EVALUATION OF THE OUTFLOW METER IN COLORADO

Robert F. LaForce
Lowell B. Steere
Colorado Department of Highways
4201 East Arkansas Avenue
Denver, Colorado 80222

Draft Final Report
July 1978

Prepared for

Implementation Division HDV-22
Office of Development
Federal Highway Administration
Washington, D.C. 20590

TABLE OF CONTENTS

EVALUATION OF THE OUTFLOW METER

EVALUATION PROCEDURES

The Outflow Meter evaluation procedures used by Colorado closely followed the guidelines recommended by the FHWA.

Preliminary test sites were chosen from two primary sources. First, as many as practical of the speed gradient sections from the "Skid Number-Speed Gradient Testing in Colorado" (October 1976) report were used. Following this search, the field data from the "1977 State Highway Sufficiency Rating and Needs Study" were reviewed to find locations with the range of skid numbers necessary for this evaluation.

Following receipt of the Outflow Meter, the first round of testing was begun. At this time, each section's exact location was chosen taking into account safety factors and skid truck turnarounds. Each section was identified by a mileage from a fixed geographical location. The start of the skid test and section number were then marked with paint on the shoulder. At this time, eight test sites (labeled A through H) were marked off, randomly spaced within the area of the 30 mph skid truck lockup. Distances from the start of each test site were measured and recorded. A black and white closeup photograph of the pavement surface and an overall view of the test section was then taken, photos 1-5 in the Appendix show typical layouts and textures of the five types of pavement surfaces used in this evaluation. Appendix Table A shows a list of the test sections along with the description of the section type and the traffic volume.

TEST PROCEDURE

After signs and cones were set up, the testing was started by recording the time, and also the air and pavement temperatures. The cones were set so that the skid vehicle could enter through them to take five skid measurements each at 30, 40, and 50 mph. The other tests were run between passes of the skid truck where possible. Generally, outflow-meter tests had to await completion of skid testing.

First the Rainhart TEXT-UR meter was used to take 40 readings scattered in the left wheelpath between test sites A and H. Then the British Portable Skid Tester was set on each test site in the left wheelpath and measurements were taken until five consecutive numbers within a three number spread were obtained. Following this the outflow meter was placed on each test site (the same spot as the BPT) and five readings were taken on each of the eight sites/section. The start and finish times of each of these test procedures was recorded on the field worksheet.

Following the outflow meter testing, the time, pavement and air temperature were again recorded. A sample field worksheet, showing all recorded data, appears in Table B of the Appendix and summaries of each round of data appear in Appendix Tables C-F.

All test equipment was transported and stored in a van during each round of testing. The outflow meter was disassembled and returned to its case for travel between sites. To provide water for the outflow meter, one gallon plastic jugs were used. They were very convenient for pouring into the meter and two per site could be set out at the start of a test run which avoided carrying a large water container. These were easily carried in the van and refilled from the skid truck tank. Following each round of testing the outflow meter was cleaned thoroughly and allowed to air dry. The packing in the carrying case was also air dried before this equipment was stored between rounds. The other equipment was also cleaned and checked before and after each round. Repair and replacement parts such as slider feet for the BPT were carried in the van in case of an equipment breakdown during testing.

RECOMMENDATIONS FOR FUNCTIONAL IMPROVEMENTS

The only design problem that hampered field operation of the outflow meter was that water would splash or be blown by the wind onto the underside of the contact pins causing the start and middle pins to be in electrical contact. Because of this, the timer did not start when water passed the first pin. It would have been a very minor problem if the underside of these pins were more accessible for drying or better isolated to prevent this problem.

The other design problem noticed was inside the electrical control box in the plug connecting the electric stopwatch to the logic circuitry. The location of this 90°, four pin plug between the timer and the sponge backing is such that either during operation or battery changes, it was cracked. Had it been broken it would have caused considerable delay in this evaluation while a replacement could be found and installed. If possible, it should be moved to a location on the timer where no pressure is put on it when resetting the timer or changing batteries.

CONVENIENCE AND OPERATIONAL IMPROVEMENTS

If the base were fastened more securely to the sides of the outflow meter, it would facilitate carrying the meter from site to site. It would also help protect the equipment in case of an emergency when test personnel and equipment had to be removed from the road quickly.

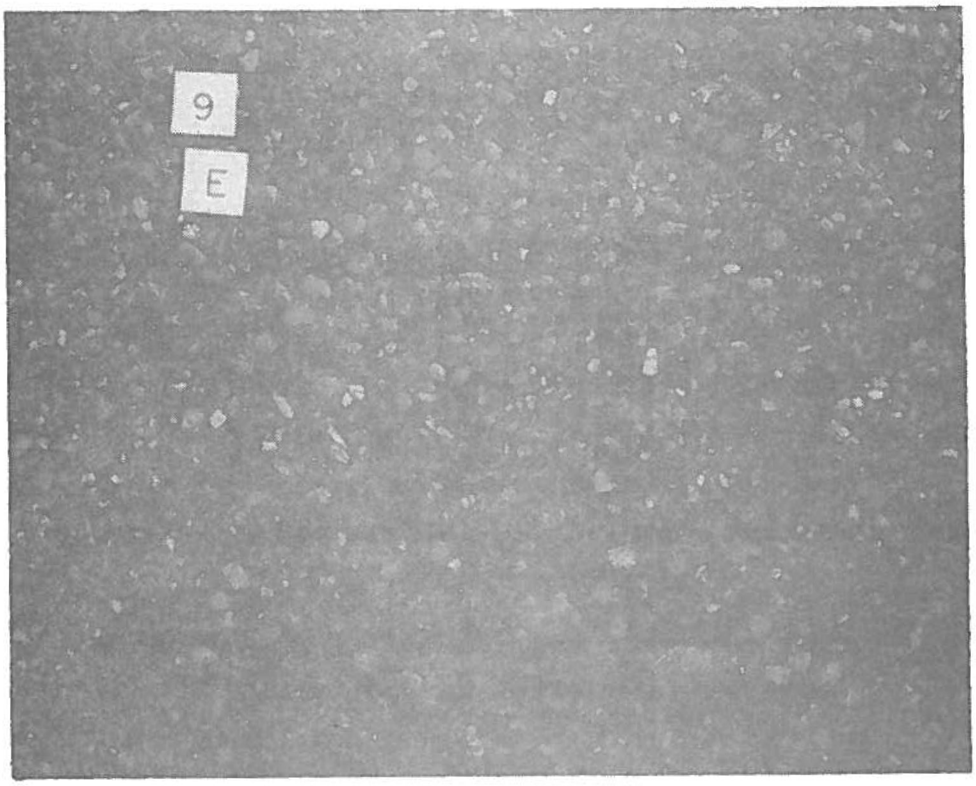
Perhaps a small field table, which permitted affixing the timer mechanism and a clipboard to hold field sheets, would be practical if the outflow meter is adopted for continued use. This could keep the machinery up off the wet pavement and permit expeditious one-handed removal from the roadway.

PERFORMANCE OF THE OUTFLOW METER

For the evaluation of the outflow meter, Sites A-H in each section were marked with paint on the shoulder and also on the lane dividing line adjacent to the left wheelpath. This was done so that the outflow meter could be placed as close as possible to the same spot on each round of the field evaluation.

Reviewing the data from the four rounds of testing, the average outflow time variation for a given section was 12.3% from the mean for outflow meter times less than 250 seconds and 20.7% for times greater than 250 seconds. For times less than 10 seconds the variation from the mean averaged 6% and 14% for times between 10 and 100 seconds. Some of this variation is due to not placing the outflow meter in exactly the same spot each time. For the longer outflow times, the pavement texture was not as coarse or uniform and moving the outflow meter only very slightly could make a large difference in the outflow time. This was especially true on some of the slick ($SN<40$) sections where the only texture was from relatively large aggregate (1/2-3/4") protruding irregularly through the surface. The following picture of Section No. 9 is a good example of this type of surface.

In this section the average skid number at 40 mph (SN_{40}) for the first four rounds was 30.5 and the outflow time was less than 250 seconds for the first two rounds, and greater than 350 seconds for the last two. Typical pavements like those pictured in the Appendix had higher skid numbers, and a more uniform surface texture, so there was less variation in outflow times as a result of not hitting exactly the same spot on consecutive rounds.



On June 22, 1978, a test was run on a typical section to demonstrate the variability of the OFM time within a given section. Forty outflow meter tests were run in the left wheel path of Section 19 between test sites A and H. The outflow meter was moved for each test, so 40 spots in the left wheel path were tested. The average of these times was 16.62 seconds, with a standard deviation of 6.06 seconds (36%). The outflow time varied from 6.08 to 35.94 seconds.

The average outflow time for this concrete section in the fourth round of testing (May 1978) was 24.41 seconds using the standard test procedure.

This procedure might be investigated to find out if better data correlations can be found between the outflow meter and other texture and skid measurements.

ANALYSIS OF TEST DATA

Following the first round of outflow meter field testing, the data was compiled and reduced. The following data for each section was transferred to computer cards for analysis.

1 - AGE - Years in Service

2 - ADT - Average daily traffic volume

3 - TM - The average of the 40 texture meter readings

4 - BPT - The average of the 40 British Portable Tester readings

5 - OFM - The average of the 40 Outflow Meter times (seconds)

6 - SN_{50} - The average of 5 skid tests at 50 mph

7 - SN_{40} - The average of 5 skid tests at 40 mph

8 - SN_{30} - The average of 5 skid tests at 30 mph

9 - SG - The speed gradient between 30 and 50 mph

10 - Air Temp - The average air temperature during field testing in ^{o}F

11 - Pavement Temp - The average pavement temperature during field testing in ^{o}F

Using the BMD (Biomedical Computer Programs) Statistical Program, BMD-02R, (step-wise linear regression analysis) numerous other variables and correlation matrices were generated to find the best types of relationships between the data.

Following is a list of the variables considered in these matrices.

1	Age	8	SN_{30}	15	log (SN_{40})
2	ADT	9	Speed Grad.	16	log (SN_{30})
3	TM	10	Avg. Air Temp.	17	$\frac{1}{OFM}$
4	BPT	11	Avg. Pave. Temp.	18	log (TM)
5	OFM	12	AGE X ADT	19	log (BPT)
6	SN_{50}	13	log (OFM)	20	log (Speed Grad.)
7	SN_{40}	14	log (SN_{50})	21	$\frac{1}{\log (OFM)}$

Tables C-G in the Appendix contain summaries of this data. Table H is a correlation matrix relating all of these variables.

OUTFLOW METER VS. SKID NUMBER

The first correlation equations derived were to relate skid number and outflow meter time. As can be seen in the list of variables numerous forms of the outflow meter time and skid numbers were correlated in order to find the best relationship between these two variables.

The best correlation using all data from the four rounds of testing was SN_{50} versus log (OFM) (Corr. Coef. -0.894). However, because the SN_{40} is a more universally known and accepted variable, it was used as the dependent variable in the OFM versus Skid Number equations. The SN_{40} and log (OFM) correlation coefficient is only slightly lower at -0.887. Figure 1 shows a plot of two equations relating SN_{40} and log (OFM). The first equation used only outflow meter times less than or equal to 250 seconds and the second equation used all data measured. As can be seen from the data plot in Figure 1, the data with outflow times greater than 250 seconds is quite scattered and using all data increased the standard error of the calculated SN_{40} by approximately 0.7. Because of the increased standard error and since the two equations are within one skid number, the equation for OFM time less than or equal to 250 seconds should be used to relate these two variables.

Using the equation relating log (OFM) and SN_{40}, the SN_{40} for each outflow time was calculated. This calculated SN_{40} was plotted against the appropriate SN_{40} measured by the skid truck. This data is presented in Figure 2 which shows the measured versus calculated data as well as the line of perfect correlation. Also plotted here are the lines enclosing two standard deviations of the equations. This data reveals that the SN_{40} can be calculated using the outflow meter time to $\pm$ 6.5 skid numbers 95% of the time.

There are some shortcomings to the above relationship because of the data used. Referring to Figure 1, there is a scarcity of data with outflow meter times between 75 and 250 seconds and a substantial amount of data in the area could change the equation relating the two variables. The log-log relationship between SN_{40} and OFM is also relatively high, (Corr.Coef. -0.868 for all data), and with more data this might be as good or better a relationship for the two variables as the one presented here.

Based on the data collected in Colorado, the outflow meter appears to be a usable tool for estimating pavement skid resistance if the skid number is greater than 40. For skid numbers less than 40, the data available is widely scattered and the OFM results are of lesser value in estimating skid resistance. More data with outflow times between 75 and 250 seconds would be very helpful in deciding on a cutoff point for the useful range of the outflow meter.

Neither the outflow meter nor the locked wheel skid trailer produced a pattern during the four test cycles that could be attributed to "seasonal variation." With only a few excursions excluded from consideration, average ambient air temperatures taken at each test varied from 48 to 72°F, and average pavement surface temperatures from 50 to 80°F. Although other factors such as precipitation, studded tire use, traffic counts, etc., also contribute to seasonal variation, temperature is assumed to be a primary influence. In that our test temperatures do not represent normal summer or winter extremes, the failure to establish a seasonal variation pattern is considered to be reasonable.

OUTFLOW METER VERSUS SPEED GRADIENT

The same procedure as that for skid numbers was used to find the best relationship between the speed gradient from 30-50 mph and the outflow meter time. Using all data the correlation coefficients for three relationships were of approximately the same magnitude.

Variables	Correlation Coefficient
Speed Gradient vs. $\frac{1}{OFM}$	-0.695
Speed Gradient vs. $\frac{1}{\log (OFM)}$	-0.699
log (Speed Gradient) vs. $\frac{1}{\log (OFM)}$	-0.695

Figure 4 shows the measured versus calculated speed gradient. From the line of perfect correlation and the lines enclosing 2 standard deviations, it can be seen that the speed gradient can be calculated to within $\pm$ 0.21 ninety-five percent of the time. This large error would appear to make the outflow meter of only marginal value for determining the speed gradient for a given section of road.

Colorado has an ongoing study in progress entitled "Skid Number-Speed Gradient Testing in Colorado." Outflow meter test sections 2, 3, 4, 5, 6, 7 and 11 are identical with test sites 5, 6, 10, 16, 18, 19 and 20 respectively, in the Skid Number-Speed Gradient Testing in Colorado report. Tests run on these sites in 1974 and 1976 were accomplished in the September-December months and therefore should closely relate seasonally to the first round of testing on this outflow meter project in October-November 1977. Updated data sheets from the speed gradient report are included as Tables I through O of the Appendix. The time lapse since the initial speed gradient testing has not yet produced sufficient data to draw final conclusions. In the first three years, there has been improvement in the speed gradient of all four types of pavement being tested, the most significant improvement is in the "sand mix" Colorado grading "F" asphalt, the average of which has improved from SG 80 to SG 50 on our five "F" test sections so far.

OUTFLOW METER VS. BRITISH PORTABLE SKID TESTER

As with the other variables, the British Portable Skid data (BPT) was compared with various forms of the outflow meter time. The best relationship found was the BPT vs. $\frac{1}{\log \text{(OFM)}}$. Figure 5 shows a graph of this data as well as the best fit equation. From this regression analyses, the BPT skid data can only be calculated to within $\pm$ 10 skid numbers 95% of the time. This is not an acceptable error especially considering the very limited range of numerical values produced by the BPT.

The best correlation using the BPT with any of the variables measured or calculated was by BPT vs. log SN_{30}. This relationship had a correlation coefficient of 0.742 for all data. This result would be anticipated because the BPT measures a wet skid resistance at a relatively slow speed where there is little or no hydroplaning. The standard error of this relationship was $\pm$ 5 skid numbers as measured with the skid test vehicle.

The correlation coefficient between the BPT and log SN_{40} was 0.702 and that between log (BPT) and log (SN_{40}) was 0.709.

Comparing these coefficients to the SN_{40} vs. log (OFM) relationship of -0.887, the results of this evaluation show that the outflow meter gives a better estimate of the skid resistance measured by the test vehicle than the BPT.

OUTFLOW METER VS. TEXTURE METER

For this study a Rainhart TEXT-UR Meter (TM) modified to use 15 pins was used to compare with the outflow meter. The best relationship between the two was TM vs. $\frac{1}{\text{OFM}}$ having a correlation coefficient of 0.788 using all data. Figure 6 is a plot of the data and also the best fit equation relating the two variables. Using this data, the texture meter reading could be calculated using OFM data to within 9, 95% of the time. The TM-$\frac{1}{\text{OFM}}$ correlation was the best using the texture meter with any of the variables listed.

OTHER VARIABLES

From the listing of text sections found in Table A of the Appendix, numerous other variables were considered in the correlation matrices for their effect on the outflow meter, skid resistance, or speed gradient. Following is a list of these variables and their inter-relating effects.

AGE - The best correlations between AGE and the other variables involved the direct methods of skid measurement i.e., the BPT and the skid truck measurements. Using all data, the correlation coefficients were -0.625, -0.625, -0.608, and -0.616 for the AGE versus BPT, SN_{50}, SN_{40}, and SN_{30} respectively. This indicates that roads get slicker with age.

ADT - The ADT seemed to have very little effect on any of the other variables listed. Its best correlation was with the OFM (-0.282).

AGE X ADT - This variable also had little effect on any of the skid or texture measures.

AVERAGE AIR TEMPERATURE AND AVERAGE PAVEMENT TEMPERATURES - The only significant correlation for either of these two variables was with each other.

CONCLUSIONS AND RECOMMENDATIONS

The outflow meter may be used for calculating skid resistance if the ± 6 error is acceptable and the pavements being considered have a skid number greater than 40.

More data having outflow times between 75 and 250 seconds would be valuable for determining the usefulness of the outflow meter on roads having marginal skid numbers. This information may become available when Colorado's findings are combined with those from other states.

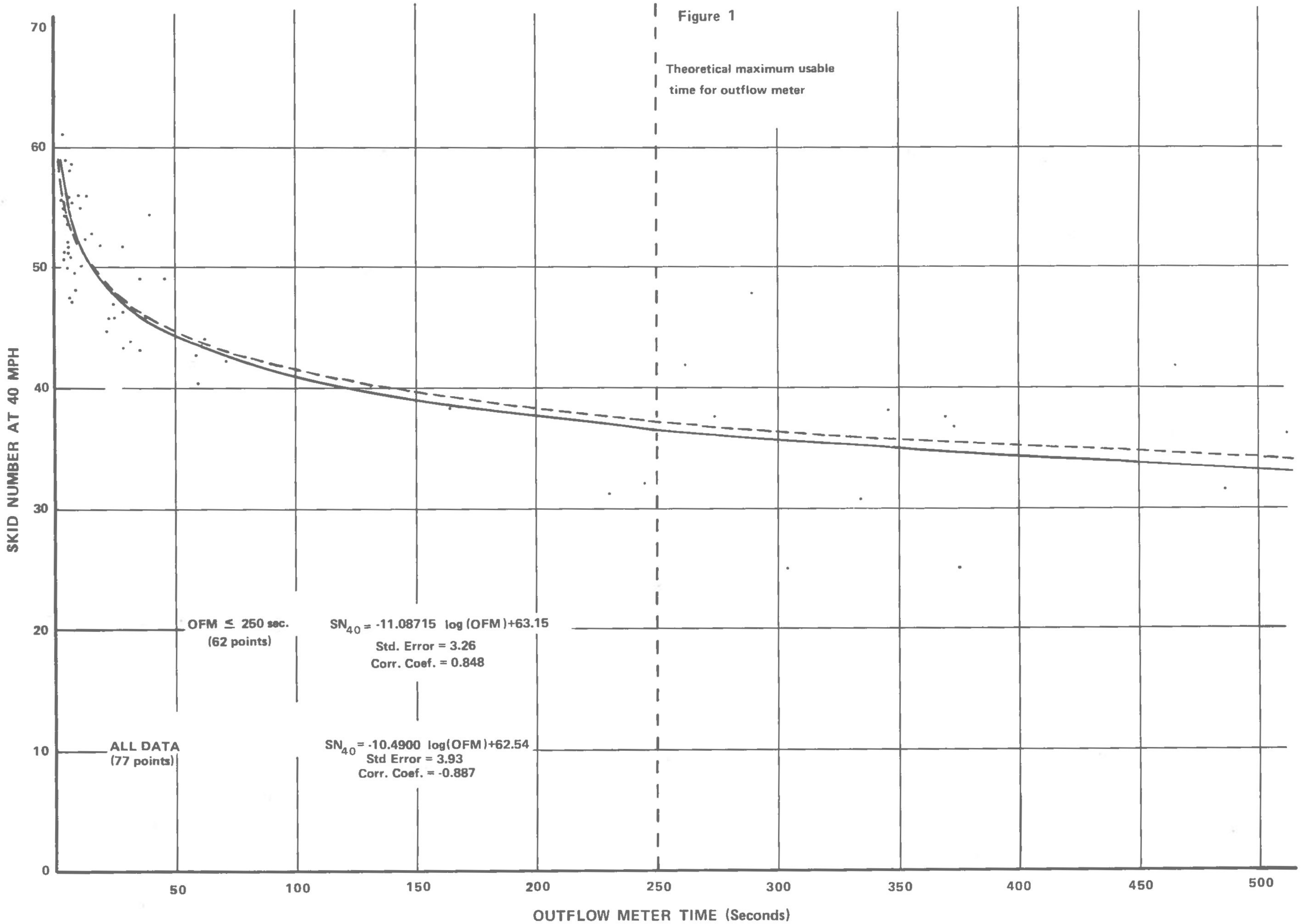
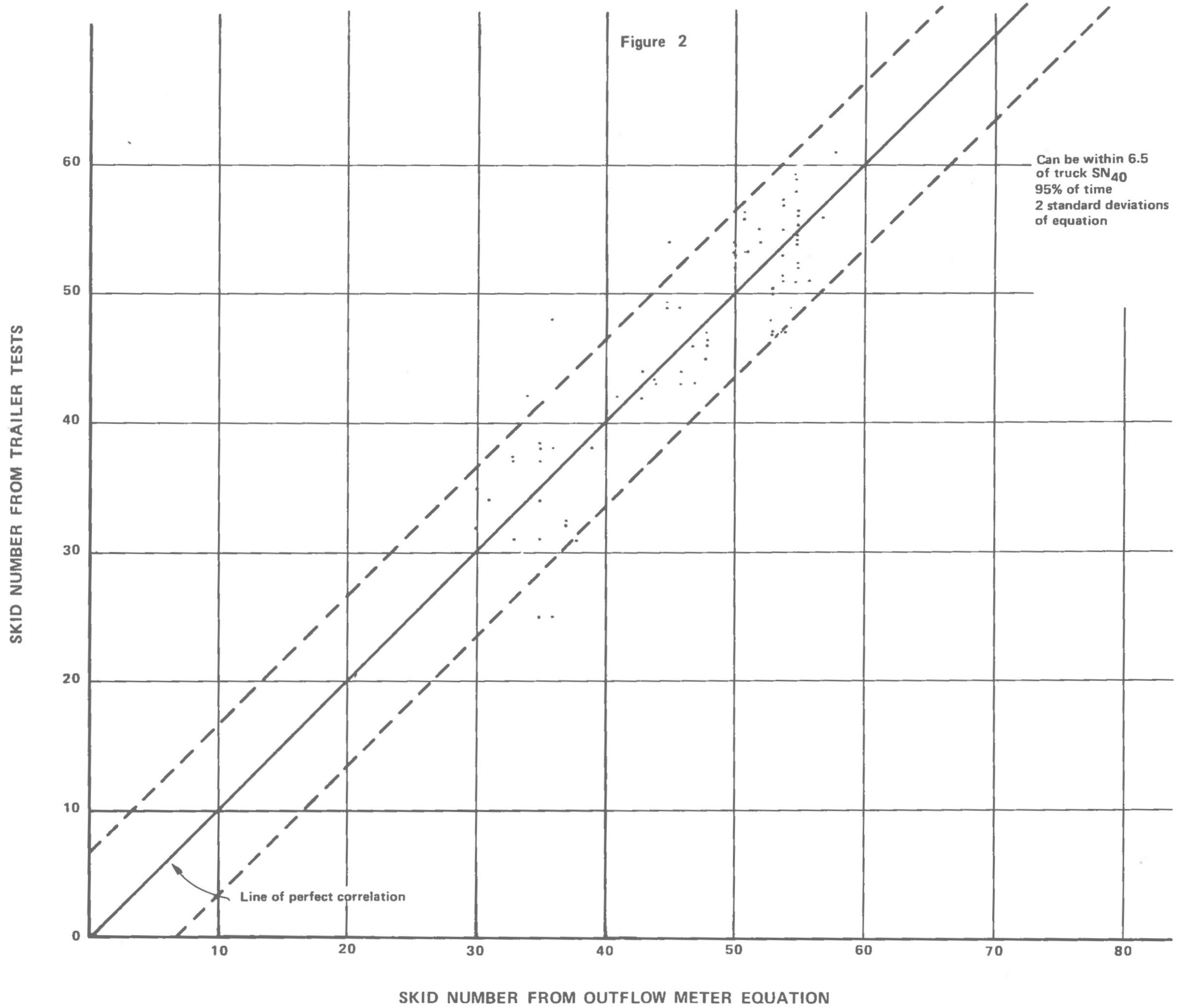

Theoretical maximum usable time for outflow meter
OFM ≤ 250 sec. (62 points)
SN40 = -11.08715 log (OFM)+63.15
Std. Error = 3.26
Corr. Coef. = 0.848
ALL DATA (77 points)
SN40 = -10.4900 log(OFM)+62.54
Std Error = 3.93
Corr. Coef. = -0.887
SKID NUMBER AT 40 MPH
OUTFLOW METER TIME (Seconds)
0
10
20
30
40
50
60
70
50
100
150
200
250
300
350
400
450
500

Figure 1

Figure 2



0
10
20
30
40
50
60
70
80
SKID NUMBER FROM TRAILER TESTS
SKID NUMBER FROM OUTFLOW METER EQUATION
Can be within 6.5 of truck SN_{40} 95% of time 2 standard deviations of equation
Line of perfect correlation

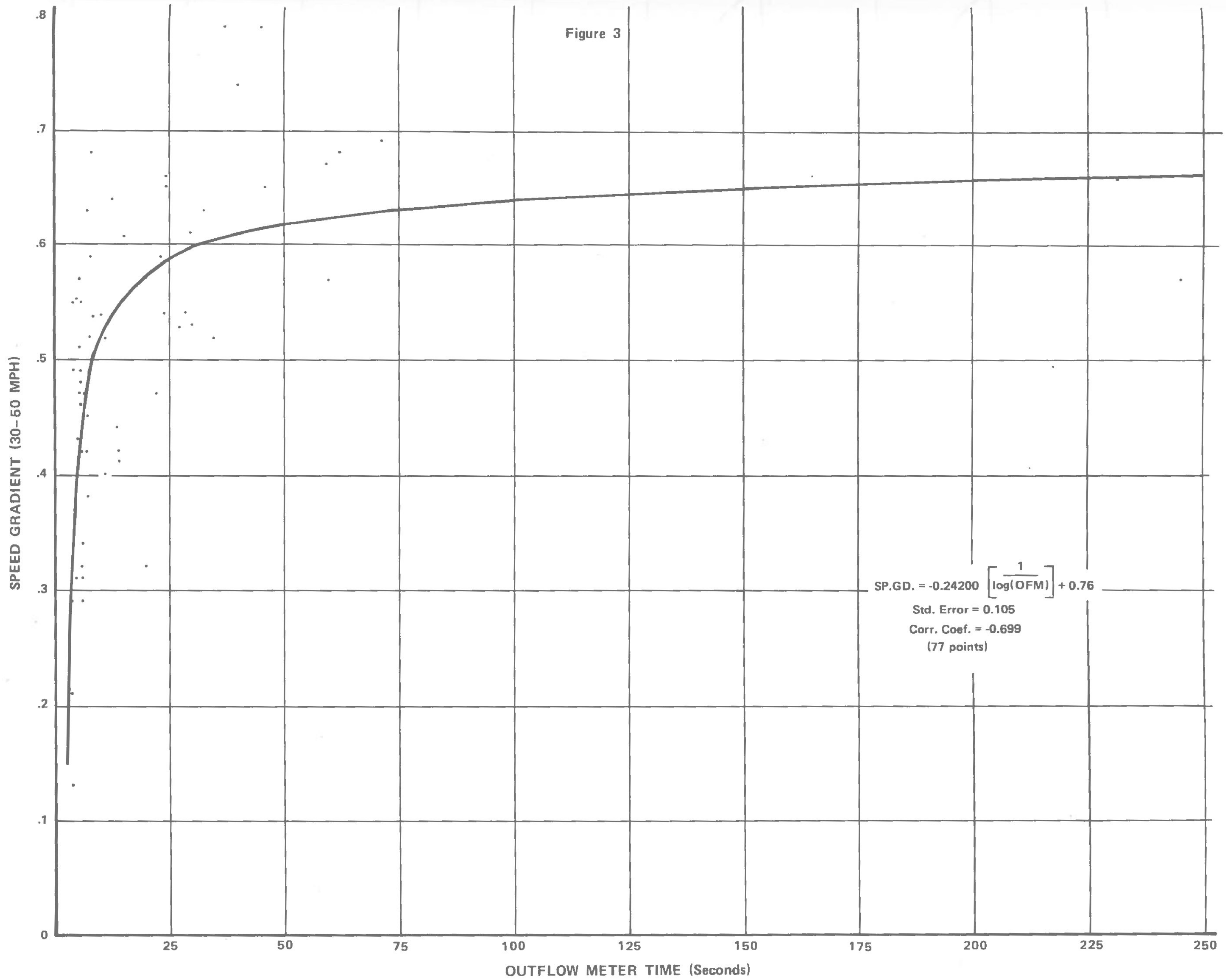
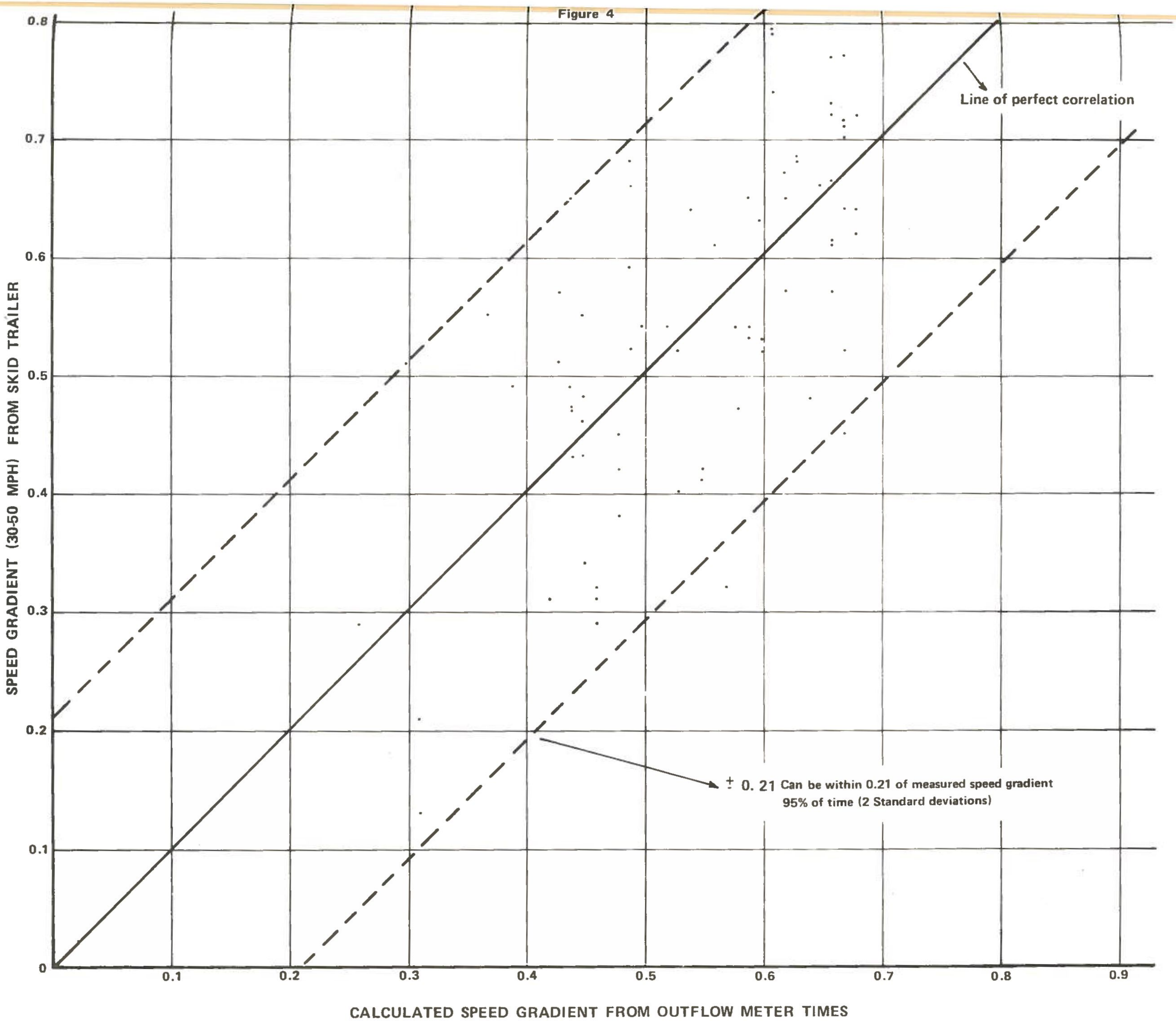


Figure 3
SPEED GRADIENT (30-50 MPH)
OUTFLOW METER TIME (Seconds)
.8
.7
.6
.5
.4
.3
.2
.1
0
25
50
75
100
125
150
175
200
225
250
SP.GD. = -0.24200 [1/log(OFM)] + 0.76
Std. Error = 0.105
Corr. Coef. = -0.699
(77 points)

Figure 4



0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
SPEED GRADIENT (30-50 MPH) FROM SKID TRAILER
CALCULATED SPEED GRADIENT FROM OUTFLOW METER TIMES
Line of perfect correlation
± 0. 21 Can be within 0.21 of measured speed gradient
95% of time (2 Standard deviations)

Figure 5

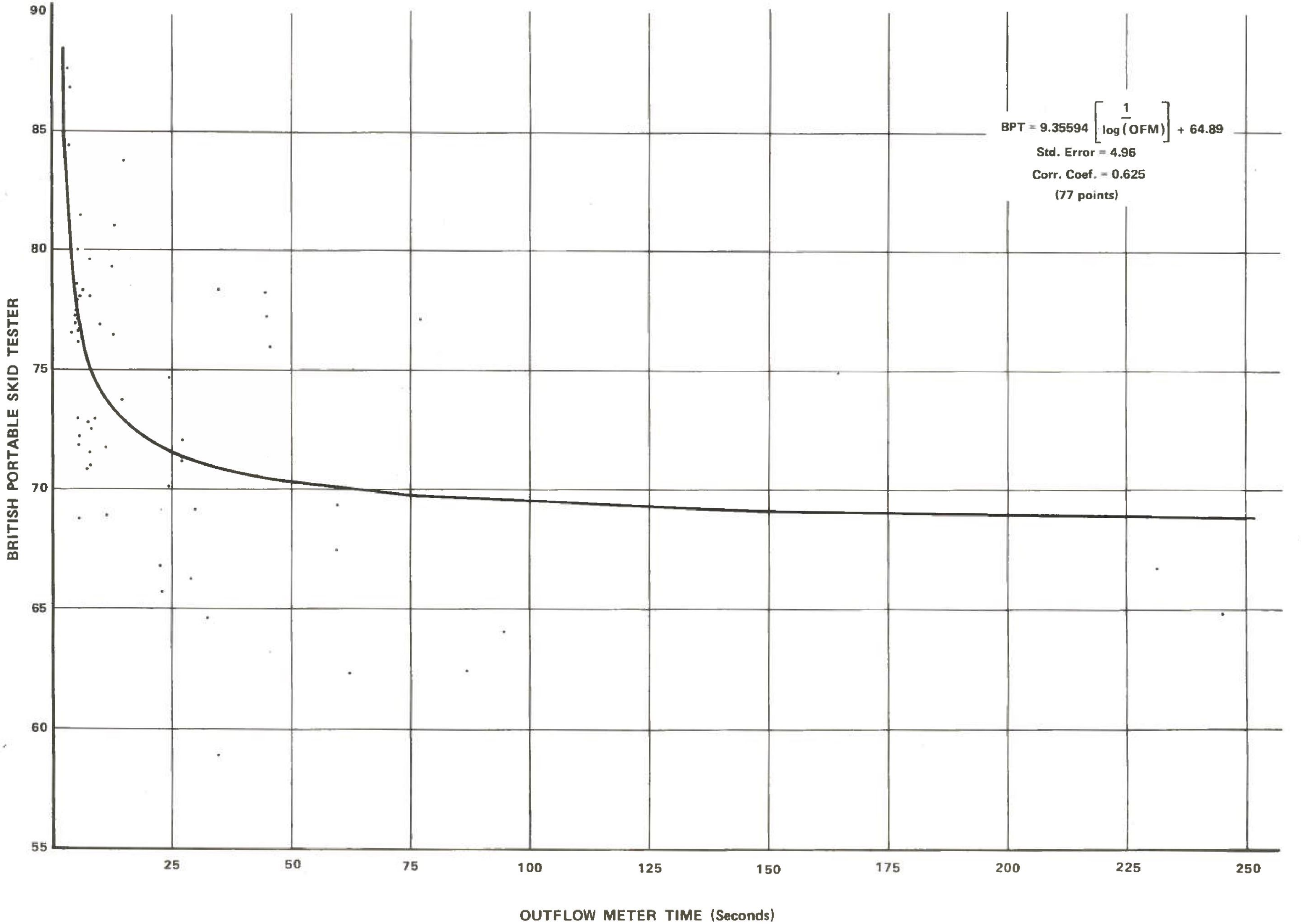
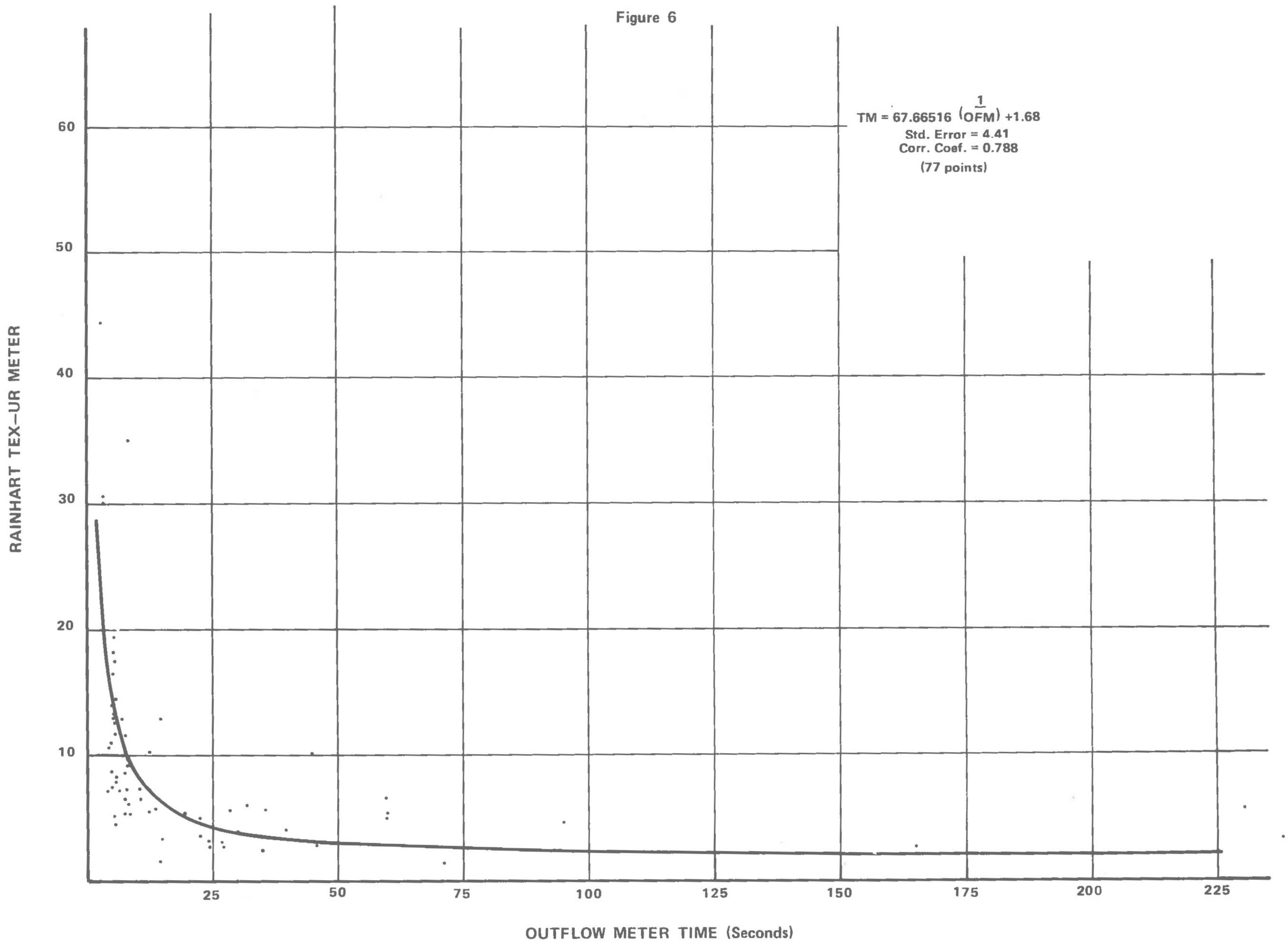

BPT = 9.35594 [1 / log (OFM)] + 64.89
Std. Error = 4.96
Corr. Coef. = 0.625
(77 points)
BRITISH PORTABLE SKID TESTER
OUTFLOW METER TIME (Seconds)
90
85
80
75
70
65
60
55
25
50
75
100
125
150
175
200
225
250

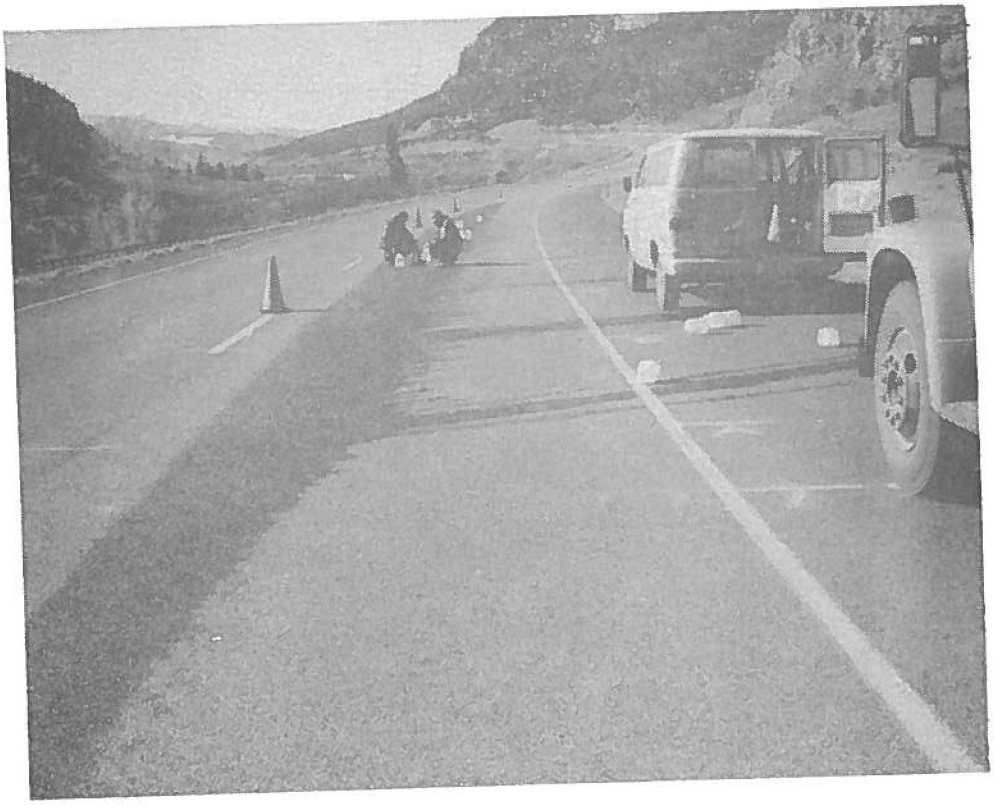
Figure 6


TM = 67.66516 (1/OFM) +1.68
Std. Error = 4.41
Corr. Coef. = 0.788
(77 points)
RAINHART TEX–UR METER
60
50
40
30
20
10
25
50
75
100
125
150
175
200
225
OUTFLOW METER TIME (Seconds)

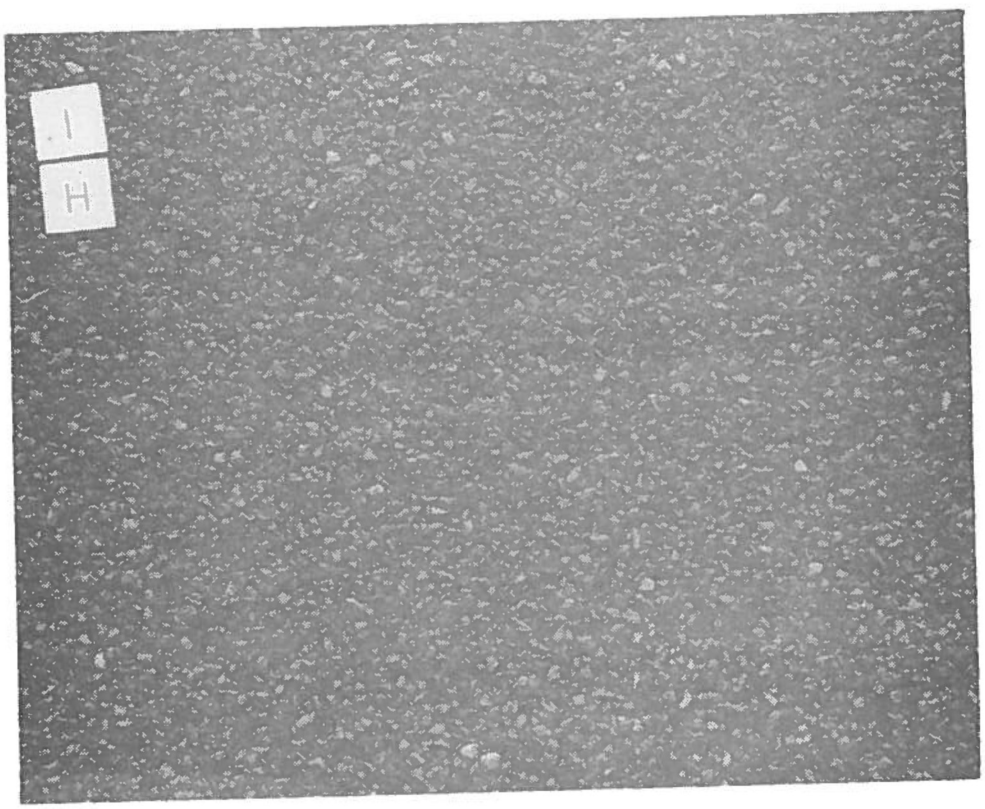
APPENDIX

PHOTOGRAPH #1

TYPE A OPEN GRADED PLANT MIX SEAL



SECTION #1 I-70 WEST OF WOLCOTT

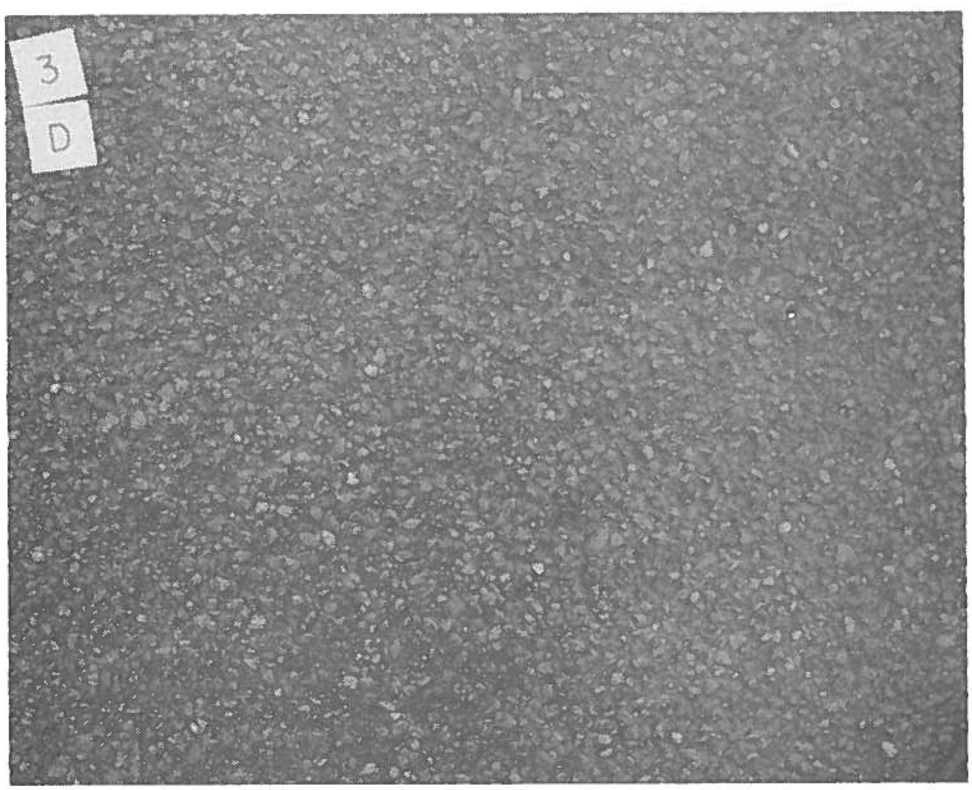


TEST SITE 1-H AVERAGE OUTFLOW TIME = 3.33 SEC.

PHOTOGRAPH #2

TYPE B OPEN GRADED PLANT MIX SEAL

SECTION #3 I-70 WEST OF RIVER BEND

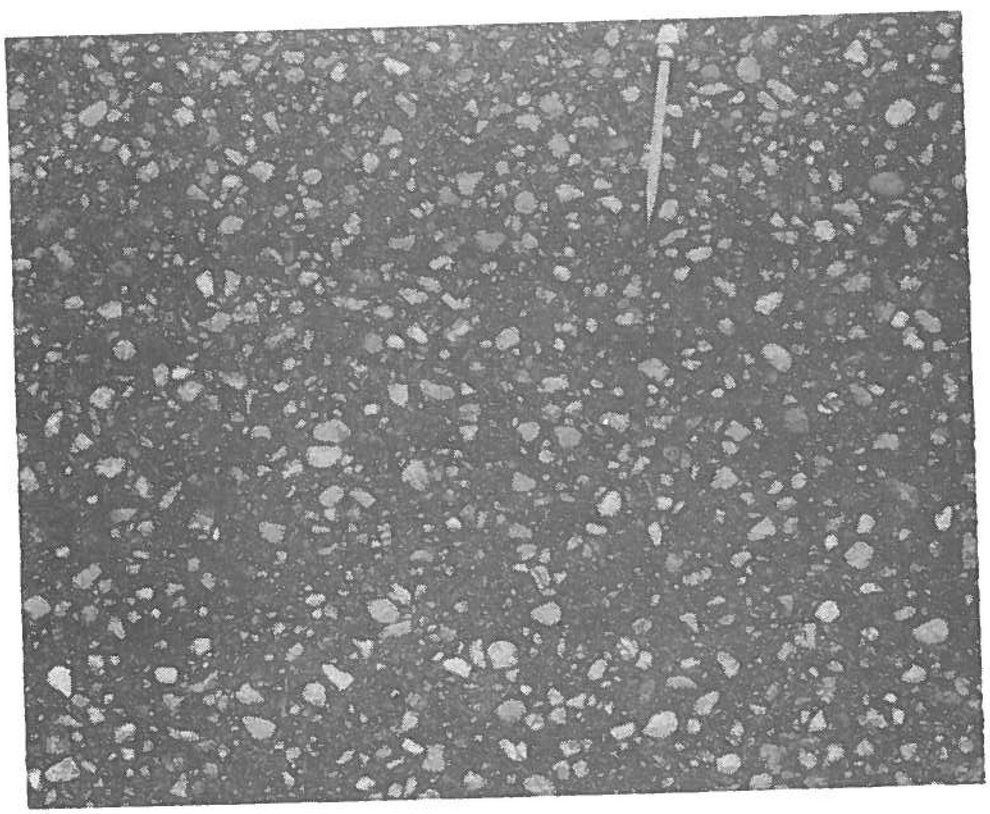


TEST SITE 3-D AVERAGE OUTFLOW TIME 5.98 SEC.

PHOTOGRAPH #3

HOT BITUMINUS PAVEMENT-GRADING E

SECTION #15 SH 128 WEST OF I-25



TEST SITE 15-B AVERAGE OUTFLOW TIME = 38.33 SEC.

PHOTOGRAPH #4

HOT BITUMINUS PAVEMENT-GRADING F

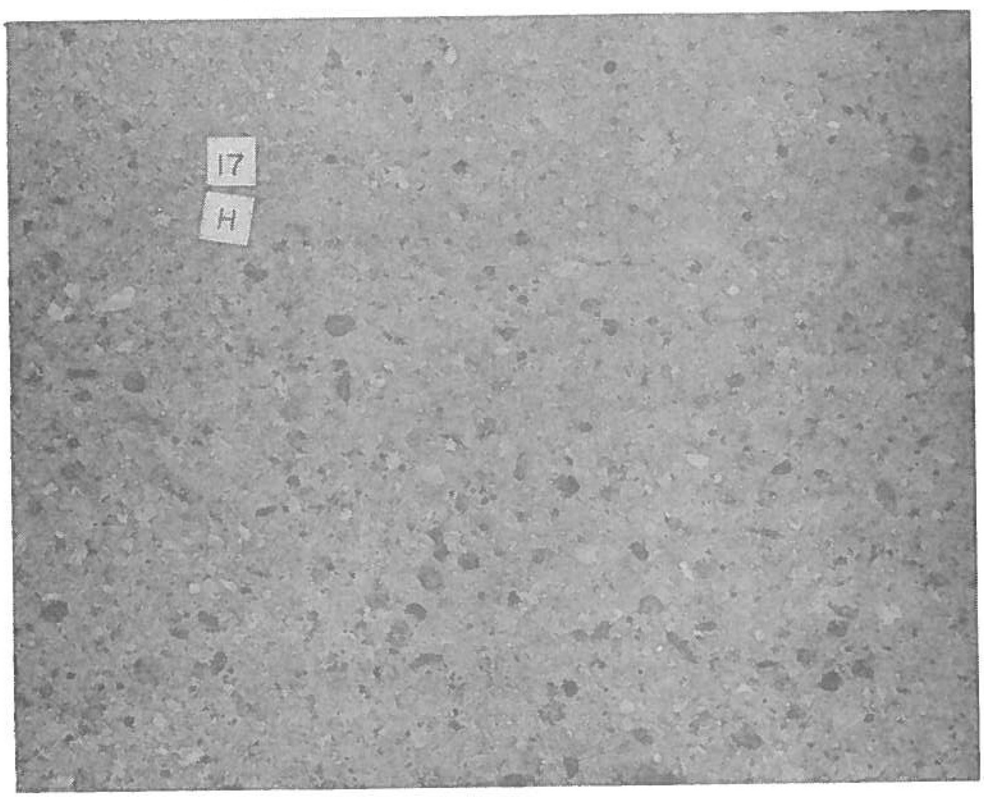
SECTION #7 SH 350 SOUTHWEST OF LAJUNTA

TEST SITE 7-G AVERAGE OUTFLOW TIME 6.71 SEC.

PHOTOGRAPH #5

PORTLAND CEMENT CONCRETE

SECTION #17 I-76 EAST OF SH 85



TEST SITE 17-H AVERAGE OUTFLOW TIME 28.85 SEC.

TABLE A

OUTFLOW METER TEST SITES

Sec. #	Location	Pavement Type	Gradation Type	No. Lanes	Year Built	ADT*	Latest Project No.
1.	I 70-West of Wolcott	PMS	A	4	1976	4,550	I 70-2(56)
2.	US 50-East of Rocky Ford	PMS	B	4	1974	7,500	C 09-0050-03
3.	I 70-West of River Bend	PMS	B	4	1974	5,250	C 34-0070-01
4.	SH 119-East of Longmont	HBP	E	4	1974	6,950	US 0119(21)
5.	SH 109-North of La Junta	HBP	F	2	1974	1,650	C 09-0109-09
6.	SH 287 North of Eads	HBP	F	2	1974	1,950	C 45-0287-01
7.	SH 350 Southwest of La Junta	HBP	F	2	1974	510	C 09-0350-01
8.	SH 10 Southwest of La Junta	HBP	F	2	1972	1,050	C 09-0010-10
9.	US 50 East of La Junta	HBP	E	4	1971	3,550	C 09-0050-00
10.	US 50 East of Swink	PMS	B	4	1977	8,700	FC 050-4(10)
11.	I 225 North of SH 83	PCC	-	4	1971	26,200	I 225-4(11)
12.	I 70 East of Rifle	PCC	-	4	1976	4,000	I 70-1(44)89
13.	US 36 East of Lyons	HBP	E	4	1973	5,900	RF 0036-1(19)
14.	SH 287 North of Lamar	HBP	E	4	1966	1,900	F 001-5(20)
15.	SH 128 West of I 25	HBP	E	4	1973	10,600	F 128-1(3)
16.	US 6 North of Atwood	HBP	F	4	1972	3,450	C 13-0006-01
17.	I 76 East of SH 85	PCC	-	4	1971	6,150	I 80S-1(38)15
18.	I 76 West of Crook	PCC	-	4	1967	4,300	I 80S-2(12)133
19.	I 70 West of Tower Road	PCC	-	4	1965	10,300	I 70-4(41)294
20.	SH 52 North of Ft. Morgan	HBP	F	4	1971	3,750	S 0052(7)

*Traffic Volumes from 1976 Traffic Volume Study

TABLE B

OUTFLOW METER TEST WORKSHEET

Date:________

Test Section No. & Location:____

____. Photos:__________

Start Time:______, Air Temp:______, Pvmt Temp:______.

Finish Time:______, Air Temp:______, Pvmt Temp:______.

Crew Mbrs:__________
____
____

Average Rdg:____

Text-Ur-Meter Readings

Time:________

1.____	6.____	11.____	16.____	21.____	26.____	31.____	36.____
2.____	7.____	12.____	17.____	22.____	27.____	32.____	37.____
3.____	8.____	13.____	18.____	23.____	28.____	33.____	38.____
4.____	9.____	14.____	19.____	24.____	29.____	34.____	39.____
5.____	10.____	15.____	20.____	25.____	30.____	35.____	40.____

British Portable Tester/Outflow Meter Tests

BPT Start/Finish Times: ______-______. Outflow Start/Fin ______-______.

BPT Overall Average__________. Outflow Meter Overall Av__________.

BPT	OM	BPT	OM	BPT	OM	BPT	OM
A. Location:____		B. ____		C. ____		D. ____	
1.____	1.____	1.____	1.____	1.____	1.____	1.____	1.____
2.____	2.____	2.____	2.____	2.____	2.____	2.____	2.____
3.____	3.____	3.____	3.____	3.____	3.____	3.____	3.____
4.____	4.____	4.____	4.____	4.____	4.____	4.____	4.____
5.____	5.____	5.____	5.____	5.____	5.____	5.____	5.____
av ____	av ____	av ____	av ____	av ____	av ____	av ____	av ____
E. ____		F. ____		G. ____		H. ____	
1.____	1.____	1.____	1.____	1.____	1.____	1.____	1.____
2.____	2.____	2.____	2.____	2.____	2.____	2.____	2.____
3.____	3.____	3.____	3.____	3.____	3.____	3.____	3.____
4.____	4.____	4.____	4.____	4.____	4.____	4.____	4.____
5.____	5.____	5.____	5.____	5.____	5.____	5.____	5.____
av ____	av ____	av ____	av ____	av ____	av ____	av ____	av ____

Start Time:_____

SKID TRAILER TESTS

Finish Time:__________

	SN_{50}	SN_{40}	SN_{30}
Values	____, ____, ____, ____, ____,	____, ____, ____, ____, ____,	____, ____, ____, ____, ____, ____,
	____, ____, ____, av____.	____, ____, ____, av____.	____, ____, ____, ____, av____.

TABLE C

FIRST ROUND
OUTFLOW METER
FIELD DATA

SEC. NO.	AVERAGE OUTFLOW TIME	AVERAGE BPT	AVERAGE TEXTURE METER	SKID NO. 50MPH	SKID NO. 40MPH	SKID NO. 30MPH
1	3.08	84.3	44.3	58.0	61.0	63.8
2	6.02	68.8	13.2	50.0	55.0	58.6
3	6.13	71.8	14.6	50.2	56.6	59.4
4	71.26	77.1	1.4	36.0	42.2	49.6
5	5.43	78.0	16.5	49.2	54.6	59.4
6	14.23	73.7	1.7	49.2	53.6	57.4
7	7.67	70.8	7.2	48.2	53.4	58.6
8	273.18	70.0	6.5	30.2	37.6	43.4
9	231.57	66.7	5.5	23.8	31.2	37.0
10	11.66	68.9	7.8	51.0	56.0	59.0
11	7.97	72.5	6.1	44.6	48.2	54.4
12	5.30	77.1	14.1	52.6	58.8	64.0
13	999.99	65.6	2.5	29.2	35.0	43.5
14	304.50	55.5	.3	19.6	25.0	31.8
15	45.07	78.2	10.1	41.2	48.8	57.0
16	999.99	66.4	1.8	24.2	31.6	37.0
17	35.06	58.9	2.5	38.8	43.0	49.4
18	59.37	69.4	5.2	36.6	42.6	48.0
19	32.32	64.7	6.0	35.6	44.2	48.2
20	7.36	75.1	7.2	49.0	55.4	61.5

SPEED GRAD.	AVG. AIR TEMP.	AVG. PAVE. TEMP.	DATE TESTED	START TIME MST	FINISH TIME MST
.29	48	54	110377	0930	1050
.43	85	94	102677	1335	1430
.46	67	70	102477	1007	1125
.68	76	88	101777	1300	1430
.51	54	58	102677	0800	0905
.41	73	84	102477	1415	1600
.52	75	82	102677	1020	1140
.66	66	75	102777	0930	1220
.66	68	75	102777	1350	1600
.40	82	96	102577	1250	1350
.49	79	87	101877	1200	1325
.57	58	63	110277	1330	1445
.72	63	73	101777	0915	1115
.61	53	58	102577	0715	0930
.79	61	71	111077	1125	1300
.64	81	89	101977	1430	1600
.52	75	83	101477	1030	1400
.57	65	66	102077	0810	1015
.63	61	63	101877	0810	0950
.63	73	80	101977	1000	1115

TABLE D

SECOND ROUND
OUTFLOW METER
FIELD DATA

SEC. NO.	AVERAGE OUTFLOW TIME	AVERAGE BPT	AVERAGE TEXTURE METER	SKID NO. 50MPH	SKID NO. 40MPH	SKID NO. 30MPH
1						
2	5.96	78.6	17.4	50.0	56.2	59.6
3	5.59	77.5	18.3	50.6	55.0	59.2
4	39.50	77.2	4.0	45.8	54.4	60.6
5	5.10	77.0	11.0	48.2	52.2	54.6
6	13.86	81.0	5.8	47.8	52.6	56.2
7	7.29	70.8	6.4	48.4	53.2	56.0
8	346.91	68.8	4.8	30.0	38.0	42.2
9	245.33	64.8	3.3	25.6	32.2	37.0
10	12.45	79.3	5.7	49.8	56.4	62.6
11	7.97	71.5	9.1	42.2	47.2	54.0
12	6.06	88.7	12.8	53.0	58.6	64.0
13	165.01	74.9	2.6	32.6	38.4	45.8
14	486.50	62.2	2.0	26.2	31.4	36.6
15	36.97	78.2	5.7	42.8	49.0	58.6
16	777.77	68.0	7.0	28.4	34.4	40.8
17	27.10	71.1	3.0	40.2	46.4	50.8
18	59.40	67.5	6.7	37.6	42.8	51.0
19	28.21	66.3	5.7	36.8	43.4	47.6
20	5.70	77.2	11.7	54.2	58.4	63.6

SPEED GRAD.	AVG. AIR TEMP.	AVG. PAVE. TEMP.	DATE TESTED	START TIME MST	FINISH TIME MST
.48	57	56	121577	0930	1030
.43	48	51	122177	1115	1335
.74	49	61	122277	1300	1335
.31	51	54	121377	1525	1640
.42	55	53	121277	1310	1500
.38	73	72	121477	1305	1405
.61	61	56	121477	0920	1135
.57	60	63	121377	1330	1550
.64	66	65	121477	1505	1615
.59	62	56	120777	1050	1135
.55	37	39	120177	1445	1545
.66	49	46	122277	1005	1120
.52	47	52	121377	0915	1125
.79	48	45	010578	1045	1200
.62	54	59	112877	1355	1515
.53	53	48	010578	1335	1445
.67	48	46	112977	1030	1225
.54	54	51	120777	1400	1500
.47	54	60	112877	1105	1210

TABLE E

THIRD ROUND
OUTFLOW METER
FIELD DATA

SEC. NO.	AVERAGE OUTFLOW TIME	AVERAGE BPT	AVERAGE TEXTURE METER	SKID NO. 50MPH	SKID NO. 40MPH	SKID NO. 30MPH
1	3.45	87.6	30.0	55.2	58.0	57.8
2	5.74	72.2	8.1	45.8	52.0	55.2
3	5.96	76.5	12.9	52.8	55.8	59.6
4	27.13	72.1	2.9	47.0	51.6	58.8
5	4.51	76.5	7.1	44.0	50.6	53.8
6	19.17	72.8	5.2	47.2	51.8	53.6
7	6.30	76.1	8.0	48.0	51.2	54.2
8	373.77	67.8	3.2	30.6	36.8	43.4
9	376.20	64.7	1.9	20.6	25.0	34.6
10	11.00	71.7	6.5	47.8	55.2	58.2
11	7.72	72.7	5.4	44.2	50.0	57.8
12	7.37	79.6	13.0	48.0	51.0	57.0
13	262.76	68.1	2.3	33.8	41.8	49.2
14	335.65	63.4	2.1	22.6	30.6	37.0
15	24.46	74.7	2.8	43.0	47.2	56.2
16	370.32	70.5	2.4	29.6	37.6	43.8
17	23.21	65.8	5.0	39.0	46.2	49.8
18	62.40	68.3	4.9	36.0	44.4	49.6
19	22.34	66.8	3.7	40.4	45.0	49.8
20	5.81	81.4	8.7	50.6	53.8	60.4

SPEED GRAD.	AVG. AIR TEMP.	AVG. PAVE. TEMP.	DATE TESTED	START TIME MST	FINISH TIME MST
.13	48	52	032278	0935	1040
.47	76	91	032978	1330	1425
.34	70	85	032778	1300	1345
.59	53	73	031478	1320	1415
.49	60	62	032878	1530	1615
.32	72	88	032778	1525	1615
.31	58	71	032978	0855	0940
.64	71	76	032978	1015	1135
.71	71	73	032878	1320	1450
.52	72	76	033078	0905	0955
.68	47	52	031378	0950	1030
.45	68	70	032178	1540	1650
.77	50	67	031478	0945	1200
.72	68	74	032878	0855	1105
.66	50	59	032478	1050	1145
.71	44	64	031578	1345	1530
.54	52	62	032478	1240	1345
.68	46	50	031678	0955	1145
.47	55	61	031378	1235	1330
.49	45	54	031578	1020	1135

TABLE F

FOURTH ROUND
OUTFLOW METER
FIELD DATA

SEC. NO.	AVERAGE OUTFLOW TIME	AVERAGE BPT	AVERAGE TEXTURE METER	SKID NO. 50MPH	SKID NO. 40MPH	SKID NO. 30MPH
1	3.46	86.8	30.7	53.0	55.6	57.2
2	5.27	80.0	7.4	49.0	54.2	57.4
3	6.24	78.3	19.3	54.0	56.8	59.8
4	15.55	83.7	3.4	48.2	52.8	60.4
5	4.18	75.1	10.7	46.8	52.8	57.8
6	12.84	76.4	10.2	48.8	53.2	57.6
7	5.56	72.9	5.1	44.2	51.4	57.2
8	467.70	70.3	1.2	36.2	41.8	45.2
9	358.64	73.0	3.0	26.2	33.5	44.0
10	10.46	76.8	7.2	49.0	54.0	59.8
11	8.20	72.9	5.4	44.0	49.6	54.8
12	7.30	78.1	8.7	45.6	47.2	54.0
13	289.40	79.7	1.5	43.0	47.8	57.6
14	512.05	76.1	3.7	29.6	36.6	45.0
15	46.82	76.0	2.8	42.2	49.0	55.2
16	559.88	70.9	1.5	35.4	37.4	49.4
17	30.03	69.2	4.0	40.4	46.8	51.0
18	94.63	64.1	4.8	35.2	41.8	44.8
19	24.41	70.1	3.2	38.2	46.0	51.2
20	6.26	78.0	4.5	48.2	54.0	54.6

SPEED GRAD.	AVG. AIR TEMP.	AVG. PAVE. TEMP.	DATE TESTED	START TIME MST	FINISH TIME MST
.21	54	59	051178	0825	0915
.42	56	65	050478	0715	0800
.29	40	48	050278	0950	1050
.61	48	62	050878	0945	1040
.55	53	70	050378	1340	1420
.44	44	48	050278	1420	1515
.65	62	67	050478	1150	1215
.45	73	83	050478	0930	1020
.89	53	61	050378	0955	1115
.54	62	78	050478	1240	1320
.54	59	72	051278	1110	1145
.42	77	80	051078	1250	1340
.73	55	73	050878	1215	1350
.77	38	44	050378	0705	0810
.65	56	68	051278	0830	0935
.70	56	63	051778	1235	1330
.53	75	78	051578	0815	0915
.48	65	70	051878	0810	0945
.65	67	78	051278	1340	1430
.32	59	66	051778	0945	1030

		20 Sites		19 Sites	
		1st Round		2nd Round	
		Mean	Std.Dev.	Mean	Std.Dev.
1	AGE	4.85	3.08	4.96	3.15
2	ADT	5910	5581	5982	5725
3	TM	8.725	9.62	7.526	4.72
4	BPT	70.675	6.825	73.72	6.61
5	OFM	156.358	303.10	120.14	208.66
6	SN_{50}	40.86	11.06	41.59	9.37
7	SN_{40}	46.69	10.41	47.38	9.01
8	SN_{30}	52.05	9.53	52.67	8.81
9	Speed Grad.	.560	.124	.554	.122
10	Avg. Air Temp.	68.15	10.37	54.00	5.89
11	Avg. Pave. Temp.	75.45	12.48	54.37	6.09
12	(AGE) X (ADT)	30564	39857	--	--
13	log (OFM)	1.50035	.79471	1.49035	.73299
14	log (SN_{50})	1.59356	.13303	1.60732	.10644
15	log (SN_{40})	1.65748	.10750	1.66742	.08866
16	log (SN_{30})	1.70864	.08700	1.71533	.07748
17	$\frac{1}{OFM}$	.08502	.08911	.07664	.07286
18	log (TM)	.73234	.47831	.79906	.26892
19	log (BPT)	1.84728	.04299	1.86591	.03889
20	log Speed Grad.	-.26341	.10459	-.26751	.10166
21	$\frac{1}{\log (OFM)}$	.87297	.45873	.83662	.37873

TABLE G

20 Sites 3rd Round Mean	20 Sites 3rd Round Std.Dev.	20 Sites 4th Round Mean	20 Sites 4th Round Std.Dev.	Overall Average Mean	Overall Average Std.Dev.
5.74	3.23	5.75	3.21	5.35	3.17
5910.	5581.	5910	5581	5960	5572
6.805	6.37	6.915	7.00	7.631	7.12
72.465	6.04	75.420	5.25	73.244	6.31
97.76	147.96	123.44	194.05	101.74	167.13
41.31	9.65	42.86	7.47	42.04	9.11
46.78	8.64	48.12	6.76	47.60	8.45
52.00	7.36	53.70	5.44	52.93	7.62
.535	.169	.542	.170	.544	.146
58.8	9.88	57.60	8.06	59.39	11.09
68.0	9.70	66.65	8.37	65.88	13.04
--	--	--	--	33558	42606
1.41813	.73048	1.44855	.78581	1.42412	.71439
1.60238	.11786	1.62504	.08257	1.61181	.10715
1.66154	.09289	1.67781	.06551	1.66979	.08642
1.71133	.06750	1.72774	.04576	1.71869	.06826
.08946	.08578	.09165	.08847	.08801	.08293
.71402	.31048	.69069	.35690	.74376	.35683
1.85874	.03546	1.87648	.03035	1.86316	.03788
-.30120	.18203	-.28940	.15338	-.28346	.13872
.89992	.43437	.90437	.45256	.89317	.42149

TABLE H

CORRELATION MATRIX OF OUTFLOW METER VARIABLES

Var./Var.	1	2	3	4	5	6	7	8	9	10
1	1.000	.095	-.441	-.625	.327	-.625	-.609	-.616	.343	-.135
2		1.000	-.044	.005	-.282	.119	.130	.195	.138	.046
3			1.000	.564	-.354	.599	.565	.486	-.598	-.183
4				1.000	-.404	.719	.702	.732	-.328	-.316
5					1.000	-.750	-.770	-.725	.446	-.109
6						1.000	.986	.955	-.627	-.010
7							1.000	.965	-.555	-.013
8								1.000	-.367	-.063
9									1.000	-.134
10										1.000

List of Variables

1 AGE
2 ADT
3 Texture Meter
4 British Portable Skid Tester
5 Outflow Meter
6 SN_{50}
7 SN_{40}
8 SN_{30}
9 Speed Gradient
10 Air Temp.
11 Pavement Temp.
12 (AGE) X (ADT)
13 log(OFM)
14 $\log(SN_{50})$
15 $\log(SN_{40})$
16 $\log(SN_{30})$
17 1/OFM
18 log(TM)
19 log(BPT)
20 log(Speed Grad.)
21 1/log(OFM)

CORRELATION

	11	12	13	14
1	-.161	.517	.481	-.597
2	.038	.862	-.217	.155
3	-.216	-.188	-.575	.540
4	-.246	-.241	-.563	.703
5	-.077	-.161	.878	-.756
6	.039	-.113	-.894	.991
7	.037	-.098	-.887	.984
8	.009	-.062	-.824	.959
9	-.099	.190	.640	-.587
10	.890	-.019	-.066	-.001
11	1.000	-.046	-.042	.047
12		1.000	-.052	-.065
13			1.000	-.877
14				1.000
15				
16				
17				
18				
19				
20				
21				

TABLE H (cont.)

MATRIX OF OUTFLOW VARIABLES

15	16	17	18	19	20	21
-.581	-.597	-.516	-.465	-.629	.347	-.520
.157	.209	.025	.048	.015	.148	.072
.521	.464	.788	.839	.546	-.662	.770
.690	.726	.620	.578	.998	-.397	.625
-.771	-.728	-.581	-.511	-.406	.397	-.667
.974	.950	.782	.695	.723	-.599	.829
.993	.962	.751	.693	.709	-.526	.803
.962	.996	.670	.620	.742	-.345	.723
-.528	-.363	-.690	-.549	-.315	.968	-.699
-.008	-.053	-.044	-.096	-.300	-.058	-.024
.043	.018	-.048	-.165	-.229	-.041	-.032
-.058	-.036	-.134	-.102	-.232	.207	-.092
-.868	-.817	-.863	-.713	-.563	.593	-.915
.988	.965	.733	.671	.711	-.553	.786
1.000	.969	.711	.677	.701	-.497	.767
	1.000	.651	.617	.739	-.343	.706
		1.000	.777	.611	-.695	.993
			1.000	.581	-.563	.784
				1.000	-.379	.617
					1.000	-.695
						1.000

TABLE I

SITE NUMBER: 5 East of Rocky Ford (Outflow Meter Test Section 2)

LANE AND LOCATION: EB Driving Lane 0.36 Miles East of 8th Road

PROJECT NUMBER: C 09-0050-03 YEAR PLACED: 1974

SURFACE TYPE AND SPECIFICATIONS: Type B Medium Graded Plant Mixed Seal Coat

ASPHALT: 6.8% AC-10

Sieve Size	% Passing
3/8"	100
#4	56
#8	34
#50	12
#200	4

CUMMULATIVE TRAFFIC:

Up to 1974 Tests	753,200
Up to 1975 Tests	None
Up to 1976 Tests	2,912,000
Up to 1977 Tests	4,720,000

TEST RESULTS

YEAR	SPEED MPH	AVERAGE SKID NUMBER	SPEED GRADIENT 30-50 MPH
1974	30	73	
1974	40	67	
1974	50	61	.60
1975			
1975	(Not Tested This Year)		
1975			
1976	30	62	
1976	40	61	
1976	50	51	.55
1977	30	59	
1977	40	55	
1977	50	50	.45

TABLE J

SITE NUMBER: 6 West of River Bend (Outflow Meter Test Section 3)

LANE AND LOCATION: WB Driving Lane 1.01 Miles West of River Bend Interchange

PROJECT NUMBER: C 34-0070-01 YEAR PLACED: 1974

SURFACE TYPE AND SPECIFICATIONS: Type B Medium Graded Plant Mix Seal Coat

ASPHALT: 5.5% AC-10

Sieve Size	% Passing
3/8"	100
#4	55
#8	35
#50	11
#200	6

CUMMULATIVE TRAFFIC:

Up to 1974 Tests	326,600
Up to 1975 Tests	None
Up to 1976 Tests	1,661,500
Up to 1977 Tests	3,142,000

TEST RESULTS

YEAR	SPEED MPH	AVERAGE SKID NUMBER	SPEED GRADIENT 30-50 MPH
1974	30	53	
1974	40	45	
1974	50	45	.40
1975			
1975	(Not Tested This Year)		
1975			
1976	30	62	
1976	40	57	
1976	50	52	.50
1977	30	59	
1977	40	57	
1977	50	50	.45

TABLE K

SITE NUMBER: 10 East of Longmont (Outflow Meter Test Section 4)

LANE AND LOCATION: WB Driving Lane 0.29 Miles West of County Highway #3(ECL)

PROJECT NUMBER: RS 0119(20) YEAR PLACED: 1974

SURFACE TYPE AND SPECIFICATIONS: Grading E (modified) Hot Bituminous Pavement

ASPHALT: 6.5% AC-10

Sieve Size	% Passing
1/2"	100
#4	69
#8	59
#200	6

CUMMULATIVE TRAFFIC:

Up to 1974 Tests	279,400
Up to 1975 Tests	None
Up to 1976 Tests	2,388,700
Up to 1977 Tests	4,232,000

TEST RESULTS

YEAR	SPEED MPH	AVERAGE SKID NUMBER	SPEED GRADIENT 30-50 MPH
1974	30	65	
1974	40	58	
1974	50	57	.40
1975			
1975	(Not Tested This Year)		
1975			
1976	30	60	
1976	40	53	
1976	50	43	.85
1977	30	50	
1977	40	42	
1977	50	36	.70

TABLE L

SITE NUMBER: 16 South of Cheraw (Outflow Meter Test Section 5)

LANE AND LOCATION: SB 1.36 Miles North of South End of Project

PROJECT NUMBER: C 09-0109-09 YEAR PLACED: 1974

SURFACE TYPE AND SPECIFICATIONS: Grading F Hot Bituminous Pavement

ASPHALT: 7.0% AC-10

Sieve Size	% Passing
1"	100
#8	73
#200	8

CUMMULATIVE TRAFFIC:

Up to 1974 Tests	150,600
Up to 1975 Tests	None
Up to 1976 Tests	566,400
Up to 1977 Tests	1,315,000

TEST RESULTS

YEAR	SPEED MPH	AVERAGE SKID NUMBER	SPEED GRADIENT 30-50 MPH
1974	30	71	
1974	40	63	
1974	50	56	.75
1975			
1975	(Not Tested This Year)		
1975			
1976	30	62	
1976	40	56	
1976	50	52	.50
1977	30	59	
1977	40	54	
1977	50	49	.50

TABLE M

SITE NUMBER: 18 North of Eads (Outflow Meter Test Section 6)

LANE AND LOCATION: SB 5 Miles South of North End of Project

PROJECT NUMBER: C 45-0287-01 YEAR PLACED: 1974

SURFACE TYPE AND SPECIFICATIONS: Grading F Hot Bituminous Pavement

ASPHALT: 6.5% AC-10

Sieve Size	%Passing
1"	100
#8	88
#20	9

CUMMULATIVE TRAFFIC:

Up to 1974 Tests	185,100
Up to 1975 Tests	None
Up to 1976 Tests	732,200
Up to 1977 Tests	1,714,000

TEST RESULTS

YEAR	SPEED MPH	AVERAGE SKID NUMBER	SPEED GRADIENT 30-50 MPH
1974	30	71	
1974	40	62	
1974	50	55	.80
1975			
1975	(Not Tested This Year)		
1975			
1976	30	58	
1976	40	51	
1976	50	48	.50
1977	30	57	
1977	40	54	
1977	50	49	.40

TABLE N

SITE NUMBER: 19 Southwest of LaJunta (Outflow Meter Test Section 7)

LANE AND LOCATION: NB 0.3 Miles North of 38th Lane, SE

PROJECT NUMBER: C 09-0350-01 YEAR PLACED: 1974

SURFACE TYPE AND SPECIFICATIONS: Grading F Hot Bituminous Pavement

ASPHALT: 7.5% AC-10

Sieve Size	% Passing
1"	100
#8	68
#200	8

CUMMULATIVE TRAFFIC:

Up to 1974 Tests 31,400

Up to 1975 Tests None

Up to 1976 Tests 150,300

Up to 1977 Tests 262,000

TEST RESULTS

YEAR	SPEED MPH	AVERAGE SKID NUMBER	SPEED GRADIENT 30-50 MPH
1974	30	71	
1974	40	62	
1974	50	54	.85
1975			
1975	(Not Tested This Year)		
1975			
1976	30	59	
1976	40	52	
1976	50	45	.70
1977	30	59	
1977	40	53	
1977	50	48	.55

TABLE O

SITE NUMBER: 20 Metro Denver (Outflow Meter Test Section 11)

LANE AND LOCATION: NB Driving Lane 0.64 Miles North of SH 83

PROJECT NUMBER: I 225-4(12) YEAR PLACED: 1971

SURFACE TYPE AND SPECIFICATIONS: Portland Cement, Burlap Drag Finish

ASPHALT: --

Sieve Size	% Passing
--	--
--	--
--	--

CUMMULATIVE TRAFFIC:

Up to 1974 Tests	6,329,200
Up to 1975 Tests	None
Up to 1976 Tests	13,701,800
Up to 1977 Tests	25,406,000

TEST RESULTS

YEAR	SPEED MPH	AVERAGE SKID NUMBER	SPEED GRADIENT 30-50 MPH
1974	30	64	
1974	40	58	
1974	50	50	.70
1975			
1975	(Not Tested This Year)		
1975			
1976	30	53	
1976	40	49	
1976	50	43	.50
1977	30	54	
1977	40	48	
1977	50	45	.45

REFERENCES

1. Steere, L. B., "Skid Number-Speed Gradient Testing in Colorado" Colorado Department of Highways, Interim Report, October 1971.

2. "1977 State Highway Sufficiency Rating and Needs Study," Colorado Department of Highways, July 1977.

3. Moore, A. B. and Humphreys, J. B., "High Speed Skid Resistance and the Effects of Surface Texture on the Accident Rate," Skid Resistance of Highway Pavements, ASTM STP 350, American Society for Testing and Materials, 1973, pp. 91-100.