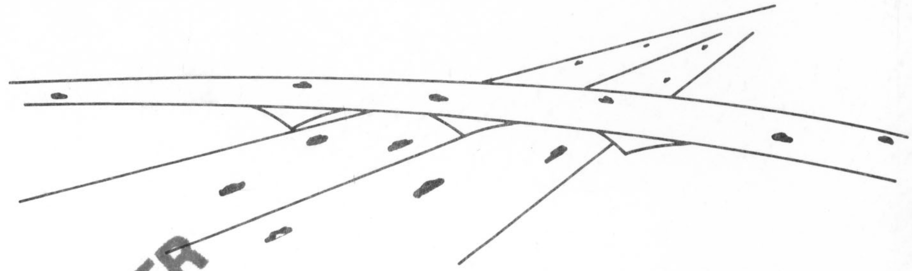

DEPARTMENTAL RESEARCH

Report Number: 45-3

A STUDY OF FACTORS AFFECTING THE OPERATION OF A LOCKED WHEEL SKID TRAILER

TEXAS HIGHWAY DEPARTMENT

A STUDY OF FACTORS AFFECTING THE OPERATION OF A LOCKED WHEEL SKID TRAILER

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Research Report No. 45-3

Determining and Evaluating Skid Characteristics of Texas Highways

Research Project 1-8-63-45

Conducted by

Highway Design Division, Research Section
The Texas Highway Department

In Cooperation with the
U. S. Department of Commerce, Bureau of Public Roads

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P R E F A C E

In an effort to provide a safer highway system in the State of Texas, the Equipment and Procurement Division shops of the Texas Highway Department are fabricating three additional skid test trailers at the present time. It is contemplated that the Maintenance Operations Division will direct the operations of the test trailers and that one trailer will be based at each of the three warehouse supply depots which feed the necessary materials to the Texas Highway Department Districts.

This report is therefore given as the basis of an Operations Manual in order that the past research may be utilized by interested personnel in the future.

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I. INTRODUCTION

Background

Shortly after the completion of the fabrication of a two-wheeled skid test trailer in March 1963, efforts were made to calibrate the equipment.[1] Contacts were made with several authorities in the field of skid resistance and the results disclosed tentative plans for two methods of calibration. The first method was similar to that in the proposed Tentative Method of Test for Skid Resistance of Pavements Using a Two-Wheel Trailer, ASTM Designation: E 274--T issued in 1965.[2] This method was then referred to as a static calibration, and the second method was designated as dynamic calibration. Originally it was thought that dynamic tests would be made with a test tire skidding along a strip of ducking or canvas of prescribed specifications. Information obtained prior to the purchase of the equipment for the dynamic test indicated that a change was to be made in the dynamic test as it was found that the canvas was subject to rapid wear. Suggestions at this time revealed the necessity of finding existing pavement surfaces relatively free from traffic wear to replace the standard canvas. In line with this suggestion, eight pavement sections were selected with low traffic volumes and varying pavement surface types.

Initial dynamic calibration tests were conducted on three separate days and the results indicated a discrepancy between the static and dynamic calibration. Repeated static calibration attempts indicated a repeated correlation between applied force and strain gage results, but there was wide variation in pavement skid resistance measured between each day on each of the eight sections. Noted also was the fact that a higher skid resistance was obtained on the third day after a short heavy rain on the second day. It was immediately apparent that the variables mentioned by several writers were in existance; however, also apparent was the fact that variation in the equipment or random error was present.[3,5] It was decided to continue testing the eight sections selected for dynamic calibration in order that various variables could be isolated and studied.

Standard deviation is a statistical term indicating the scatter of measured points about the true mean.[6] This is to say, if a test is obtained and the result of this test is given, this result may not be the same as if several identical tests were obtained and the results averaged. The average result of the several tests would be closer to the true mean generally. The individual test results scatter about the mean with some tests being higher and some lower than the mean. Therefore, standard deviation is a measure of scatter about the mean and in this instance the smaller the standard deviation the greater the reproducibility of the equipment.

The number of standard deviations the engineer will permit is a measure of the accuracy of the results. If 1,000 measurements are used as a basis, 997 tests out of 1,000 are within a range of plus or minus three standard deviations from the mean. If plus or minus two standard deviations from the mean are allowed, 950 tests out of 1,000 are expected within this range; and plus or minus one standard deviation from the mean encompasses 680 tests out of 1,000.

Another statistical media used is the "Analysis of Variance" procedure. By collecting the correct data it is possible to isolate variation from the mean caused by certain variables. These variables may be due to environment, operating personnel, the equipment or a combination of these, etc. Using this measure, it may be determined which treated variation from the mean is more significant, or if it is significant with respect to the random error, which is always present. If the random error is large other variables may be sought and measured which decreases the random error measured. Once a variable has been determined to be significant, corrections for this variable may be sought. Probably some correction, either statistical or physical, can be made for every variable noted; however, this report has been divided into treatments of those vaiables which were not corrected and variables which were corrected.

Objective

The object of this report is to establish various variables associated with the Texas Highway Department skid resistance equipment and to reveal correction formats as indicated.

II. NON-CORRECTED TREATMENTS

Procedure

Precision. Seven roadway sections were selected for a study of the precision of the skid resistance equipment. The coefficient of friction on these sections ranged from 0.32 to 0.82. Four areas on each section were established and five skids were performed on each area. Each of the five skids was obtained as close as possible to the same area with little variation in beginning or ending points and in transverse placement of the tire. Variables such as surface condition, surface type, aggregate type, binder amount and type, texture, and surface contamination were therefore held constant. A slight temperature variation was experienced, but an attempt was made to hold the variation as low as possible.

It should be noted that the precision of the equipment is not a variable in skid resistance,but measures the accuracy with which tests may be made. Interpolation of the data to smaller units than the precision is wasted effort unless the average of several tests is determined. The concept of the number of tests required to approximate the mean leads to the determination of the sample size.

Surface Variation. Before determining the sample size it should be determined if more variation exists in tests measured along the roadway than tests over one spot as described in the "Precision" paragraph above. If there is more variation in tests measured along the roadway than over one spot the sample size must be determined from the tests along the roadway since a larger standard deviation would be encountered.

The skid tests reported in the "Precision" paragraph in which five skids obtained on one spot in each of four locations were used in this study. An "analysis of variance" procedure was used to analyze the data.

Sample Size. Since the number of tests needed to represent the mean depends upon the scatter or standard deviation quantity, the statistical term "standard error of the mean" was used to determine the sample size. The term

$$\text{Standard Error} = \frac{\text{Standard Deviation}}{\sqrt{n}}$$

where n = number of tests needed

was the format used. Two decisions must be made by the engineer before using this equation:

1. The number of standard deviations to be used (determining the percentage of tests likely to be included).

2. The value of the accuracy of skid resistance which it is desired to measure.

For trial purposes two standard deviations expected to include 950 tests out of 1,000 were used and a coefficient of friction accuracy of 0.010 was selected since this was as close as the data chart can be read.

Chart Reading Error. There is a possibility that errors in reading the data from the recorder output chart could cause some of the scatter in the resulting coefficient of friction values determined. If this is the case, several people may be required to read the same chart to determine the average value read. To check this possibility four operators read eighteen values from each of five paths and an "analysis of variance" procedure was used to determine if the variation in reading the chart was greater than the random error. The eighteen values were determined from skids over the same spot on the same roadway. Air temperature varied approximately 5^{o}F during these tests.

Effects of a Worn Tire. It should be stated that all tests made with the Texas Highway Department test trailer have been collected while using the ASTM 7.50-14 Pavement Test Tire. This tire is fabricated with a wear protrusion ring near the outer edge. This ring was so fabricated that an inspection may be made of the wear and when the tire is worn down to the protrusion the tire is replaced.

Soon after testing procedures were initiated the skid resistance equipment was sent into an area of the state in which highly skid resistant surfaces were found. The tire was worn rapidly and an inspection of the tire revealed that the tire was worn past the protrusion (See Figures 1 and 2). It was decided to check the results using a new tire with the results of the worn tire.

Three roadway sections were selected and 20 miles per hour tests were obtained with both the worn tire and the new tire. These sections resulted in coefficients of friction ranging from 0.3 to 0.6. An "analysis of variance" procedure was used to determine if significant difference at a 95 percent probability was present between the means of the tests of the two tires.

Results of Analysis

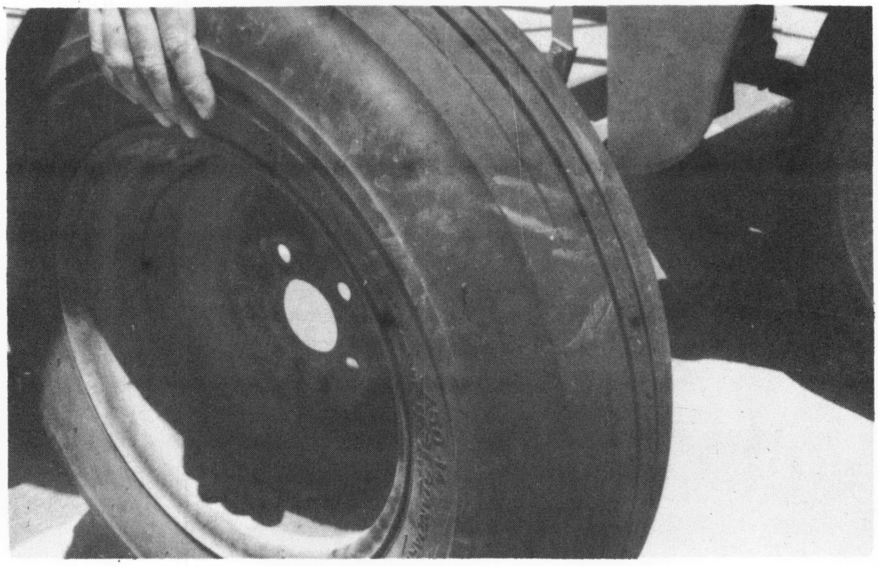
Precision. The tests obtained indicated the precision of the equipment ranged from 0.005 to 0.020 with the mean being 0.012. The precision did not vary with the coefficient of friction measured, but was random within any one roadway.

If the precision is expressed as a percent of the mean the resulting value is termed coefficient of variation. The resulting coefficients of variation ranged from 0.61 percent to 5.70 percent, and higher percentages were found on the roadways with lower coefficients of friction.

Surface Variation. The "analysis of variance" procedure revealed that the scatter of readings measured along the roadway was greater than the variation produced by the equipment on six of the eight roadways tested as indicated in Table I. This was to be expected because of the variation in placement of materials during construction. This means that sample size should be determined from tests obtained along the roadway.

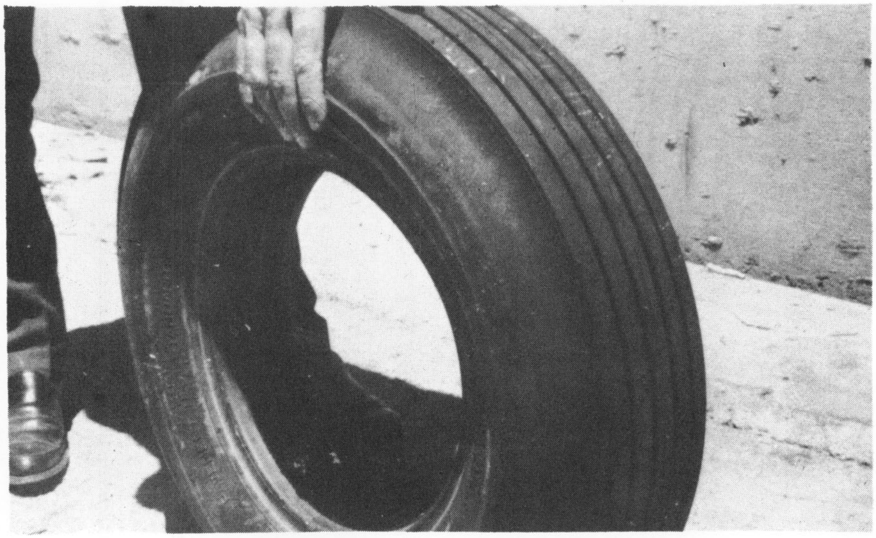
Sample Size. There appears to be two methods of collecting data for use in evaluating roadway surfaces. The first is to obtain a result which is an indicator of the skid resistance by spot sampling a random section generally consisting of several closely spaced tests in one locale.

The second method of collecting data is to perform one skid test at periodic intervals, such as one skid every one-half mile over the full length of the pavement job limits. This method obtains not only the average condition of the



Worn Test Tire
(Approximately 3000 Braking Tests)

FIGURE 1



New Test Tire

FIGURE 2

TABLE I

SURFACE VARIATION RESULTS

Pavement Type	F Observed*	F Check
ACP - Type C	0.33	5.19
ACP - Type D	13.23	5.19
Concrete	8.36	6.59
Surface Treatment - Dolomite	14.34	6.59
Surface Treatment - Trap Rock	1.59	6.59
Surface Treatment - Limestone	30.22	6.59
Surface Treatment - Lightweight Aggregate	70.05	6.59
Surface Treatment - (Very worn)	12.99	5.59

*F Observed greater than F Check indicates greater variation of measurements along the roadway than the variation of the ramdon error.

roadway, but reveals slick areas within any job limit.

Determination of the number of tests needed was found for both methods of data collection. The first method of several closely spaced tests in one locale was accomplished by analyzing the data from fifteen roadway surfaces. The number of skids performed was five on each roadway, and the coefficient of friction ranged from 0.3 to 0.8. It was found the sample size required ranged from one test to forty tests with a mean of fifteen skids needed.

Three roadways were used to determine the sample size of the second method of data collection. Twenty-five skids were collected at periodic intervals along each roadway. The coefficient of friction ranged from 0.3 to 0.6 on the surfaces selected. The resulting sample size needed ranged from twenty-five tests to sixty-seven tests with a mean of forty-three tests needed.

Chart Reading Error. The "analysis of variance" procedure used in checking the error in chart reading by the operating personnel revealed only slight variation produced by reading force values from the chart. This leads to the fact that only one operator is needed in chart reading.

Effects of a Worn Tire. The differences in coefficients of friction between the two tires ranged from 0.010 to 0.070 with the worn tire having the higher coefficient. The section with the lower coefficient of friction resulted in the higher differential. However, the "analysis of variance" procedure revealed no significant difference between the means as compared with an estimate of the universe mean. It is again stated that these tests were obtained at 20 miles per hour in artificially wet conditions. Higher speeds could reverse the trends found, and trailers with better precision could be more susceptible to tire wear. Even though it was decided to use the information collected during the latter stages of tire wear, caution is dictated in that the tire should be discarded when the tire has worn to the protrusion ring. Especially, no tests should be made when the outer treads wear slick.

Application of Results

Pavement surfaces become slick under repeated applications of traffic, therefore, periodic tests should be performed to check the acceptability of skid resistance. A guide for surface improvements has been established in Texas which suggests minimum coefficient of friction values of 0.3 at 50 miles per hour or 0.4 at 20 miles per hour.[7] Surface improvements could be made on the basis of this guide. However, caution should be used and engineering judgment not dismissed when reviewing test results as compared to the suggested minimums. For instance, if tests have been made at selected intervals along the roadway and a slick area has been found within the job limits with a coefficient of friction of 0.3 at 50 miles per hour, the information in this report indicates this value may represent a value of from 0.276 to 0.324 due to the variation of the test equipment (95 percent). This range is due to two standard deviations and should include 950 tests out of 1,000. Also this statement is based on one skid being performed on the slick section. If an accuracy of plus or minus 0.010 is desired it is suggested that six tests be performed over the slick area, and the results averaged.

On many occasions, it is not economically feasible to accrue the dictated sample size. For instance, if an accuracy of 0.010 is required and 950 tests out of 1,000 are expected to be included within this range on a 10 mile section of roadway that is to be tested for skid resistance, then, tests every 0.15 mile are dictated from information in this report. This assumes that tests are to be made at selected intervals along the roadway. Shorter pavement lengths would dictate a shorter test interval. This quantity of skids soon consumes considerable time and expenditure. If this method of testing is selected, it is suggested that at least fifteen skids be performed on any one job limit and a variation around the true mean of plus or minus 0.017 be expected.

If the skid resistance of a job limit is being determined by spot sampling in one locale, it is suggested that at least five skids be collected and a variation of plus or minus 0.017 around the mean be expected. This should include 950 tests out of 1,000. Table II lists the suggested sample sizes for use with the Texas Highway Department skid test trailer.

TABLE II

SUGGESTED NUMBER OF TESTS

	Method 1- Tests In One Locale	Method 2 - Tests At Intervals Along Roadway	Method 2- Tests At One Area or Interval
Number of Tests	5 Tests	15 Tests (between Job Limits)	6 Tests
Coefficient Accuracy Expected at 95% Level	0.017	0.017	0.010

III. CORRECTIVE TREATMENTS

Procedure

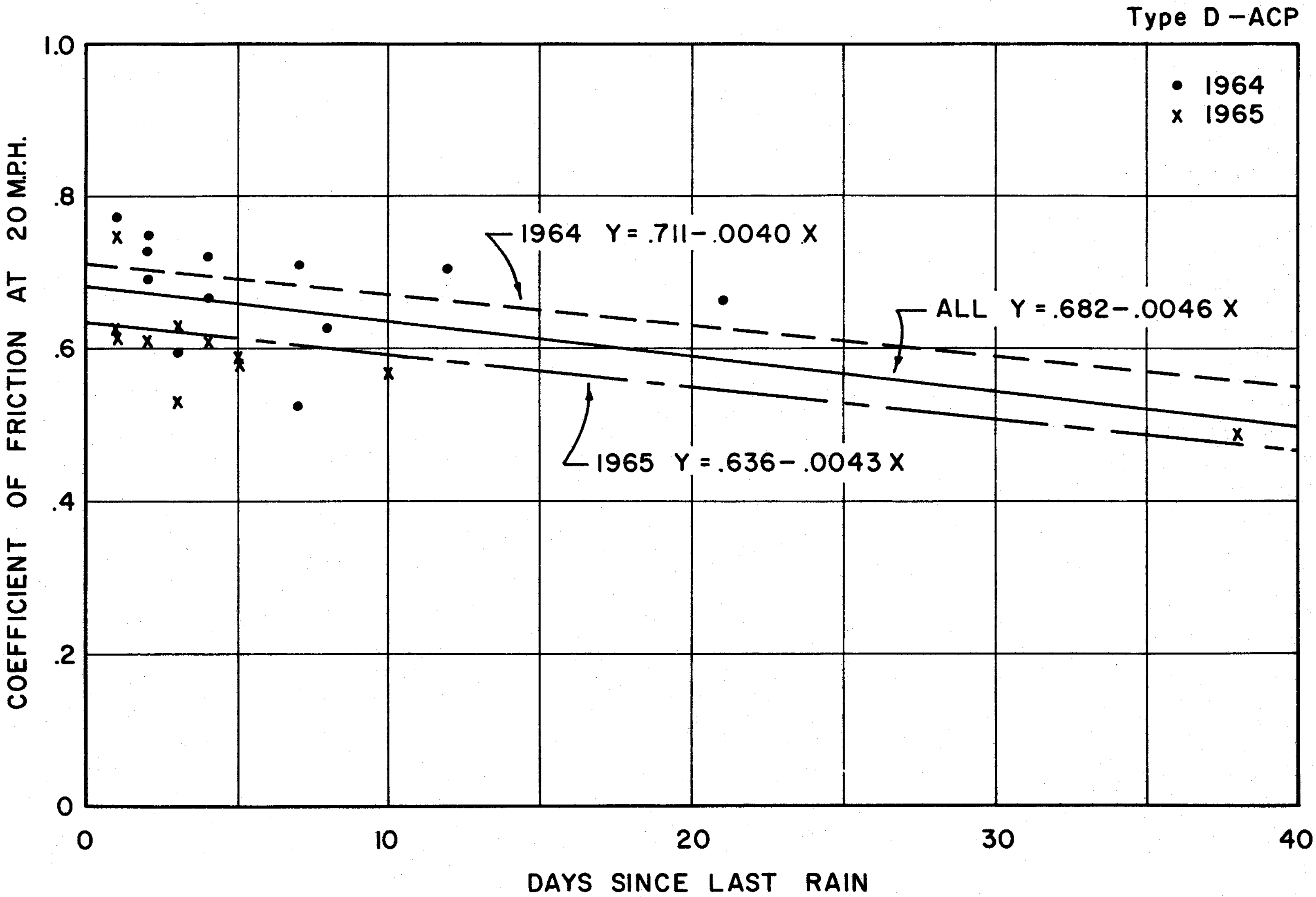
Road Film and Skid Resistance. To study road film effect, six of the eight original roadway sections for dynamic tests were selected consisting of hot mix, using Texas Specification Type C and Type D; Surface Treatment, using silicious and limestone, crushed and uncrushed aggregate; and concrete surfaces.[8] Skid resistance tests were obtained with the trailer at random time intervals over a two year period. The number of days since the last rain was detetmined from "Local Climatological Data" published by the U. S. Department of Commerce, Weather Bureau and from personal observations. Figure 3 is a typical plot of the skid resistance values obtained in terms of the number of days since the last rain for each section. It may be noted that the distribution of points indicates a linear function. Linear lines were placed through the points using the least squares method for the tests obtained in 1964, tests in 1965, and for all the tests combined.

Temperature and Skid Resistance. Four sections were used in studying air temperature effects. The coefficient of friction obtained on each section was collected along with the air temperature,and tests were gathered at random time intervals over a two year period.

To check the data obtained during the two year period special 12-hour tests were obtained on two of the six road film sections previously mentioned. Also, a short study was obtained on an eight-hour basis on five of the six previously mentioned road film sections.

Results

Road Film and Skid Resistance. The slope of the line in Figure 3 indicates the loss of coefficient per day and the "y intercept" indicates the coefficient immediately after a cleaning rain. Table III reveals the correlation of the six roadways tested. If the slopes of the linear



ROAD FILM EFFECTS AND SKID RESISTANCE

Figure 3

TABLE III

RESULT OF CORRELATING COEFFICIENT OF FRICTION AND ROAD FILM

Section	Y - Intercept.	Slope of Regression Line	Coefficient of Correlation	No. of Tests	Significance
Balcones Road	0.345	0.0019	28.75	24	82.6%
U S 183 Shoulder	0.582	0.0030	52.78	24	99.3%
U S 183 Main Lanes	0.682	0.0046	48.55	24	98.5%
McNeil Road	0.675	0.0045	45.70	22	96.7%
IH 35 North	0.399	0.0019	29.85	19	78.5%
IH 35 Bridge	0.549	0.0038	67.55	18	99.8%

Note: Regression values shown are based on a two-year period.

lines for various sections are compared with the "y intercept" values it is found that the loss of coefficient per day is related to the skid resistance of the roadway immediately after a rain. That is, the slope values decrease as the skid resistance of the roadway decreases. If the slope of the line is divided by the "y intercept" coefficient a relatively constant value is found. An equation

$$C_c = \frac{C_m}{1 - 0.0057(D)}$$

where: C_c = coefficient immediately after a rain

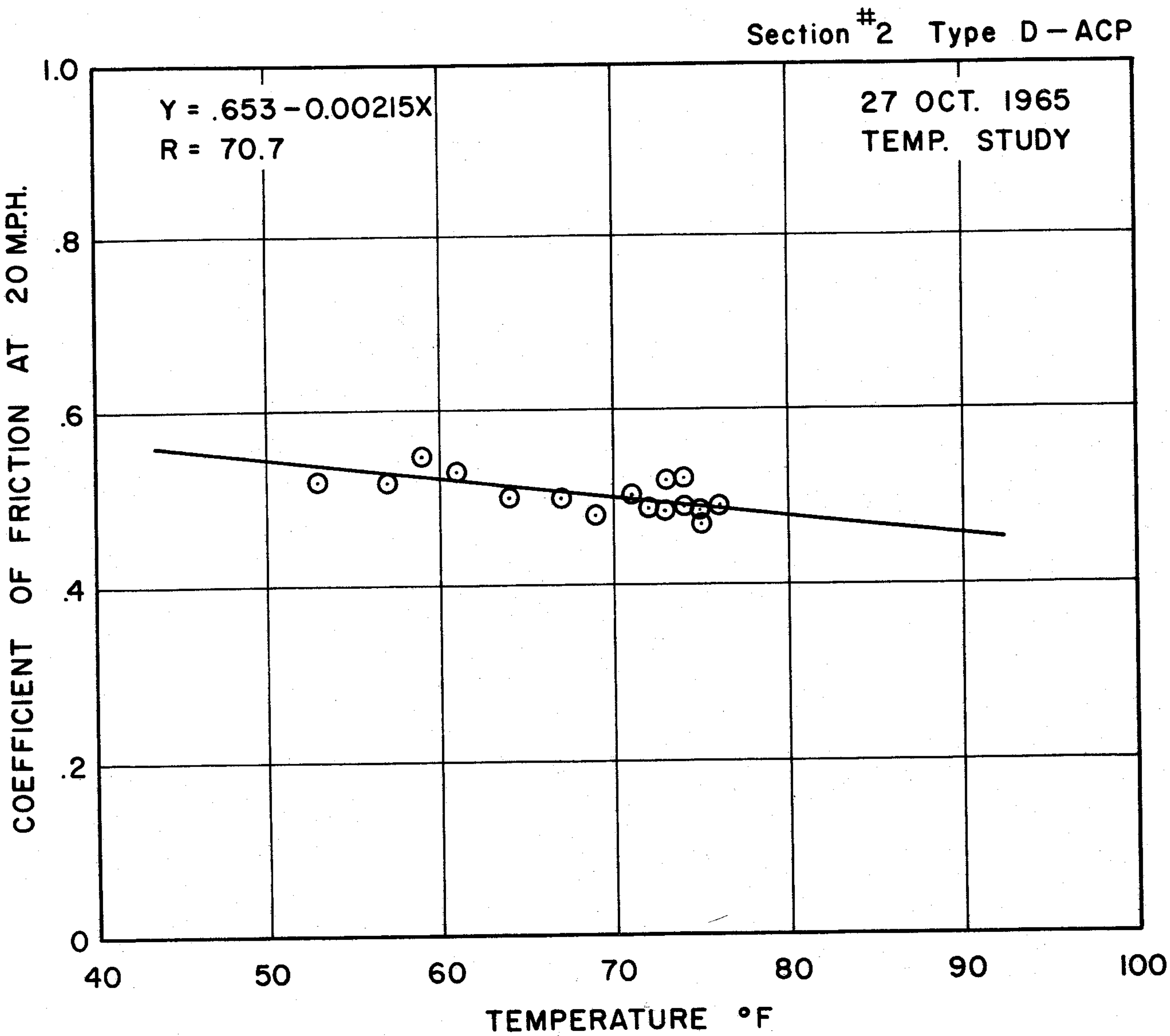
C_m = any measured coefficient of friction

D = days without a rain

may be formed which will predict the coefficient immediately after a rain, given a measured coefficient at any random time and the number of days since the last rain before which the random coefficient was measured.

Even though it is not within the scope of this report the difference between the "y intercept" coefficient for 1964 and 1965 should be noted. It was found that the 1964 intercept is always higher than the 1965 intercept. This difference is believed to be the wear experienced by traffic applications. However, the slopes of the three lines, in general, are parallel indicating repeatability of the phenomena.

Temperature and Skid Resistance. Figure 4 is a typical plot indicating the reduction in coefficient of friction as the temperature increases. Table IV indicates the results obtained by linear correlation using the least squares method for the sections previously mentioned. The reduction of coefficient of friction with increased temperature was random regardless of pavement type and random with coefficient of friction values. The curve slopes were averaged with a resulting value of -0.0016. If a standard temperature is selected for reporting such as 75° F, it is possible to subtract or add to the measured



TEMPERATURE EFFECTS AND SKID RESISTANCE

Figure 4

TABLE IV

RESULT OF CORRELATING COEFFICIENT OF FRICTION AND TEMPERATURE

Section	Y Inter-cept.	Curve Slope	Coeff. of Correlation	Number of Tests	Confidence of Coefficient of Correlation
#1-8 hr.	.472	-.00145	68.9	4	60.4%
#2-8 hr.	.625	-.00187	84.2	4	77.8
#3-8 hr.	.638	-.00108	77.5	4	70.2
#4-8 hr.	.741	-.00234	92.5	4	90.2
#5-8 hr.	.496	-.00194	81.4	4	74.2
#2-12 hr.	.653	-.00215	70.7	18	99.8
#3-12 hr.	.627	-.00102	65.2	18	99.7
#3-2 Yr.	.820	-.00173	29.6	24	84.2
#4-2 Yr.	.781	-.00140	30.7	21	81.8
#5-2 Yr.	.475	-.00101	35.9	18	85.6
#6-2 Yr.	.707	-.00198	64.4	18	99.6

coefficient 0.0016 for each degree fahrenheit differential. This means a change in friction value of 0.016 for each 10° F temperature change. The correction equation would be as follows:

$$C_{75} = C_m + 0.0016\ (T_m - 75)$$

where: C_m = Measured coefficient

T_m = Air temperature in $^{\circ}$F at time of measurement.

Discussion of Results

Road Film. Road film is not a new concept in skid resistance. Mr. Moyer [3] reported the presence of surface contamination in 1934, and it has been postualted by many Engineers in Texas that surfaces are very slick during the initial stages of a rain shower. The initial calibration with the test trailer indicates the presence of a surface contamination which was removed with a cleansing rain. Several tests have been conducted since the initial tests where it was noted that loose soil on the pavement surface seemed to reduce the skid resistance.

The results presented were found to be reproducible, that is, the skid resistance being reduced after a period of no rain was found to increase to approximately the same value each time the surface was cleaned with a rain. The intensity of the cleaning rain was studied to some extent but no correlation was found; however, the rain was not considered to be cleansing under a magnitude of 0.01 inch. Also the number of days of rain was studied to determine if a higher or lower skid resistance resulted, but no correlation was found.

It should be stated that on the average roadway the coefficient of friction could be reduced as much as 0.1 with 30 days of no rain. This means that during the initial stages of a rain after an extended period of drought, the surface can be expected to be very slick.

Engineers should be aware of this fact when determining the level at which surfaces should be upgraded, especially in areas of Texas which are without rain for long periods. It is also suggested this correction be used in studies such as the tests of surface polishing characteristics.

Temperature. The following paragraph has been taken from a report published by the Department of Highways, Ontario, Canada, in order that a greater knowlege of the temperature variable may be obtained:(4)

> "It has been widely observed and reported that skid resistance tends to decrease with increasing temperatures (ambient, pavements, and tire temperatures). A typical reduction in skid resistance might be 0.02 for a 10° F rise in air temperature. This phenomenon has been recently traced back to the hysteresis characteristics of the tire rubber; with increasing temperatures the hysteresis losses in the rubber are reduced, resulting in lower frictional resistance. On very smooth surfaces (such as glass plate), where the effect of hysteresis losses is negligible, the temperature effect is also negligible. Also, since rubber hysteresis changes more rapidly at lower temperatures, skid resistance measurements are more sensitive to temperature changes at lower temperatures."

It has been found in this study that a reduction in skid resistance is apparent with increasing air temperatures; however, a linear fit and correlation format has been suggested in this report. No curvilinear tendency was found but the data was collected with temperatures ranging from +40° F to +100° F. Also, no correlation of skid resistance-temperature was found with smoothness of surface. The reduction in skid resistance with increased temperature did agree with the typical reduction mentioned in the above paragraph.

IV. SUMMARY

Discussion

No studies have been made of seasonal effects; however, periodic tests over the same sections which were corrected for temperature and road film reveal discrepancies which indicate seasonal changes. The range of the seasonal change appears to be on the order of 0.05 to 0.10 with the higher coefficient values found in the winter. Continued study will be made on this subject.

It should be noted that all skid resistance values herein reported were obtained at 20 miles per hour with the exception of the tests at intervals along the roadway which were obtained at 40 miles per hour. In the opinion of the authors the treatments and corrections reported would be applicable within the range of speeds expected in normal passenger vehicle operation.

Recommendations as to Operation

The following is recommended in the operational procedures of the Texas skid test trailer or trailers:

Sample Size:

Type of Test	Number of Tests for Accuracy Of	
	0.010	0.017
Method #1 - Tests in One Locale	15 Tests	5 Tests
Method #2 - Tests at Intervals Along Roadway (between job limits)	43 Tests	15 Tests
Method #2 - Tests over one area or at one Interval	6 Tests	2 Tests

Chart Reading: One operator only.

Tire Condition: Tire should be discarded when the tire has worn to the protrusion ring.

Corrective Treatments for Road Film and Temperature:

$$C_f = \frac{C_m + 0.0016\ (T_m - 75)}{1 - 0.0057\ D}$$

where:

C_f = Corrected Coefficient of Friction

C_m = Measured coefficient of friction

T_m = Measured Ambient (air) temperature at the time of test

D = Days of no rain preceding the test.

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