	0.054	0.022	0.010	III			NO
			5	WB	Random	IV	40	0.509	0.543	0.466	0.077	0.030	0.014	IV			--
			14	EB	0.25	I	50	0.438	0.495	0.401	0.094	0.032	0.008	I	NO	NO	NO
			7	EB	0.50	II	50	0.442	0.495	0.401	0.094	0.035	0.013	II		NO	NO
			5	EB	0.72	III	50	0.442	0.489	0.401	0.088	0.033	0.015	III			NO
			5	EB	Random	IV	50	0.427	0.477	0.401	0.076	0.031	0.014	IV			--

* Based on five percent level of significance

Table 4: Typical Seal Coat (SC) and Bituminous Treated (BT) Surfaces Sampled With the Standard Sampling Procedure at 40 mph.

Surface	Length (Miles)	No.of Tests	Lane	Test Interval (Miles)	Coefficient of Friction, CF Mean	Max.	Min.	Range	S	$S_{\bar{x}}$
SC	1.30	5	WB	0.26	.197	.250	.171	.079	.033	.015
			EB	0.26	.172	.199	.148	.051	.024	.011
SC	3.00	5	SB	0.60	.435	.468	.351	.117	.050	.022
			NB	0.60	.447	.490	.447	.043	.043	.019
SC	4.35	5	SB	0.87	.468	.515	.402	.113	.045	.020
			NB	0.87	.459	.516	.413	.103	.042	.019
BT	1.87	5	EB	0.37	.300	.395	.186	.209	.078	.035
			WB	0.37	.289	.362	.215	.147	.070	.031
BT	4.20	5	SB	0.84	.474	.613	.256	.357	.155	.078
			NB	0.84	.420	.531	.302	.229	.111	.050
BT	4.96	5	SB	0.99	.388	.412	.340	.072	.028	.013
			NB	0.99	.399	.428	.369	.059	.024	.011

Table 5: Average Number of Tests Required to Obtain Reliable Averages On All Surface Types of the Primary and Supplementary State Systems.

System	No.of Test Sections	Avg. $S_{\bar{x}}$	Avg. % Error	No. of Tests Req'd. Per Project(N) Avg.	Max.	Min.	Avg. No. of Tests Req'd. Per Mile(Nm)
Primary	145	0.016	3.4	7.9	83	1	2.89
Supplementary	60	0.022	4.7	7.8	93	1	3.10

Table 6: Stepwise Multiple Regression Analysis of Special Temperature Tire Pressure Study at 40 mph.

Surface	No.of Obs.	Independent Variable X (a)	Multiple Correlation Coefficient, R	Coeff. of Determination R^2	Std. Error Y_C	Final Equation Regression Coefficients K	C	Std. Error Y_C	R^2
PCC (Traffic Lane)	48	Air Temp.	.283	.080	.013	-.0008	.430	.013	.192
		Tire Press.(b)	.438	.192	.013	-.0016			
PCC (Passing Lane)	50	Air Temp.(b)	.353	.125	.020	-.0010	.503	.020	.125
AC (Traffic Lane)	50	Pavement Temp.	.555	.308	.020	-.0009	.364	.019	.362
		Tire Temp.(b)	.602	.362	.019	.0008			
AC (Passing Lane)	50	Air Temp.	.573	.328	.025	-.0023	.682	.025	.328

(a) Arranged in order of entry.

(b) Last entry with significant "t" for the regression coefficients.

Table 7: Special Study of the Effect of High and Low Temperatures on CF. (Tire pressure range of 24-28 psi).

Data:

Surface Type	Temperature Range: High, CF Run 1	High, CF Run 2	Low, CF Run 1	Low, CF Run 2
PCC	.308	.308	.338	.333
	.290	.330	.337	.330
	.400	.448	.464	.428
	.395	.400	.418	.458
$\bar{X}$	.360		.388	
S	.058		.059	
AC	.337	.357	.357	.369
	.367	.372	.394	.398
	.449	.436	.533	.495
	.459	.474	.552	.532
$\bar{X}$	.406		.454	
S	.053		.082	

Analysis of Variance:

Source	df	Sum of Squares	Mean Square	F-Ratio	Significance*
Temperature	1	.011476	.011476	2.875	No
Surface	1	.025088	.025088	6.285	Yes
Pooled Error Term **	29	.115764	.003992		
Total	31	.152328	.004914		

* Based on 5 percent level.
** Pooled Error Term includes the non-significant interaction.

Table 8: Range of Independent Variables Entered Into Multiple Regression Analysis of Environmental Effects.

Surface Type		Independent Variable Xn (a)								
		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
PCC	Min.	5	36	40	98	1	152	40	0	4
	Max.	11	93	107	150	4	21,238	60	19	9
AC	Min.	5	60	64	118	1	233	30	0	1
	Max.	11	91	112	150	3	3,331	60	10	5

(a)

X_n	Description
1	Test Tire Tread Depth (1/32")
2	Air Temperature (F)
3	Dry Pavement Temperature (F)
4	Static Test Tire Temperature (F)
5	Season (Winter, Spring, Summer or Fall)
6	Log_e Age-Traffic-Index (ATI)
7	Test Speed
8	Days Without Precipitation ≥ 0.10 in. prior to test
9	Surface texture classification by Wear Code

Table 9: Stepwise Multiple Regression Analysis of Environmental Effects on Measures of Surface Friction From a Sample of Portland Cement Concrete Surfaces.

Dependent Variable Y	No.of Obs.	Independent Variable X (a)	Multiple Correlation Coefficient R	Coeff. of Determination R^2	Std.Error Y_C	Final Equation Regression Coefficients K	C	Std.Error Y_C	R^2
CF	158	7	.739	.543	.048	-.0049	.9879	.034	.776
		9	.840	.705	.039	-.0091			
		6	.865	.749	.036	-.0182			
		4(b)	.881	.776	.034	-.0013			
SLC	158	7	.596	.355	.068	-.0044	1.5424	.046	.713
		9	.742	.550	.057	-.0115			
		4	.800	.640	.051	-.0032			
		6	.840	.705	.046	-.0191			
		5(b)	.845	.713	.046	.0149			
SLC/CF	158	7	.748	.560	.136	.0149	.7890	.122	.648
		6	.798	.636	.124	.0388			
		9(b)	.805	.648	.122	.0148			

(a) Arranged in order of entry into regression analysis. See Table 8 for variable identification.

(b) Last entry with significant "t" for the regression coefficients.

Table 10: Stepwise Multiple Regression Analysis of Environmental Effects on Measures of Surface Friction From a Sample of Asphaltic Concrete Pavements.

Dependent Variable Y	No. of Obs.	Independent Variable X (a)	Multiple Correlation Coefficient R	Coeff. of Determination R^2	Std. Error Y_C	Final Equation Regression Coefficients K	C	Std. Error Y_C	R^2
CF	141	7	.392	.154	.095	.0006	.4937	.071	.553
		3	.522	.272	.089	-.0081			
		9	.659	.434	.078	.0039			
		2	.689	.474	.076	.0094			
		6	.708	.500	.074	-.0482			
		5	.729	.530	.072	-.0490			
		4(b)	.744	.553	.071	.0027			
SLC	141	3	.486	.236	.103	-.0083	1.0459	.083	.525
		9	.604	.365	.094	-.0036			
		7	.646	.416	.091	-.0034			
		6	.672	.450	.088	-.0443			
		1	.693	.480	.086	.0090			
		2	.710	.502	.085	.0091			
		5(b)	.725	.525	.083	-.0367			
SLC/CF	141	7	.536	.287	.188	.0126	1.953	.165	.465
		9	.644	.414	.171	-.0089			
		3	.659	.433	.169	.0113			
		2(b)	.681	.465	.165	-.0157			

(a) Arranged in order of entry into regression analysis. See Table 8 for variable identification

(b) Last entry with significant "t" for the regression coefficients.

Table 11: Ordering of Independent Variable X By Beta Coefficients (a).

Dependent Variable Y	Independent Variable X: PCC Surface		AC Surface	
CF	7	Test Speed	3	Pavement Temperature
	6	Log_e ATI	2	Air Temperature
	9	Surface Texture	7	Test Speed
	4	Tire Temperature	9	Surface Texture
			5	Season
			6	Log_e ATI
			4	Tire Temperature
SLC	7	Test Speed	3	Pavement Temperature
	4	Tire Temperature	2	Air Temperature
	6	Log_e ATI	9	Surface Texture
	9	Surface Texture	7	Test Speed
	5	Season	6	Log_e ATI
			5	Season
			1	Tread Depth
SLC/CF	7	Test Speed	3	Pavement Temperature
	6	Log_e ATI	2	Air Temperature
	9	Surface Texture	7	Test Speed
			9	Surface Texture

(a) Defined as a measure of the relative importance of the different x-variables (18).

Table 12: Effect of Profile Grade on CF.

Group	A		B		C	
Area	A_1	A_2	B_1	B_2	C_1	C_2
Percent Grade	+0.40	-0.40	+2.40	-2.40	+4.00	-4.00
CF_{40}	.393	.425	.426	.413	.438	.407
	.421	.424	.403	.422	.393	.387
	.441	.426	.415	.412	.434	.382
	.412	.412	.412	.410	.420	.401
	.401	.455	.416	.406	.436	.409
Average	.414	.428	.414	.413	.424	.397
Area Mean	.421		.414		.411	

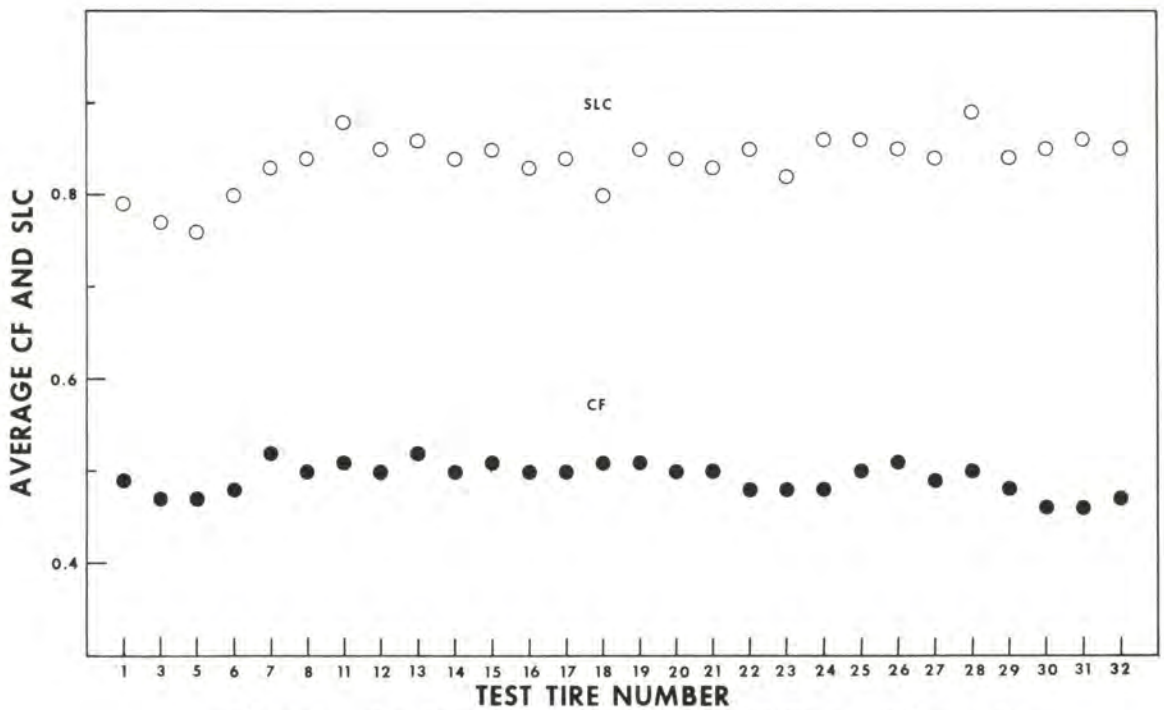


Figure 6: Average CF and SLC at 40 mph for ASTM E-17 test tires.

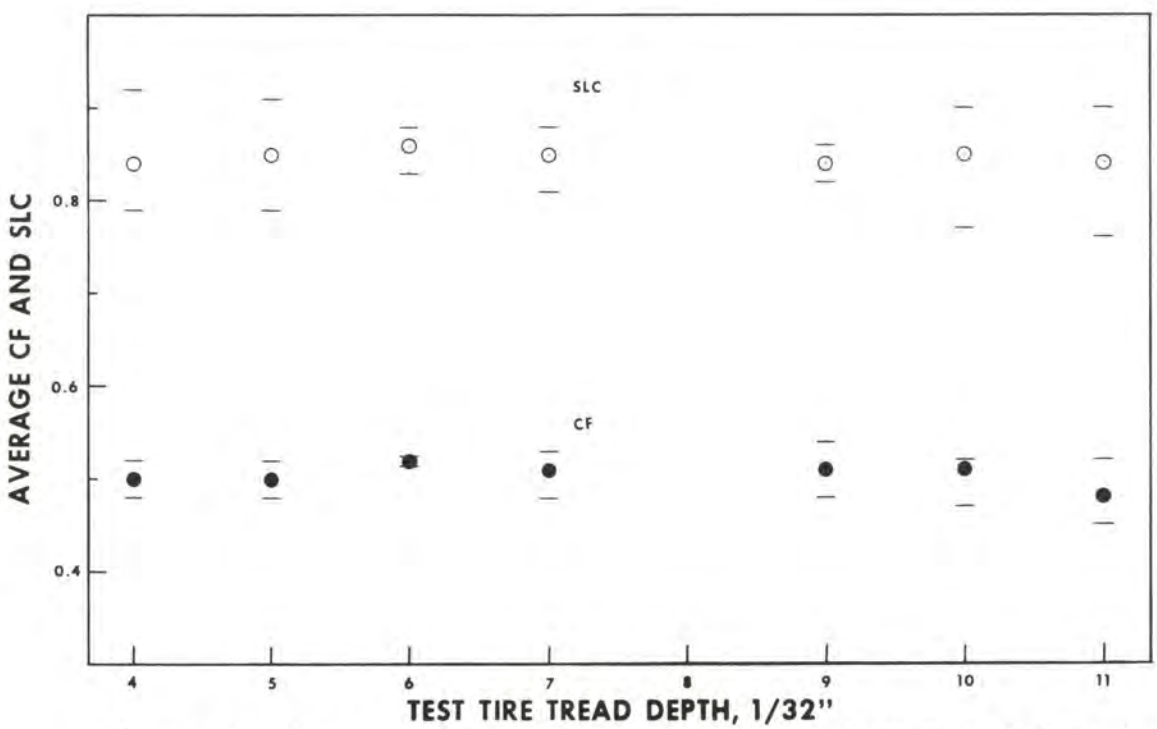


Figure 7: Average and range of CF and SLC at 40 mph for ASTM E-17 test tire tread depths.

Table 13: Contingency Table Comparing CF With Tire Tread Depth.

Number of Tires With Range of Tread Depth (1/32")	Number of Tires With CF		Total
	≤ .49	≥ .50	
4-7	6	16	22
8-11	31	22	53
Total	37	38	75

Table 14: Contingency Table Comparing CF With Tire Tread Depth.

Number of Tires With Range of Tread Depth (1/32")	Number of Tires With CF		Total
	≤ .49	≥ .50	
4-7	6	16	22
8-10	5	17	22
Total	11	13	44

Table 15: Contingency Table Comparing SLC With Tire Tread Depth.

Number of Tires With Range of Tread Depth (1/32")	Number of Tires With CF		Total
	≤ .84	≥ .85	
4-7	10	12	22
8-11	32	21	53
Total	42	33	75

Table 16: Average CF, SLC, and Speed Gradients for Six Fine Aggregate Sources Used in Portland Cement Concrete Pavements.

Fine Aggregate Source		Test Speed, mph 30	40	50	Speed Gradient(b) G_{30-40}	G_{40-50}	G_{30-50}
Arkansas River	Sample(a)	61.892	64.587	61.892			
	CF	.50	.46	.38	.0040	.0080	.0060
	SLC	.84	.80	.73	.0040	.0070	.0055
Current River	Sample	8.765	8.765	8.765			
	CF	.46	.41	.36	.0050	.0050	.0050
	SLC	.81	.79	.78	.0020	.0010	.0015
Grand River	Sample	5.186	5.186	5.186			
	CF	.50	.43	.36	.0070	.0070	.0070
	SLC	.85	.80	.72	.0050	.0080	.0065
LaGrange (Glacial Deposit)	Sample	25.312	25.312	25.312			
	CF	.53	.47	.39	.0060	.0080	.0070
	SLC	.86	.82	.76	.0040	.0060	.0050
Mississippi River	Sample	16.296	16.296	15.113			
	CF	.51	.43	.36	.0080	.0070	.0075
	SLC	.86	.80	.76	.0060	.0040	.0050
Missouri River	Sample	46.760	50.999	46.475			
	CF	.48	.42	.36	.0060	.0060	.0060
	SLC	.81	.76	.70	.0050	.0060	.0055

(a) Travel Way Miles Sampled
(b) All values negative unless shown as positive(+)

Table 17: Tabulation of CF at 40 mph Cumulative Frequency Distribution of Travel Way Miles Sampled for Six Fine Aggregate Sources Used in Portland Cement Concrete Pavement.

Fine Aggregate Source	Travel Way Miles Sampled	Percent of Travel Way Miles With CF Less Than .30	.35	.40	.45	.50	.55	.60	.65
Arkansas River	64.587	0	2.0	7.4	48.8	80.6	92.5	97.3	100
Current River	8.765		0	10.6	100				
Grand River	5.186		0	39.4	52.5	100			
LaGrange Deposit	25.312	0	4.2	9.9	32.4	61.0	100		
Mississippi River	16.296		0	11.4	63.4	92.4	100		
Missouri River	46.760	0	1.2	27.7	68.9	98.0	100		

Table 18: Average CF, SLC, and Speed Gradients for Five Coarse Aggregate Stone Formations Used in Portland Cement Concrete Pavements.

Coarse Aggregate		Test Speed, mph 40	50	60	Speed Gradient[b] G_{40-50}	G_{50-60}	G_{40-60}
Bethany Falls Limestone	Sample[a]	119.301	116.255	18.276			
	CF	.38	.33	.27	.0050	.0060	.0055
	SLC	.70	.66	.59	.0040	.0070	.0055
Burlington Limestone	Sample	110.038	109.375	8.849			
	CF	.42	.37	.31	.0050	.0060	.0055
	SLC	.76	.72	.68	.0040	.0040	.0040
Kimmswick Limestone	Sample	16.353	16.353	1.008			
	CF	.36	.31	.34	.0050	+.0030	.0010[c]
	SLC	.68	.64	.67	.0040	+.0030	.0005
Plattin Limestone	Sample	39.369	39.369	10.306			
	CF	.40	.36	.26	.0040	.0100	.0070
	SLC	.72	.69	.56	.0030	.0130	.0080
St. Louis Limestone	Sample	42.596	42.596	6.193			
	CF	.36	.31	.29	.0050	.0020	.0035
	SLC	.70	.65	.65	.0050	.0000	.0025

(a) Travel Way Miles Sampled
(b) All values negative unless shown as positive (+)
(c) Sample size at 60 mph too small for reliable results

Table 19: Tabulation of CF at 40 mph Cumulative Frequency Distribution of Travel Way Miles Sampled for Five Coarse Aggregate Formations Used in Portland Cement Concrete Pavements.

Coarse Aggregate	Travel Way Miles Sampled	Percent of Travel Way Miles With CF Less Than .20	.25	.30	.35	.40	.45	.50	.55	.60
Bethany Falls Limestone	119.301		0	8.1	30.4	58.5	76.9	100		
Burlington Limestone	110.038			0	6.8	22.9	86.9	100		
Kimmswick Limestone	16.353			0	30.3	93.8	100			
Plattin Limestone	39.369			0	19.0	49.1	72.2	92.6	92.6	100
St. Louis Limestone	42.596	0	2.4	16.2	43.8	80.8	96.1	100		

Table 20: Average CF, SLC, and Speed Gradients for Twelve Coarse Aggregate Stone Formations Used in Asphaltic Concrete Pavements.

Coarse Aggregate		Test Speed, mph 30	40	50	Speed Gradient[b] G30-40	G40-50	G30-50
St. Louis Limestone	Sample[a]	25.605	25.605	15.970			
	CF	.47	.40	.40	.0070	.0000	.0035
	SLC	.73	.69	.72	.0040	.0030	.0005
Plattin Limestone	Sample	80.891	80.891	78.890			
	CF	.39	.33	.30	.0060	.0033	.0045
	SLC	.68	.64	.62	.0040	.0020	.0030
Bethany Falls Limestone	Sample	98.882	97.882	89.854			
	CF	.51	.45	.39	.0060	.0060	.0060
	SLC	.77	.74	.71	.0030	.0030	.0030
Higginsville Limestone	Sample	48.326	48.326	48.326			
	CF	.53	.46	.41	.0070	.0050	.0060
	SLC	.82	.78	.74	.0040	.0040	.0040
Winterset Limestone	Sample	28.668	28.668	28.668			
	CF	.61	.57	.50	.0040	.0070	.0055
	SLC	.89	.87	.82	.0020	.0050	.0035
Burlington Limestone	Sample	154.220	152.108	148.829			
	CF	.51	.45	.40	.0060	.0050	.0055
	SLC	.81	.78	.74	.0030	.0040	.0035
Chouteau Limestone	Sample	34.437	34.437	32.754			
	CF	.52	.45	.41	.0070	.0040	.0055
	SLC	.82	.78	.77	.0040	.0010	.0025
Warsaw Limestone	Sample	42.423	41.709	41.709			
	CF	.44	.39	.33	.0050	.0060	.0055
	SLC	.76	.73	.69	.0030	.0040	.0035
Kimmswick Limestone	Sample	30.410	30.410	30.410			
	CF	.44	.38	.32	.0060	.0060	.0060
	SLC	.77	.73	.68	.0040	.0050	.0045
Stanton Limestone	Sample	43.017	43.017	43.017			
	CF	.58	.51	.45	.0070	.0060	.0065
	SLC	.87	.84	.80	.0030	.0040	.0035
Amazonia Limestone	Sample	25.614	25.614	25.614			
	CF	.50	.42	.36	.0080	.0060	.0070
	SLC	.77	.74	.70	.0030	.0040	.0035
Jefferson City Dolomite	Sample	97.752	97.752	95.834			
	CF	.61	.55	.50	.0060	.0050	.0055
	SLC	.91	.88	.85	.0030	.0030	.0030

(a) Travel Way Miles Sampled
(b) All values negative unless shown as positive(+)

Table 21: Tabulation of CF at 40 mph Cumulative Frequency Distribution of Travel Way Miles Sampled for Twelve Coarse Aggregate Formations Used in Asphaltic Concrete Pavement.

Coarse Aggregate	Travel Way Miles Sampled	Percent of Travel Way Miles With CF Less Than .15	.20	.25	.30	.35	.40	.45	.50	.55	.60	.65	.70
St. Louis Limestone	25.605	0	7.7	7.7	12.0	36.8	53.4	53.4	78.2	100			
Plattin Limestone	80.891		0	8.0	27.9	59.5	89.7	91.6	100				
Bethany Falls Limestone	97.882			0	0.3	6.1	30.5	51.2	75.6	84.1	100		
Higginsville Limestone	48.326					0	8.4	39.3	69.9	100			
Winterset Limestone	28.668								0	19.2	86.9	100	
Burlington Limestone	152.108		0	0.8	1.2	4.2	16.0	46.8	71.6	89.9	99.2	100	
Chouteau Limestone	34.437				0	4.9	8.7	33.8	89.2	100			
Warsaw Limestone	41.709			0	1.2	16.5	60.2	86.8	95.5	100			
Kimmswick Limestone	30.410			0	14.4	28.9	49.4	84.8	92.4	100			
Stanton Limestone	43.017						0	17.4	25.4	61.5	100		
Amazonia Limestone	25.614				0	3.2	48.6	65.4	87.9	100			
Jefferson City Dolomite	97.752			0	1.4	1.4	2.8	3.4	9.1	34.5	90.3	97.0	100

Table 22: Average CF, SLC, and Speed Gradients for Five Coarse Aggregate Stone Formations Used in Plant Mix Bituminous Pavements.

Coarse Aggregate		Test Speed, mph 30	40	50	Speed Gradient (b) G_{30-40}	G_{40-50}	G_{30-50}
Bethany Falls Limestone	Sample(a)	25.271	34.160	17.071			
	CF	.47	.40	.37	.0070	.0030	.0050
	SLC	.72	.67	.68	.0050	+.0010	.0020
Winterset Limestone	Sample	16.022	16.022	13.166			
	CF	.49	.44	.39	.0050	.0050	.0050
	SLC	.74	.69	.66	.0050	.0030	.0040
Burlington Limestone	Sample	27.263	27.263	27.263			
	CF	.51	.44	.39	.0070	.0050	.0060
	SLC	.82	.78	.75	.0040	.0030	.0035
Stanton Limestone	Sample	18.096	18.096	18.096			
	CF	.56	.50	.44	.0060	.0060	.0060
	SLC	.81	.78	.75	.0030	.0030	.0030
Deer Creek Limestone	Sample	24.145	23.445	23.445			
	CF	.54	.45	.38	.0090	.0070	.0080
	SLC	.78	.74	.71	.0040	.0030	.0035

(a) Travel Way Miles Sampled
(b) All values negative unless shown as positive (+)

Table 23: Tabulation of CF at 40 mph Cumulative Frequency Distribution of Travel Way Miles Sampled for Five Coarse Aggregate Formations Used in Plant Mix Bituminous Pavements.

Coarse Aggregate	Travel Way Miles Sampled	Percent of Travel Way Miles With CF Less Than .25	.30	.35	.40	.45	.50	.55	.60	.65
Bethany Falls Limestone	34.160		0	13.8	58.0	85.8	97.3	100		
Winterset Limestone	16.022		0	2.1	7.2	52.7	100			
Burlington Limestone	27.263		0	5.3	9.0	51.2	84.5	100		
Stanton Limestone	18.096					0	50.0	90.4	100	
Deer Creek Limestone	23.445	0	17.3	17.3	17.3	34.4	66.0	87.2	97.8	100

Table 24: Average CF, SLC, and Speed Gradients for Surface Type and Coarse Aggregate Types.

Surface Type	Coarse Aggregate Type		Test Speed, mph 30	40	50	60	Speed Gradient[b] G_{30-40}	G_{40-50}	G_{30-50}
PCC	Limestone	Sample[a]	27.231	257.451	257.451	75.519			
		CF	.44	.37	.32	.28	.0070	.0050	.0060
		SLC	.75	.69	.65	.62	.0060	.0040	.0050
	Dolomite	Sample	6.408	10.580	10.580				
		CF	.39	.36	.30		.0030	.0060	.0045
		SLC	.68	.63	.60		.0050	.0030	.0040
AC	Limestone	Sample	684.297	792.562	762.553	111.087			
		CF	.49	.43	.38	.31	.0060	.0050	.0055
		SLC	.78	.74	.72	.66	.0040	.0020	.0030
	Dolomite	Sample	132.605	164.916	154.033	17.839			
		CF	.60	.53	.48	.42	.0070	.0050	.0060
		SLC	.91	.86	.84	.80	.0050	.0020	.0035
	Gravel	Sample	15.224	15.224	15.224	4.168			
		CF	.54	.51	.45	.42	.0030	.0060	.0045
		SLC	.89	.87	.82	.85	.0020	.0050	.0035
PM	Limestone	Sample	124.729	132.918	112.973				
		CF	.50	.44	.39		.0060	.0050	.0055
		SLC	.77	.74	.71		.0030	.0030	.0030
	Dolomite	Sample	5.095	5.095	5.095				
		CF	.54	.48	.44		.0060	.0040	.0050
		SLC	.87	.81	.81		.0060	.0000	.0030
	Gravel	Sample	126.440	126.440	106.178				
		CF	.53	.49	.46		.0040	.0030	.0035
		SLC	.85	.85	.81		.0000	.0040	.0020
SC	Limestone	Sample	96.686	96.686	96.686				
		CF	.36	.33	.30		.0030	.0030	.0030
		SLC	.70	.66	.63		.0040	.0030	.0035
	Dolomite	Sample	33.832	33.832	33.832				
		CF	.48	.43	.38		.0050	.0050	.0050
		SLC	.85	.79	.75		.0060	.0040	.0050
	Gravel	Sample	144.577	153.897	140.017				
		CF	.53	.51	.47		.0020	.0040	.0030
		SLC	.86	.84	.80		.0020	.0040	.0030

(a) Travel Way Miles Sampled
(b) All values negative unless shown as positive (+)

Table 25: Tabulation of CF at 40 mph Cumulative Frequency Distribution of Travel Way Miles Sampled for Surface Types and Coarse Aggregate Types.

Surface Type	Coarse Aggregate Type	Travel Way Miles Sampled	Percent of Travel Way Mileage With CF Less Than .15	.20	.25	.30	.35	.40	.45	.50	.55	.60	.65	.70
PCC	Limestone	257.451		0	0.4	6.3	26.0	68.9	93.6	100				
	Dolomite	10.580				0	20.8	100						
AC	Limestone	792.562		0	1.4	2.6	13.2	24.4	41.0	60.5	77.5	92.2	99.3	100
	Dolomite	164.916			0	1.0	1.0	1.9	3.6	21.8	49.0	93.4	98.0	100
	Gravel	15.224						0	12.8	38.7	87.6	100		
PM	Limestone	132.918			0	3.0	11.4	27.9	52.8	78.5	96.0	100		
	Dolomite	5.095							0	100				
	Gravel	126.440			0	1.0	3.3	3.3	23.4	39.2	82.6	98.9	100	
SC	Limestone	96.686	0	4.4	12.6	31.8	59.7	78.8	91.0	96.9	100			
	Dolomite	33.832					0	19.3	67.0	100				
	Gravel	153.897					0	1.3	9.8	41.9	73.4	91.6	100	

Table 26: Weighted Average CF and SLC With Speed Gradients For PCC Pavements Constructed in 1967, 1968, and 1969.

Year Surface Constructed		Test Speed, mph			Speed Gradient(b)		
		40	50	60	G_{40-50}	G_{50-60}	G_{40-60}
1967	Sample(a)	93.578	93.578	13.468			
	CF	.45	.40	.32	.0050	.0080	.0065
	SLC	.80	.74	.68	.0060	.0060	.0060
1968	Sample	84.303	82.805	7.621			
	CF	.45	.38	.33	.0070	.0050	.0060
	SLC	.80	.75	.66	.0050	.0090	.0070
1969	Sample	69.863	69.863	9.804			
	CF	.44	.38	.33	.0060	.0050	.0055
	SLC	.79	.73	.68	.0060	.0050	.0055

(a) Travel Way Miles Sampled
(b) All values minus unless shown as plus(+).

Table 27: Tabulation of CF at 40 mph Cumulative Frequency Distribution of Travel Way Miles Sampled for PCC Pavements Constructed in 1967, 1968, and 1969.

Year Surface Constructed	Travel Way Miles Sampled	Percent of Travel Way Miles With CF Less Than								
		.25	.30	.35	.40	.45	.50	.55	.60	.65
1967	93.578		0	3.6	17.4	44.5	73.4	95.6	100	
1968	84.303		0	8.0	22.4	41.8	72.8	98.9	100	
1969	69.863		0	7.6	27.1	56.3	84.1	90.0	100	

Table 28: Weighted Average CF and SLC With Speed Gradients For AC Pavements Constructed in 1970, 1971, and 1972.

Year Surface Constructed		Test Speed, mph 40	50	60	Speed Gradient(b) G_{40-50}	G_{50-60}	G_{40-60}
1970	Sample(a)	119.838	115.976	12.379			
	CF	.44	.39	.30	.0050	.0090	.0070
	SLC	.78	.74	.66	.0040	.0080	.0060
1971	Sample	81.002	81.002	10.135			
	CF	.48	.42	.42	.0060	.0000	.0030
	SLC	.84	.80	.79	.0040	.0010	.0025
1972	Sample	29.040	27.405	15.600			
	CF	.49	.46	.48	.0030	+.0020	.0005
	SLC	.81	.81	.88	.0000	+.0070	+.0035

(a) Travel Way Miles Sampled
(b) All values minus unless shown as plus(+).

Table 29: Tabulation of CF at 40 mph Cumulative Frequency Distribution of Travel Way Miles Sampled for AC Pavements Constructed in 1970, 1971, and 1972.

Year Surface Constructed	Travel Way Miles Sampled	Percent of Travel Way Miles With CF Less Than .25	.30	.35	.40	.45	.50	.55	.60	.65
1970	119.838		0	2.2	18.8	57.1	79.1	90.4	100	
1971	81.002	0	.7	.7	9.3	31.4	48.4	90.0	100	
1972	29.040			0	11.9	59.4	63.3	63.3	72.5	100

Table 30: Tabulation of Wear Factors (k) For Coarse Aggregate Formation, Type, and Region.

		Surface Type	k_{CF}	k_{SLC}	Estimated Vehicle Passes For CF_{40}=0.40
Coarse Aggregate Formation	Bethany Falls Limestone	PCC	-0.076	-0.054	2.25×10^6
	Burlington Limestone	PCC	-0.028	0.000	60.00×10^6
	Plattin Limestone	PCC	-0.224	-0.016	16.50×10^6
	Plattin Limestone	AC	-0.039	-0.043	$.81 \times 10^6$
	Bethany Falls Limestone	AC	-0.090	-0.059	3.15×10^6
	Burlington Limestone	AC	-0.107	-0.088	16.50×10^6
	Jefferson City Dolomite	AC	+0.011	+0.014	--
Coarse Aggregate Type	Limestone	PCC	-0.083	-0.046	4.50×10^6
	Limestone	AC	-0.053	-0.042	18.00×10^6
	Dolomite	AC	-0.032	-0.034	$15,000.00 \times 10^6$
	Limestone	PM	+0.288	+0.170	--
Region	Northwest	PCC	-0.116	-0.103	3.9×10^6
	Northeast	PCC	-0.116	-0.068	12.60×10^6
	South	PCC	-0.046	-0.060	51.00×10^6

Table 31: Accident Study for Four Locations Comparing CF and SLC Before and After Surface Treatment.

				Surface Friction				Number of Reported Accidents									
								Before					After				
Location	Length	Geometric Condition	Test Speed (mph)	Before CF	Before SLC	After CF	After SLC	Study Period (Month)	No. Wet	Wet Per Year	No. Dry	Dry Per Year	Study Period (Month)	No. Wet	Wet Per Year	No. Dry	Dry Per Year
1	0.94	Horiz. Curve	40	.39	.68	.40	.71	12	7	7.00	1	1.00	13	0	0	0	0
2	0.17	Horiz. & Vert. Curve	40	.25*	.54*	.56	.86	19	29	18.32	20	12.63	11	0	0	7	7.64
3	5.86	Variable	40	.44	.77	.16	.30	28	1	0.43	3	1.28	26	12	5.14	4	1.71
4	17.18	Variable	40	.20	.40	.54	.89	22	29	15.82	10	5.45	20	1	0.60	28	16.80

* Estimated from friction tests obtained adjacent to this area, for similar surface types.

Table 32: Contingency Table For Accident Type and Road Condition, for 1970-1971 Accidents.

Road Condition	Accident Type		
	One-Vehicle	Other	Total
Wet	432	798	1230
Dry	996	3654	4650
Total	1428	4452	5880
Wet/Dry Ratio	0.434	0.218	

Table 33: Comparison of 1970-1971 One-Vehicle Type Accidents for Wet and Dry Road Condition with Average CF at 40 mph.

Road Condition	Range of Average CF						
	≤.31	.32-.35	.36-.39	.40-.43	.44-.47	≥.48	Total
Wet	18	17	23	8	11	6	83
Dry	27	17	29	39	50	29	191
Total	45	34	52	47	61	35	274
Wet/Dry Ratio	0.667	1.000	0.793	0.205	0.220	0.207	
Total Travel Way Miles Sampled	24.74	28.25	74.96	107.01	126.14	77.53	438.63

Table 34: Minimum Interim Skid Numbers as Recommended in NCHRP Report 37.

Mean Traffic Speed, V (mph)	Skid Number [a]	
	SN_V [b]	SN_{40} [c]
0	60	--
10	50	--
20	40	--
30	36	31
40	33	33
50	32	37
60	31	41
70	31	46
80	31	51

(a) Skid Number equals Coefficient of Friction x 100.

(b) Skid Number measured at mean traffic speeds.

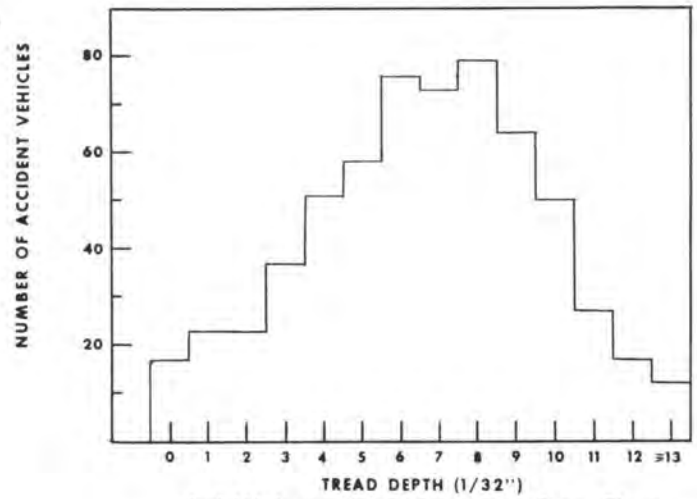
(c) Skid Number measured at 40 mph, including allowance for the skid number reduction with speed using a mean speed gradient of 0.5.

Table 35: Distribution of Minimum Tread Depths for all Vehicles Involved in Greene County Accidents Between 9/15/71 and 12/15/71.

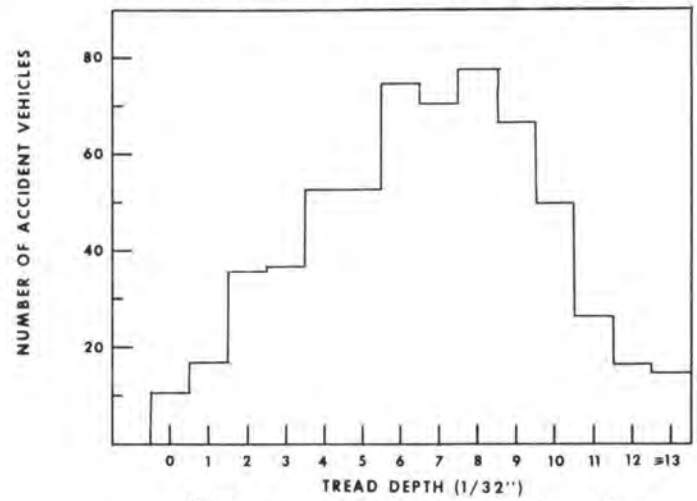
Minimum Tread Depth (1/32")	Vehicles Involved In Accidents					
	Front Tires	%	Rear Tires	%	Front or Rear Tires	%
0	17	2.8	11	1.8	27	4.5
1	23	3.8	17	2.8	29	4.8
2	23	3.8	36	5.9	42	6.9
3	37	6.1	37	6.1	53	8.7
4	51	8.4	53	8.7	71	11.7
5	58	9.6	53	8.7	68	11.2
6	76	12.5	75	12.4	82	13.5
7	73	12.0	71	11.7	65	10.7
8	79	13.0	78	12.9	65	10.7
9	64	10.6	67	11.1	45	7.4
10	50	8.2	50	8.2	32	5.3
11	27	4.4	27	4.4	13	2.1
12	17	2.8	17	2.8	8	1.3
≥13	12	2.0	15	2.5	7	1.2
Total	607	100.0	607	100.0	607	100.0

Table 36: Contingency Table for Accident Type and Tread Depth for Wet Pavement Accidents.

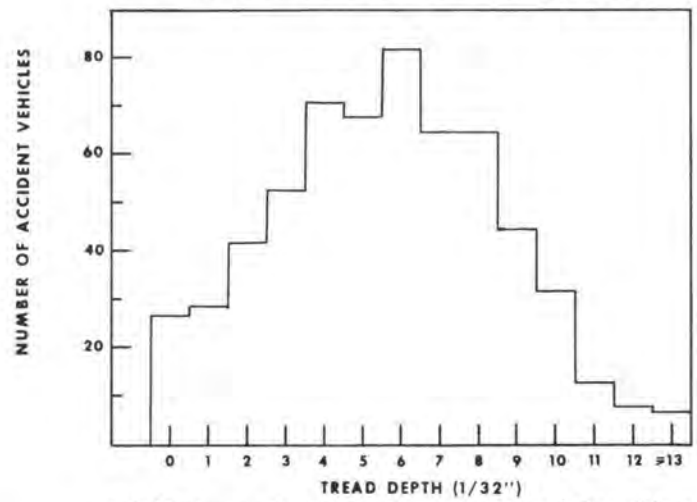
Min. Vehicle Tire Tread Depth (1/32 in.)	Accident Type		
	One-Vehicle	Multi-Vehicle	Total
0-2	5	8	13
≥3	11	50	61
Total	16	58	74



(a.) Minimum Tread Depths -- Front Tires



(b.) Minimum Tread Depths -- Rear Tires



(c.) Minimum Tread Depths -- Front and Rear Tires

Figure 8: Histogram of tire tread depths.

Table 37: Contingency Table for Accident Type and Tread Depth for Wet and Dry Road Conditions.

Min. Vehicle Tread Depth (1/32")	Accident Type		
	One-Vehicle	Multi-Vehicle	Total
0-2	12	74	86
3-5	19	119	138
6-8	12	65	77
≥ 9	6	13	19
Total	49	271	320

Table 38: One Vehicle Accidents Classified by Road Condition (Wet or Dry) and Minimum Vehicle Tire Tread Depth.

Min. Vehicle Tire Tread Depth (1/32 inch)	No. Wet	% Wet	No. Dry	% Dry	Wet/Dry Ratio	Total
0-5	12	24.5	19	38.7	.632	31
≥ 6	4	8.2	14	28.6	.286	18
Total	16	32.7	33	67.3	.485	49

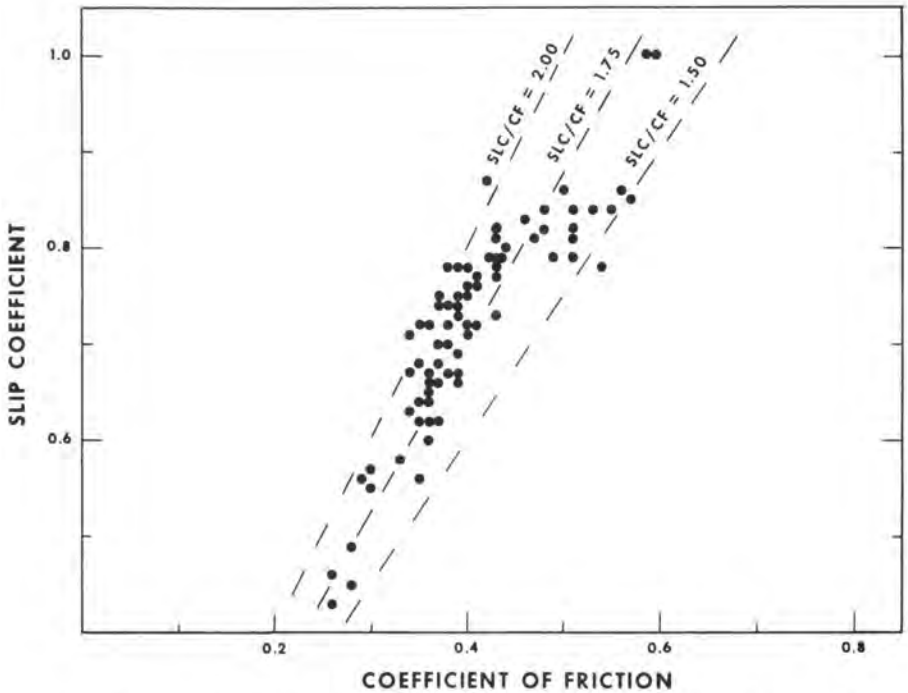


Figure 9: Plot of Slip Coefficient versus Coefficient of Friction at 40 mph for a sample of PCC pavements.

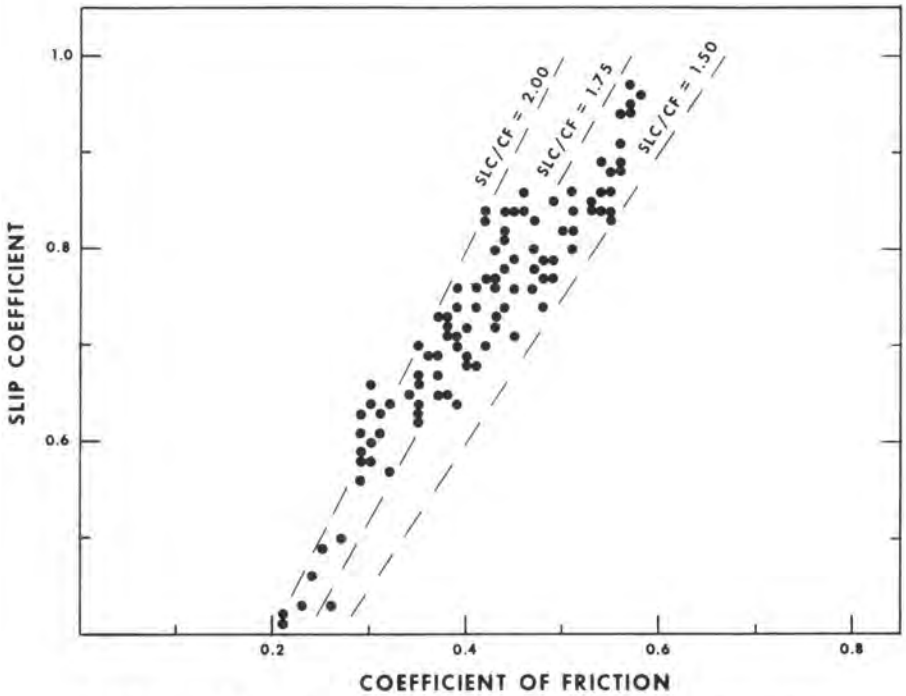


Figure 10: Plot of Slip Coefficient versus Coefficient of Friction at 40 mph for a sample of AC pavements.

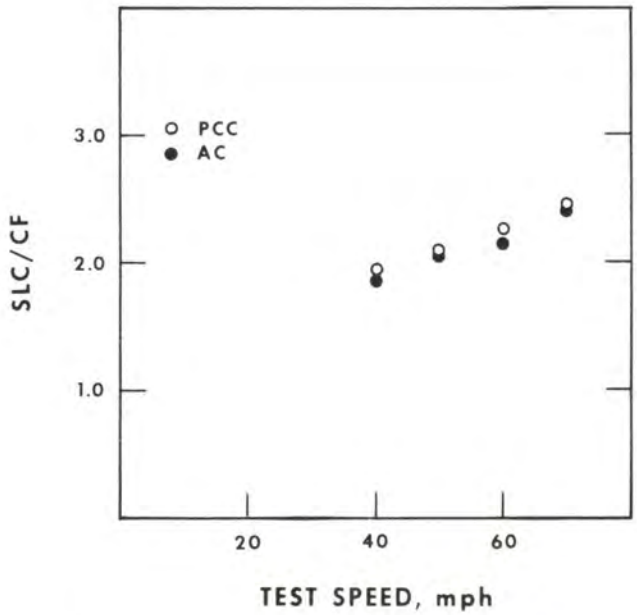


Figure 11: Plot of SLC/CF versus test speed.

Table 39: Comparison of Average SLC/CF Ratios for Surface Texture Classifications from a Sample of Portland Cement Concrete at 40 mph.

	Surface Voids	
Knobbiness	Absent	Present
Smooth	1.83 (40)	1.76 (35)
Knobby	1.74 (3)	1.79 (3)

( ) Number of data points used to compute averages.

Table 40: Comparison of Average SLC/CF Ratios for Surface Texture Classifications from a Sample of Asphaltic Concrete at 40 mph.

	Surface Voids	
Knobbiness	Absent	Present
Smooth	1.80 (4)	1.62 (28)
Knobby	1.83 (42)	1.68 (65)

( ) Number of data points used to compute averages.

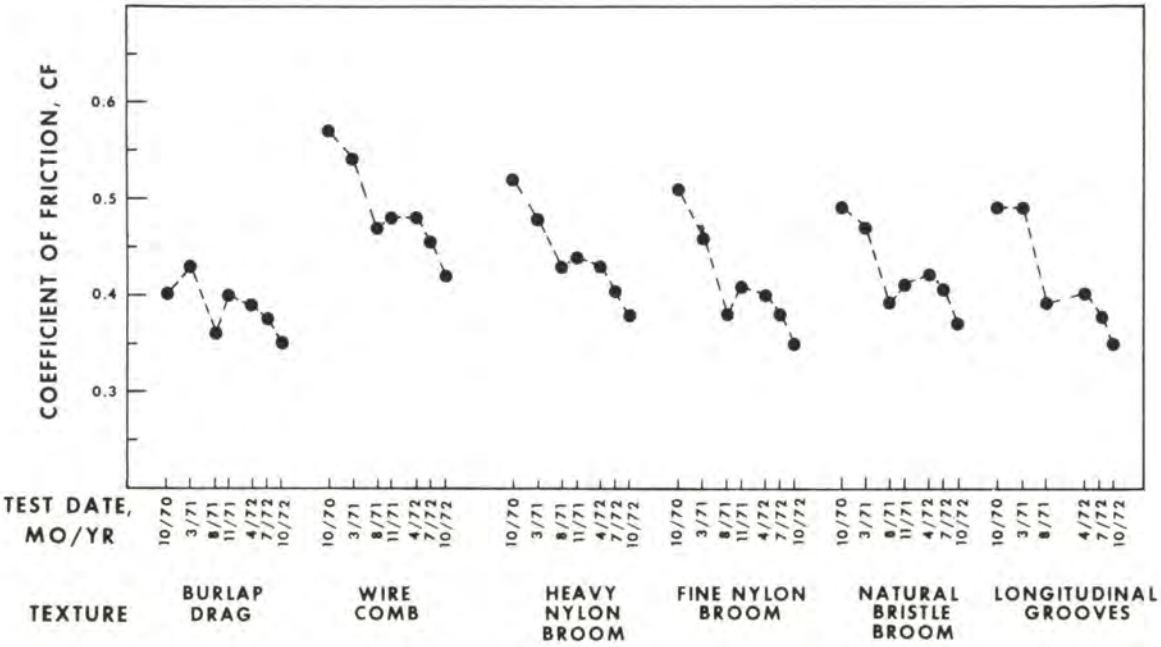


Figure 12: Illustration of fluctuation of CF at 40 mph for special PCC textures.

Table 41: Special Surface Finishes Used in Plastic and Hardened PCC Pavements.

Location	Surface Finish	Beginning Service	Date Tested	Estimated Total Vehicle Passes Per Lane	CF mph 30	40	50	60	70	Speed Gradient (a) G_{30-50}	G_{40-60}	G_{50-70}	CF Wear Factor(e) k
1A	Longitudinal	8/70	10/70	90,000	.47	.40	.36	.32	.26	.0055	.0040	.0050	
	Burlap Drag		11/71	1,082,000	(b)	.40	.36	.35	.30	--	.0025	.0030	
	(Std. Finish)		10/72(c)	1,948,000	.38	.35	.27	.27	.22	.0055	.0040	.0025	-.043
1B	Transverse	8/70	10/70	90,000	.63	.57	.53	.50	.47	.0050	.0035	.0030	
	Wire Comb		11/71	1,082,000	-	.48	.46	.41	.38	--	.0035	.0040	
			10/72	1,948,000	.44	.42	.31	.32	.29	.0065	.0050	.0010	-.099
1C	Transverse	8/70	10/70	90,000	.60	.52	.49	.47	.42	.0055	.0025	.0035	
	Heavy Nylon		11/71	1,082,000	-	.44	.40	.37	.35	--	.0035	.0025	
	Broom		10/72	1,948,000	.40	.38	.29	.30	.27	.0055	.0040	.0010	-.102
1D	Transverse	8/70	10/70	90,000	.59	.51	.47	.43	.36	.0060	.0040	.0055	
	Fine Nylon		11/71	1,082,000	-	.41	.37	.33	.31	--	.0040	.0030	
	Broom		10/72	1,948,000	.40	.35	.27	.28	.23	.0065	.0035	.0020	-.122
1E	Transverse	8/70	10/70	90,000	.58	.49	.45	.44	.35	.0065	.0025	.0050	
	Natural Bristle		11/71	1,082,000	-	.41	.39	.33	.30	--	.0040	.0045	
	Broom		10/72	1,948,000	.41	.37	.29	.28	.25	.0060	.0045	.0020	-.091
1F	Longitudinal	8/70	10/70	90,000	.50	.49	.46	(d)	-	.0020			
	Grooves		11/71	1,082,000	-	-	-						
			10/72	1,948,000	.38	.35	.28	-	-	.0050			-.109
2A	Longitudinal	9/71	9/71	207,000		.61	.54	.50			.0055		
	Grooves		9/72	4,712,000		.36	.31	.28			.0040		-.169
2B	Transverse	9/71	9/71	207,000		.54	.49	.46			.0040		
	Nylon Broom		9/72	4,712,000		.40	.33	.30			.0050		-.096
	(Std. Finish)												
3A	Longitudinal	6/71	11/71	197,000		.49	.43	.37			.0040		
	Burlap Drag		9/72	452,000		.43	.41	.36			.0035		-.157
3B	Longitudinal	6/71	11/71	197,000		.50	.48	.42			.0040		
	Grooving		9/72	452,000		.51	.46	.42			.0045		+.024

(a) All values negative unless shown as positive (+).
(b) No 30 mph tests were made due to inclement weather.
(c) Only inner or left wheelpath tests were made due to equipment malfunctions.
(d) Section too short for 60 and 70 mph tests.
(e) Based on initial and last tests at 40 mph.

Table 42: Change in Sand-Patch Texture Depths for Location 1.

Section	Type Of Texture	Average Sand-Patch Texture Depth* (inches)			Percent Change Sand-Patch Texture Depth (inches)		
		1970	1971	1972	1970-71	1971-72	1970-72
1	Burlap Drag	0.020	0.013	0.011	-35	-15	-45
2	Wire Comb	0.029	0.019	0.016	-34	-16	-45
3	Heavy Nylon Bristle Broom	0.030	0.016	0.012	-47	-25	-60
4	Fine Nylon Bristle Broom	0.026	0.012	0.011	-54	- 8	-58
5	Natural Bristle Broom	0.021	0.011	0.011	-48	0	-48
7	Longitudinal Grooving	0.036	0.017	0.015	-53	-12	-58

* Average obtained in wheelpaths.

Table 43: Asphaltic and Bituminous Mixes with Special Materials.

Location	Mix No.	Percent Coarse Aggregate	Percent Fine Aggregate	Percent Voids	Percent Asphalt	Beginning Service	Date Tested	Estimated Total Vehicle Passes Per Lane	CF_{mph} 20	30	40	50	60	Speed Gradient (a) G_{20-30}	G_{30-40}	G_{20-40}	G_{40-50}	G_{40-60}	CF Wear Factor(b) k	Estimated Vehicle Passes For CF_{40}=0.40
1A	C69-471	79.6 Trap Rock	12.0	5.64	5.0	11/69	7/70	235,000		.59	.54				.0050					
							8/71	874,000	.68	.61	.57			.0070	.0040	.0055				
							9/72	1,558,000	.59	.54	.49			.0050	.0050	.0050			-.051	8332×10^4
1B	D69-624	79.3 Blast Furnace Slag	10.0	5.71	7.0	11/69	7/70	235,000		.63	.58				.0050					
							8/71	874,000	.76	.69	.63			.0070	.0060	.0065				
							9/72	1,558,000	.67	.60	.56			.0070	.0040	.0055			-.019	8254×10^{10}
2	C69-104	80.2 Trap Rock	11.0	5.86	5.2	9/69	7/70	2,048,000	.53	.41				.0120						
							5/72	7,670,000	.55	.46				.0090						
3	D71-338	74.4 Trap Rock	15.4	5.68	5.2	7/71	5/72	3,383,000			.50	.44					.0060			
4	C68-410	70.3 Trap Rock	20.3	1.96	4.4	10/68	6/70	4,289,000	.50	.44				.0060						
							5/71	6,958,000	.56	.49				.0070						
							6/72	8,137,000	.52	.44				.0080						
5	X71-62	61.7 Expanded Shale	26.0	5.87	8.0	8/71	8/71	90,000(c)			.50	.45					.0050			
								120,000			.50	.47					.0030			
							10/71	966,000			.62	.54					.0080			
								1,288,000			.61	.56					.0050			
							8/72	4,136,000			.50	.44					.0060			
								5,515,000			.46	.42					.0040			
							10/72	5,194,000			.52	.43					.0090		+.010	
								6,925,000			.48	.40					.0080		-.010	57348×10^{10}
6	C67-381	59.2 Trap Rock	32.0	4.19	4.5	9/67	3/71	4,968,000(c)		.55	.48	.44			.0070		.0040			
								2,264,000		.55	.46				.0090					
7	C69-430	80.2 Trap Rock	11.0	5.86	5.2	11/69	8/71	4,498,000(c)	.53	.47				.0060						
								2,248,000	.59	.50	.45			.0090		.0070				
8	D70-259	77.9 Trap Rock	13.3	5.19	4.8	9/70	10/71	(d)		.51	.44				.0070					
							10/72			.45	.41				.0040					
9	D71-344	80.0 Trap Rock	11.0	5.80	5.0	7/72	11/72	520,000			.53	.47	.46				.0060	.0035		
10A	BP70-127M	85.0 Crushed Stone	15.0 Joplin Chat	5.13	5.3	11/70	11/70	0		.67	.68				+.0010					
								0			.68		.63					.0025		
								0			.70	.69	.62				.0010	.0040		
								0			.67	.63	.60				.0040	.0035		
							10/71	256,000(c)		.62	.48				.0140					
								344,000			.51	.48	.42				.0030	.0045		
								381,000			.51	.48	.44				.0030	.0035		
								538,000			.46	.42	.36				.0040	.0050		
							11/72	562,000(c)		.55	.49				.0060				-.025	1884×10^6
								709,000			.50	.45	.41				.0050	.0045	-.023	11591×10^6
								797,000			.50	.44	.41				.0060	.0045	-.025	5995×10^6
								1,341,000			.41	.37					.0040		-.035	1341×10^3
10B	BP70-124M	45.0 Crushed Stone	15.0 Joplin Chat	7.44	6.0	11/70	11/70	0		.68	.65	.60			.0030		.0050			
								0			.68	.65	.55				.0030	.0065		
		40.0 Joplin Chat					10/71	684,000(c)		.55	.49				.0060					
								868,000			.50	.48	.40				.0020	.0050		
							11/72	1,661,000(c)		.53	.47				.0060				-.023	1843×10^6
								2,082,000		.52	.46				.0060				-.027	369×10^6
10C	BP70-121M	72.0 Joplin Chat	28.0 Limestone Screening	7.91	6.0	11/70	11/70	0			.72	.67	.65				.0050	.0085		
							10/71	918,000			.55	.50	.48				.0050	.0035		
							11/72	2,216,000		.58	.53	.47			.0050		.0060		-.021	14634×10^8
	BP72-80M	85.0 Crushed Stone	15.0 Joplin Chat	5.13	5.3	6/72	6/72	0		.60	.59	.55			.0010		.0040			
							11/72	193,000		.55	.51	.46			.0040		.0050		-.012	
	BP71-86M	85.0 Crushed Stone	15.0 Mo. River	4.56	4.6	6/71	6/72	115,000		.46	.42	.38			.0040		.0040			

(a) All values negative
(b) Based on initial and last tests at 40 mph
(c) Differences on the same date are due to test sections with different ADT
(d) No ADT available

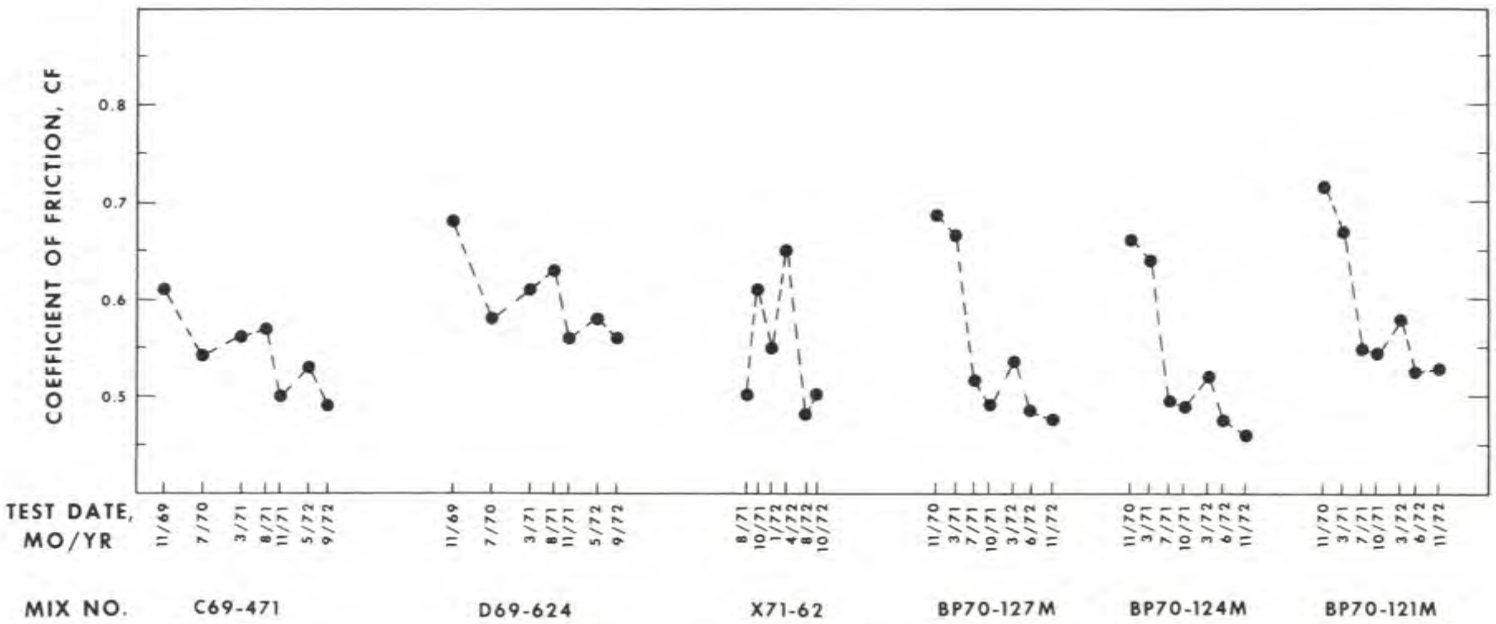


Figure 13: Illustration of fluctuation of CF at 40 mph for special asphaltic and bituminous mixes.

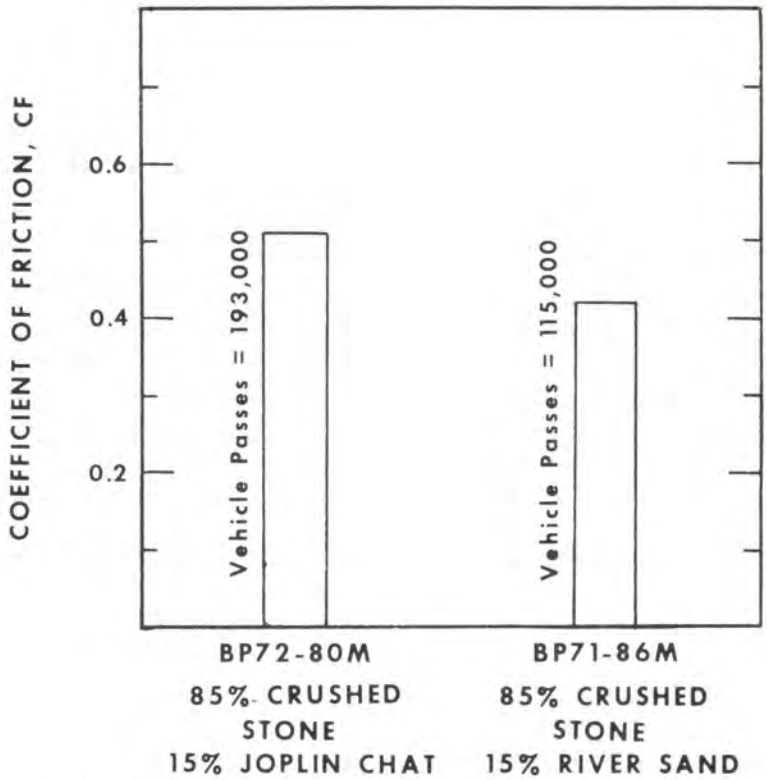


Figure 14: Comparison of CF at 40 mph for two bituminous leveling course mixes.

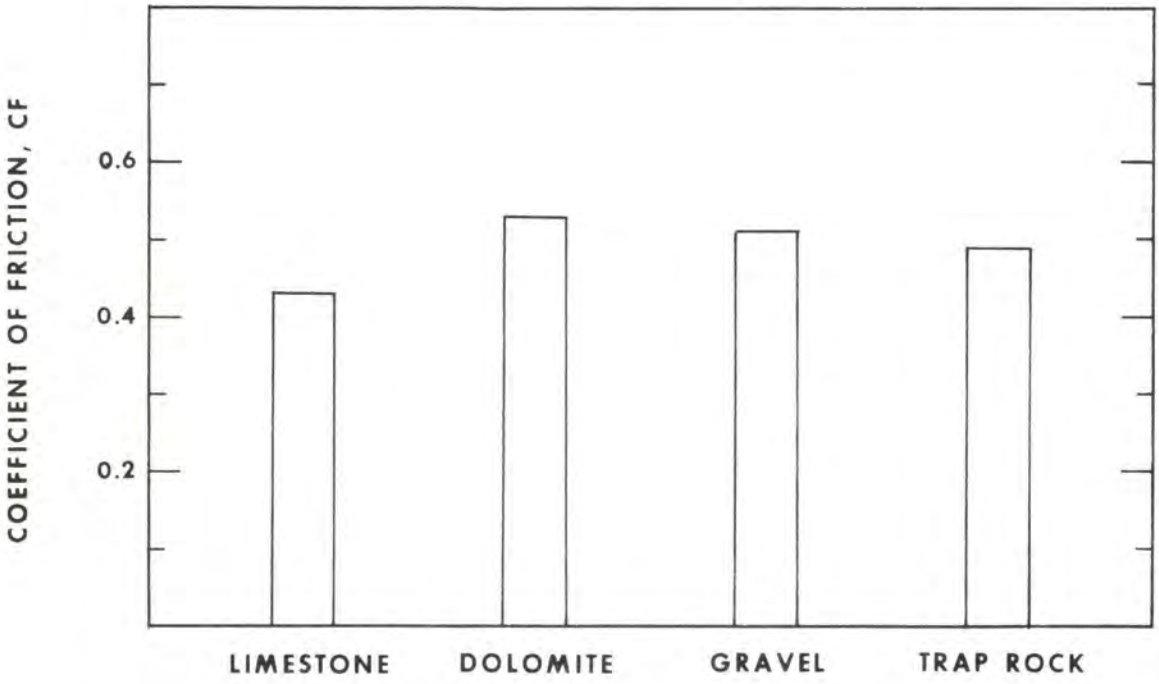


Figure 15: Comparison of CF at 40 mph of four types of coarse aggregates used in AC mixes.

Table 44: Test Results of New Skid Resistant Surfaces Constructed on an Airport Runway.

Surface	CF_{mph}		SLC_{mph}		CF Speed Gradient	Ratio SLC/CF	
	40	60	40	60		40 mph	60 mph
PCC, Transverse Wire Comb With Transverse Grooves	.67	.64	.96	.90	-.0015	1.44	1.42
Bituminous Porous Friction Course	.55	.46	.92	.87	-.0042	1.69	1.88

APPENDIX B

FORMULAS

FORMULAS

AGE-TRAFFIC-INDEX (ATI) = $\frac{(Am)\ (ADT)}{100}$, where

Am = Age of surface in months,
ADT = Average daily traffic

Wear Factor (k) = $\frac{\log CF_{v_a} - \log CF_{v_b}}{\log_{v_a} - \log_{v_b}}$, where

v_a = Number of accumulated vehicle passes for day (a),

v_b = Number of accumulated vehicle passes for day (b),

CF_{v_a}, CF_{v_b} = CF measured at the respective number of accumulated vehicle passes.

Speed Gradient (G) = $\frac{CF_A - CF_B}{A - B}$, where

A, B = Test Speeds, mph;

CF_A, CF_B = CF determined at respective test speeds.

APPENDIX C

DESCRIPTION OF PCC TEXTURING DEVICES

MISSOURI DESCRIPTION OF EXPERIMENTAL TEXTURING DEVICES ON PORTLAND CEMENT CONCRETE PAVEMENTS

Wire Comb

A device 12 feet long with a single line of wires exposed to a length of 3 inches. The wire (blue tempered and polished spring steel) is .028 inches in thickness and 1/16 inch wide. The wires are spaced at 1/4 inch centers and are mounted in an aluminum head.

Heavy Nylon Bristle Broom

A device made of polypropylene plastic with two rows, at approximately one inch centers, of plastic strands consisting of 11 clusters, per foot of broom length, in each row. Cluster holes are 3/8 inch diameter. There are approximately 48 oval strands of plastic, with dimensions of .031 by .046 inch, exposed to a length of 4-1/4 inches in each cluster. The broom length was 13 feet.

Fine Nylon Bristle Broom

This broom has an identical description to the heavy nylon bristle broom except the dimensions of the oval strands of plastic are .032 by .041 inch.

Natural Bristle Broom

A device made of palmyra fiber with three rows of fibers consisting of 11 clusters per foot in each row. Cluster holes are 3/8 inch diameter with the rows spaced at 3/4 inch and the middle row of clusters are staggered with respect to the two outside rows. There are approximately 50 strands of fiber exposed to a length of 4 inches in each cluster.

APPENDIX D

MISSOURI SAND-PATCH TEST METHOD

MISSOURI METHOD FOR MEASUREMENT OF PAVEMENT SURFACE TEXTURE DEPTH BY THE SAND-PATCH METHOD

SCOPE:

This method describes a procedure for determining the average texture depth of a selected portion of a concrete pavement surface.

1. APPARATUS

The apparatus shall consist of the following:

a. Sand spreading tool consisting of a 2½-in. diameter flat wooden disc with a 1/16 inch thick hard rubber disc of the same diameter attached to one face and a short dowel serving as a handle attached to the other face.

b. Metal cylinder with a volume of approximately 1.5 cu. in. (A cylinder 3.40 inches in height with an inside diameter of 0.75 inches has a volume of 1.50 cubic inches.)

c. Natural silica sand from Ottawa, Illinois designated AFS 50/70 sand graded to pass a No. 40 (297-micron) sieve and retained on a No. 100 (149-micron) sieve, with 95% passing No. 50 sieve.

d. Balance sensitive to 0.1 gram.

e. Ruler, 12 in. long with markings in divisions of every 0.1 inch.

f. Wire brush and soft bristled hand brush.

g. Small plastic or metal containers for storing the required weight of sand for a single test. The container interior must be designed to permit emptying entire weight of sand for a single test. A 3 oz. tinned metal ointment box would be satisfactory.

2. PROCEDURE

a. Determine the exact volume, V, of the metal cylinder by weighing the water required to fill the cylinder and then calculating the volume in cubic inches. One cubic inch of water at 4°C (39.2°F) weighs 16.4 grams. Therefore, the following formula can be used to convert the net weight of water to volume.

$$V = \frac{\text{Net weight, in grams, of water at } 4^{o}C(39.2^{o}F)}{16.4 \text{ grams per cubic inch}}$$

b. Using the following formula prepare a conversion table in which texture depths, T, can be determined for sand patch diameter, D, ranging from 4 to 12 inches in increments of 0.1 inch.

$$T = \frac{4V}{\pi D^2}$$

T = Texture Depth in inches

V = Volume of metal cylinder in cubic inches

D = Sand Patch diameter in inches

c. Determine the weight of sand needed to fill the metal cylinder. Fill the cylinder to the top with dry sand and gently tap the base of the cylinder three times on a rigid surface. Add sand to again fill the cylinder to the top then level the top with a straight edge. Obtain the net weight of sand to the nearest 0.1 gram.

Repeat this procedure a minimum of ten times to determine the average weight of sand required to fill the cylinder. This amount (weight) of sand should then be used for every sand patch test. Sand for several tests may be weighed in advance and stored in the small plastic or metal containers.

d. The pavement surface selected for test must be dry. If the concrete pavement has not been subjected to traffic, scrub the test surface with a wire brush to remove any loosely bonded particles or curing compounds that will be worn away by a small amount of traffic. Otherwise, the pavement surface should be swept with a soft hand brush. Care should be taken on concrete surfaces tested at an early age. Excessive brushing or scrubbing will alter the surface texture.

e. Pour the previously measured weight of sand on the test surface and spread it with the rubber disc spreading tool into a circular patch until the surface depressions are filled to the level of the peaks. The sand spreading tool should be kept flat on the surface and moved in a circular motion. Avoid losing any sand, especially during windy conditions. Sand used for one test should not be reused for another test.

f. Measure the diameter of the sand patch at four or more equally spaced locations and record to the nearest 0.1 in.

For textured pavement surfaces with texture depths ranging from .020 to .040 inch, 1.5 cubic inches of sand will produce patch diameters ranging between 7 and 10 inches. For larger patch diameters, it becomes more difficult to obtain proper distribution of the sand as outlined in Section 2e. Much better distribution of the sand can be obtained by using approximately one-half the volume of sand (0.75 cubic inches). For texture depths ranging from .020 to .040 inches, a volume of 0.75 cubic inches of sand produces patch diameters ranging between 5 and 7 inches.

g. Calculation of Texture Depth

Compute the average diameter of the sand patch from the measured diameters then determine the texture depth by using the computed conversion table or by use of the formula

$$T = \frac{4V}{\pi D^2}$$

3. REPORT

The report shall contain

a. The date of test,

b. The location of the test (County, Route, Project, Station Number, Lane Designation, and Distance right or left of centerline),

c. The average sand patch diameter,

d. The volume and weight of sand used,

e. The texture depth,

f. and Remarks.

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