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COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT 72-2

CORRELATION OF A PORTABLE SKID TESTER WITH THE MISSOURI SKID TRAILER

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MISSOURI STATE HIGHWAY DEPARTMENT
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CORRELATION
OF A PORTABLE SKID TESTER
WITH THE MISSOURI SKID TRAILER

Prepared by

MISSOURI STATE HIGHWAY DEPARTMENT

Division of Materials and Research

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In cooperation with

U.S. DEPARTMENT OF TRANSPORTATION

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

SYNOPSIS

This investigation was a pilot study to generally evaluate the Keystone Mark IV Skid Resistance Tester and determine if such equipment could be used to complement the Missouri skid trailer.

Although the portable tester had good repeatability and the results were not adversely affected by different operators or variations in the amount of water used to wet the surface, the correlation obtained between the portable tester and the Missouri skid trailer was generally unsatisfactory.

CONTENTS

Introduction 1

Conclusions 3

Implementation 5

Scope 7

Procedure 9

Results and Discussion 13

Repeatability of Portable Tester 13

Correlation Tests 22

Portland Cement Concrete Surfaces 23

Asphaltic Concrete and Bituminous Surfaces 28

All Surface Types 29

Effect of Surface Texture 29

Pavement Friction Evaluation 37

Problems Encountered 41

Bibliography 43

Appendix A 44

Appendix B 45

LIST OF TABLES

Table

I a&b Effect of Quantity of Water Applied to Surface on Drag Tester Number (DTN) For Asphaltic and Portland Cement Concrete Surfaces 15

II a&b Effect of Operators on Drag Tester Number (DTN) For Asphaltic and Portland Cement Concrete Surfaces 16

III a&b Effect of Operators on Drag Tester Number (DTN) For Bituminous Treated Surface 18

IV Difference in Drag Tester Number (DTN) Between Replicate Measurements on Asphaltic and Portland Cement Concrete Surfaces 20

V Difference in Drag Tester Number (DTN) Between Replicate Measurements on a Bituminous Treated Surface 24

Correlation and Regression Results - - Portable Tester Drag Tester Number (DTN) vs. Missouri Skid Trailer Coefficient of Friction (CF):

VI - - Portland Cement Concrete Surfaces (PC) . . 26

VII - - Plant Mix Bituminous Surface (PM) 30

VIII - - Bituminous Treated Surface (BT) 30

IX - - Plant Mix Bituminous Maintenance Leveling Course Surface (LC) 30

X - - Asphaltic Concrete Surfaces (AC) 34

XI - - Asphaltic Concrete and Bituminous Surfaces 36

XII - - All Surface Types 38

XIII Evaluation of Pavement Friction Using the Portable Tester and Missouri Skid Trailer . . . 40

LIST OF FIGURES

Figure

1. Comparison of DTN Between Operators on Asphaltic and Portland Cement Concrete Surfaces 17

2. Comparison of DTN Between Operators on Bituminous Treated Surface 19

3. Comparison of DTN Between Replicate Measurements on Asphaltic and Portland Cement Concrete Surfaces 21

4. Comparison of DTN Between Replicate Measurements on a Bituminous Treated Surface 25

5. DTN By Portable Tester vs. CF By Missouri Skid Trailer For Portland Cement Concrete Surfaces . . . 27

6. DTN By Portable Tester vs. CF By Missouri Skid Trailer For Plant Mix Bituminous Surfaces 31

7. DTN By Portable Tester vs. CF By Missouri Skid Trailer For a Bituminous Treated Surface 32

8. DTN By Portable Tester vs. CF By Missouri Skid Trailer For Plant Mix Bituminous Maintenance Leveling Course Surfaces 33

9. DTN By Portable Tester vs. CF By Missouri Skid Trailer For Asphaltic Concrete Surfaces 35

10. DTN By Portable Tester vs. CF By Missouri Skid Trailer For All Surface Types 39

INTRODUCTION

The Missouri State Highway Department is presently involved in a research program investigating skid resistance characteristics of various pavement types and materials used throughout the state. A skid trailer, conforming to ASTM E-274-70, is being used in that program. The skid trailer is a commercial model manufactured as Model 965A, by K. J. Law Engineers, Incorporated.

Due to the length required to obtain a test, the skid trailer is undesirable for testing short bridge deck spans, short sections of experimental skid resistant overlays, or certain inaccessible accident areas. A portable skid tester having a good correlation with a skid trailer could be used to determine surface friction properties for these conditions. It was therefore considered necessary to determine the correlation that existed between a portable skid tester and the Missouri skid trailer.

The Keystone Mark IV Skid Resistance Tester was chosen for this correlation because a literature search indicated that it would be the most feasible for a correlation study and field application. The tester was purchased from Die-A-Matic, Inc. of York, Pennsylvania and is shown in Appendix A. The Keystone Mark IV Skid Resistance Tester, the commercial version of the Penn State Drag Tester, has been described in detail by Kummer (1), (2)*.

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* Number in parenthesis refers to references given in Bibliography.

This investigation was a pilot study to generally evaluate the portable tester. The repeatability of results with this equipment as well as the correlation between the Missouri trailer and the portable tester were evaluated over a limited scale.

CONCLUSIONS

Based on the field work and the statistical analyses carried out in this study, the following conclusions have been reached:

1. The statistical analyses made in this study indicate that the portable tester-skid trailer correlation did not produce acceptable relationships. The standard errors of the regression equations (one equation for each trailer speed) for the combination of all surface types were too large. Better linear regressions were found on a Portland cement concrete surface than on asphaltic concrete or any of the other bituminous surfaces included in this study.

2. There appears to be an effect of surface texture on the correlations obtained. This would require an additional test to measure surface texture, to be used with the portable tester results, to adequately evaluate the surface friction properties.

3. Evaluation of the pavement friction using the portable tester and skid trailer resulted in the portable tester classifying a much larger percentage of the test locations as having inadequate surface friction when test results obtained by each piece of equipment were compared to published standards in NCHRP Report 37.

4. The overall sensitivity of the portable tester appeared to be inadequate as evidenced by the range of Drag Tester Numbers obtained.

5. The portable tester results were not affected by the quantities of water used when testing asphaltic concrete or Portland cement concrete. Also, the results were not affected by the operator on asphaltic concrete, Portland cement concrete, or a bituminous treated surface. Replicate measurements were found to be within three Drag Tester Numbers on asphaltic or Portland cement concrete and within seven Drag Tester Numbers on a bituminous treated surface, using a 99 percent probability level in both cases.

IMPLEMENTATION

The results of this pilot correlation study indicates the Keystone Mark IV Skid Resistance Tester to be an unsatisfactory instrument, used alone, for complementing the Missouri skid trailer. Use of an auxiliary test to measure surface texture combined with the Drag Tester Number might be required to provide a satisfactory multiple correlation between the two pieces of equipment. Such an additional measurement would, in our opinion, defeat the purpose for which we had intended to use this equipment. It is, therefore, not recommended at this time to continue this study as the portable tester did not adequately evaluate the pavement friction.

SCOPE

Repeatability of Portable Tester

Several tests were conducted with the portable tester to determine the equipment's repeatability. There were three objectives for the series of tests performed: (1) to determine what effect, if any, the amount of water applied to the pavement surface had upon the Drag Tester readings; (2) to determine the influence of different operators on the Drag Tester readings; and (3) to determine the precision with which the portable tester could repeat itself.

Tests were conducted on asphaltic concrete, Portland cement concrete, and a bituminous treated surface. Analysis of variance was used to help evaluate the results from each series of tests.

Correlation Tests

Portland cement concrete, asphaltic concrete and other bituminous surfaces were tested over the same area by the portable tester and the Missouri skid trailer to determine if a satisfactory correlation existed between them. The locations selected for the correlation tests were those pavements which were scheduled to be tested with the skid trailer. As a result, surfaces in several areas of the state were sampled during October, 1971.

Simple linear correlation and regression analyses, using the least squares method, were performed using the data from each individual test location within a test site

(five locations per site). Separate analyses were made for individual speeds ranging from 20 to 50 MPH.

The Portland cement concrete surfaces sampled were located within four Highway Department districts and ranged in age from one year to sixteen years. A total of 12 separate test sites (sections of pavement) were sampled.

The surfaces composed of asphaltic concrete (AC), plant mix bituminous surface (PM), plant mix bituminous maintenance leveling course (LC), or bituminous treated surface (BT) (comparable to a sealcoat) were located within six Highway Department districts and ranged in age from less than one year to seven years. A total of seven separate test sites were sampled on asphaltic concrete, four on a plant mix bituminous surface, seven on a plant mix bituminous maintenance leveling course, and one on a bituminous treated surface.

PROCEDURE

Tests were conducted generally in accordance with ASTM procedures for the skid trailer and the manufacturer's procedures for the portable tester. One exception in the test procedure for the portable tester was the temperature correction. The tests obtained with the Drag Tester were corrected to a dry surface temperature of 80 $\pm$ 6°F rather than a wet surface temperature of 76 $\pm$ 6°F, as no standard procedure was given for determining the wet surface temperature.

There were some indications that a new slider pad gave higher Drag Tester Numbers (DTN) than a used pad. Repeated tests on one pad at the same location resulted in the DTN becoming fairly constant after sliding approximately 180 to 200 feet. Therefore, before any new slider was used to obtain data, it was required to be preconditioned by making approximately 12 or more tests on a wetted surface.

A total of four tests (each 15 feet long) were obtained at each test location. These were averaged to obtain the DTN to be used in repeatability tests and the correlation study.

The drag tester was calibrated weekly using the manufacturer's calibration procedure. The field check for calibration was performed periodically throughout each testing day. These calibrations and checks were found to be satisfactory within the period of the actual field tests during the study.

Repeatability of Portable Tester

Quantity of Test Water - One factor which would appear to determine how well a test value could be repeated is the amount of water on the surface when the test was made. The manufacturer's instructions were to "thoroughly flush surface" with clean water.

Sites on asphaltic concrete and Portland cement concrete surfaces were tested which were to represent relatively high and low friction levels. Three locations at each site were tested with four Drag Tester readings obtained at each location.

Water was applied with a garden-type sprinkler can. Tests were run with a single application of water and a double application (two passes with the sprinkler can). The same operator ran the tests for each application of water, and all of the tests were run within a time period of approximately two hours. No temperature corrections were made because the temperature was practically constant on each surface type.

Operator Influence - Tests to determine the operator influence were made on the same locations which were used to determine the effect of the quantity of the test water. Three operators were used with a random order of testing, and all of the tests were run within a time period of approximately three hours. Again no temperature corrections were made because the pavement surface temperatures were within $\pm$ 8°F of each other.

Tests to determine the operator influence were also conducted on a bituminous treated surface (representing conditions encountered on a sealcoat surface). Locations were chosen with a bleeding asphalt surface as well as a surface with coarse aggregate well exposed and protruding through the asphalt binder. Three operators were used with a random order of testing.

Replicate Tests - When conducting the tests to determine the operator influence, replicate measurements were made by all operators. This was done to assist in the analysis of operator influence and also to determine the precision with which the average of four readings could be duplicated over the same surface. The replicate measurement was taken immediately following the initial measurement.

Correlation Tests

The field procedure for the correlation tests was established to provide for the portable tester measurements to be taken over the same area of the roadway which the skid trailer had tested. Five tests, at a given test speed, are normally made with the skid trailer on a predetermined length of pavement. The five test locations were temporarily identified at sites which were to be used for the correlation study. All test cycles with the skid trailer were initiated at these reference points at each location. The testing with the portable tester was also referenced from these points so that the portable tester results, to

be correlated with a specific trailer speed, would be obtained over the same area of the roadway which was tested with the skid trailer. The portable tester was run on the same day as the skid trailer in each case. The locked wheel coefficient of friction was the principal coefficient investigated. The Missouri skid trailer also measures the incipient or slip coefficient which is normally from 1.5 to 2.0 times greater than the locked wheel coefficient. The relationship of the slip coefficient to the portable tester DTN, varied according to the speed at which the slip number was obtained. It became evident that a study of this relationship could not be thoroughly evaluated during the time period of this pilot study. Therefore, only locked wheel coefficients are discussed.

Test speeds for the skid trailer were established as 20, 30, 40, and 50 MPH. Test speeds on undivided pavement were 20, 30, and 40 MPH in one lane (direction) and 40 and 50 MPH in the opposite lane. Sites located on divided pavement were tested generally at 40 and 50 MPH. On one occasion, tests were made at 20 MPH on divided pavement. Tests used in the correlation were obtained with the left wheel of the trailer. For each speed tested, four tests were made with the portable tester to arrive at an average DTN to be used for the correlation. The dry pavement surface temperature was measured periodically at a test site and the DTN was corrected to a common temperature of 80 $\pm$ 6°F, according to the procedure outlined by the manufacturer in Appendix B.

RESULTS AND DISCUSSION

Repeatability of Portable Tester

Quantity of Test Water - The data from the tests to determine the influence of quantity of test water are shown in Table Ia. Analysis of variance (Table Ib) was used to determine if the amount of water on the surface made a significant difference in the test results. The analysis did not show the quantity of water to be a significant factor in the amount of variation observed. The significance level (α) of the F-Ratio in the analysis of variance tables must be at least equal to, or less than, the 0.05 level for the factor to be judged as significant in this analysis.

The quantity of test water applied not having a significant effect on the portable tester results was somewhat unexpected. Previous evidence of this effect has been obtained by several skid trailer units. The sensitivity of the portable tester did not appear to be adequate for detecting small differences.

Operator Influence - The data from the tests to determine the operator influence on asphaltic concrete and Portland cement concrete are shown in Table IIa and illustrated in Figure 1. Analysis of variance (Table IIb) was used and it was determined that the variation in operators was not a significant contributor to the amount of variation observed. Most of the variation in this analysis was found to exist between test sites.

Results from the tests to determine the operator influence on a bituminous treated surface are shown in Table IIIa and illustrated in Figure 2. Analysis of variance (Table IIIb) did not show the operators to be a significant contributor to the variation measured. Most of the variation in this analysis was found to exist between surface textures.

Replicate Tests - An analysis of the replicate tests for asphaltic and Portland cement concrete, using all operators, was made to determine the precision with which the average of four readings could be duplicated over the same surface. The difference between average DTN for each replicate, at each test location, was determined. These data are shown in Table IV and illustrated in Figure 3. From these differences, a standard deviation of a single average DTN was determined according to the procedure outlined by Youden (3) and given as:

$$\text{Standard Deviation } (\sigma) = \sqrt{\frac{(\text{Difference})^2}{2n}}$$

where Difference = $DTN_{Repl.1} - DTN_{Repl.2}$.

The average difference between replicates is related to the standard deviation, as shown in Youden, with

Average Difference Between Replicates = 1.128 (σ).

This gives an estimated average difference between replicate DTN of $\pm$ 1 Drag Tester Number for Portland cement concrete and asphaltic concrete surfaces. The "t" distribution was used due to the small sample size (n = less than 30). Using a 99 percent probability and n = 18 the average difference between replicate DTN would be estimated to be within $\pm$ 3 Drag Tester Numbers.

Table Ia

Effect of Quantity of Water Applied to Surface
on Drag Tester Number (DTN)
For Asphaltic and Portland Cement Concrete Surfaces

Site	Location	DTN* Single Application of Water	DTN* Double Application of Water	Avg. DTN For Site
II (PCC)	1	36.25	38.25	37.50
	2	35.50	38.50	
	3	36.75	39.75	
III (AC)	1	43.25	43.75	42.50
	2	42.75	40.25	
	3	42.50	41.00	
Avg. DTN For Application		39.50	40.25	

* DTN is an average of four tests at each location.

Table Ib

Effect of Quantity of Water Applied to Surface
on Drag Tester Number (DTN)
For Asphaltic and Portland Cement Concrete Surfaces
Analysis of Variance Table

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio	α
Sites (R)	1	67.688	67.688	59.1	0.001
Water (F) Application	1	1.688	1.688	0.2	N.S.
Sites x Water Appl.	1	11.020	11.020	9.6	0.025
Residual	8	9.166	1.146		
Total	11	89.562	8.142		

(R) = Random effect
(F) = Fixed effect
N.S. = Not Significant

Table IIa

Effect of Operators on Drag Tester Number (DTN)
For Asphaltic and Portland Cement Concrete Surfaces

Site	Location	Replicate	DTN* Operator A	DTN* Operator B	DTN* Operator C	Avg. DTN For Site
	1	1	33.50	34.25	34.00	
		2	33.00	33.75	34.25	
II	2	1	35.75	32.50	33.00	34.18
(PCC)		2	33.75	31.75	33.50	
	3	1	39.25	34.00	35.00	
		2	35.00	34.00	35.00	
	1	1	47.00	43.50	44.25	
		2	46.25	44.00	43.50	
III	2	1	43.25	41.50	43.50	43.22
(AC)		2	42.50	41.25	42.25	
	3	1	42.75	44.50	41.50	
		2	42.25	43.50	40.75	
Avg. DTN For Operator			39.52	38.21	38.38	

* DTN is an average of four tests at each location.

Table IIb

Effect of Operators on Drag Tester Number (DTN)
For Asphaltic and Portland Cement Concrete Surfaces
Analysis of Variance Table

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio	α
Operators (R)	2	12.253	6.127	5.9	N.S.
Sites (R)	1	735.766	735.766	85.4	0.001
Locations Within Sites (R)	4	34.451	8.613	2.7	N.S.
Operators x Sites	2	2.073	1.036	0.3	N.S.
Operators x Locations Within Sites	8	25.528	3.191	4.0	0.01
Within Cells	18	14.406	.800		
Total	35	824.477	23.556		

(R) = Random effect
N.S. = Not Significant

Figure 1: Comparison of DTN Between Operators
On Asphaltic and Portland Cement Concrete Surfaces

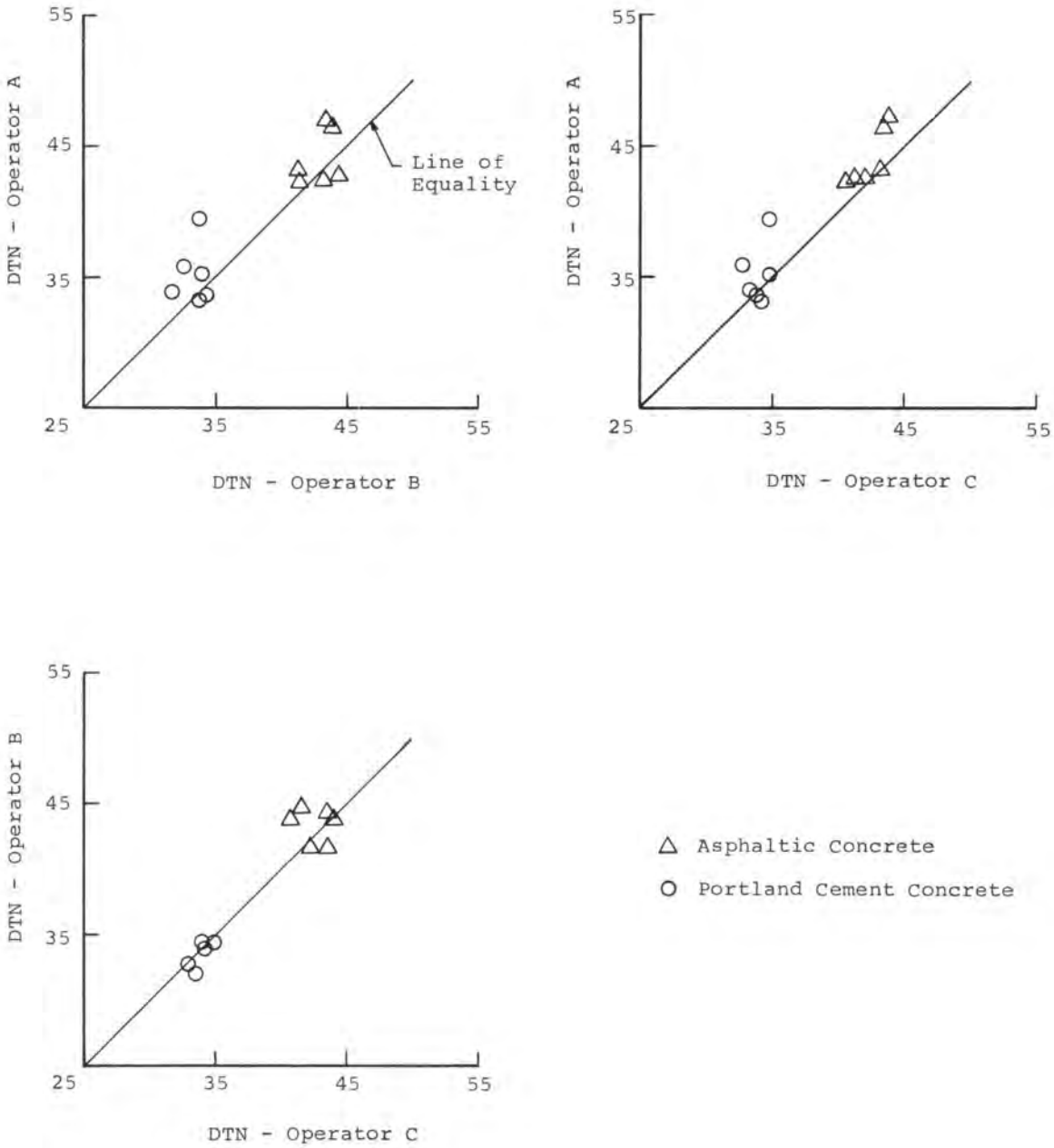


Table IIIa

Effect of Operators on Drag Tester Number (DTN)
For Bituminous Treated Surface

	DTN*					
	Site I			Site II		
	Knobby Surface Texture			Smooth Surface Texture		
Location	Oper.A	Oper.B	Oper.C	Oper.A	Oper.B	Oper.C
1	34.25	35.00	34.25	25.50	23.00	24.50
	34.50	34.75	36.50	21.00	25.00	21.50
2	35.50	34.25	37.75	27.50	26.50	26.50
	38.00	36.50	38.75	23.00	25.50	22.75
Avg. DTN For Oper.	35.50	35.00	36.75	24.25	25.00	23.75
Avg. DTN For Site		35.75			24.50	

* DTN is an average of four tests at each location.

Table IIIb

Effect of Operators on Drag Tester Number (DTN)
For Bituminous Treated Surface
Analysis of Variance Table

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio	α
Surface Texture (F)	1	790.628	790.628	189.4	0.01
Operators (R)	2	0.672	0.336	0.5	N.S.
Location (R)	1	21.565	21.565	34.4	0.05
Surface Textures x Operators	2	8.349	4.174	4.2	N.S.
Surface Textures x Location	1	0.003	0.003	0.0	N.S.
Operators x Location	2	1.255	0.628	0.2	N.S.
Surface Textures x Operators x Locations	2	1.974	0.987	0.3	N.S.
Within Cells	12	43.031	3.586		
Total	23	867.477			

(F) = Fixed Effect
(R) = Random Effect
N.S. = Not Significant

Figure 2: Comparison of DTN Between Operators
On Bituminous Treated Surface

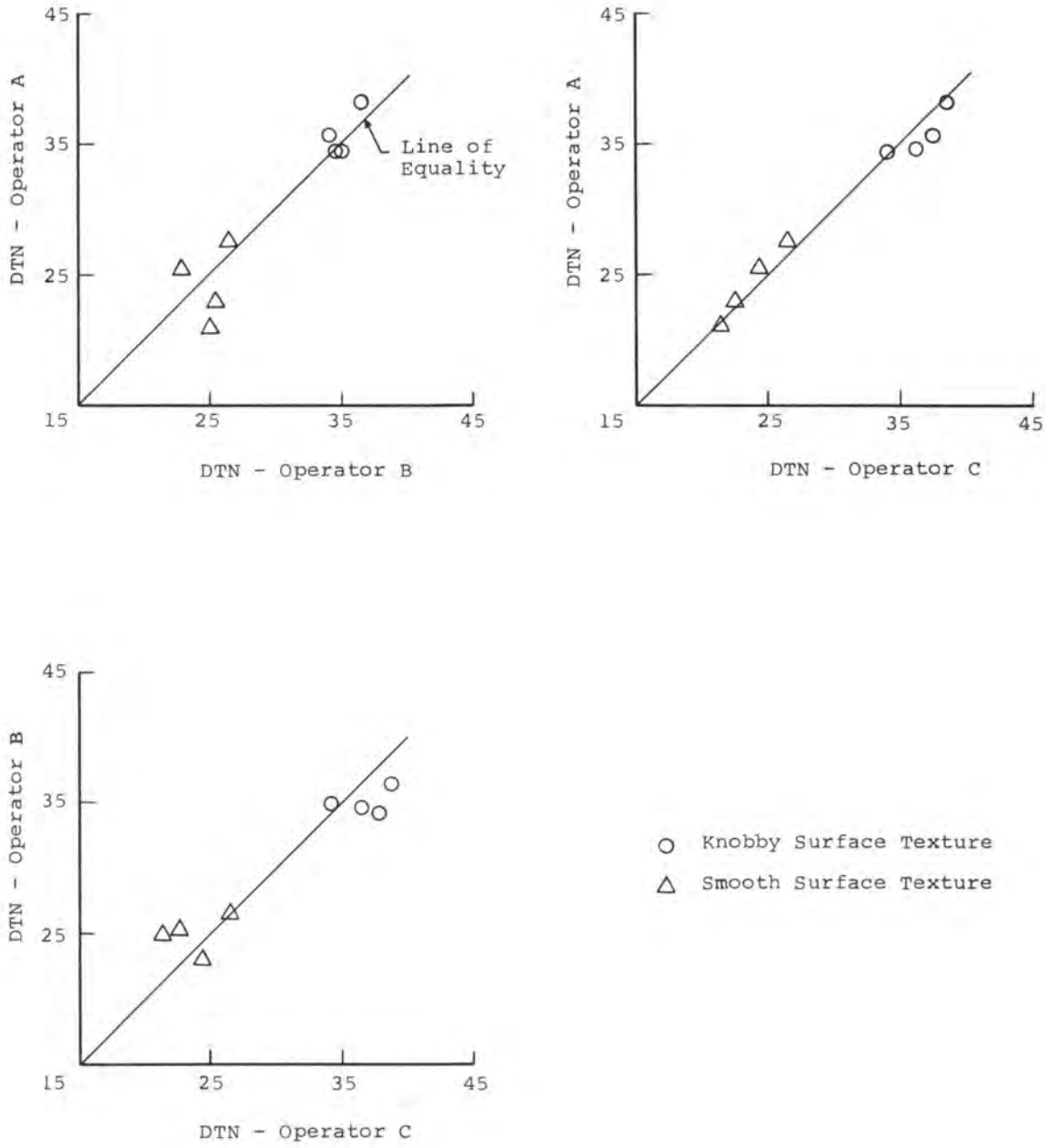


Table IV

Difference in Drag Tester Number (DTN)
Between Replicate Measurements on
Asphaltic and Portland Cement Concrete Surfaces

DTN*		
Replicate 1	Replicate 2	Difference
33.50	33.00	+0.50
35.75	33.75	+2.00
39.25	35.00	+4.25
47.00	46.25	+0.75
43.25	42.50	+0.75
42.75	42.25	+0.50
34.25	33.75	+0.50
32.50	31.75	+0.75
34.00	34.00	0.00
43.50	44.00	-0.50
41.50	41.25	+0.25
44.50	43.50	+1.00
34.00	34.25	-0.25
33.00	33.50	-0.50
35.00	35.00	0.00
44.25	43.50	+0.75
43.50	42.25	+1.25
41.50	40.75	+0.75

* DTN = Average of four tests

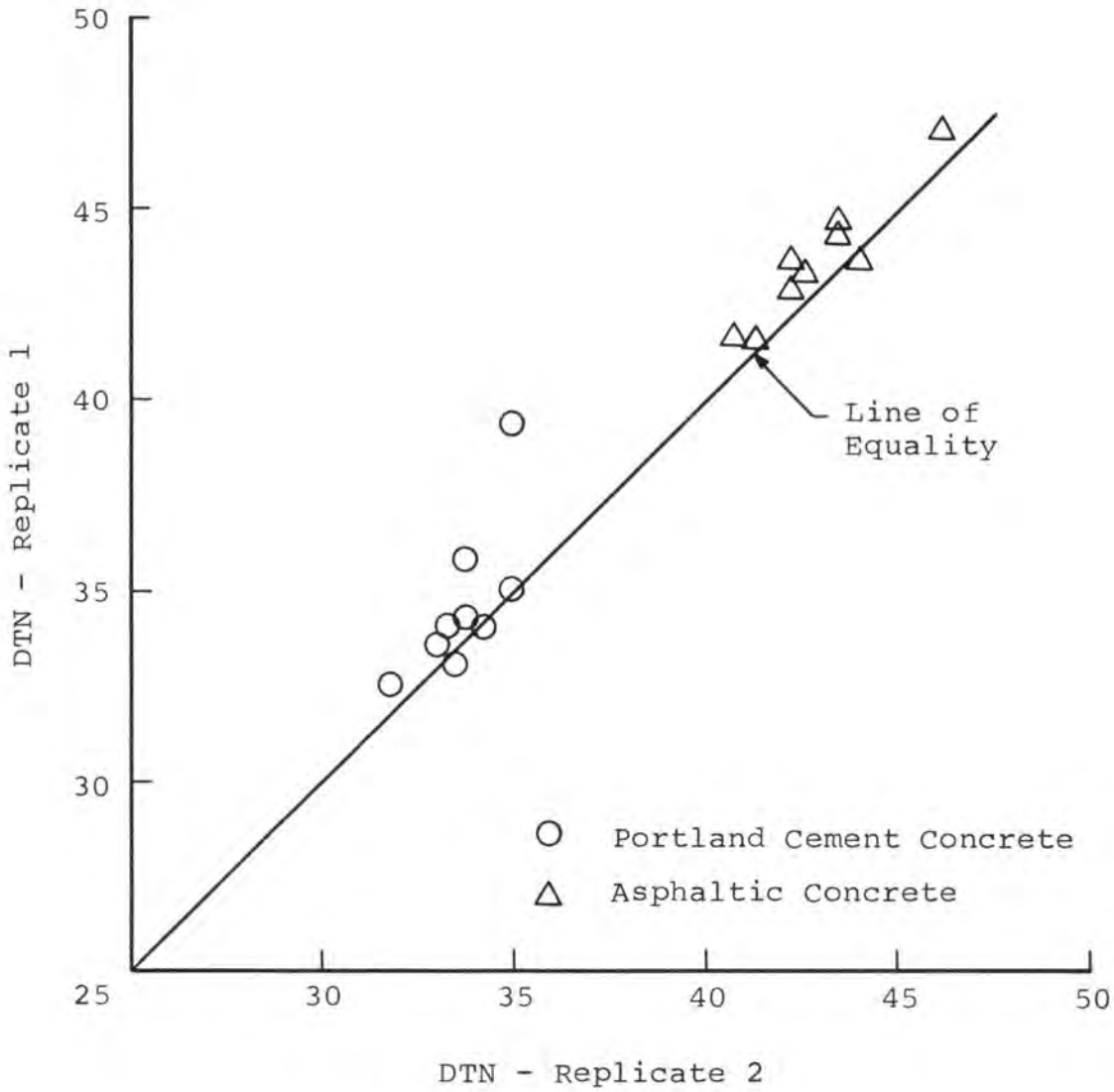
Standard Deviation (σ) of single DTN =

$$\sqrt{\frac{28.8125}{36}} = 0.8946$$

Average Difference Between Replicates =

$$1.128\ (0.8946) = 1.01$$

Figure 3: Comparison of DTN Between Replicate Measurements on Asphaltic and Portland Cement Concrete Surfaces



A similar analysis was made for the replicate tests on the bituminous treated surface. The analysis of the replicate tests (Table V, Figure 4) gave an average difference between replicate DTN of $\pm$ 2 Drag Tester Numbers. Using a 99 percent probability and n = 12, the average difference between DTN would be estimated to be within $\pm$ 7 Drag Tester Numbers.

The difference between replicates is much greater on a bituminous treated surface than on a Portland cement concrete or asphaltic concrete surface. Field observations substantiated these findings as the deflection of the indicator on the portable tester dial varied over a much wider range on the bituminous treated surface. Variation in surface texture within a wheelpath is much greater on the bituminous treated surface which contributes to the larger error found between replicates.

Correlation Tests

Correlation tests between the drag tester and skid trailer were made on Portland cement concrete surfaces, asphaltic concrete surfaces, plant mix bituminous surfaces, maintenance leveling courses, and a bituminous treated surface. The surfaces were judged as being a smooth or knobby textured surface at the time the field tests were made. For each type of surface, separate analyses were made on those projects falling into the knobby or smooth categories, as well as analyses of all projects combined.

Analyses were also made for all projects on all surface types and textures.

Portland Cement Concrete Surfaces - The results of the simple linear correlation and regression analyses for the Portland cement concrete surface are shown in Table VI and the data are plotted in Figure 5.

The correlation coefficient "r" was tested for significance using the table of correlation coefficients given in Brownlee (4). In this study, the "r" must have a significance level (α) of at least the 0.05 level in order to be judged as significant. Significant correlation coefficients were obtained in all cases except for the knobby textured surface. As can be seen in Table VI, the standard error of the predicted skid trailer coefficient of friction (CF) ranged from $\pm$ 0.031 to $\pm$ 0.040 for the significant correlation coefficients.

There does appear to be a small reduction in the standard error of predicted CF if the surfaces are stratified (Table VI) according to whether the surface texture is smooth or knobby. This indicates there may be some effect of surface texture on the correlation between the portable tester and the skid trailer.

Table V

Difference in Drag Tester Number (DTN) Between Replicate Measurements on a Bituminous Treated Surface

DTN*		
Replicate 1	Replicate 2	Difference
34.25	34.50	-0.25
35.50	38.00	-2.50
35.00	34.75	+0.25
34.25	36.50	-2.25
34.25	36.50	-2.25
37.75	38.75	-1.00
25.50	21.00	+4.50
27.50	23.00	+3.50
23.00	25.00	-2.00
26.50	25.50	-1.00
24.50	21.50	+3.00
26.50	22.50	+4.00

* DTN = Average of four tests

Standard Deviation (σ) of single DTN =

$$\sqrt{\frac{88}{24}} = 1.9149$$

Average Difference Between Replicates =

$$1.128\ (1.9149) = 2.16$$

Figure 4: Comparison of DTN Between Replicate Measurements on a Bituminous Treated Surface

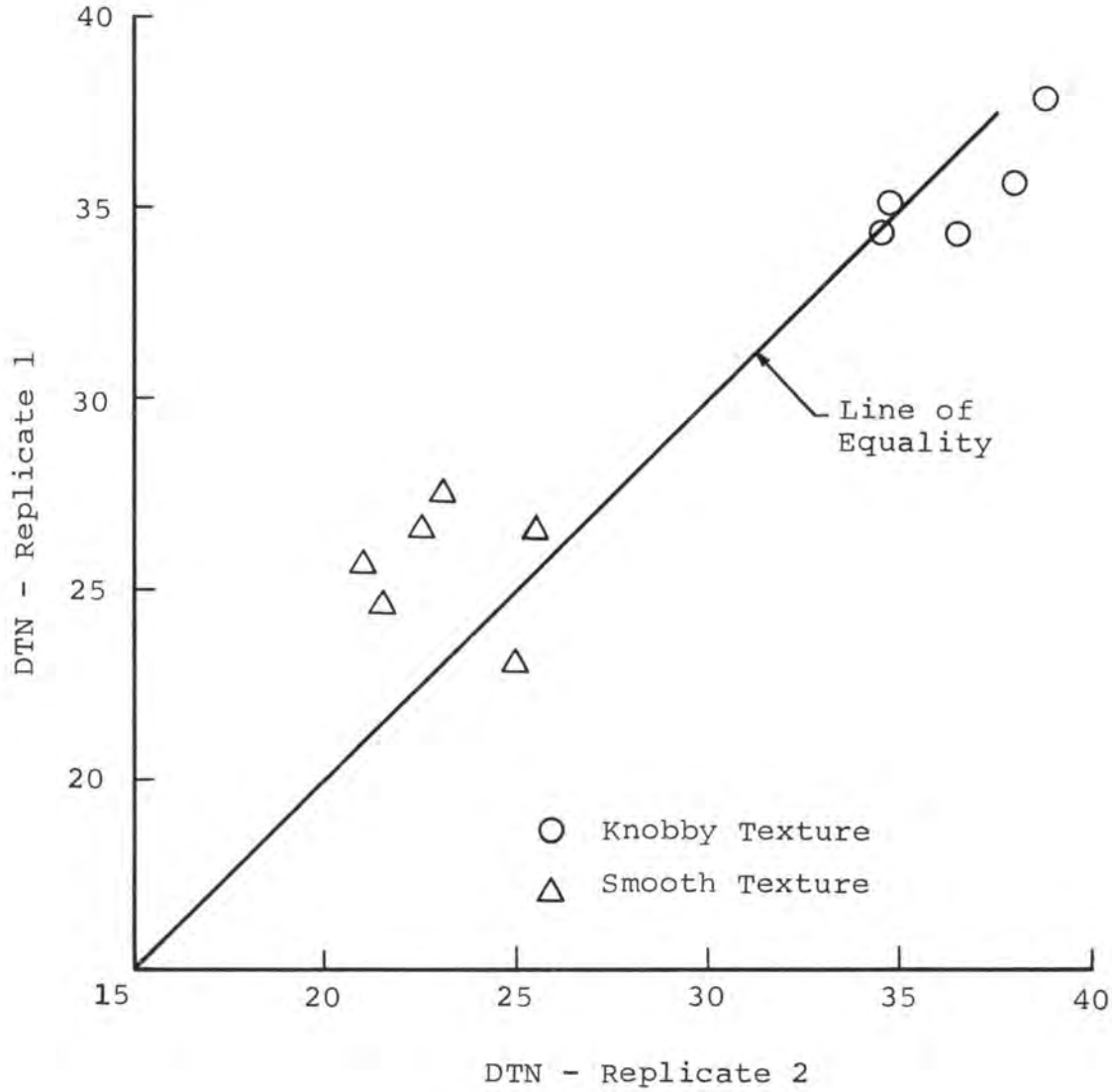


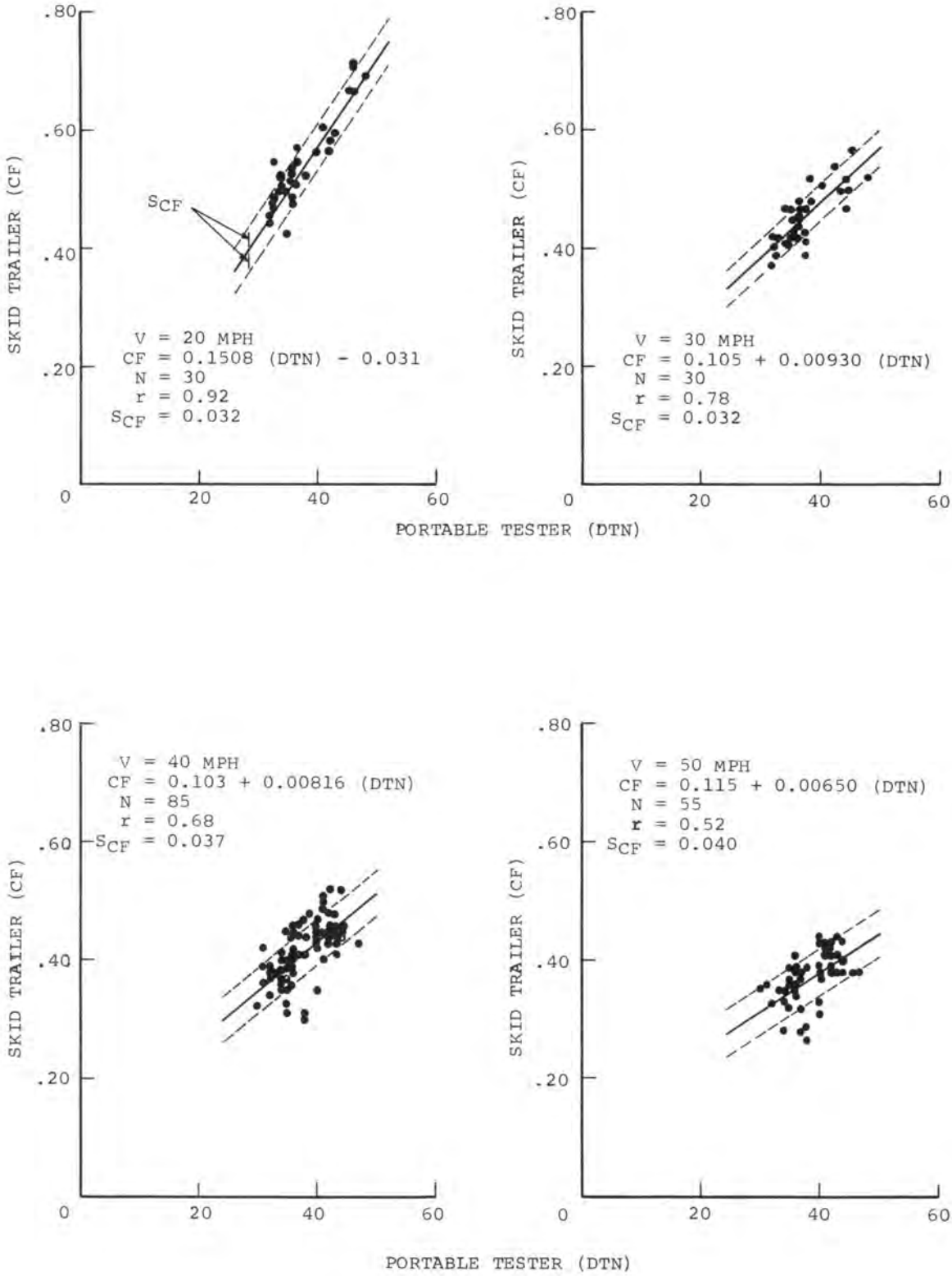
Table VI

Correlation and Regression Results
Portable Tester Drag Tester Number (DTN)
vs.
Missouri Skid Trailer Coefficient of Friction (CF)
Portland Cement Concrete Surfaces (PC)

Surface Texture	Trailer Speed	N	Regression Equation CF = a + b(DTN)		Correlation Coefficient		Std. Error of "CF"	Coeff. of Variation %
			a	b	"r"	α		
Combined	20	30	-0.03142	0.01508	0.92	0.001	0.032	5.9
	30	30	0.10503	0.00930	0.78	0.001	0.032	7.0
	40	85	0.10337	0.00816	0.68	0.001	0.037	9.0
	50	55	0.11487	0.00650	0.52	0.001	0.040	11.0
Smooth	20	25	-0.01452	0.01471	0.91	0.001	0.031	5.6
	30	25	0.13279	0.00864	0.72	0.001	0.035	7.5
	40	70	0.14473	0.00728	0.68	0.001	0.031	7.4
	50	50	0.13818	0.00607	0.59	0.001	0.032	8.7
Knobby	20	5	0.70727	-0.00770	-0.49	N.S.	0.021	4.7
	30	5	0.17808	0.00680	0.86	N.S.	0.007	1.7
	40	15	0.45132	-0.00306	-0.32	N.S.	0.027	7.8
	50	5	0.14811	0.00371	0.58	N.S.	0.105	5.2

N.S. = Not Significant

Figure 5: DTN by Portable Tester vs. CF by Missouri Skid Trailer For Portland Cement Concrete Surfaces



Asphaltic Concrete and Bituminous Surfaces - The analyses for the asphaltic concrete, plant mix bituminous surfaces, maintenance leveling courses and bituminous treated surfaces are shown in Tables VII through X. The data are plotted in Figures 6 through 9. The results are erratic regarding significant correlations obtained. Significant correlations are obtained at all speeds on the plant mix bituminous (PM) surface while no significant correlations were found at any speed on the bituminous treated (BT) surface.

The only significant correlation on the leveling course (LC) surface was obtained at 20 MPH. The test speeds of 20, 40, and 50 MPH gave significant correlations on the asphaltic concrete (AC) surface.

The standard error (of the predicted CF) ranges from $\pm$ 0.034 to $\pm$ 0.118 on the various surface types. Regression equations with errors of this magnitude would not be useful for purposes of predicting a coefficient of friction based on results of the portable tester alone.

Like the Portland cement concrete surface, the asphaltic concrete and bituminous surfaces were also subdivided according to smooth or knobby textures. The asphaltic concrete could be divided into two groups, according to smooth or knobby textured surfaces and the results of the analyses for these groups are shown in Table X. There is a reduction in standard error when the test sites are stratified according to the two surface texture groups. The significance of the

correlations remains the same at 30, 40, and 50 MPH. The 20 MPH data on the smooth textured surface produced an equation with a negative slope which would be unrealistic for this relationship.

The combination of asphaltic concrete and all bituminous surfaces was analyzed with stratifications according to smooth or knobby textures. The results are shown in Table XI. Significant correlations were obtained at all speeds for both textures except the 30 MPH speed on the smooth texture. However, the range in standard error of CF did not change appreciably, from what was found when analyzing the data according to surface types.

All Surface Types - Simple linear correlation and regression analyses were performed on the combination of all projects for all surface types. The results of the analyses are shown in Table XII and the regression equations are plotted in Figure 10. Significant correlations were obtained at all speeds, but the standard error (of the predicted CF) ranged from $\pm$ 0.060 to $\pm$ 0.078. Regression equations (one for each trailer speed) for all surface types, with errors of this magnitude, would not be useful for purposes of predicting a coefficient of friction based upon results of the portable tester alone.

Effect of Surface Texture

It has been previously noted that there appears to be a small reduction in the standard error of predicted CF if the surfaces are stratified according to whether the

Table VII

Correlation and Regression Results
Portable Tester Drag Tester Number (DTN)
vs.
Missouri Skid Trailer Coefficient of Friction (CF)
Plant Mix Bituminous Surface (PM)
Knobby Surface Texture

Trailer Speed	N	Regression Equation CF = a + b(DTN)		Correlation Coefficient		Std. Error of "CF"	Coeff. of Variation %
		a	b	"r"	α		
20	24	-0.00593	0.01519	0.60	0.01	0.080	14.5
30	24	-0.04625	0.01449	0.54	0.01	0.118	25.3
40	30	-0.56165	0.02553	0.72	0.001	0.088	21.7
50	15	-0.37807	0.01949	0.62	0.02	0.097	27.9

Table VIII

Correlation and Regression Results
Portable Tester Drag Tester Number (DTN)
vs.
Missouri Skid Trailer Coefficient of Friction (CF)
Bituminous Treated Surface (BT)
Knobby Surface Texture

Trailer Speed	N	Regression Equation CF = a + b(DTN)		Correlation Coefficient		Std. Error of "CF"	Coeff. of Variation %
		a	b	"r"	α		
20	5	0.12790	0.00667	0.46	N.S.	0.040	12.9
30	5	0.17913	0.00336	0.32	N.S.	0.035	12.9
40	10	0.08030	0.00541	0.24	N.S.	0.054	23.5
50	5	1.12270	-0.03109	-0.64	N.S.	0.059	24.7

Table IX

Correlation and Regression Results
Portable Tester Drag Tester Number (DTN)
vs.
Missouri Skid Trailer Coefficient of Friction (CF)
Plant Mix Bituminous Maintenance Leveling Course Surface (LC)
Smooth Surface Texture

Trailer Speed	N	Regression Equation CF = a + b(DTN)		Correlation Coefficient		Std. Error of "CF"	Coeff. of Variation %
		a	b	"r"	α		
20	34	0.34773	0.00776	0.60	0.001	0.034	5.3
30	23	0.35135	0.00508	0.38	N.S.	0.045	8.2
40	66	0.38516	0.00263	0.17	N.S.	0.046	9.4
50	33	0.25114	0.00474	0.26	N.S.	0.051	11.7

N.S. = Not Significant

Figure 6: DTN by Portable Tester vs. CF by Missouri Skid Trailer For Plant Mix Bituminous Surfaces

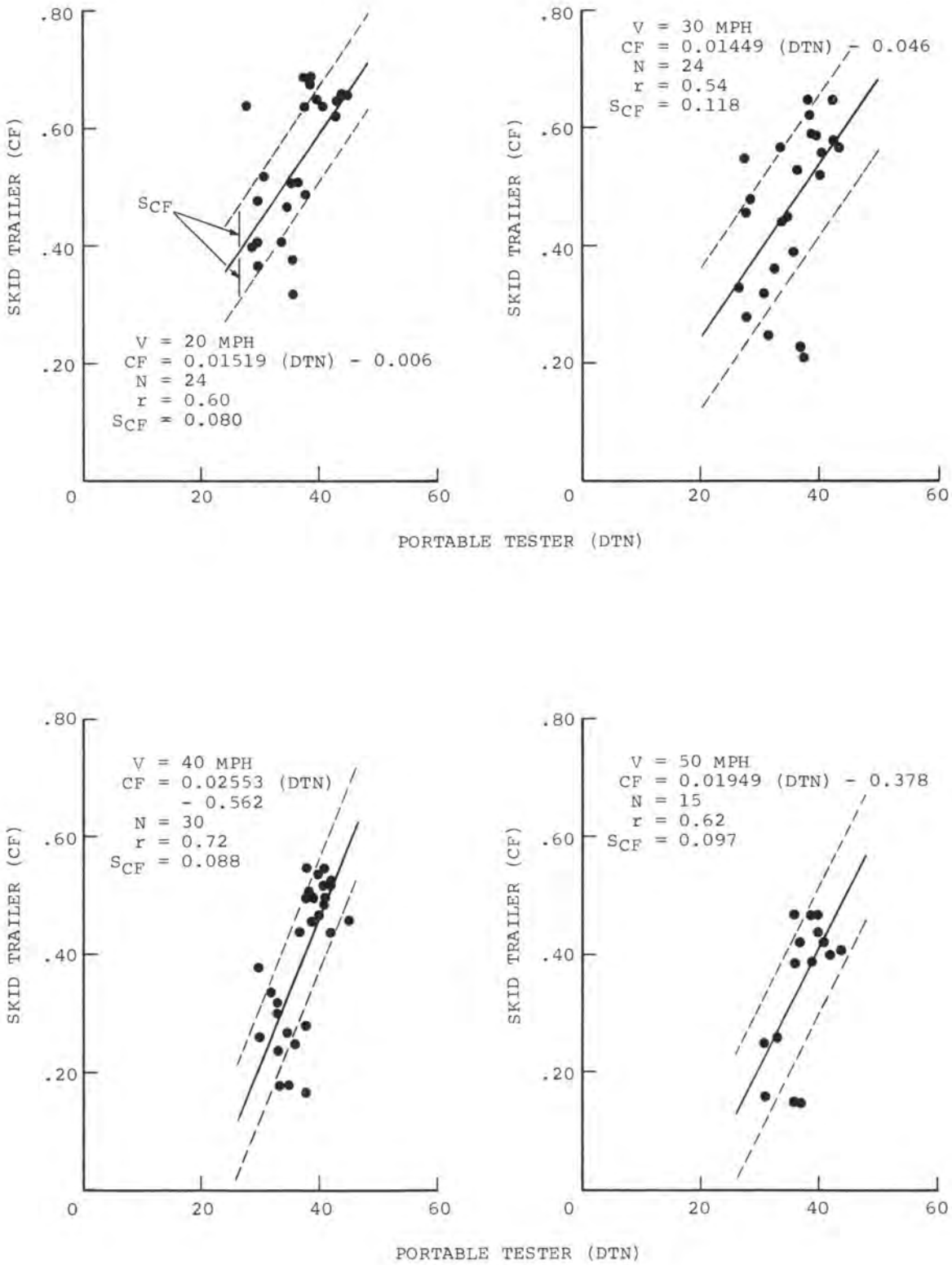


Figure 7: DTN by Portable Tester vs. CF by Missouri Skid Trailer For a Bituminous Treated Surface

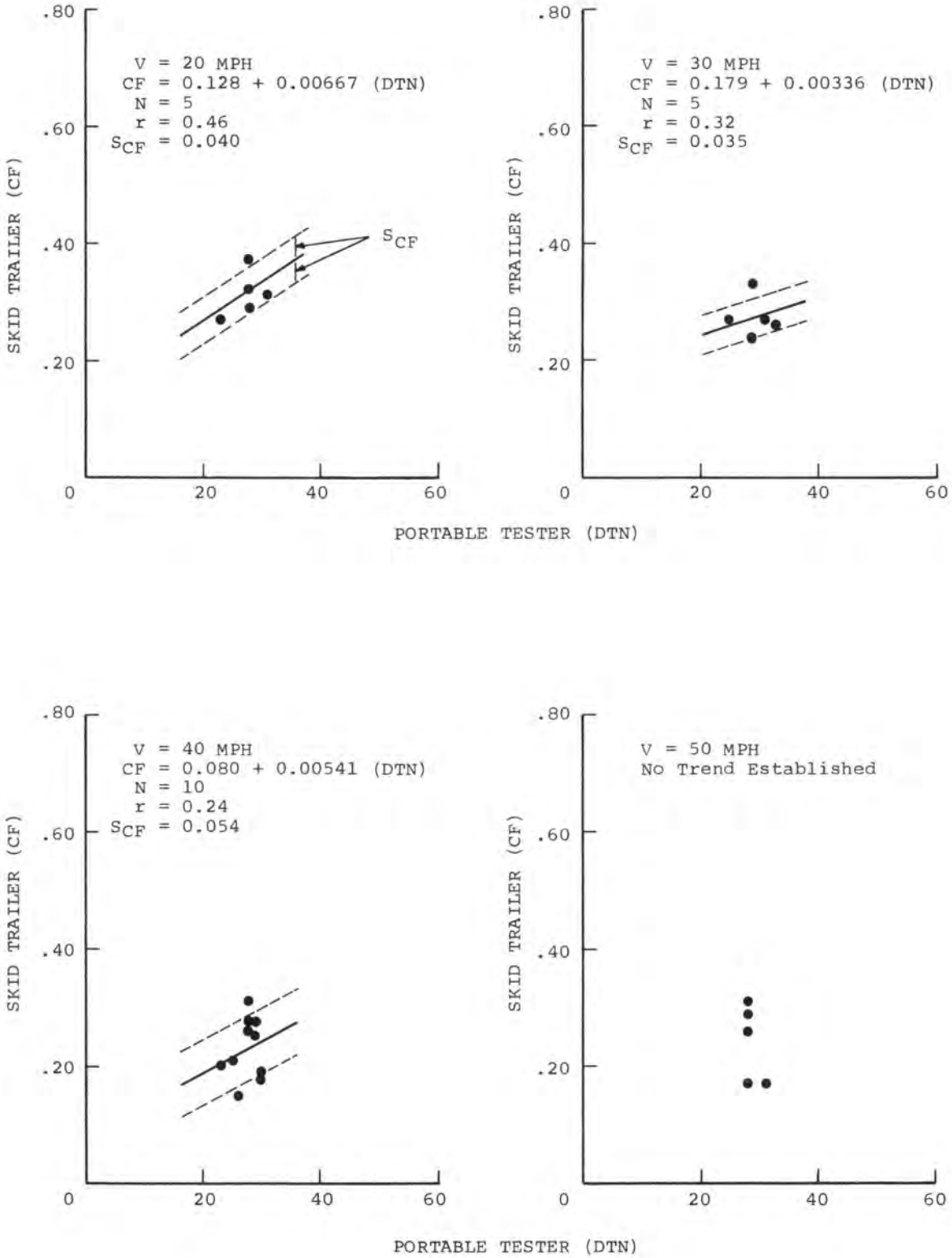


Figure 8: DTN by Portable Tester vs. CF by Missouri Skid Trailer For Plant Mix Bituminous Maintenance Leveling Course Surfaces

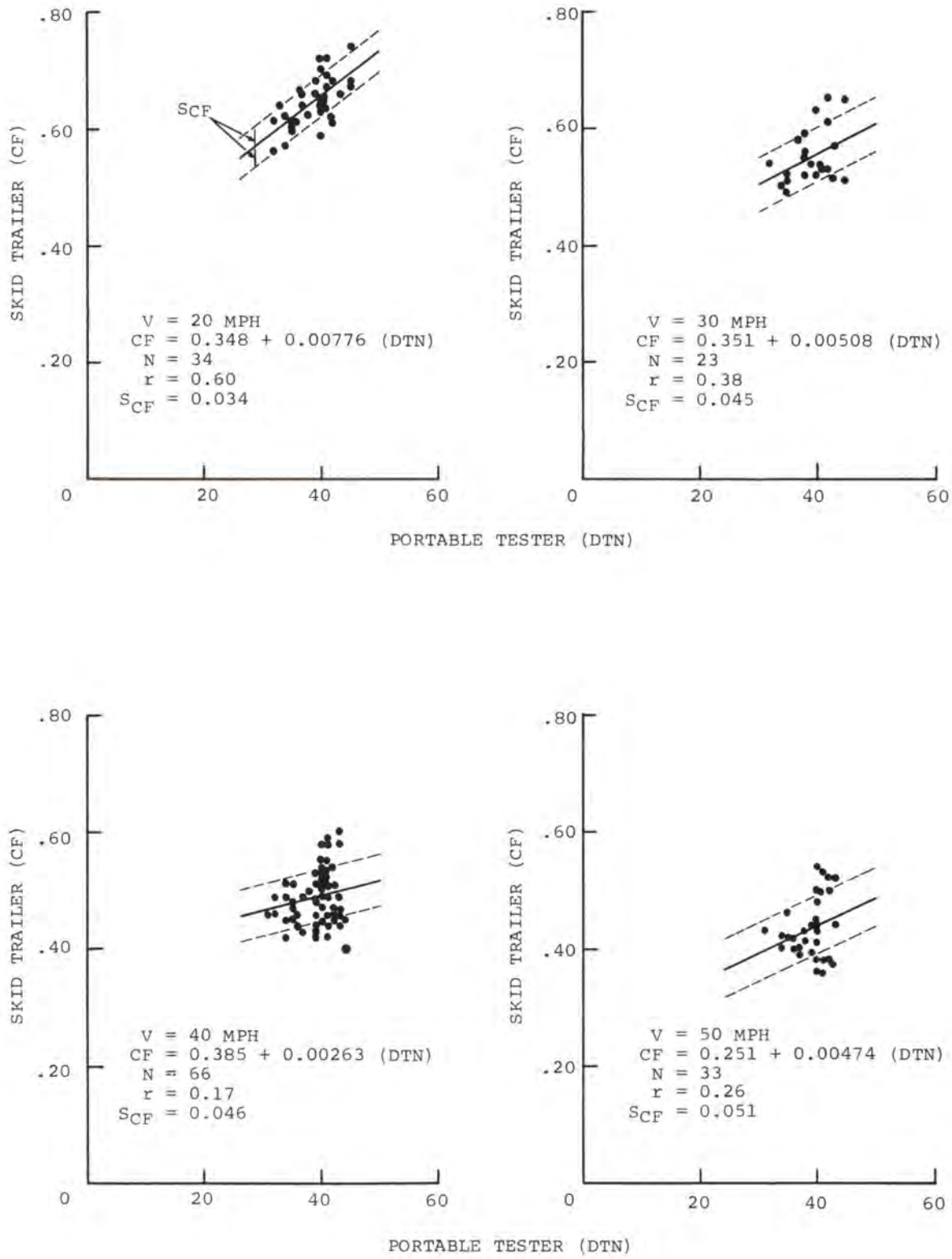


Table X

Correlation and Regression Results
Portable Tester Drag Tester Number (DTN)
vs.
Missouri Skid Trailer Coefficient of Friction (CF)
Asphaltic Concrete Surfaces (AC)

Surface Texture	Trailer Speed	N	Regression Equation CF = a + b(DTN)		Correlation Coefficient		Std. Error of "CF"	Coeff. of Variation %
			a	b	"r"	α		
Combined	20	20	-0.66988	0.03204	0.69	0.001	0.096	16.4
	30	10	0.30154	0.00384	0.23	N.S.	0.047	10.6
	40	45	0.02486	0.01066	0.66	0.001	0.056	13.5
	50	35	0.06750	0.00854	0.79	0.001	0.035	9.4
Smooth	20	10	0.71594	-0.00023	-0.03	N.S.	0.029	4.1
	40	20	0.25565	0.00591	0.67	0.01	0.021	4.3
	50	20	0.17651	0.00619	0.68	0.001	0.021	4.6
Knobby	20	10	-0.18849	0.01747	0.70	0.05	0.041	8.9
	30	10	0.30154	0.00384	0.23	N.S.	0.047	10.6
	40	25	0.19773	0.00461	0.53	0.01	0.035	9.8
	50	15	0.14988	0.00531	0.74	0.01	0.030	9.2

N.S. = Not Significant

Figure 9: DTN by Portable Tester vs. CF by Missouri Skid Trailer For Asphaltic Concrete Surfaces

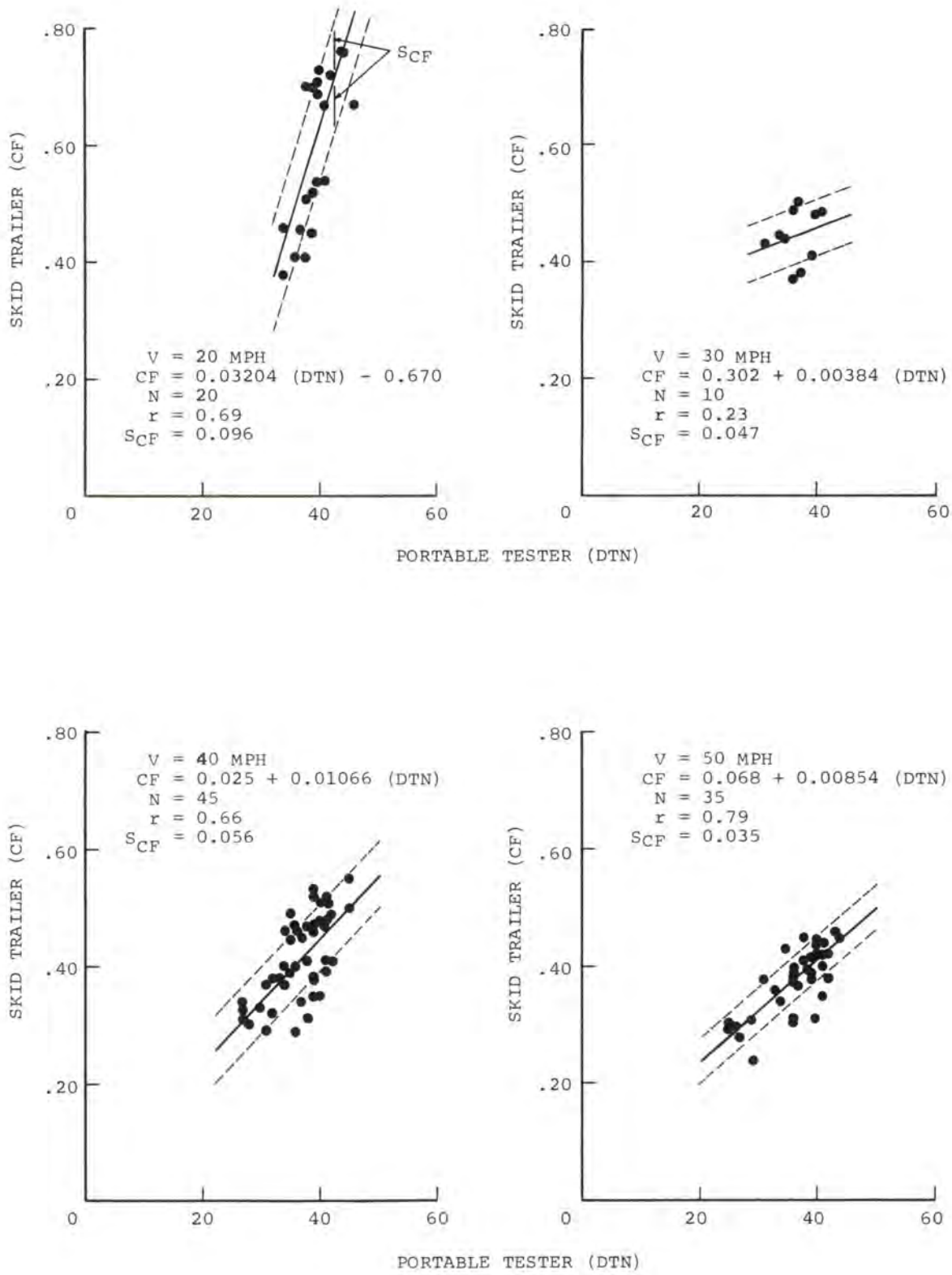


Table XI

Correlation and Regression Results
Portable Tester Drag Tester Number (DTN)
vs.
Missouri Skid Trailer Coefficient of Friction (CF)
Asphaltic Concrete and Bituminous Surfaces

Surface Texture	Trailer Speed	N	Regression Equation CF = a + b(DTN)		Correlation Coefficient		Std. Error of "CF"	Coeff. of Variation %
			a	b	"r"	α		
Combined	20	83	-0.14494	0.01931	0.72	0.001	0.086	14.8
	30	62	-0.08613	0.01553	0.67	0.001	0.089	18.6
	40	151	-0.13706	0.01525	0.69	0.001	0.073	16.8
	50	88	-0.04486	0.01167	0.64	0.001	0.065	16.8
Smooth	20	44	0.33347	0.00822	0.55	0.001	0.040	6.0
	30	23	0.35135	0.00508	0.38	N.S.	0.045	8.2
	40	86	0.35510	0.00339	0.22	0.05	0.041	8.7
	50	53	0.21834	0.00540	0.35	0.02	0.043	10.1
Knobby	20	39	-0.11670	0.01724	0.69	0.001	0.094	18.8
	30	39	-0.10084	0.01548	0.63	0.001	0.100	22.9
	40	65	-0.15821	0.01478	0.71	0.001	0.077	21.4
	50	35	-0.00562	0.00961	0.58	0.001	0.076	23.6

N.S. = Not Significant

surface texture is smooth or knobby. The reduction in standard errors, when stratifying by surface textures, may suggest that surface texture influences the correlation between the two types of testers. There is evidence (5) that surface texture determines the magnitude of the speed gradient (change in CF per unit change in speed). It is the effect of the surface texture on the speed gradient which some investigators believe to be responsible for the poor correlation between the portable tester and skid trailers.

It appears that the regression equations are dependent on the surface type and texture. Results indicate that a better correlation would be obtained if a measure of the effects of surface type and texture were included. To be of value, however, the resultant equation would have to be significant over the entire range of speed gradients. This, along with the portable tester's inability to have good repeatability over a bituminous treated surface, would indicate that the equipment would be inadequate to use for determining a pavement's friction level.

Pavement Friction Evaluation

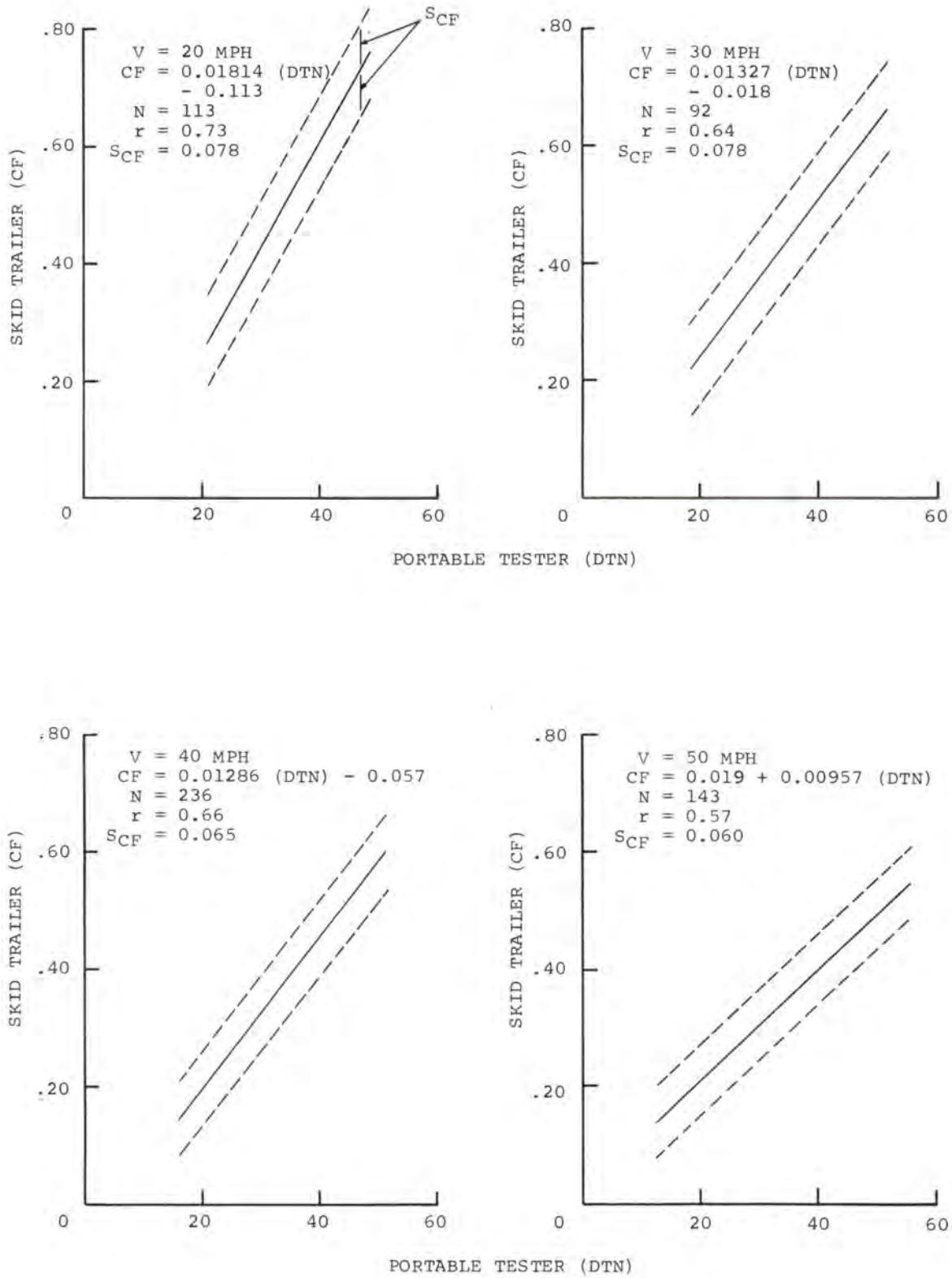
The evaluation of the skid resistance of pavement surfaces tested in this study yields different results, depending on whether the portable tester or skid trailer was used. This statement is based on a comparison of the correlation test results with the recommended minimum interim Skid Numbers (SN) and Drag Tester Numbers (DTN) as given in NCHRP Report 37 (5). The coefficient of

Table XII

Correlation and Regression Results
Portable Tester Drag Tester Number (DTN)
vs.
Missouri Skid Trailer Coefficient of Friction (CF)
All Surface Types

Surface Texture	Trailer Speed	N	Regression Equation CF = a + b(DTN)		Correlation Coefficient		Std. Error of "CF"	Coeff. of Variation %
			a	b	"r"	α		
Combined	20	113	-0.11295	0.01814	0.73	0.001	0.078	13.7
	30	92	-0.01779	0.01327	0.64	0.001	0.078	16.6
	40	236	-0.05706	0.01286	0.66	0.001	0.065	15.3
	50	143	0.01903	0.00957	0.57	0.001	0.060	15.9

Figure 10: DTN by Portable Tester vs. CF by Missouri Skid Trailer For All Surface Types



friction (CF) obtained with the Missouri trailer can be converted to Skid Number by multiplying CF by 100. Distributions of the individual test readings for both the portable tester and skid trailer were determined and the percent of tests with SN or DTN values less than the minimum recommended values were determined. These results are shown in Table XIII and it can be seen that there is a much larger percentage of DTN values below the recommended minimum DTN than there are trailer test values below the recommended minimum SN. The discrepancy raises doubt concerning the validity of the recommended minimum DTN values given in NCHRP Report 37 and indicates that these values may need to be re-evaluated.

Table XIII

Evaluation of Pavement Friction Using
The Portable Tester and Missouri Skid Trailer

Mean Traffic Speed V MPH	Recommended* Minimum SN_V	Recommended* Minimum DTN	Percent of Correlation Tests In This Study With Values Less Than Recommended Minimum	
			SN	DTN
20	40		9	
30	36	35	13	26
40	33	40	14	65
50	32	45	21	97

* Recommended Minimum Skid Numbers (SN) and Drag Tester Numbers (DTN) taken from Tables 18 & 19, pgs. 54 & 55 of NCHRP Report 37. SN_V is Skid Number measured at Mean Traffic Speed.

Problems Encountered

A major problem was encountered when the tester was first received as consistent calibrations were not obtained. The equipment was returned to the manufacturer, but the problem re-occurred after the manufacturer repaired the equipment. The seal covering the opening where the slider shaft enters the housing was later found to be interfering with the free movement of the slider shaft. This seal was replaced by department personnel with a non-restraining seal and satisfactory subsequent calibration results were obtained. This problem resulted in a delay of four to six weeks in field testing.

The hydraulic system in the tester is affected by only slight amounts of entrapped air. It was found that if the system had to be bled to remove the air that the procedure was very time consuming.

Another problem encountered was the low clearance of the portable tester where the two side panels are connected by means of a pivot to the chassis. There was approximately 1/8 inch clearance between the side panels and the pavement surface. On a pavement with a rough or knobby surface texture, the side panels would sometimes drag on the surface, at times stopping the tester. This was particularly noticeable on the plant mix bituminous and bituminous treated surfaces. By the time the testing had been completed, the side panels had worn considerably, and it appeared that enough wear could eventually occur to let the chassis separate from the side panels.

This problem could probably be eliminated through the use of larger diameter wheels on the portable tester.

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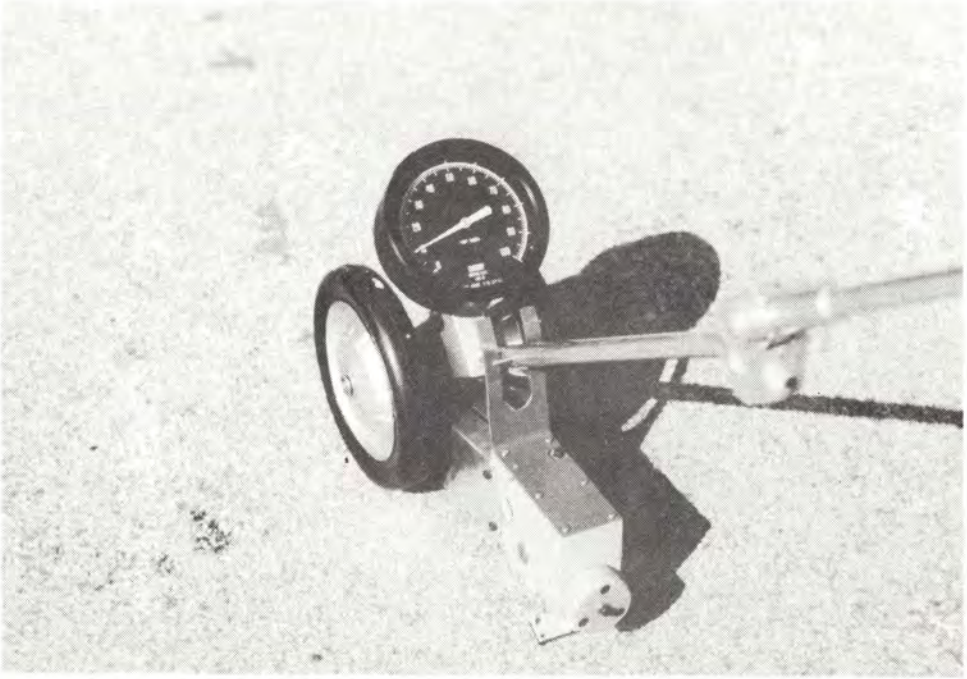
APPENDIX A

KEYSTONE MARK IV SKID RESISTANCE TESTER



APPENDIX B

Keystone Mark IV Skid Resistance Tester
MANUFACTURER'S TEST PROCEDURE

1. Check rubber shoe for wear. Replace when edge is worn by more than 3/16" as measured with rule laid flat across slider width.

2. Adjust handle to most comfortable position. Always operate in green area.

3. Prepressurize hydraulic system until pointer of indicator is displaced by ten dial units. (Counterclockwise rotation of knurled knob on left side of housing produces pressure increase).

4. When testing on highways, select most polished section (such as wheel tracks) and test in direction of traffic.

5. Thoroughly flush surface with clean water to remove grit and dust.

6. Keep handle within stops provided, and walk at uniform brisk pace (about 3 MPH) but do not run.

7. Test pavement section over length of about 15 ft., monitor gage reading, and keep average in mind.

8. Lift off rubber shoe by raising handle and roll Tester over distance of about ten to fifteen feet for second test.

9. Depending on pavement homogenuity, repeat Stages 7 and 8 and average all readings.

10. Report data as Drag Tester Number (DTN) to identify Tester and test method.

11.* Record other pertinent data such as wet surface temperature; (if temperature is different from 76 $\pm 6^{o}F$, make correction by adding (subtracting) three dial units per $10^{o}F$ increase (decrease)); type of pavement and aggregate shape and size.

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* Missouri Modification--Use "dry" surface temperature and correct to "80 $\pm 6^{o}F$".