INTERIM REPORT

ON

FRICTIONAL CHARACTERISTICS OF PAVEMENT SURFACES

by

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to

The Arizona Highway Department
and
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ABSTRACT

The research has been concerned with the measurement of pavement slipperiness and the search for means to anticipate the rate of change of this characteristic. The stopping distance method has been used for obtaining the condition of the pavement surfaces. These measurements were made at speeds ranging from 30 to 60 mph on ten sections of roads in the state. Decelerometer measurements were also made. The test sites were sampled for 6-inch diameter cores which were then tested in the laboratory for surface friction and surface texture. All skidding measurements were made on wet pavement surfaces.

Preliminary studies of data indicate that the surfaces tested have more than adequate resistance to skidding. The fine and gritty surface was as good if not better than the knobby texture for resistance to skidding. At the present, sufficient data have not been obtained to show relationships between laboratory and field friction value nor to establish the rate of friction deteriometion for the test sites.

INTRODUCTION

General

This investigation was initiated to obtain knowledge concerning the condition of pavement surfaces with respect to frictional characteristics. In turn, this knowledge will be used in the design and construction of paving mixtures and their future maintenance. Of course, the final objective is to assure that our highways will have an acceptable skid resistance in consideration of safety.

Much of the work reported herein is limited to that which is felt to have some degree of acceptance or which appears to have some merit but which at the present can not be verified. These limitations are necessary because presently these are insufficient amounts of data or trials for analyzing the data collected.

Definitions

It would seem unnecessary to have a section to define terms used in the area of pavement friction. However, such a subdivision is necessary because of the misuse of the word *friction* and our better understanding of the forces developed as a tire slides on a pavement surface. A minimum of definitions will be presented, and these are generally given in the form presented by Kummer [1]*.

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*Numbers in parentheses refer to literature citations given at the end of this report.

(1) *Friction* - According to most dictionaries friction "is the resistance to relative motion between two bodies in contact." The use and concept of friction as applied to highway pavements are quite often in error or not understood. One should realize that a pavement surface does not have a so-called coefficient of friction. The "resistance to relative motion" between tire and pavement depends on many factors, and thus, conditions existing at the time of determining this "resistance" must be defined.

(2) *Rubber Friction* - The resistance to sliding of rubber in contact with another material is composed of two parts: one due to adhesion and the other one comes from hysteresis [2]. No amplification of these components will be given here except for a later explanation for differences between winter and summer values of pavement skid resistance.

(3) *Friction Number (FN)* - "FN . . . is defined as the ratio of (tire) friction to (wheel) load times 100." This terminology was developed for highway conditions utilizing a dimensionless number to express friction as a percent of wheel load.

(4) *Skidding* - This term is the uncontrolled movement of a car under locked wheel conditions. It also applies to the conditions of tires during road friction measurements.

(5) *Skid Number (SN)* - Similar to FN, its use is related to highway surfaces and expresses the skid resistance at the locked tire-pavement interface as a percent of the wheel load.

(6) *Stopping Distance Number (SDN)* - The skid resistance value SDN is obtained by determing the distance travelled in bringing a speeding vehicle to a complete stop by locking its wheels and calculating FN.

The above terminology applies to highway pavements and the values of concern are generally those associated with wet surfaces. Because wet pavements present the critical condition with respect to skid resistance, all of the testing done for the study was on wet surfaces.

General Programs

In order to achieve the objectives of the study, a combination of field and laboratory testing are presently being performed. Briefly, the plan is to obtain a measure of the present skid resistance of relatively new pavement surfaces and then follow its change(s) caused by traffic-polish. Different surface types and traffic volumes have been selected for the evaluation.

Core samples from the test sites will be evaluated in the laboratory for surface friction and surface asperity, and these data will be analyzed in search for correlations with field skid resistance values.

The following sections present the early results obtained from the field and laboratory work and their comparisons.

FIELD MEASUREMENTS

Test Sites

In cooperation with the Arizona Highway Department, ten test sites were selected with consideration of (a) surface age being less than 1½ years, (b) type of surface material, and (c) amount of traffic. Figure 1 shown the relative locations of sections being tested. Additional information is given in Table 1 of the Appendix. From Table 1 it is noted that the pavement surfaces include the "gritty" and also "knobby" types which are predominantly used in the Districts containing test sites. Of particular interest will be the relative values of skid resistance for 3/8" dense graded asphaltic concrete and 3/8" open graded plant-mix seal.

In general, the test sites were chosen primarily on the basis of age since it has been reported [2] that a final level of skid resistance for pavements is reached after a certain number of vehicle passages. As a consequence, an attempt was made to select surfaces less than two years of age. Of the ten sites, three had not been opened to the public when the first skid measurements were made, six were between one and two years of age, and one section was over two years of age but was selected because of the large aggregate in the surface material.

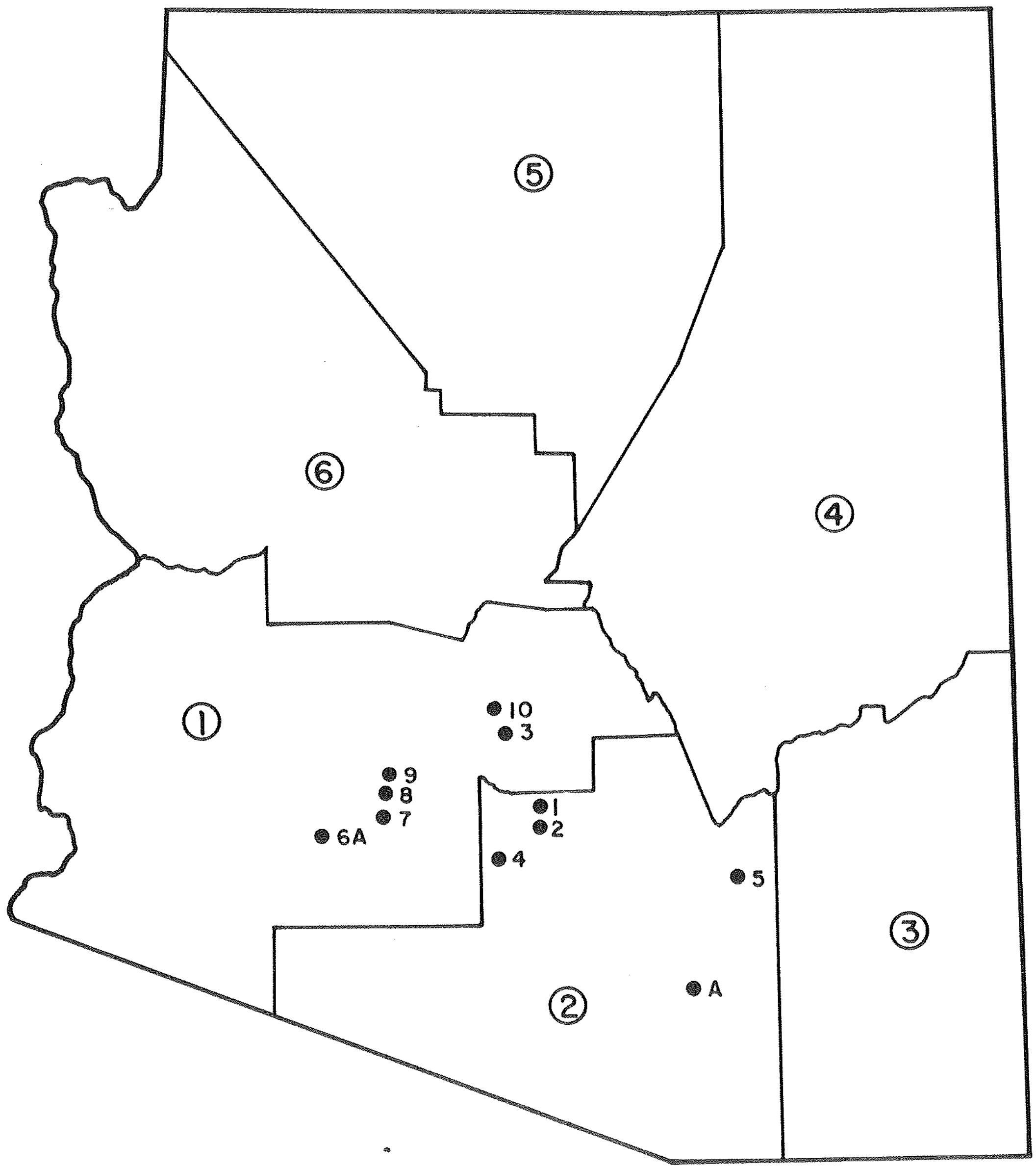


Figure 1. Location of Skid Testing Sites

Field Testing

At least three methods are available for the determination of pavement friction. These are (a) stopping distance, (b) deceleration, and (c) skid trailer. Initial planning of low budget and literature review [3, 4] indicated the desirability of considering the decelerometer method in the study. Certainly there is ample evidence that the towed skid trailer is the most efficient and safest method for obtaining measurements of skid resistance. However, because of the exploratory nature of the program and the apparent acceptability of either the stopping distance or decelerometer method, the trailer method was considered too expensive.

The press of time to initiate the field measurements of pavement friction limited the amount of training and calibration for use of the decelerometer method. As a consequence, the stopping distance method was used along with the decelerometer in field measurements since its procedure is relatively simple to duplicate. A brief description of these two methods follows:

In the decelerometer method, which was first promoted in England, a pendulum type decelerometer is used to obtain the deceleration of the test vehicle upon the momentary and firm application of the brakes. Marshall [3] and Dillard [4] have shown the period of braking to be approximately one second. The "coefficient of friction" is considered to be numerically equal to the deceleration in terms of gravity, g. Under the condition of braking the frictional force, F, is equal to the weight of the vehicle, W, times the "coefficient of friction," f, between the tires and pavement surface as shown by the equation,

$$F = fW. \qquad (1)$$

From kinematics, acceleration of a body due to a force is given by the equation,

$$F = Ma = \frac{Wa}{g} , \qquad (2)$$

where a is the acceleration of the body and g is the acceleration due to gravity. Substituting fW of Equation (1) into F of Equation (2) leads to

$$f = a/g. \qquad (3)$$

The stopping distance method has been used quite extensively in the United States. Its major drawback is related to safety; that is, test speeds have been limited to below 30 to 40 miles per hour [5], and traffic must be completely controlled. With this procedure, the brakes are applied and held for a vehicle travelling at a known speed, and the distance required to stop is determined. The "coefficient of friction" or stopping distance number (SDN) is calculated with a simple equation developed from equating work to change in kinetic energy as follows:

$$FS = \tfrac{1}{2}M(V_1{}^2 - V_2{}^2) \qquad (4)$$

$$fWS = \frac{WV^2}{2g} , \quad V_2 = 0, \tag{5}$$

$$f = \frac{V^2}{2gS} , \tag{6}$$

where S is the stopping distance in feet and V is initial velocity in feet per second. If velocity is expressed in miles per hour and the value of 32.2 is given to g, Equation (6) reduces to

$$f = \frac{V^2}{30S} . \tag{7}$$

It is generally accepted that the stopping distance method is the most representative of a panic stop [1] and as such will respond to characteristics of vehicles and drivers. It should be noted that the distance S of Equation (7) needs to be defined as to whether it is only skidding distance or whether it includes the distance travelled from the time of applying the brakes to the locked wheel condition. Further comments of the method of measurements of friction will be presented at the time of discussing results obtained.

The general procedure for testing a section was as follows. Traffic was controlled over a distance of approximately 1,500 feet with the aid of signs and flagmen. A watering truck made three passes over a 400-foot long by 12-foot wide test site, and, on the last pass, it kept moving ahead for a distance of about 200 feet. As soon as possible the test vehicle, which was waiting upstream, made the approach run to reach the saturated test section at the desired speed. The first measurement was with the decelerometer, and as soon as the instrument was read, the test vehicle was backed up and a second run made without rewetting. A second pair of decelerometer measurements was made after another passing of the watering truck.

Following the decelerometer tests, stopping distance determinations were made; however, in this case, the pavement surface was watered prior to each of three test runs. If the differences between the low and high value of the first four decelerometer readings was greater than four, then two or four additional decelerometer runs were made.

The first test speed was usually 40 mph and then increased to 50 and up to 60 mph if vehicle behavior and environment indicated a probable safe test.

The photographs of Figure 2 show the test vehicle to have been a 1961 four-door Ford Fairlane. The only modification made to the vehicle was the installation of front spring spreaders and the use of 7.50 x 14 standard ASTM-E-17 pavement test tires. The weight distribution of the car without driver with approximately one half tank of gasoline and four wheels in the trunk was determined once to be 1620 lbs on the front wheels and 1720 lbs on the rear wheels.

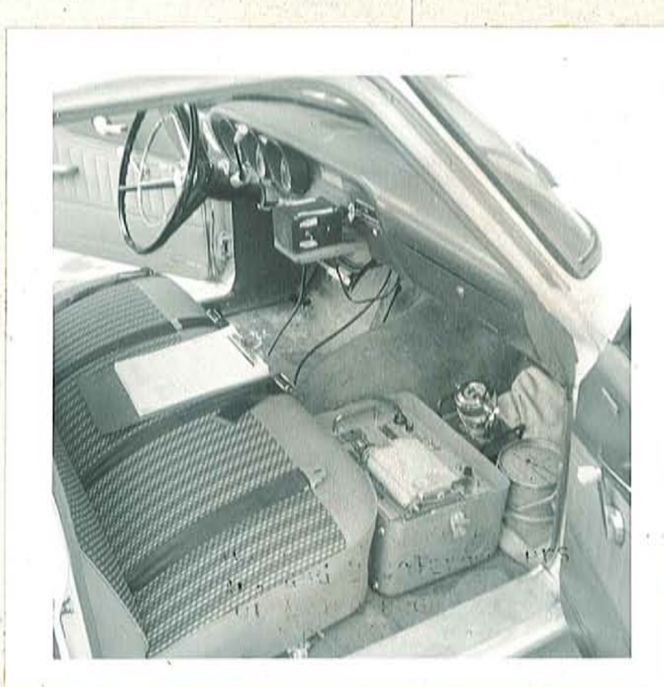
Instrumentation in the car was as follows:

(1) Two decelerometers - a Tapley and a James

(2) A Marbelite speed recorder

(3) A brake activated chalk gun

(a) 1961 Ford Fairlane - Skid Test Vehicle



(b) Instrumentation of Brake Pedal Switch, Speed Recorder, and Decelerometers

Figure 2. Skid Test Vehicle

For all but the 60 mph test, a driver and recorder were in the front seat of the car; at 60 mph, the driver served also as a recorder.

Results of Field Testing

The discussion presented under this section must be somewhat limited since the data obtained are not extensive with respect to quantity or to range. The list of stopping distance numbers SDN in Table 2 of Appendix A shows the effects of speed and temperature. It is apparent that the resistance to skidding on these wet pavements is high and the range of SDN is small. The wet pavement surface temperature varied from 110° to 118°F for summer conditions, and for winter conditions the variation was from about 40° to 55°F.

The differences between the summer and winter values of SDN are attributed in part to the hysteresis component of friction rather than on the adhesive component. These components are described by Kummer and Meyer in Reference [6]. Not all sections show an increase in value of SDN from summer to winter measurements. It is expected that a certain loss of resistance would have been brought about by the polishing action of traffic. The data indicate that the influence of temperature was reduced at the higher speeds. This behavior would be reasonable since more heat would be generated to result in a smaller temperature differential at the tire-pavement interface.

Selected data from Table 2 are plotted in Figure 3, which relates the effect of speed on stopping distance number. Of particular interest are the different slopes as affected by surface type and time of testing. It is noted that the frictional resistance decreases as speed increases; therefore, one recognizes that in the stopping distance procedure a steady state of skidding is not in operation and a constant value of friction also is not in operation. As a consequence, higher friction values should be obtained by this method than by one utilizing a steady skid such as held by a towed skid trailer.

Decelerometer Results

Earlier mention was made that two decelerometers were carried in the test car. In this report, data obtained with the Tapley decelerometer will be presented rather than those from the James. Table 3 lists the values obtained at various speeds on the test sections. The data listed are not as complete as those for the stopping distance method, but it is apparent that decelerometer value also decreases as speed increases. At the present stage of the study, extensive analyses have not been made of the decelerometer data to determine the repeatability of the procedure or to determine its sensitivity. A preliminary opinion of this writer is that the Tapley decelerometer procedure will be acceptable to rate a pavement surface in a broad sense of having good or bad skid resistance properties. The preceding is a qualified opinion since the pavement surfaces rated thus far have had high resistance to skidding.

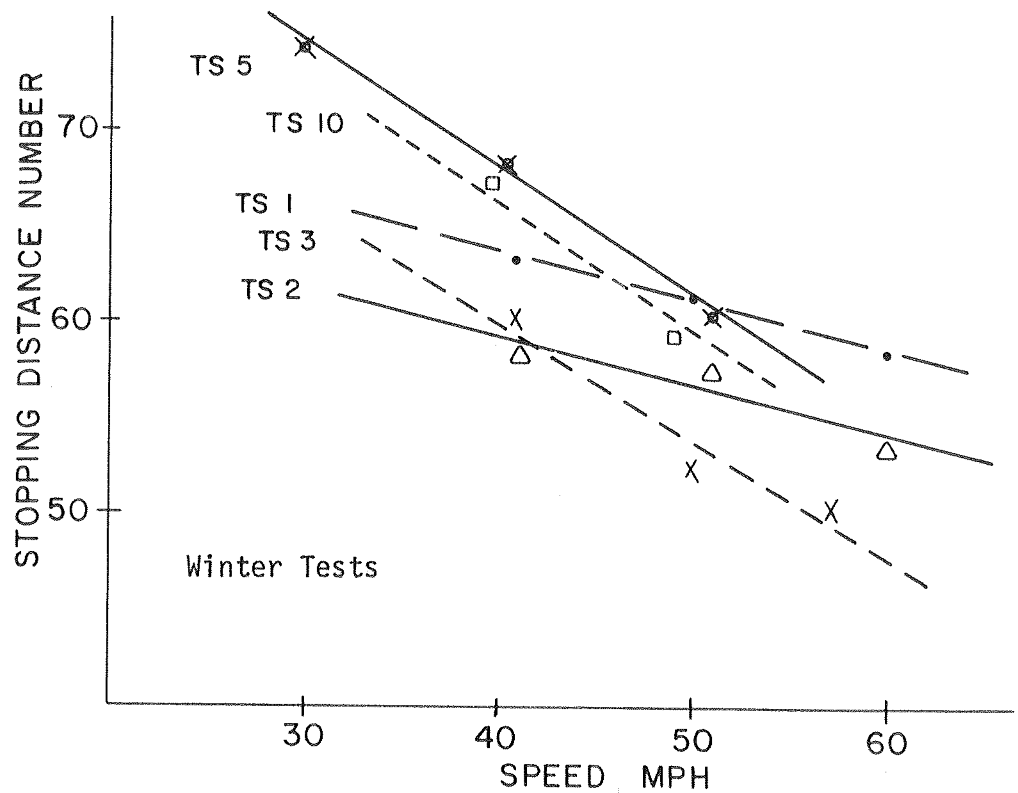


Figure 3. Effects of Speed on Stopping Distance Number

GENERAL DISCUSSION OF FIELD TESTING RESULTS

Stopping Distance

The stopping distance procedure used has been found to be quite adequate for determining the skid resistance condition of a pavement. The low operating budget precluded the use of a skid trailer which is gaining rapid acceptance as the primary method for field measurements of pavement friction. Although a skid trailer (BPR's) was used to make a few measurements, no discussion will be presented concerning skid trailers. A brief report [7] has been presented to the Arizona Highway Department.

Since the skid resistance measurements are made because of concern with highway safety, we suggest that all investigators of skid resistance be familiar and acquainted with the stopping distance method. The driver feelings and responses during stopping distance tests are valuable experiences which aid in the understanding of vehicle skids. Of interest to the reader should be the report by Alexander [10] and others concerning the behavior of a moving vehicle upon the sudden application of the brakes. In essence, the performance will be as follows:

(1) When all wheels lock simultaneously, the vehicle will continue in a straight line or maybe drift down the crown slope. The stopping distance will not be affected by the front-to-rear braking or weight distribution of the car. Since the front wheels are locked, the car cannot be steered during a skid.

(2) When only the front wheels lock the response is similar to that for all wheels locking.

(3) When only the rear wheels lock, the vehicle will loose initial direction and go into a spin.

Item (3) of the above listing is perhaps the most pertinent to the safety of skidding. The situation of rear wheels locking only or first can occur due to fading of the front brakes and also would be more apt to occur on a surface of high skid resistance. It is believed that failure to complete a few of the high speed "panic stop" tests was initiated by this behavior.

At this time a detailed comparison of performance among the different types of surfacing can only be made in a general sense. The reasons for this situation are that too few measurements have been made; however, certain behaviors are worth mentioning as listed below for the test sites.

TS (1) The first skid measurements were made in the summer time and prior to being opened to traffic. The paving mixture is a fine graded asphaltic concrete having a high value of SDN. The reverse trend of decrease in values of SDN for winter was due to relatively high surface temperatures.

TS (2) This open-graded hot plant seal showed improvement from summer to winter measurements; however, the improvement is judged to be due to the loss of asphalt films from the stones since the winter time measurements were made at high surface temperature. Attempts to skid at 60 mph during the first trials resulted in the initiation of a spin and braking had to cease in order to recover. After six months of service, the gritty texture of TS (1) is judged to be better than the open texture of TS (2). The reason for this may be due to the greater number of water piercing points of TS (1).

TS (3) The first measurement of this portland cement concrete surface was made prior to being opened to public traffic. The summer SDN value at 40 mph is quite high; however, the value at 50 mph represents one run only since subsequent skids could not be held due to spin-out. High speed winter time skids were successful, but the values are somewhat lower than expected for the colder temperature effect. We suspect this surface will be quite susceptible to polishing.

TS (4) This slurry seal surface shows the expected high SDN values for a gritty texture. The pavement surface was over two years old at the time of the winter testing.

TS (5) The first high SDN value at 40 mph for this Type D chip seal surface and also decelerometer values at 50 mph lulled the test driver into unpreparedness. The first run for a 50 mph skid resulted in the tearing of the chips from the surface. The loose chips caused the vehicle to enter a spin. It was apparent that a dangerous skid condition existed even for the dry pavement in which asphalt viscosity would have been even lower with less capability of retaining the chips.

TS (6a) This section had a Type B chip seal which seemed to be flushed and was scheduled for an overlay. The appearance and traffic sound of the surface certainly suggested a slippery pavement; however, the SDN of 54 at 40 mph is greater than the value of 41 as recommended by Kummer [1]. The results of testing this section and TS (5) show that visual examination should not be used for rating the skid resistance of a road surface.

TS (6b) The surface of this overlay on TS (6a) was a fine graded asphaltic concrete similar to TS (1). It is too early to evaluate the results obtained but in consideration of the lower test temperature for TS (6b), then SDN values would be expected to be higher than for TS (1).

TS (7) & TS (8) These surfaces are Type D chip seals, but the binder for TS (7) was a standard emulsion, RS-3K, and that for TS (8) an RS-2R (rubberized) emulsion. The differences in SDN values may be attributed to the binder type; however, other variables, such as quantity of coverstone may be affecting the test results.

TS (9) The coverstone for this chip seal was of Type C. The difference in gradation may account for the lower summer values of SDN in comparision with TS (7) and (8). The larger differences in SDN values for the winter measurements are attributed to a prior application of Reclamite® to the test section.

TS (10) This section is on the Maricopa County road system and is an unsealed coarse graded asphaltic concrete. The SDN values are relatively high.

Stopping Distance vs. Decelerometer

One of the objectives of this study program was to investigate the use of the Tapley decelerometer for pavement friction evaluation. Early reports [3, 4] and a fairly recent one [8] suggest that the decelerometer method is an excellent method for determining the skid resistance of a pavement surface. Our decelerometer data have not been analyzed statistically, but, by observation of the range of values obtained for one speed by various operators on one section, it is apparent that our repeatability and reproducibility are not as good as determined by Dillard's [4] procedure. At the present, and in view of our limited data, we believe that the decelerometer might have the capability of distinguishing between surfaces having low or high friction values but cannot be as sensitive as the stopping distance method. The decelerometer procedure appears to have a slight operational advantage at speeds lower than 40 mph, but for testing speeds of 50 mph, we would suggest that as much traffic control would be required as for the stopping distance method.

Table 3 shows pavement friction values obtained with the Tapley decelerometer, and in general these values were affected by speed and pavement temperature in the same way as were the SDN.

Figure 4 shows a plot of pavement friction values obtained by the decelerometer and stopping distance methods at a vehicle speed of 40 mph. The broken line shown is not a regression line, but it does appear to suggest an equality between the two values. There is no desire to propose this relationship since there is sufficient published data to contradict such a proposal. Further, in the stopping distance method the friction between the tires and pavement is increasing as the vehicle is slowing down while the friction force is relatively constant during the short period of braking for the decelerometer methods. Therefore, we suspect a fairly complex and empirical relationship would exist between SDN and decelerometer values for various speeds and pavement types, even though Marshall [3], Dillard [4], and Giles [9] report a simple linear relationship between the two.

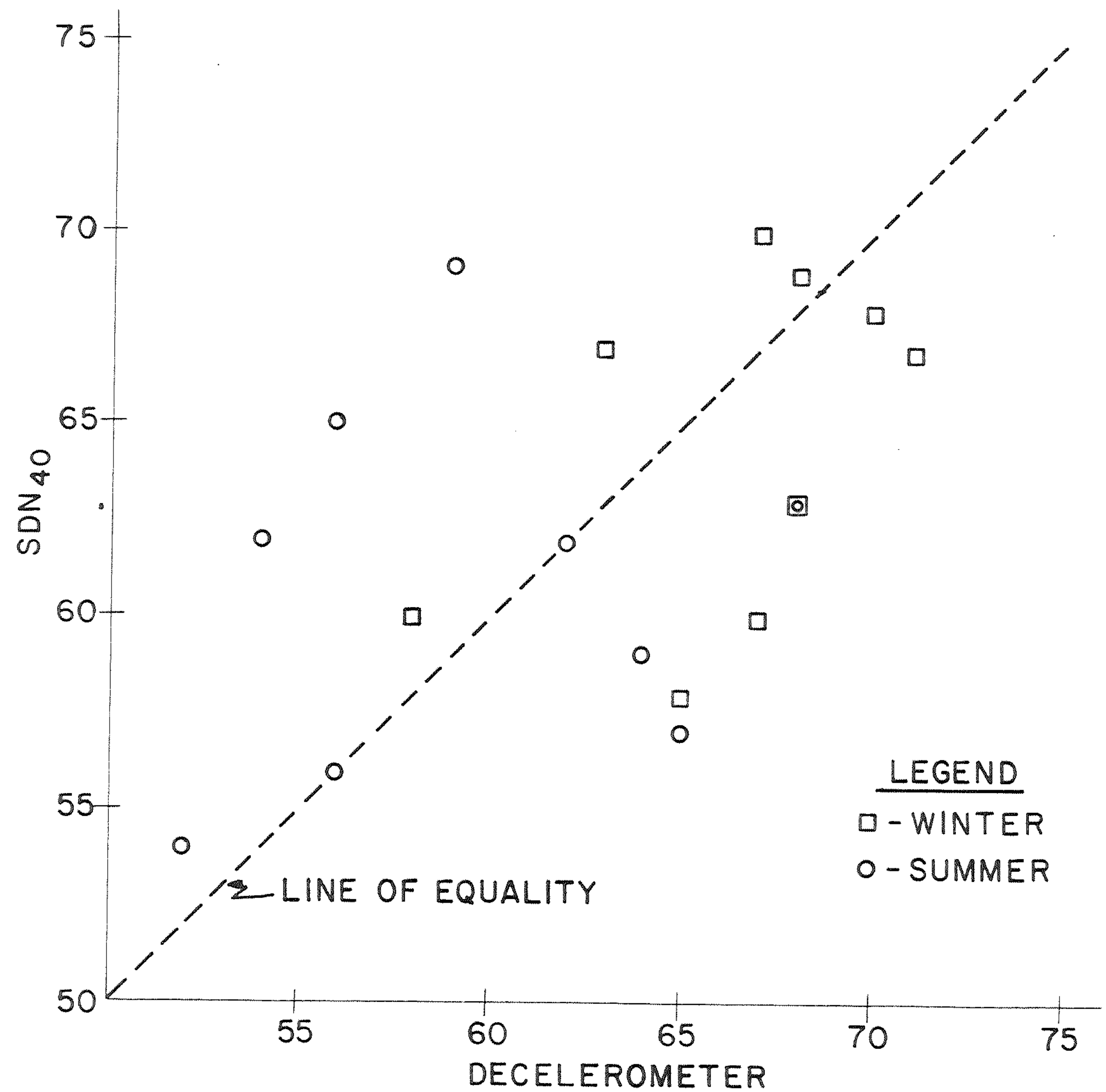


Figure 4. Comparison Between Decelerometer Value and Stopping Distance Numbers Obtained at 40 mph

LABORATORY MEASUREMENTS

It is common knowledge that generally a pavement surface has its highest resistance to sliding soon after construction. As traffic uses the road, the surface is subjected to abraiding stresses which polish the aggregates and cause a decrease in the frictional character of the surface material. The rate of surface polish is dependent on the type of traffic using a pavement, but it is apparent that this rate of wear is also dependent upon the kind of material being polished.

Since aggregates are susceptible to the polishing action of traffic, it is desirable to pre-evaluate them prior to their placement on a pavement. Such pre-evaluation can be done in a laboratory using devices to simulate actual conditions that exist in the field. A laboratory friction tester was used to study the relative sliding resistance of laboratory prepared specimens as well as of pavement cores.

Differences of opinion have existed with reference as to whether a knobby pavement surface has better frictional characteristics than a gritty one. In this comparison we are concerned with differences in the gross pavement surface and not of individual particles that make up the surface. The Civil Engineering Department had an apparatus for producing a profilograph of the surface of laboratory or field specimens. This device was used to obtain profilographs of cores taken from test sites and certain characteristics of the profilographs were compared to the surface friction.

Laboratory Friction Tester

The laboratory friction tester is illustrated by the photograph of Figure 5. The power unit consists of a Blakeslee C-50 Mixer to which has been attached a water swivel and a rubber-like scrubbing head. A specimen holder is mounted on a hydraulic jack through a radial thrust bearing so that resistance to rotation is minimized. When the specimen is raised to come into contact with the rotating scrubber head, rotation of the specimen holder is prevented by a restraining cantilever bar. The restraining bar is strain-gaged so that the frictional resistance to sliding between the test head and specimen surface can be computed.

A brief description of the gross testing procedure is as follows:

(1) The test head cast from Devcon Flexane® 60 (hardness of 60 durometers) is "conditioned" by scrubbing upon a dummy specimen having an 80 grit silicon carbide surface.

(2) The test specimen previously used on the profilometer is mounted and leveled on the holder.

(3) The Blakeslee C-50 Mixer is started, and the speed of rotation is brought to 68 RPM. Then the valve to the water swivel is opened.

(4) The hydraulic jack is operated to bring the specimen onto contact with the rotating test head. A gage pressure of 125 psi between the specimen and the test head is held for 15 seconds and then released. The water is then closed.

(5) Replace the test head with the polishing head made of Flexane 85. Raise the specimen to contact the rotating polishing head at a gage pressure of 50 psi for a

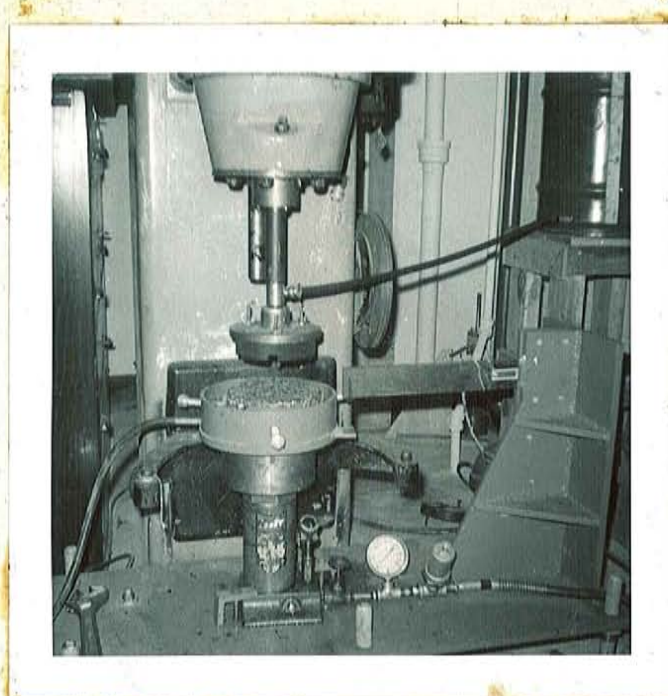


Figure 5. Laboratory Friction Tester

period of 30 seconds and then release. Repeat the polish cycle usually 5 times. Flood specimen with water during polishing.

(6) After the 5 polishing cycles, obtain profilograph of specimen and then retest for friction.

(7) Repeat steps 1-6 as many times as desired.

A discussion of details of temperature control, operation of the Sanborn Dual Channel Recorder, and test head fabrication is not felt to be necessary at this time.

Laboratory Pavement Surface Profilometer

As indicated earlier, consideration has been given to the contribution of surface texture to the skid resistance characteristics of a pavement. Various agencies have made studies of different devices in searching for correlations between macro- and/or micro-pavement surface texture and skid number [11, 12, 13]. Yet, there is no one method that has received national acceptance. Limitation of our equipment and poor correlation between profilometer data and skid number [12] were overruled for our study.

Our simple profilometer is illustrated in the photograph of Figure 6. Again, as for the friction tester, only a brief description of the profilometer will be given in this interim report. With reference to Figure 6, it can be seen that a specimen is secured and leveled on the turntable. The turntable is revolved by means of a cord wrapped around the base of the table, and the other end is pulled by a nut driven by a rotating threaded shaft. The surface of the specimen is

Figure 6. Device for Obtaining Pavement Surface Profile

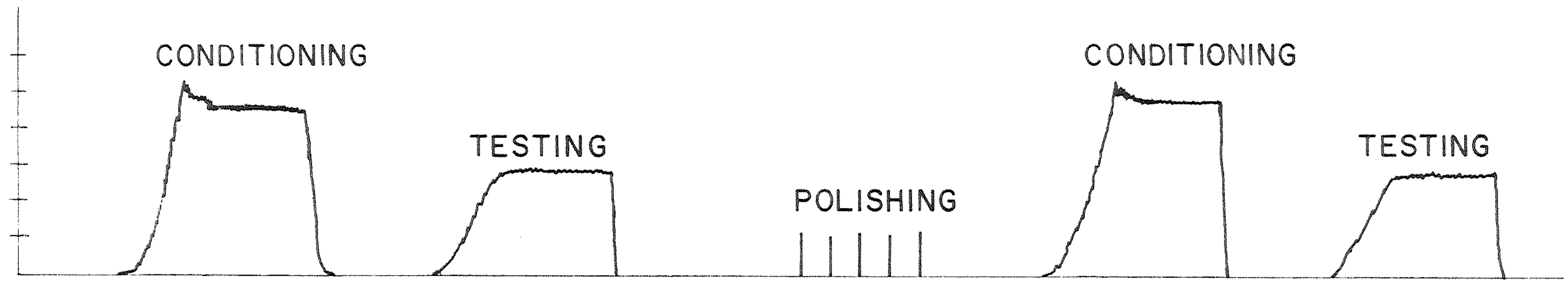
contacted by a metal pin attached to a flexible cantilever beam. As the pin moves up and down over the surface asperities of the rotating specimen, the strains of the strain gage attached near the fixed end of the beam are graphed on the same recorder used with the friction tester.

A reproduction of a typical recorder tape is shown in Figure 7. The upper portion of this figure is for friction testing and shows records for the conditioning of the test head, then the actual testing for friction. Following the testing curve are five lines indicating that the specimen had received five polishing cycles. Because the first testing of the specimen had changed the surface texture of the head, then reconditioning is indicated by the next curve prior to the next friction measurement.

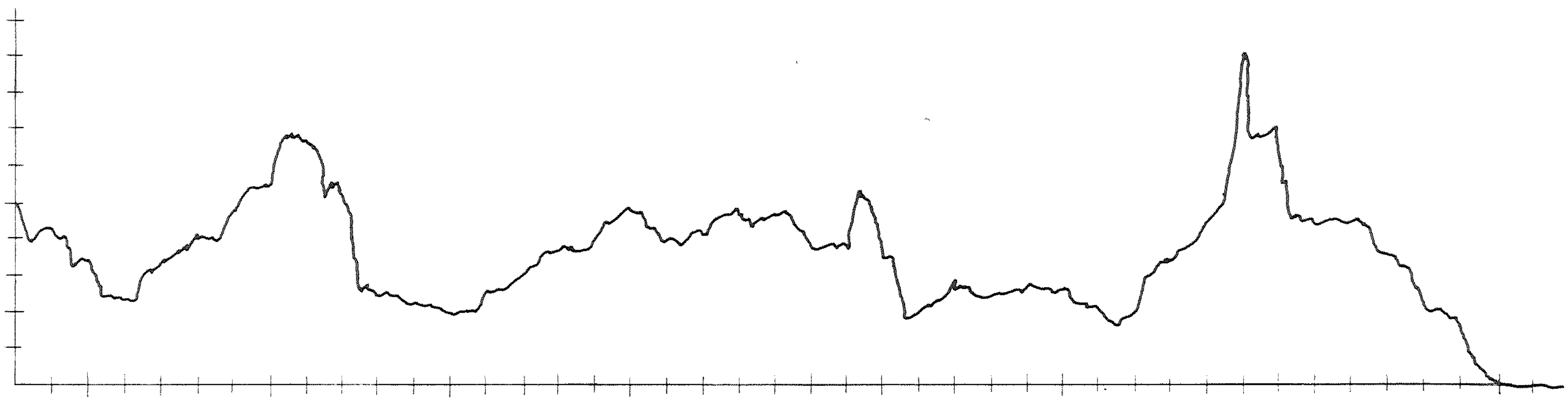
The bottom of Figure 7 is simply a trace of the surface profile for a particular line on the specimen. Results obtained from these measurements follow in the next sections.

Results of Laboratory Testing

Laboratory Specimens. Various mixtures and asphaltic surface types were used in a preliminary study of the friction tester. Results obtained with these mixtures are shown in Table 4 and Figures 8 and 9. Figure 8 shows the effects of test head speed and also contact pressure on the laboratory friction numbers for three mixtures. The effect of rotational speed does not appear to be greatly significant nor clearly defined especially at the higher contact pressures.



(a) Friction Testing Record



(b) Pavement Surface Profile

Figure 7. Reproduction of Recorder Tape Showing Typical Friction Testing and Profilometer Data

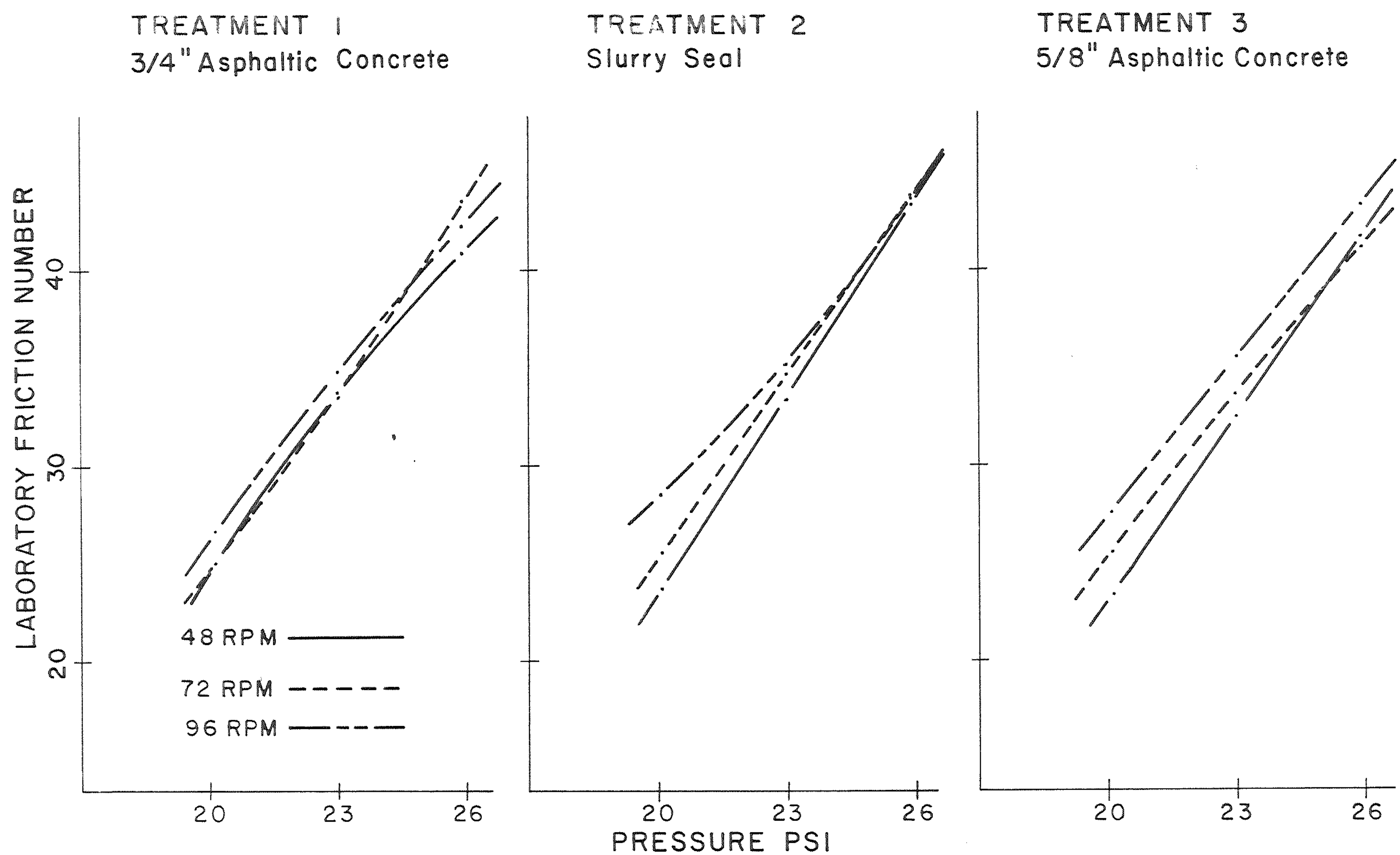


Figure 8. Effect of Test Pressure and Speed on Specimen Friction Determined in the Laboratory

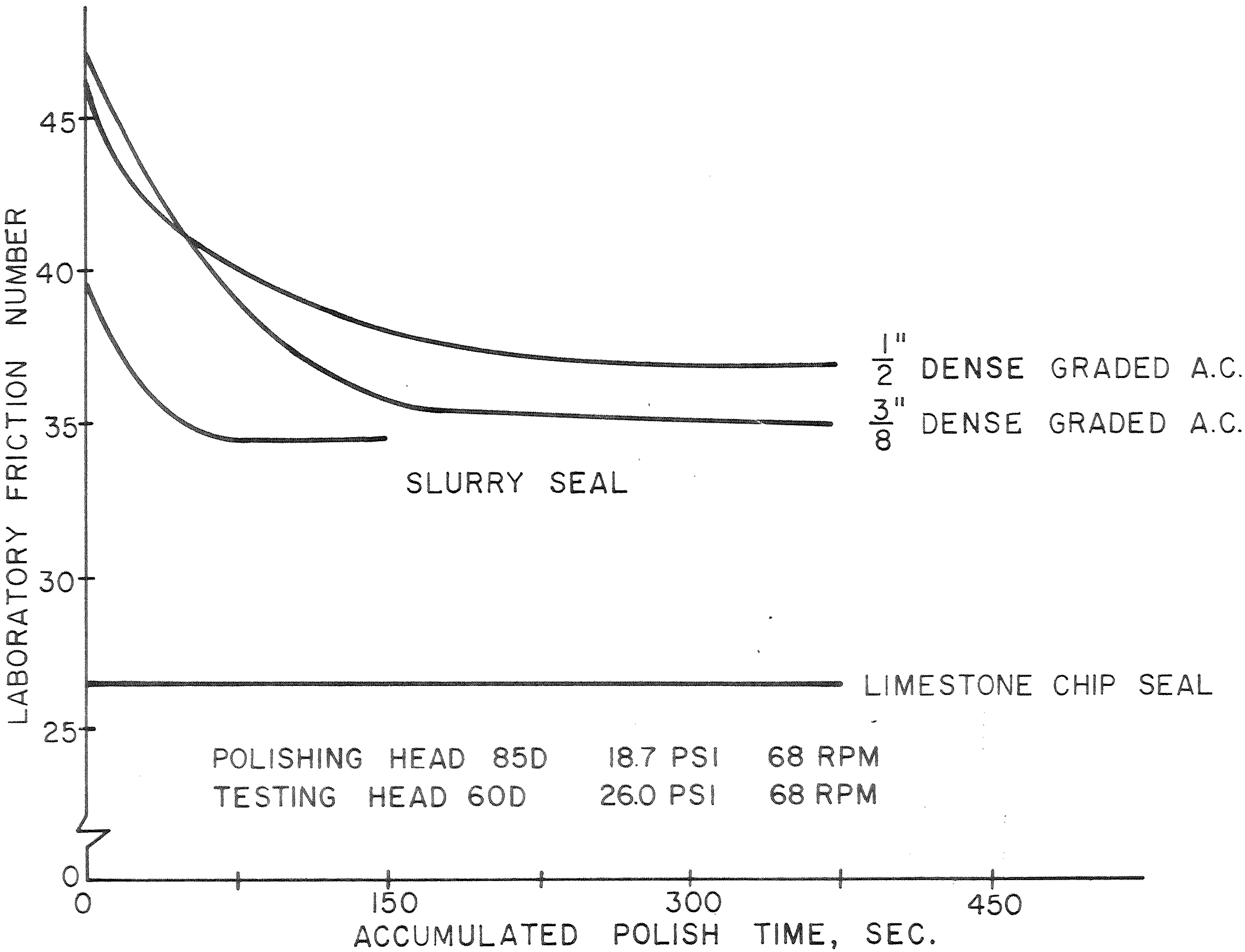


Figure 9. Effect of Laboratory Polishing on Pavement Surface Friction

In Figure 9 the effects of surface polish or wear on the frictional resistance are illustrated. It can be seen that after a certain amount of polishing, the frictional characteristics of a surface become stabilized.

The information represented by Figures 8 and 9 is interesting but not representative of actual paving mixtures or field conditions. Although the friction values are lower than those found in the field study, the rating of the materials shown in Figure 9 appears to be verified in the field.

Field Specimens. As mentioned earlier, 6-inch diameter cores were taken from the test sites. These cores were processed through the laboratory friciton tester and profilometer. From the profilograph (Figure 7b) three values were obtained; these were as follows:

(1) Average of the average peak height, mm

(2) Profile ratio, true length/projected length

(3) Root-mean-square of the positive area, $\sqrt{\Sigma a^2/n}$

The above surface profile characteristics were determined after establishing a reference line parallel to the specimen surface and passing through the deepest point of the surface. Then the plot was broken into triangles and trapezoids bounded by the profilograph and reference line.

A listing of laboratory friction numbers obtained for the road samples is shown in Table 5; also appearing on this table are the values of SDN for summer and winter time conditions. The plot of

Figure 10 shows bias in the location of the two lines since no attempt has been made as yet to treat the data statistically.

Table 6 presents surface characteristics of the pavement samples in terms of the three measurements obtained from the profilograph; also for easy comparison the laboratory friction numbers are included in the table. Our main interest in not in relating profilometer characteristics to laboratory friction values but to actual field measurements of friction. Graphic comparisons between the profilograph measurements and stopping distance numbers are shown in Figures 11 to 13.

In Figure 11 there appears to be an optimum average peak height related to a maximum value of SDN. Although no rigorous analysis of the data has been made, the above indication appears reasonable since the surface becomes smoother and covered with water as the peak height decreases, and the number of contact points between the tire and pavement surface decrease as the peak height increases. The above relationship is associated with aggregates of essentially the same composition and surface texture and would not necessarily hold for aggregates having smoother surface textures.

From Figure 12 it appears that the root-mean-square of the positive area is related to the average heak height, and therefore, an optimum value of RMS-A existed for a maximum value of SDN.

The plot of profile ratio vs. SDN_{40} shown in Figure 13 indicates that the profile ratio had no determinable effect upon the friction value of the pavements tested.

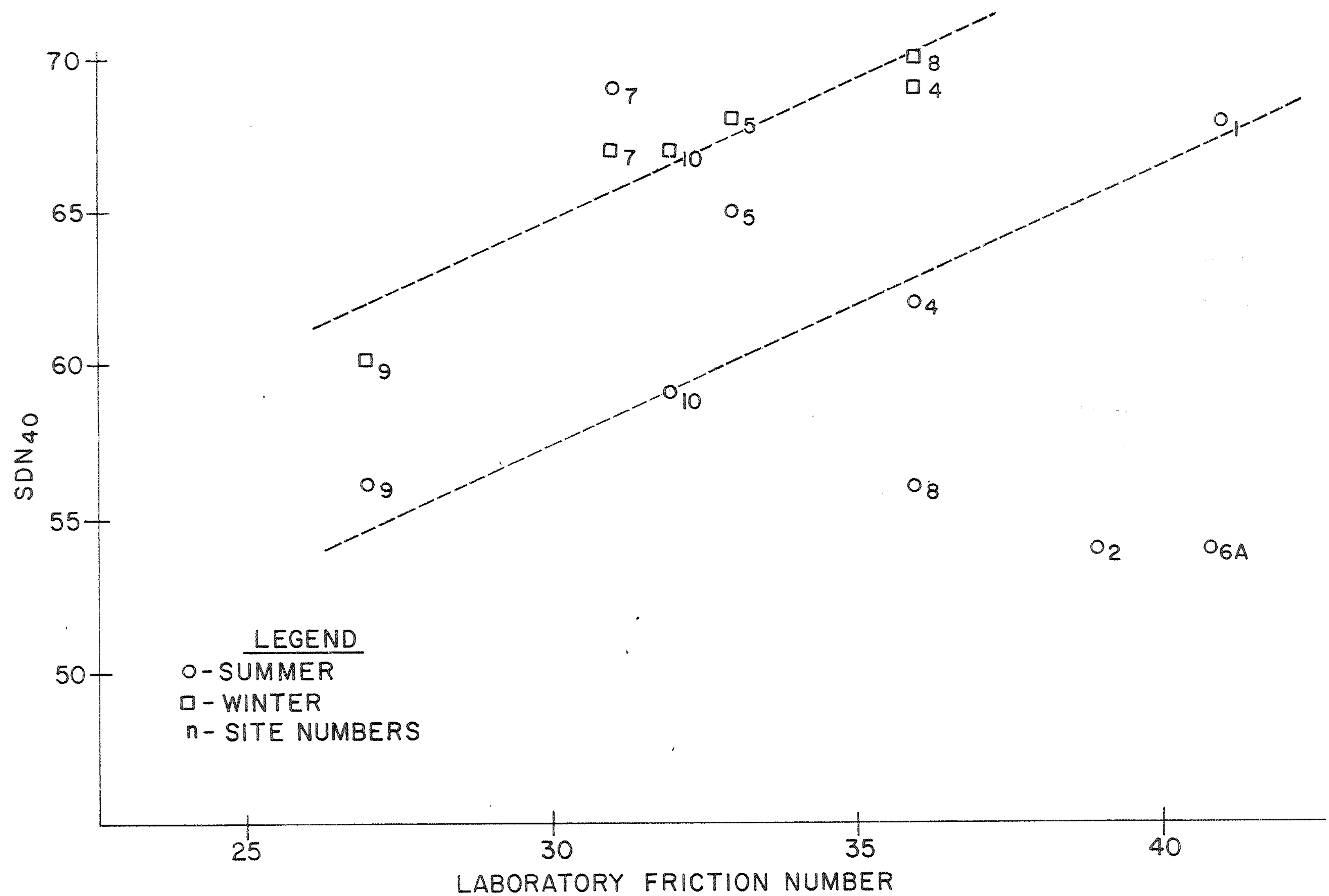


Figure 10. Comparison of Laboratory and Field Measurements of Surface Friction

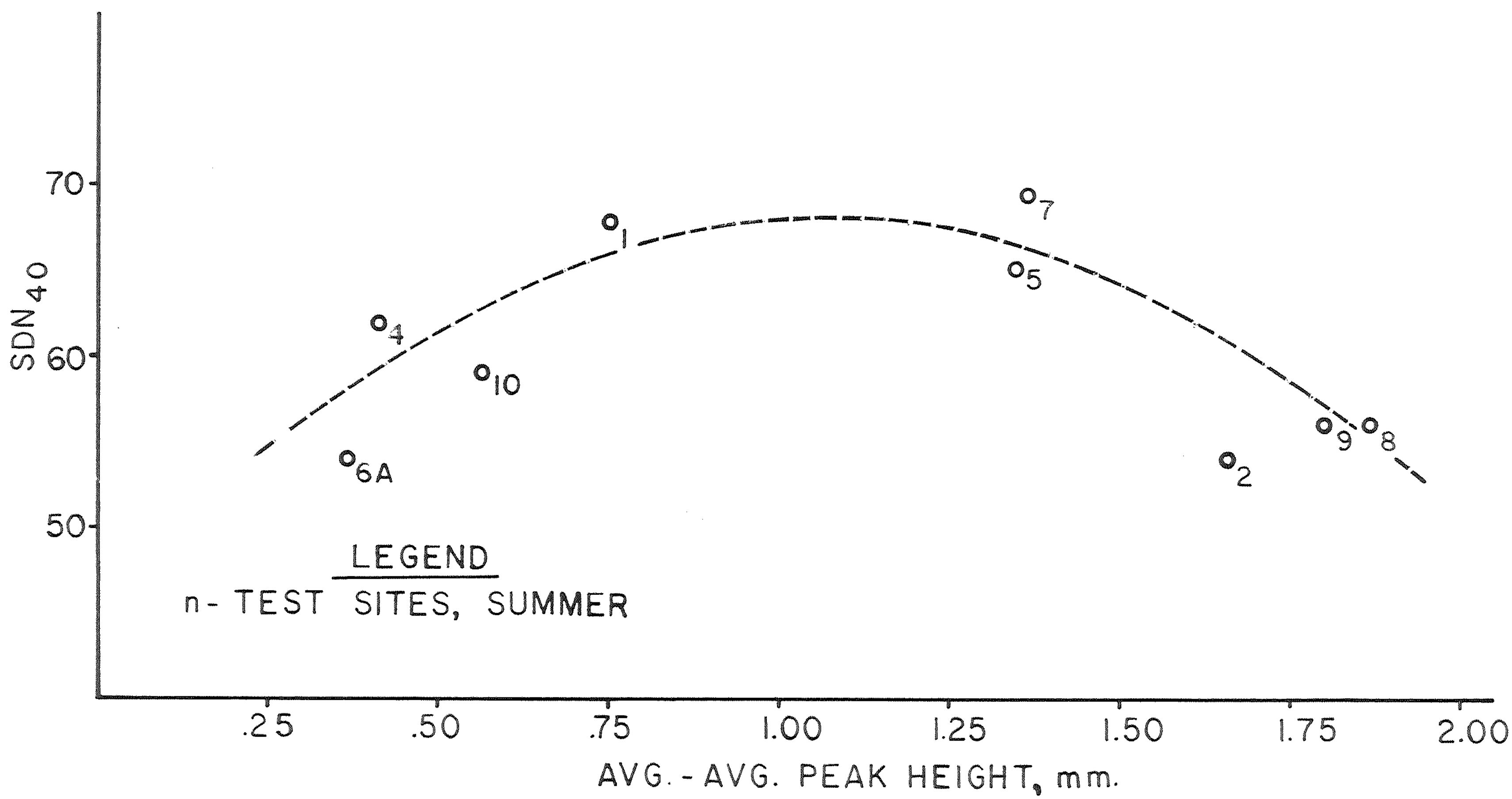


Figure 11. Comparison of Surface Texture and Stopping Distance Number

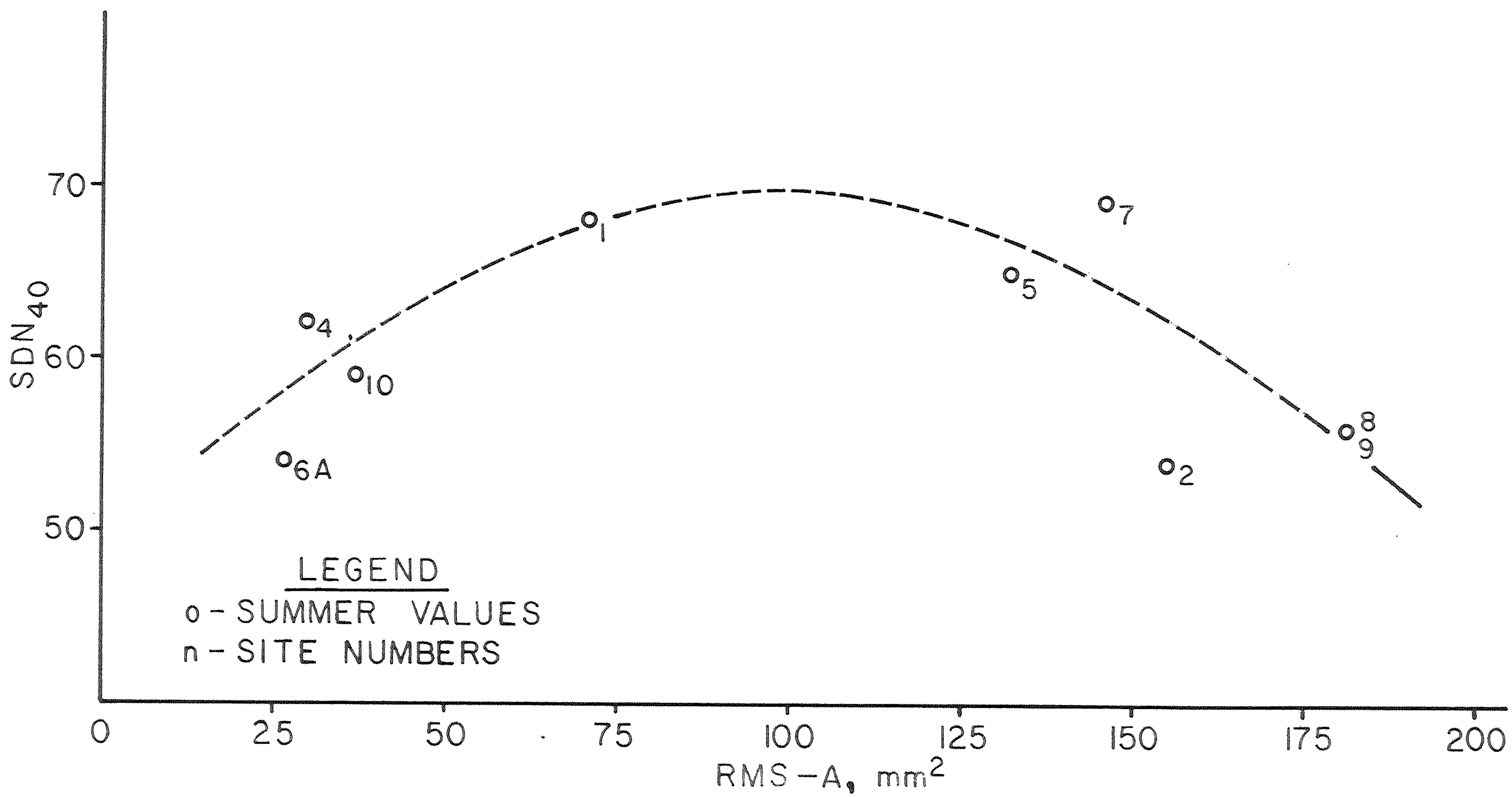


Figure 12. Comparison of Profilograph Measurements and Stopping Distance Numbers

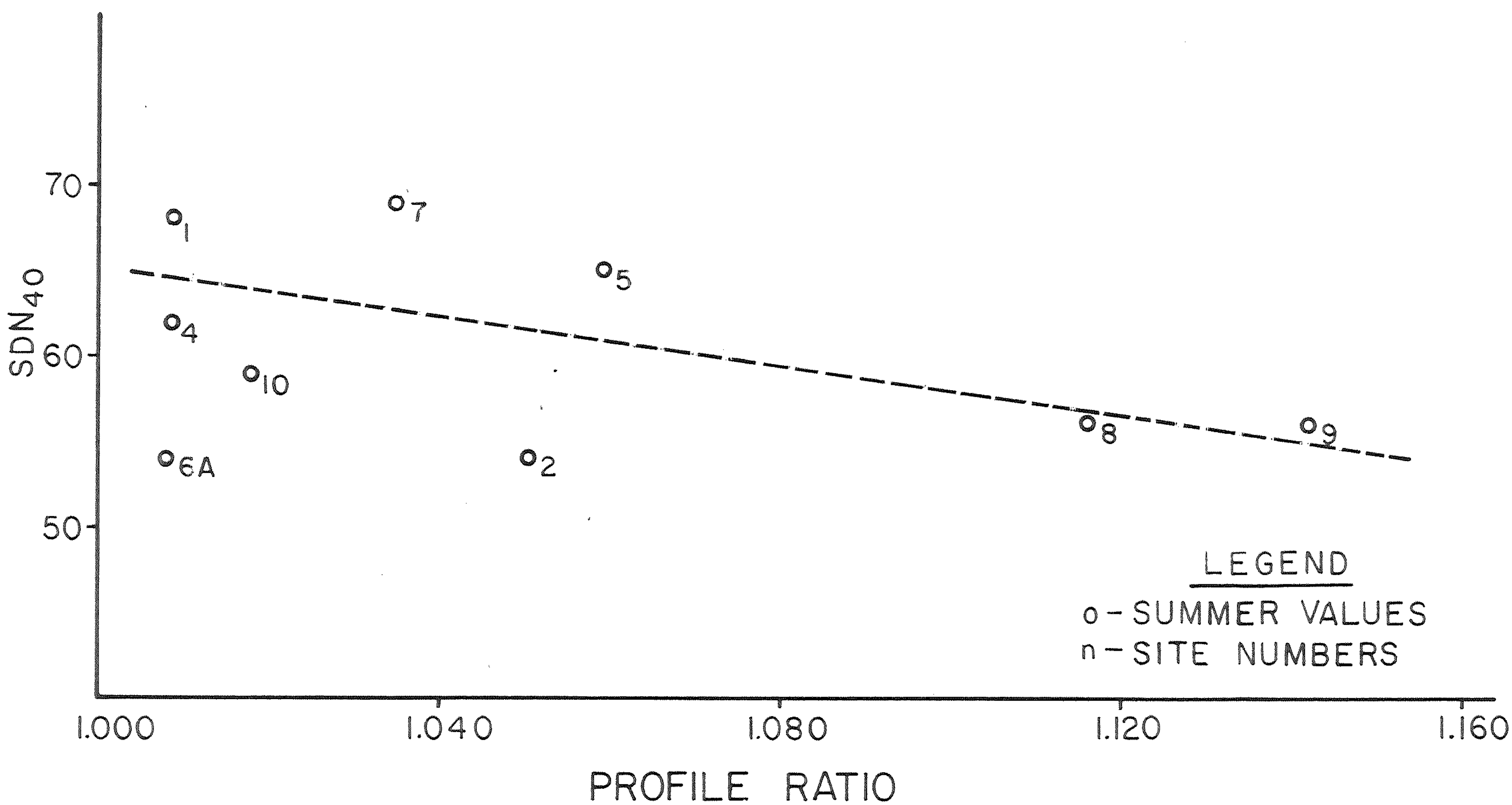


Figure 13. Comparison Between Profile Ratio of Profilograph and Stopping Distance Number

SUMMARY AND CONCLUSIONS

Ten sections of pavments in the State have been tested for slipperiness by field methods and also laboratory procedures. The study has not been completed, but the data obtained, although somewhat limited in amount and range, do warrant the following conclusions:

(1) The stopping distance method of determining pavement slipperiness is good where a great number of tests do not need to be taken. Testing at 60 mph should be done only after initial tests at 40 and 50 mph have been performed and indicate safe execution at the faster speed.

(2) The stopping distance numbers obtained for two periods of testing (summer and winter) are quite high and exceed the minimum value recommended by Kummer [1] for a mean traffic speed of 60 mph.

(3) The data suggest that the aggregates and mixtures used in the test sections are not susceptible to polishing. The loss of good surface friction characteristics will be due to loss or embedment of coverstone in chip seals or due to bleeding (excess asphalt with respect to voids in aggregate system) of asphaltic concrete. One case (TS 5) showed low binder strength in a chip seal which resulted in tearing of the surface during a skid.

(4) Friction values were generally higher for the winter measurements than for the summer ones. The exception to this was a portland cement concrete (TS 3) subjected to the highest traffic volume.

(5) At the present no statistical treatments have been done in attempting to correlate laboratory measurements with field values of friction. However, one rough comparison seems to indicate that either an asphaltic concrete or chip seal made with a 3/8-inch maximum-size aggregate will give the highest friction value as determined by skidding from 40 mph.

ACKNOWLEDGEMENT

The cooperation and help received from the Arizona Highway Department and Bureau of Public Roads are greatly appreciated. In particular we would like to acknowledge the special consideration shown to us by the Maintenance and Materials and Test personnel.

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APPENDIX A

Table 1. Description of Test Sites

Test Site	Location	Surface	1968 Traffic A.D.T.	1968 Traffic % Truck
1	I-10, N.B., Mile Post 176.8	3/8"-Dense Graded A.C.	5125	22.8
2	I-10, N.B., Mile Post 176.1	Open-Graded Hot Seal	5125*	22.8
3	I-10, W.B., Mile Post 152.9	Portland Cement Conc.	5013*	22.8
4	Ariz. 84, W.B., Mile Post 159	Slurry Seal	2855	33.1
5	Ariz. 77, N.B., Mile Post 118.2	Type-D Chip Seal	1431	28.6
6a	I-8, W.B., Mile Post 98.6	Type-B Chip Seal	4433	33.8
6b**	I-8, W.B., Mile Post 98.6	3/8"-Dense Graded A.C.	4433	33.8
7	U.S. 80, N.B., Mile Post 127	Type-D Chip Seal	2654	29.8
8	U.S. 80, N.B., Mile Post 132.1	Type-D Chip Seal	2559	29.8
9	U.S. 80, N.B., Mile Post 138.6	Type-F Chip Seal	2559	29.8
10	Thunderbird Rd., W.B., 51st Ave.	3/4"-Dense Graded A.C.	1454	11.8

*These sections had skid measurements made on new construction prior to opening for the public. Traffic data are estimated because of new alignment.

**Overlay of 6a.

Table 2. Listing of Stopping Distance Numbers Obtained for Summer and Winter Conditions, 1968-1969

	SUMMER				WINTER			
	Nominal Speeds				Nominal Speeds			
Test Site	30 mph	40 mph	50 mph	60 mph	30 mph	40 mph	50 mph	60 mph
1	-	68	65	58	-	63	60	58
2	-	54	50	-	-	58	57	53
3	-	69	63	-	-	60	52	50
4	-	62	-	-	-	69	65	-
5	-	65	-	-	74	68	60	-
6a	59	54	50	-	-	-	-	-
6b	-	-	-	-	-	60	56	52
7	-	67	59	-	-	67	60	59
8	-	56	56	-	-	70	62	57
9	-	56	53	-	-	55	51	-
10	-	59	53	-	-	67	59	-
Airport	61	59	56	-	69	69	64	-

Table 6. Surface Characteristics of Pavement Cores

Test Site	Average of Average Peak Height, mm	Profile Ratio	Root-Mean-Square of Positive Area	Laboratory Friction Number
1	.75	1.009	71	41
2	1.66	1.051	155	39
3	-	-	-	-
4	.42	1.009	30	36
5	1.34	1.059	133	33
6a	.37	1.008	27	41
6b	-	-	-	-
7	1.37	1.035	146	31
8	1.87	1.116	181	36
9	1.80	1.142	181	27
10	.57	1.018	38	32

Table 5. Values of Laboratory Friction Number (LFN) and Stopping Distance Number SDN_{40} for Summer and Winter Testing

Test Site	LFN	SDN_{40} (Summer)	SDN_{40} (Winter)
1	.41	68	63*
2	.39	54	58*
3	-	69	60
4	.36	62	69
5	.33	65	68
6a	.41	54	-
6b	-	-	60
7	.31	69	67
8	.36	56	70
9	.27	56	60
10	.32	59	67

*Exceptionally warm winter day.

Table 4. Laboratory Friction Values for Three Surfaces

	Treatment #1			Treatment #2			Treatment #3		
Pressure in psi	20.1	23.0	25.9	20.1	23.0	25.9	20.1	23.0	25.9
Speed #1 48 rpm	.244	.345	.406	.246	.341	.430	.233	.325	.416
	.254	.328	.410	.226	.325	.436	.233	.325	.416
Average	.249	.3365	.408	.236	.333	.433	.233	.325	.416
Speed #2 72 rpm	.244	.325	.436	.254	.328	.446	.254	.335	.406
	.254	.345	.436	.254	.355	.426	.254	.335	.416
Average	.249	.335	.436	.254	.3215	.436	.254	.335	.411
Speed #3 96 rpm	.268	.345	.426	.286	.345	.436	.274	.355	.430
	.264	.345	.426	.284	.349	.436	.274	.355	.437
Average	.266	.345	.426	.285	.347	.436	.274	.355	.4335

Table 3. Values of Tapley Decelerometer for Summer and Winter

	SUMMER				WINTER			
Test Site	30 mph	40 mph	50 mph	60 mph	30 mph	40 mph	50 mph	60 mph
1	-	68	63	-	-	68	65	64
2	-	54	50	-	-	65	64	63
3	-	69	68	-	-	60	52	-
4	-	62	-	-	-	69	65	-
5	-	69	68	-	-	68	60	-
6a	-	54	-	-	-	-	-	-
6b	-	-	-	-	-	60	55	-
7	-	63	59	-	-	67	60	-
8	-	57	55	-	-	70	62	-
9	-	56	53	-	-	60	51	-
10	-	59	53	-	-	67	59	-