REPORT NO. TC-159

Prepared by the

CENTRAL/WESTERN FIELD TEST AND EVALUATION CENTER

for

TEXAS STATE DEPARTMENT OF
HIGHWAYS AND PUBLIC TRANSPORTATION
Texas-Austin
System No. 2

Under Contract

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Prepared By

Project Staff

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
and
Texas A&M Research Foundation

College Station, Texas 77843

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FEDERAL HIGHWAY ADMINISTRATION POLICY

This report expresses the views of the Central/Western Field Test and Evaluation Center which is responsible for the facts and accuracy of the data presented. It does not necessarily reflect the official views or policies of the Federal Highway Administration, Department of Transportation; nor does the report constitute a standard, specification or regulation.

INTERPRETATION OF DATA

The calibration and correlation material reported for the Texas-Austin No. 2 skid measurement system is valid only if no modifications are made, and if no changes occur in the mechanical and electrical components. The validity of the material also requires that the system be operated in the same manner as it was at the time of evaluation at the Central/Western Field Test and Evaluation Center. Calibration tests should be performed on a periodic basis to maintain confidence in the measurement process.

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INTRODUCTION

The Central Field Test and Evaluation Center was established in 1971 at the Texas Transportation Institute by the Federal Highway Administration (FHWA) to reduce interstate variations in locked-wheel skid measurements of pavement surfaces. With the closing of the Western Field Test and Evaluation Center at the end of 1975, the Central Center was redesignated as the Central/Western Field Test Center (C/W FTC). In 1979 the C/W FTC became known as the Central/Western Field Test and Evaluation Center (C/W FT&EC) and currently serves central, western and southeastern states, Alaska, Hawaii and Puerto Rico. The Central/Western FT&EC also has the responsibility of calibrating and evaluating Mu-Meter systems. The Eastern FT&EC, located at East Liberty, Ohio and operated by Transportation Research Center of Ohio, serves eastern and southern states.

This report results from the calibration, statistical correlation and evaluation of the Texas-Austin No. 2 skid measurement system. The calibration, correlation and evaluation began October 1, 1984 and was completed October 4, 1984, a total of 4 working days.

Two dynamic skid number correlations were performed. The first correlation with the Texas-Austin No. 2 skid measurement system compared skid number readings in the initial (as arrived) condition with those of the C/W FT&EC Area Reference Skid Measurement System (ARSMS) on three reference surfaces of various textures at three different test speeds. After calibration, water flow measurements and water distribution tests, the second correlation was conducted at the same speeds and on the same surfaces used during the first correlation.

FIGURE 1. TEXAS-AUSTIN NO. 2 PERSONNEL
(Doug Chalman & Randy Beck)

FIGURE 2. TEXAS-AUSTIN NO. 2 SMS

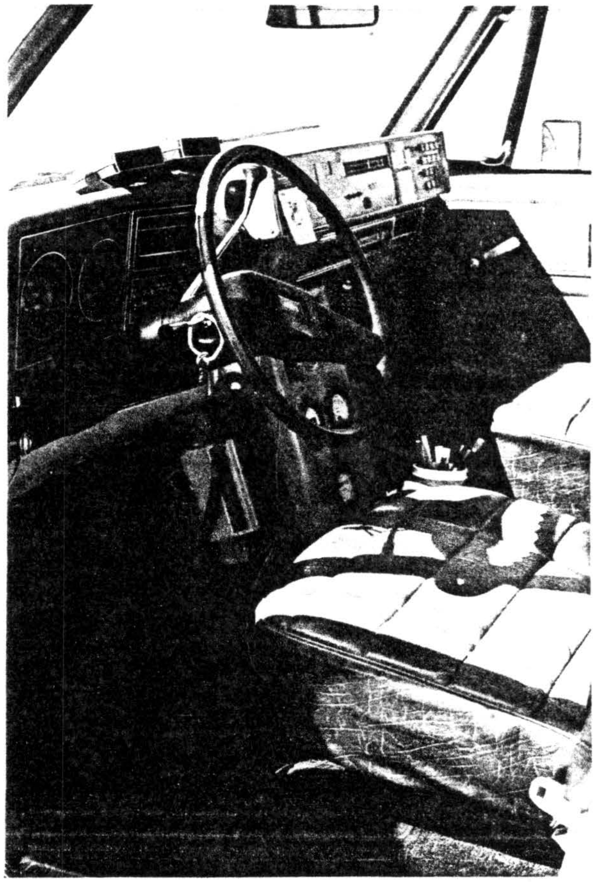


FIGURE 3. INTERIOR VIEW OF TEXAS-AUSTIN NO. 2

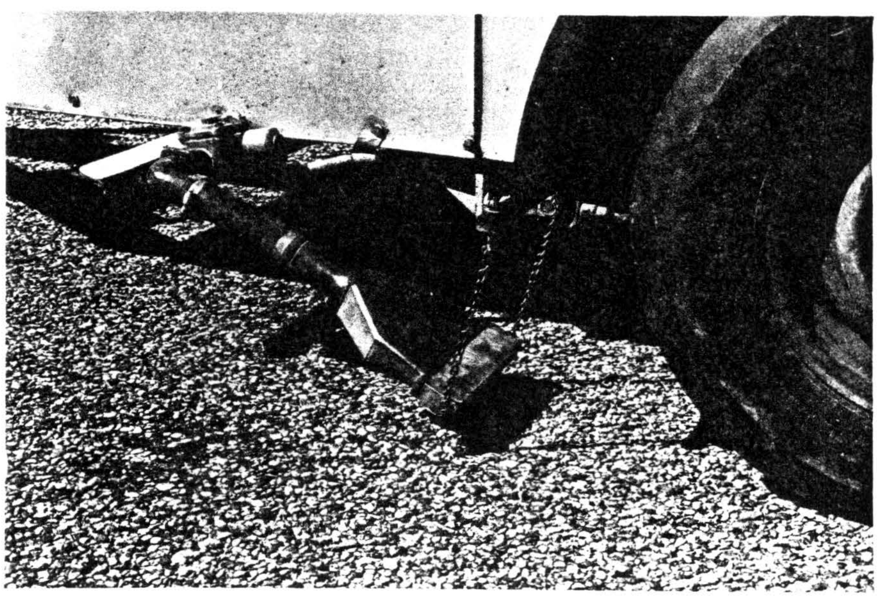


FIGURE 4. NOZZLE VIEW OF TEXAS-AUSTIN NO. 2

SUMMARY OF TESTS AND RESULTS

The following paragraphs summarize the various segments of the correlations, calibrations and evaluation of the Texas-Austin No. 2 skid measurement system by the Central/Western Field Test and Evaluation Center.

First Correlation

As soon as possible after arrival at the Center, a full scale skid number correlation was conducted between the Texas-Austin No. 2 skid measurement system, in the as arrived condition, and the Area Reference Skid Measurement System (ARSMS). The correlation was conducted on three different test surfaces at speeds of 20, 40 and 50 mph.

A summary of the results of the first correlation is found in Tables A1 and A2 of Appendix A. The Texas-Austin No. 2 system recorded higher average skid numbers than the ARSMS in 8 of the 9 speed-surface combinations. The differences ranged from -1.0 SN on surface SRS 1 at 50 mph to 3.2 SN on surface SRS 2 at 20 mph. The overall average absolute difference was 1.8 SN. The skid numbers measured by the Texas-Austin No. 2 system were of the same level of variability as the values recorded by the ARSMS. The standard deviation for the Texas-Austin No. 2 system, pooled over all surfaces and speeds, was 2.26 SN, whereas the pooled standard deviation for ARSMS was 1.80 SN. The two systems were highly correlated in their measurement of skid numbers at all three speeds.

Force Subsystem Calibration

An air bearing force plate which has been calibrated by using load cells calibrated at the National Bureau of Standards (NBS) was used to determine the actual vertical and traction force of the test wheel. The vertical load of the left test wheel was stated to be 1095 lbs. on arrival and was measured at

1095 lbs. The vertical load of the left test wheel remained at 1095 lbs. The vertical load of the right test wheel was stated to be 1031 lbs. on arrival and was measured at 1031 lbs. The vertical load of the right test wheel remained at 1031 lbs. The tongue load was 125 lbs. on arrival and remained at 125 lbs.

The value of the left traction calibration signal was stated to be 1.5 volts = 500 lbs., and actual measurement showed it at 1.5 volts. The value of the left traction calibration signal remained at 1.5 volts = 500 lbs. A comparison of the C/W FT&EC force plate with the Texas-Austin No. 2 system transducer, found in Tables F2 through F4 of Appendix F, shows the transducer to be linear.

Force Plate Calibration

A force plate calibration fixture was used to calibrate the Texas-Austin No. 2 force plate. All load cells and readout devices used in the calibration were calibrated at the NBS. Results of this calibration are found in Table F5 and F6.

The value of the R-cal for horizontal force was stated to be 500 lbs., and actual measurement showed it to be 500 lbs. The value of the R-cal remaind at 500 lbs. The value of the R-cal for vertical force was stated to be 700 lbs., however actual measurement showed it to be 703 lbs. The value of the R-cal was adjusted to 700 lbs.

Water Subsystem Evaluation

The water flow rate was measured at equivalent speeds of 20, 40 and 50 mph. The Texas-Austin No. 2 system arrived equipped with the non-divergent (ASTM E 274-79) water nozzle. The nozzle was positioned as shown in Figure F1. The results and analysis of these tests are shown in Table E1 and Figure E1.

Speed Subsystem Calibration

The speed readout device was compared to the calibrated reference fifth wheel. The results are given in Table F7.

Tire Pressure Gage Calibration

The Texas-Austin No. 2 system tire pressure gage were calibrated using the C/W FT&EC reference air pressure gage. The results of the calibration are given in Table F8.

Second Correlation

After all calibrations and adjustments to the Texas-Austin No. 2 system were completed, a second correlation with the ARSMS was performed. The second correlation was conducted using the same procedure as in the first correlation. The results of the second correlation are found in Tables B1 and B2 of Appendix B. The Texas-Austin No. 2 system recorded higher average skid numbers in 8 of the 9 speed-surface combinations. The differences were smaller than in the first correlation, ranging from -0.6 SN on surface SRS 2 at 20 mph to 2.6 SN on PRS 4 at 50 mph with an overall average absolute difference of 1.6 SN.

The variation in skid number measurements was slightly larger for the Texas-Austin No. 2 system than for the ARSMS in 4 of 9 cases. The overall pooled standard deviation was 1.67 SN for Texas-Austin No. 2 system and 1.65 SN for the ARSMS. Again, the two systems displayed a high correlation in their measurement of skid numbers.

Correlation Overview

There was a decrease in the absolute difference in average skid numbers between the two correlations in 4 of the 9 cases. The overall average absolute difference was 1.8 SN during the first correlation and 1.6 SN during the second correlation.

The skid numbers measured by the Texas-Austin No. 2 system showed a decrease in their level of variability; a standard deviation of 2.26 SN was recorded during the first correlation while a value of 1.67 SN was recorded for the second correlation. The standard deviations pooled over both correlations were 1.73 SN for the ARSMS and 1.99 SN for the Texas-Austin No. 2 system.

The correlation between the measured skid numbers was 0.97 for the first correlation and 0.98 for the second correlation reflecting a high degree of linearity between the two systems in their measurement of skid numbers for both correlations.

General Recommendations

1. Monthly estimates of the Texas-Austin No. 2 skid measurement system variability should be made using the procedures outlined under "Procedures for Estimating System Variability" in Appendix D. If a significant change in variability is noted, the system should be investigated to determine the cause of the change and restored to a satisfactory condition.
2. A detailed checklist should be devised and used periodically in a regular maintenance program to monitor the condition of the skid measurement system components. The list should include such items as condition of brakes, speed measuring instrument, position and condition of water nozzle, water flow rate, force transducer, suspension and loose or leaking water connections.
3. The friction factor on wet pavement is speed dependent. Therefore, emphasis should be placed on maintaining the appropriate test speed in accordance with the speed calibration provided by the C/W FT&EC.

4. With the non-divergent water nozzle, it is even more important that flow from the nozzle be checked periodically to ascertain that the 1/8" and 1/4" holes have not been obstructed by trash, scale, etc., from the water tank. In the case of one system visiting the C/W FT&EC (Figure 5), the nozzle was partially clogged by the wire from a deteriorated wire reinforced water hose leading to the nozzle.

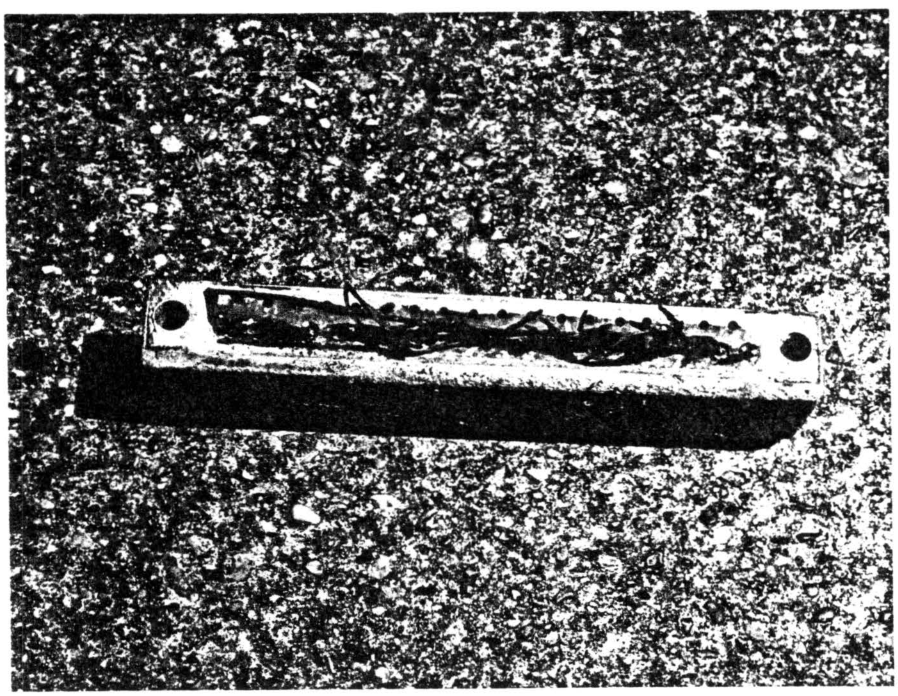


FIGURE 5. PARTIALLY CLOGGED NOZZLE.

APPENDIX A

FIRST CORRELATION

FIRST CORRELATION

The first correlation consisted of 12 skids on surface SRS 2, 12 skids on surface PRS 4, and 12 skids on surface SRS 1. This pattern was repeated for 20, 40 and 50 mph.

The results of the first correlation are given in Tables A1 and A2. Considering all speed-surface combinations, the Texas-Austin No. 2 system recorded higher average skid numbers in 8 of the 9 speed-surface combinations; the average absolute difference being 1.8 SN. Furthermore, it was observed that the Texas-Austin No. 2 system had a slightly larger pooled standard deviation than the ARSMS, 2.26 SN versus 1.80 SN.

The linear regression equations relating the measurements of the Texas-Austin No. 2 system to those of the ARSMS are graphed in Figure A1.

If the regression equations are used to estimate the results that would have been obtained by the ARSMS, Figures A2 through A5 may be used to indicate the range of confidence. That is, if the Texas-Austin No. 2 system is used to obtain an average skid number of a given surface based on K measurements, then these measurements have a variance of SD^2/K and refer to the left-hand scale of the appropriate figure to find the range which indicates 90% confidence limits that would have been obtained by ARSMS.

AVERAGE SKID NUMBER						
REFERENCE SURFACE	20 MPH		40 MPH		50 MPH	
	ARSMS	TEXAS-AUSTIN NO. 2	ARSMS	TEXAS-AUSTIN NO. 2	ARSMS	TEXAS-AUSTIN NO. 2
SRS 2	22.1	25.3	15.3	18.4	13.7	15.3
PRS 4	26.6	28.9	20.0	21.4	18.3	18.4
SRS 1	48.0	51.1	43.7	43.8	42.1	41.1
AVERAGE	32.2	35.1	26.3	27.9	24.7	24.9
POOLED STANDARD DEVIATION	1.75	2.71	1.66	1.92	1.96	2.08

TABLE A1. RESULTS OF THE FIRST CORRELATION

STANDARD DEVIATION OF SKID NUMBER						
REFERENCE SURFACE	20 MPH		40 MPH		50 MPH	
	ARSMS	TEXAS-AUSTIN NO. 2	ARSMS	TEXAS-AUSTIN NO. 2	ARSMS	TEXAS-AUSTIN NO. 2
SRS 2	1.96	3.96	1.76	2.58	2.14	2.86
PRS 4	1.92	2.31	1.99	1.78	2.31	1.73
SRS 1	1.32	1.00	1.10	1.14	1.28	1.31
POOLED	1.75	2.71	1.66	1.92	1.96	2.08

TABLE A2. STANDARD DEVIATION OF SKID NUMBER - FIRST CORRELATION

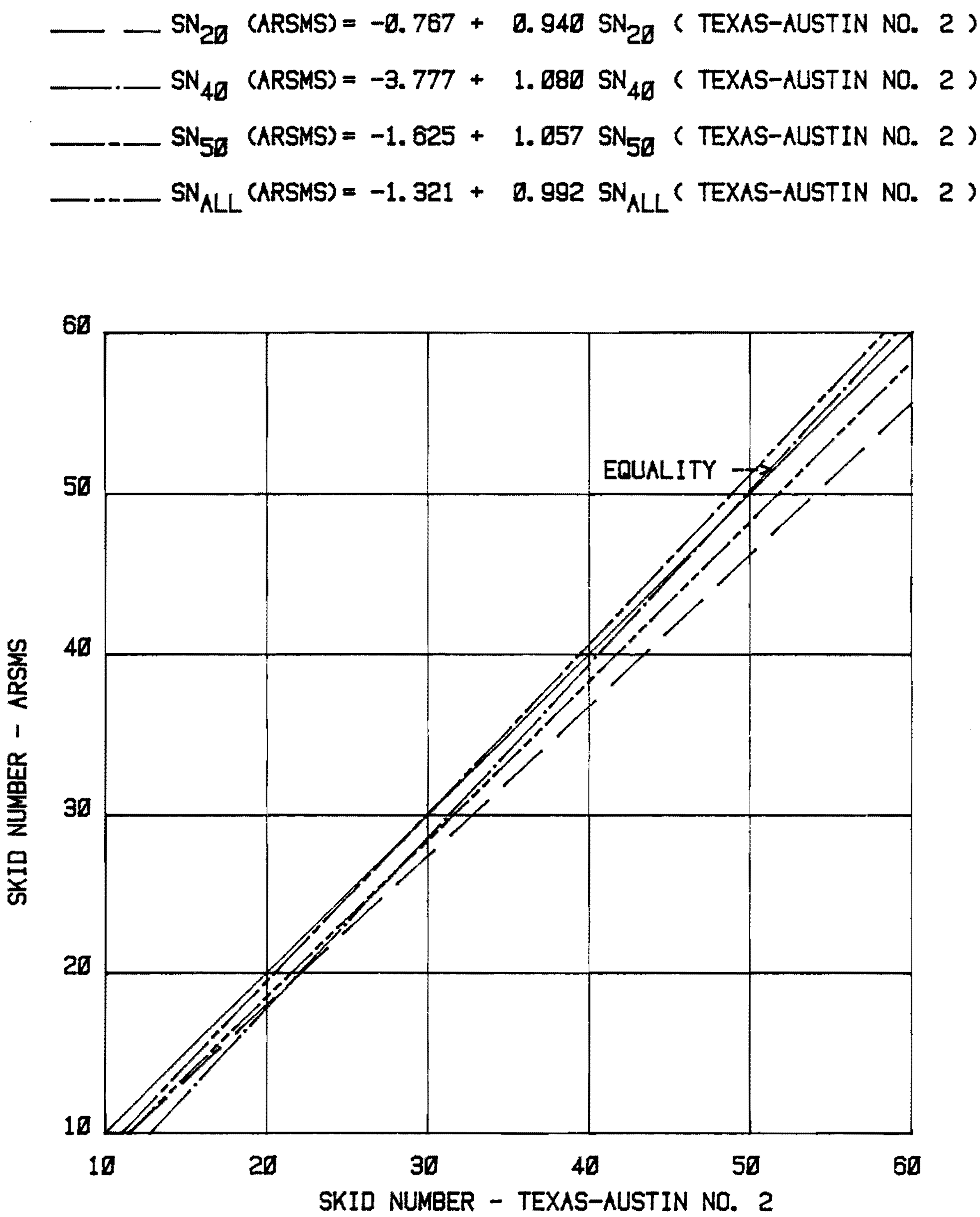


FIGURE A1. FIRST SKID NUMBER CORRELATION

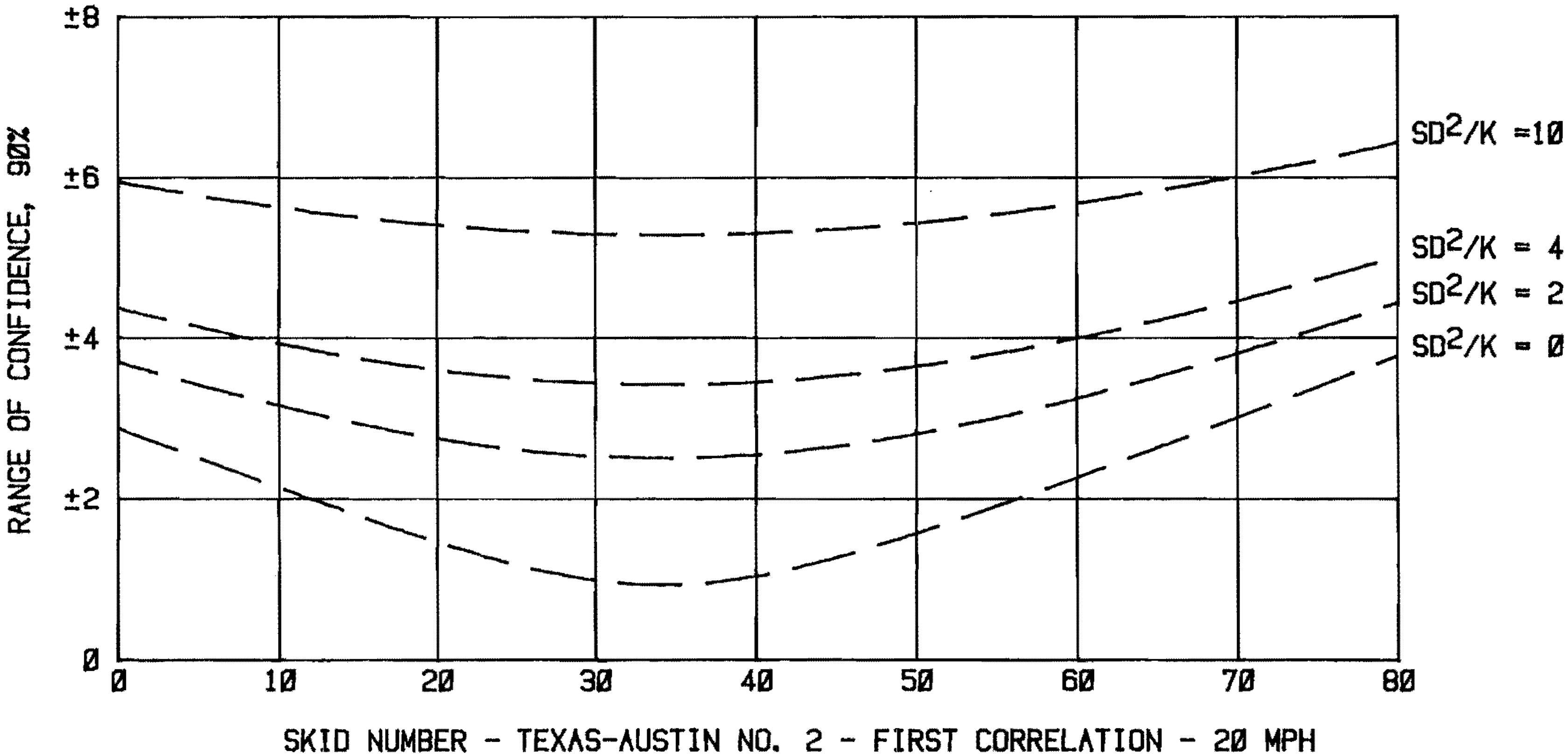


FIGURE A2. DETERMINATION OF RANGE OF THE VALUE OF AVERAGE SN WHICH WOULD HAVE BEEN DETERMINED BY ARSMS (20 MPH)

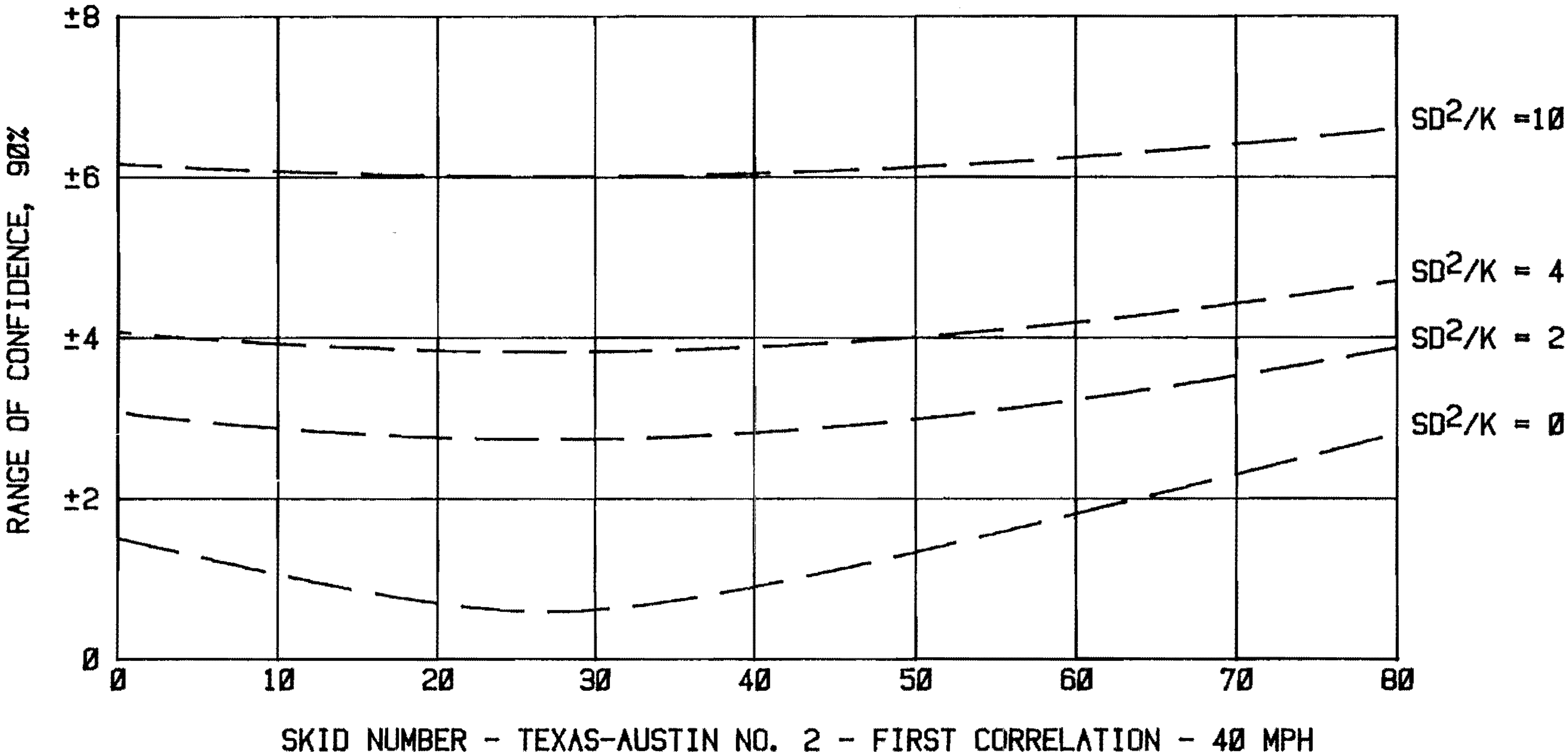


FIGURE A3. DETERMINATION OF RANGE OF THE VALUE OF AVERAGE SN
WHICH WOULD HAVE BEEN DETERMINED BY ARSMS (40 MPH)

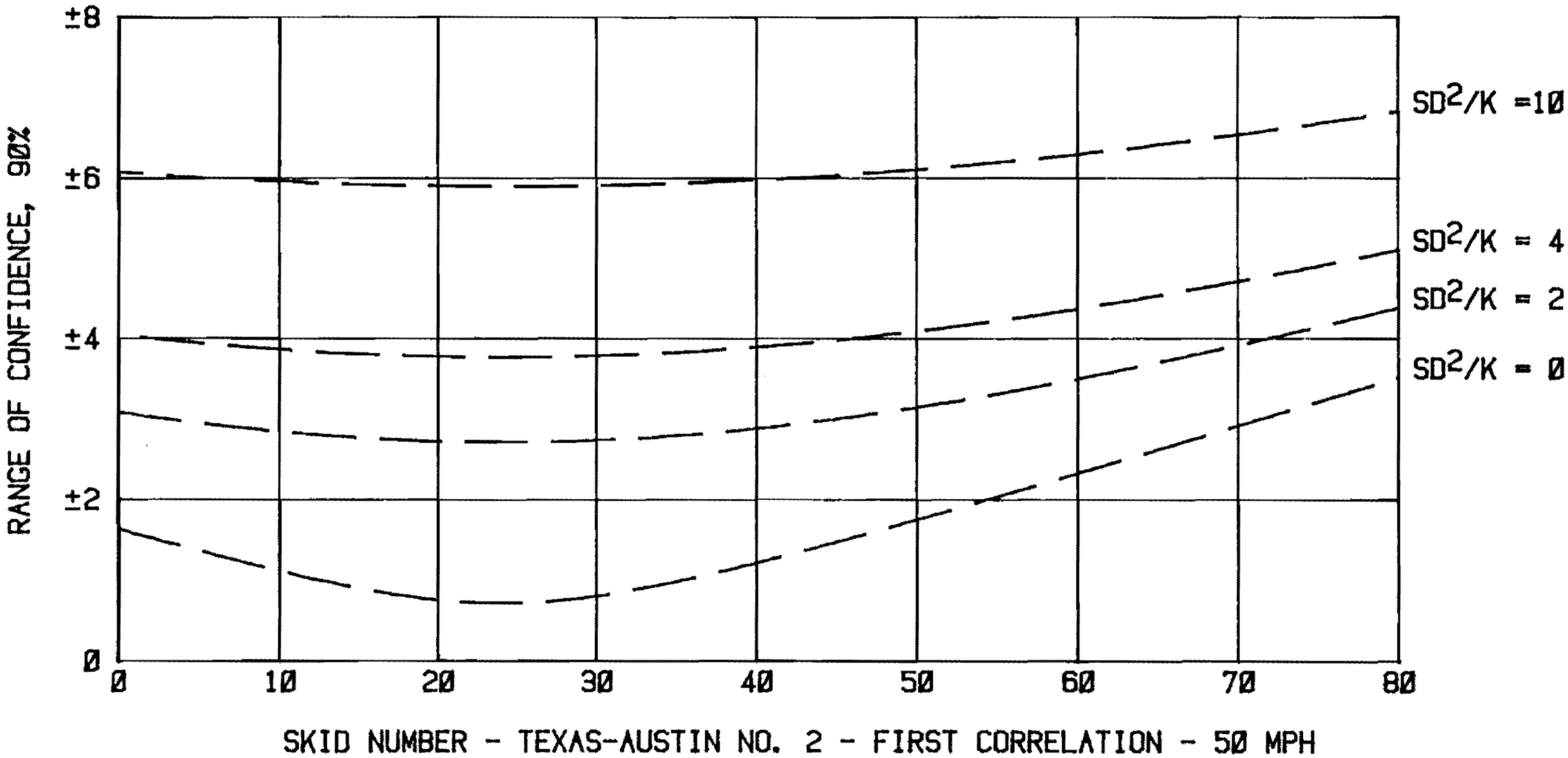


FIGURE A4. DETERMINATION OF RANGE OF THE VALUE OF AVERAGE SN WHICH WOULD HAVE BEEN DETERMINED BY ARSMS (50 MPH)

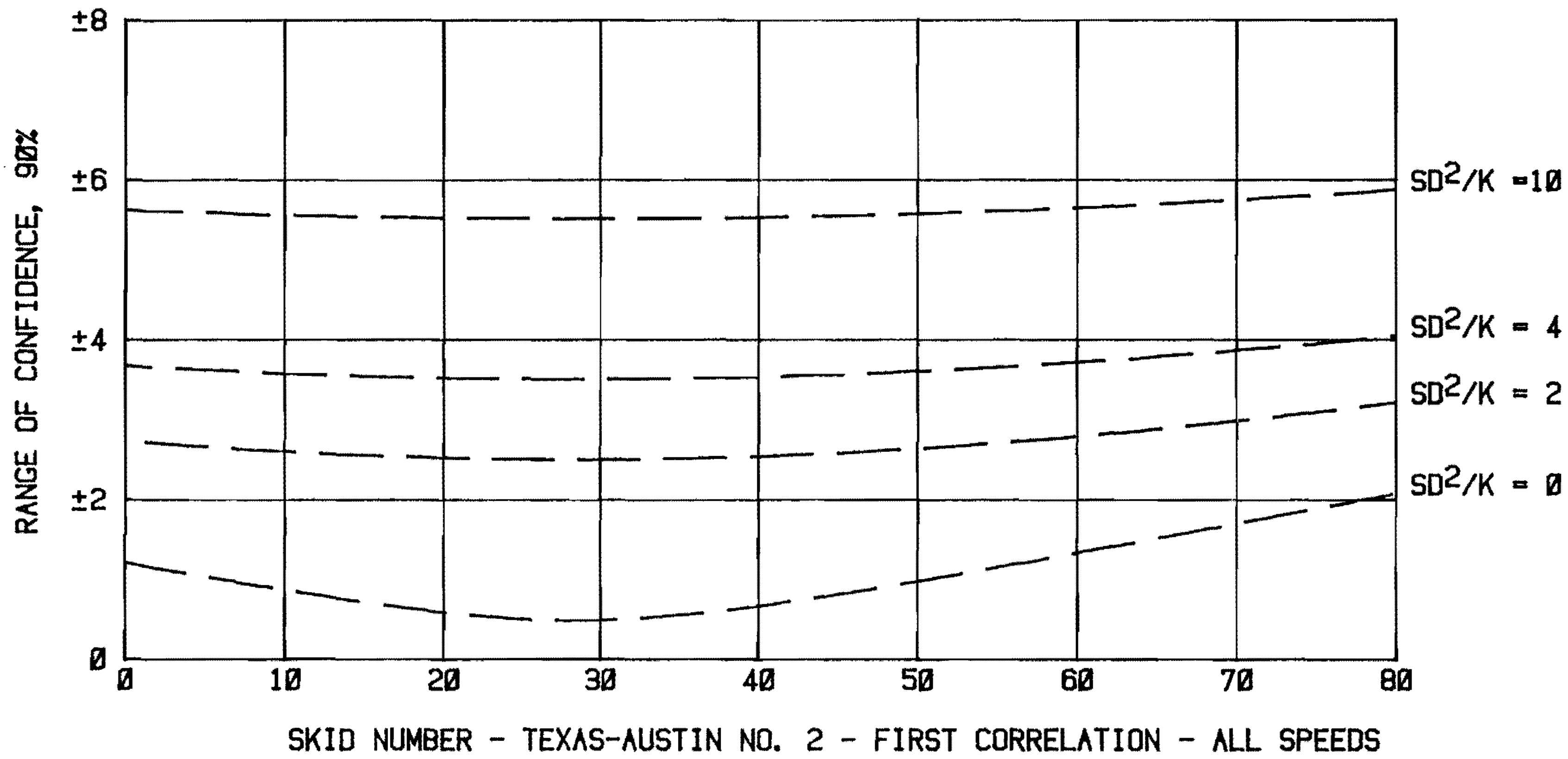


FIGURE A5. DETERMINATION OF RANGE OF THE VALUE OF AVERAGE SN WHICH WOULD HAVE BEEN DETERMINED BY ARSMS (ALL SPEEDS)

APPENDIX B

SECOND CORRELATION

SECOND CORRELATION

The second correlation was performed after the calibration of all subsystems of the Texas-Austin No. 2 system were completed. The skid number evaluation procedure was the same as that used in the first correlation.

The results of the second correlation are given in Tables B1 and B2. The Texas-Austin No. 2 system recorded higher skid number values in 8 of the 9 speed-surface combinations. The differences ranged from -0.6 to 2.6 SN with an overall average absolute difference of 1.6 SN. The Texas-Austin No. 2 system had a slightly larger standard deviation, 1.67 for the system versus 1.65 SN for the ARSMS.

The linear regression equations relating the measurements of the Texas-Austin No. 2 system to those of the ARSMS are displayed both algebraically and graphically in Figure B1.

AVERAGE SKID NUMBER						
REFERENCE SURFACE	20 MPH		40 MPH		50 MPH	
	ARSMS	TEXAS-AUSTIN NO. 2	ARSMS	TEXAS-AUSTIN NO. 2	ARSMS	TEXAS-AUSTIN NO. 2
SRS 2	22.6	22.0	15.2	17.3	13.4	15.9
PRS 4	26.4	27.3	19.8	21.6	17.7	20.3
SRS 1	49.1	49.8	44.3	46.1	42.2	43.4
AVERAGE	32.7	33.1	26.4	28.3	24.4	26.5
POOLED STANDARD DEVIATION	1.78	1.44	1.26	1.93	1.84	1.60

TABLE B1. RESULTS OF THE SECOND CORRELATION

STANDARD DEVIATION OF SKID NUMBER						
REFERENCE SURFACE	20 MPH		40 MPH		50 MPH	
	ARSMS	TEXAS-AUSTIN NO. 2	ARSMS	TEXAS-AUSTIN NO. 2	ARSMS	TEXAS-AUSTIN NO. 2
SRS 2	1.52	1.76	1.37	1.37	1.52	1.31
PRS 4	2.51	1.23	1.51	2.84	2.12	1.71
SRS 1	0.96	1.27	0.78	1.08	1.83	1.73
POOLED	1.78	1.44	1.26	1.93	1.84	1.60

TABLE B2. STANDARD DEVIATION OF SKID NUMBER - SECOND CORRELATION

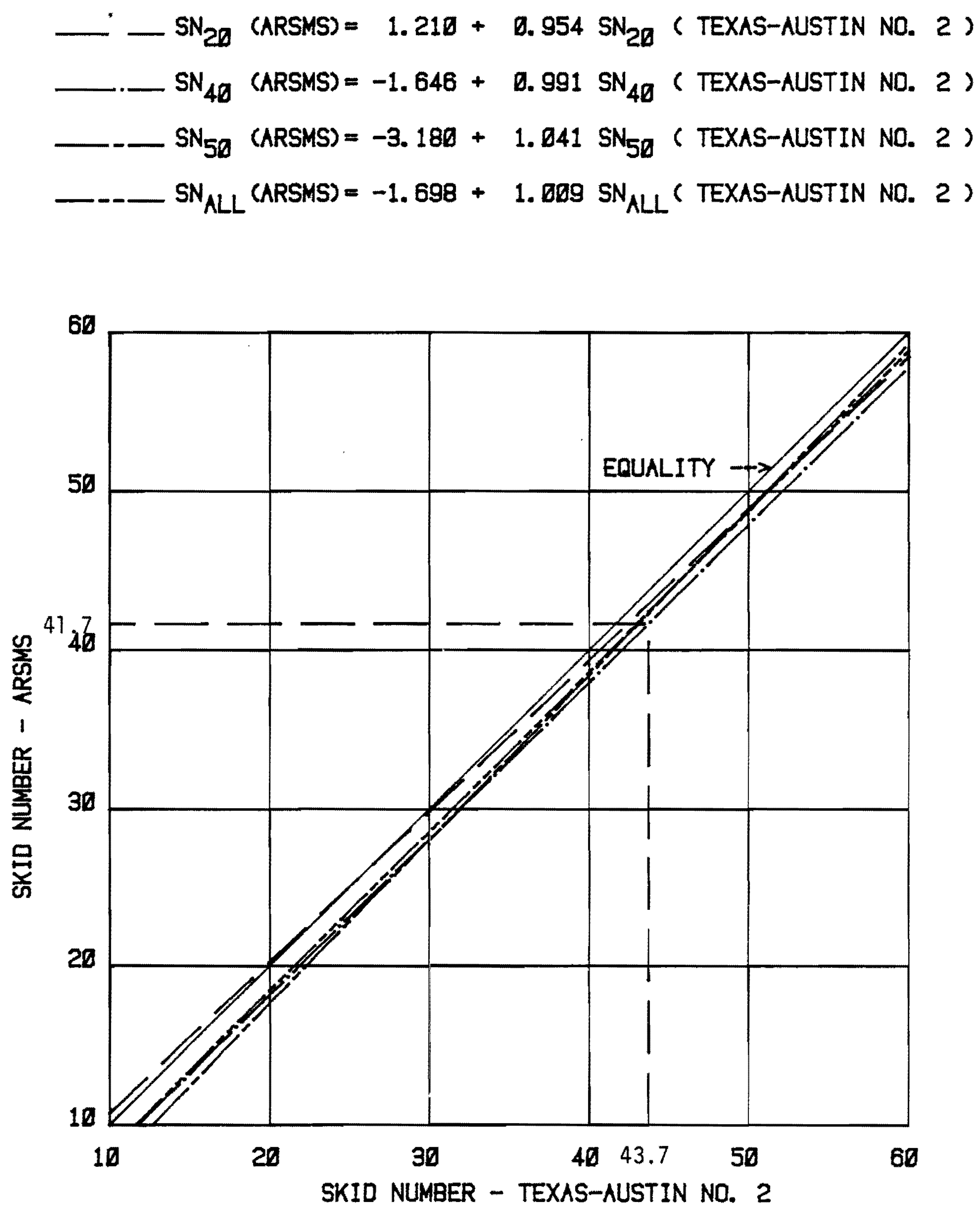


FIGURE B1. SECOND SKID NUMBER CORRELATION

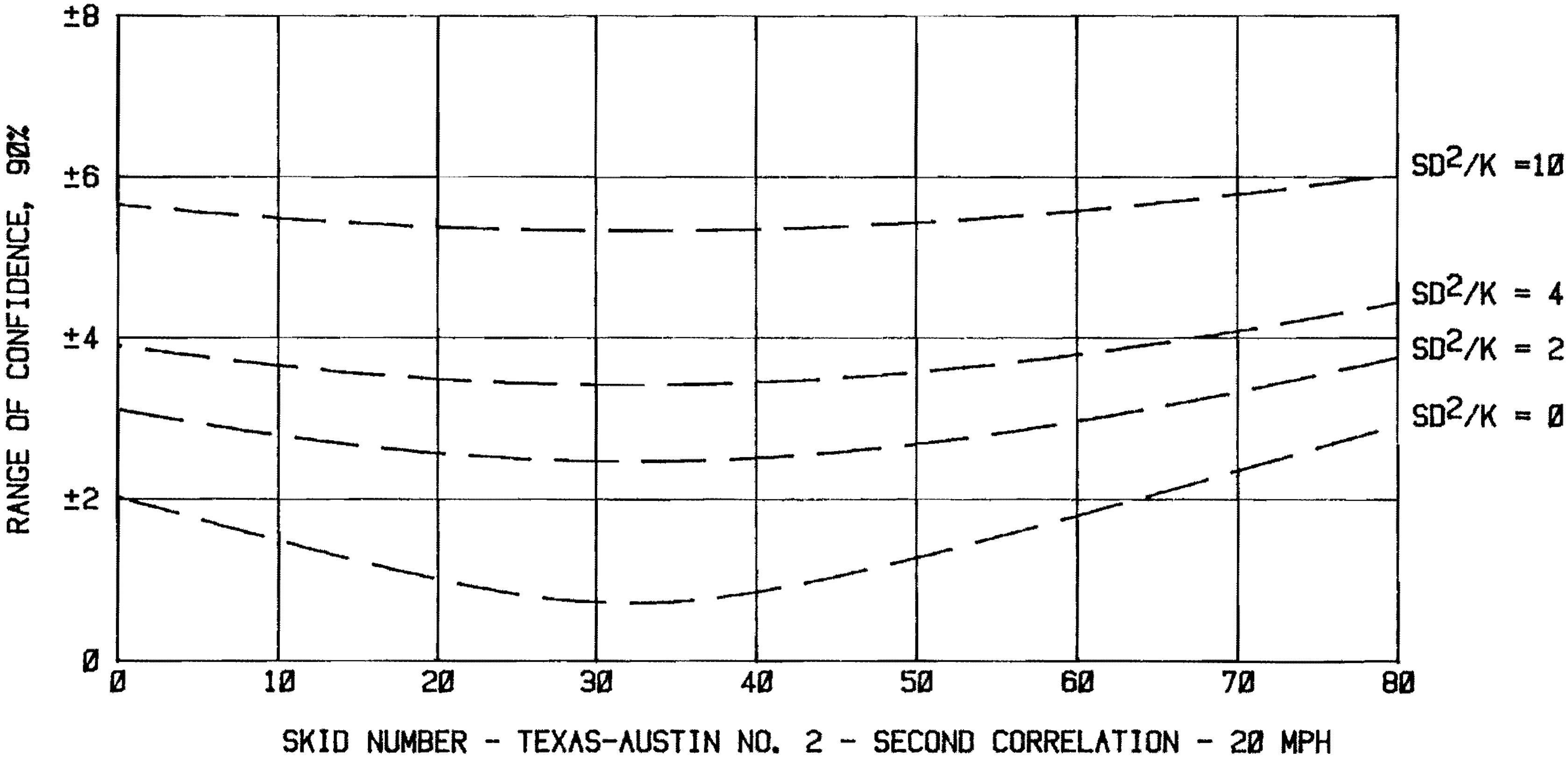


FIGURE B2. DETERMINATION OF RANGE OF THE VALUE OF AVERAGE SN WHICH WOULD HAVE BEEN DETERMINED BY ARSMS (20 MPH)

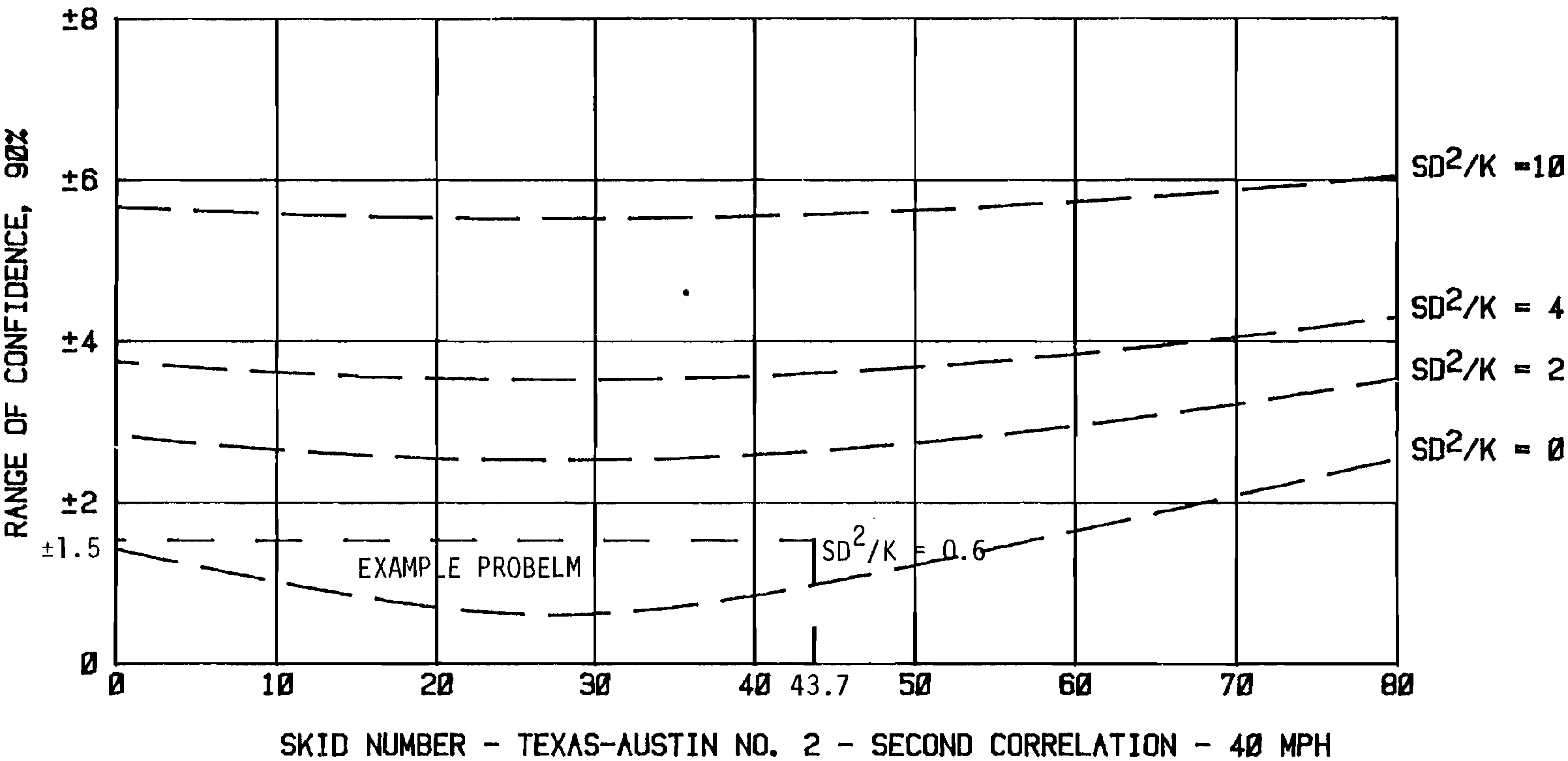


FIGURE B3. DETERMINATION OF RANGE OF THE VALUE OF AVERAGE SN WHICH WOULD HAVE BEEN DETERMINED BY ARSMS (40 MPH)

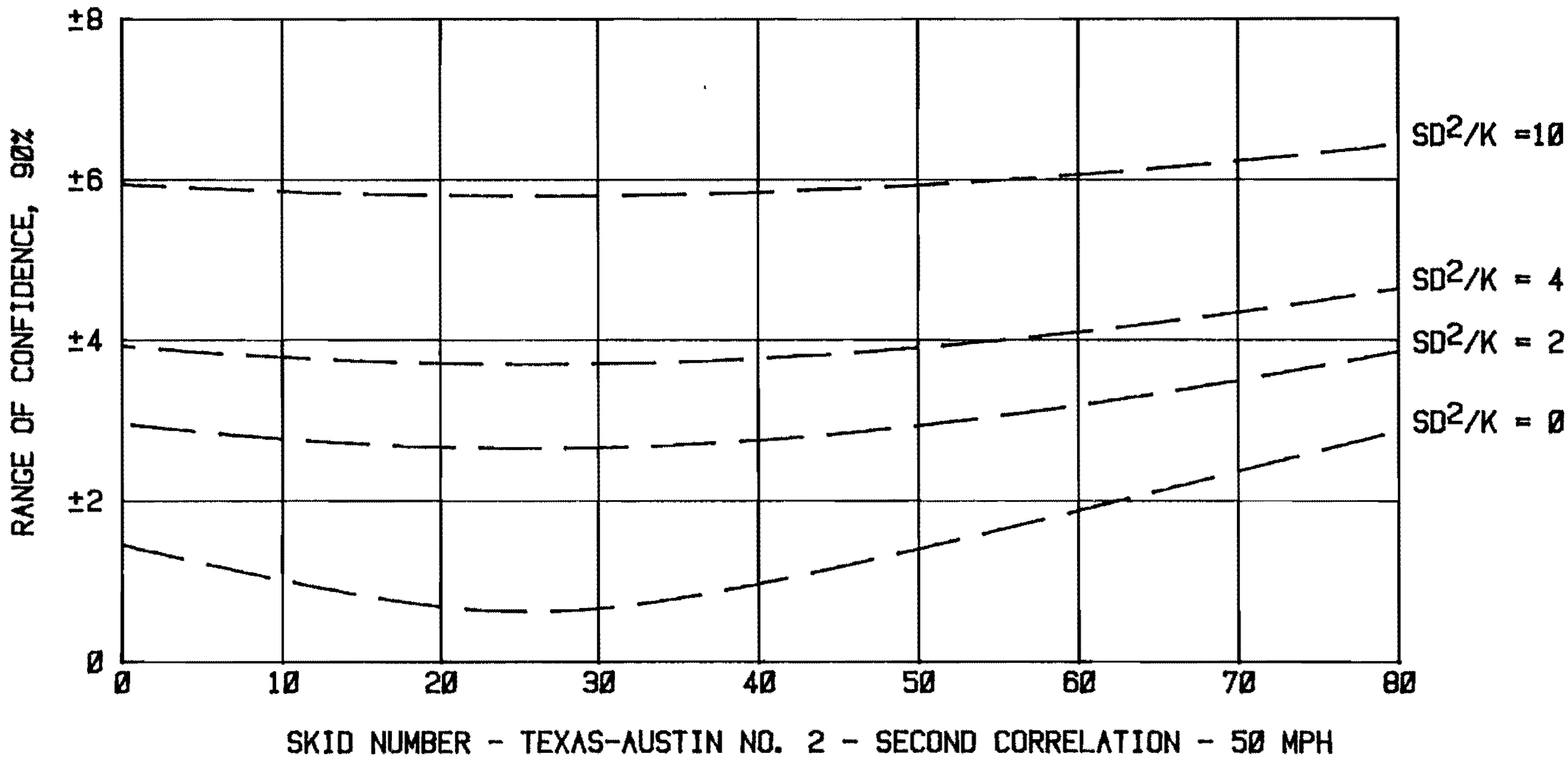


FIGURE B4. DETERMINATION OF RANGE OF THE VALUE OF AVERAGE SN WHICH WOULD HAVE BEEN DETERMINED BY ARSMS (50 MPH)

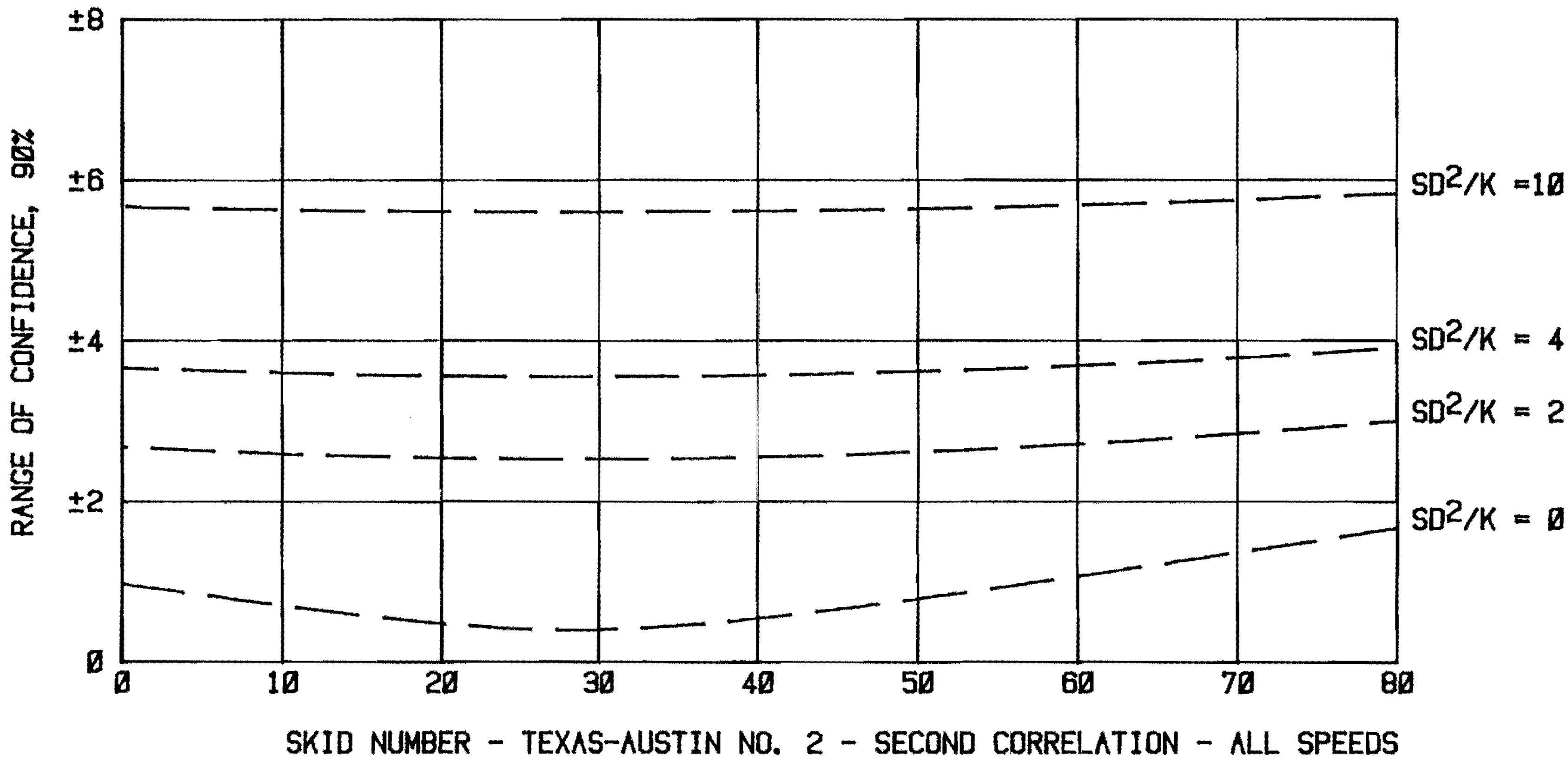


FIGURE B5. DETERMINATION OF RANGE OF THE VALUE OF AVERAGE SN WHICH WOULD HAVE BEEN DETERMINED BY ARSMS (ALL SPEEDS)

APPENDIX C

COMPARISON OF FIRST AND SECOND CORRELATIONS

COMPARISON OF FIRST AND SECOND CORRELATIONS

The average absolute difference in measured skid numbers between the two systems decreased by 0.2 SN from the first to the second correlations. There was a decrease in the difference between the two systems in 4 of the 9 speed-surface combinations.

The skid number variation of each system was approximately the same during both correlations. The ARSMS showed a decrease between the two correlations, 1.80 SN versus 1.65 SN with an overall pooled standard deviation of 1.73 SN. The Texas-Austin No. 2 system also showed a decrease in variability, 2.26 SN versus 1.67 SN with an overall pooled standard deviation of 1.99 SN.

The linear regression equations relating the measurements of the Texas-Austin No. 2 system to those of the ARSMS are graphed by speed in Figures C1 through C4.

1984 AS ARRIVED

SN_{20} (ARSMS) = −0.767 + 0.940 SN_{20} (TEXAS-AUSTIN NO. 2)

1984 DEPARTING

SN_{20} (ARSMS) = 1.210 + 0.954 SN_{20} (TEXAS-AUSTIN NO. 2)

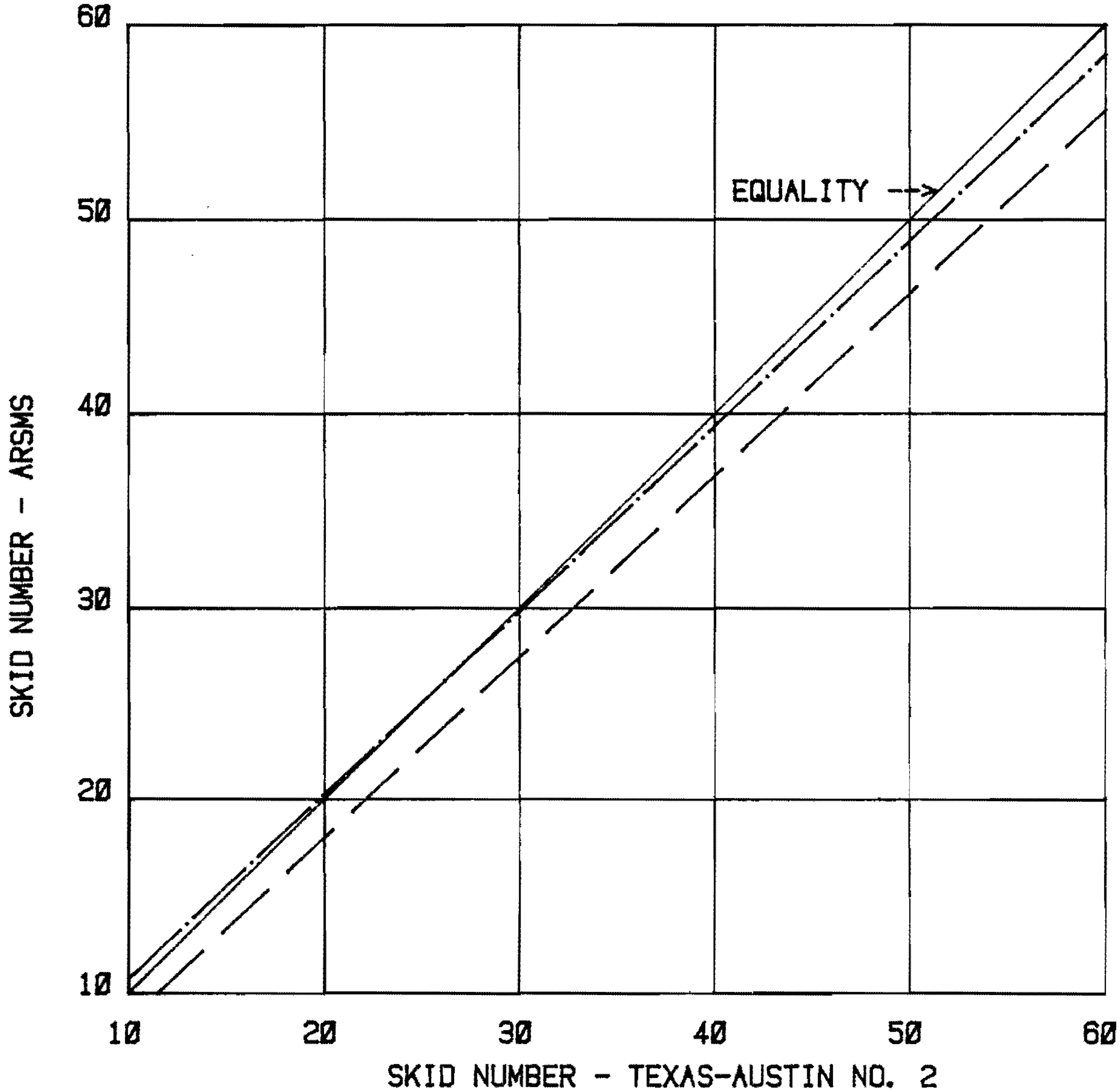


FIGURE C1. COMPARISON OF 1984 AS ARRIVED AND DEPARTING REGRESSION EQUATIONS AT 20 MPH

1984 AS ARRIVED

— — SN_{40} (ARSMS) = −3.777 + 1.080 SN_{40} (TEXAS-AUSTIN NO. 2)

1984 DEPARTING

—.— SN_{40} (ARSMS) = −1.646 + 0.991 SN_{40} (TEXAS-AUSTIN NO. 2)

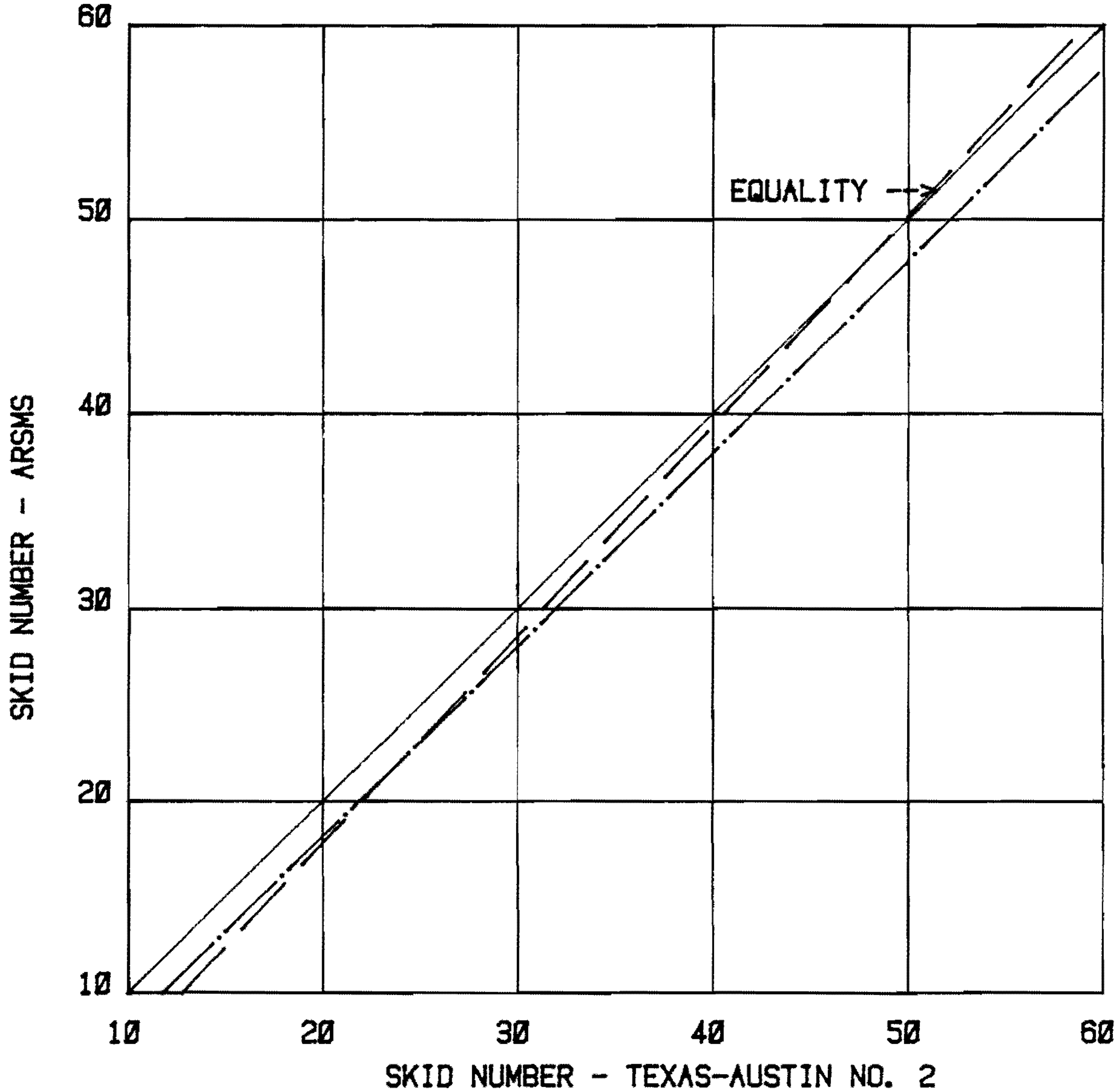


FIGURE C2. COMPARISON OF 1984 AS ARRIVED AND DEPARTING REGRESSION EQUATIONS AT 40 MPH

1984 AS ARRIVED

— — SN_{50} (ARSMS) = −1.625 + 1.057 SN_{50} (TEXAS-AUSTIN NO. 2)

1984 DEPARTING

—·— SN_{50} (ARSMS) = −3.180 + 1.041 SN_{50} (TEXAS-AUSTIN NO. 2)

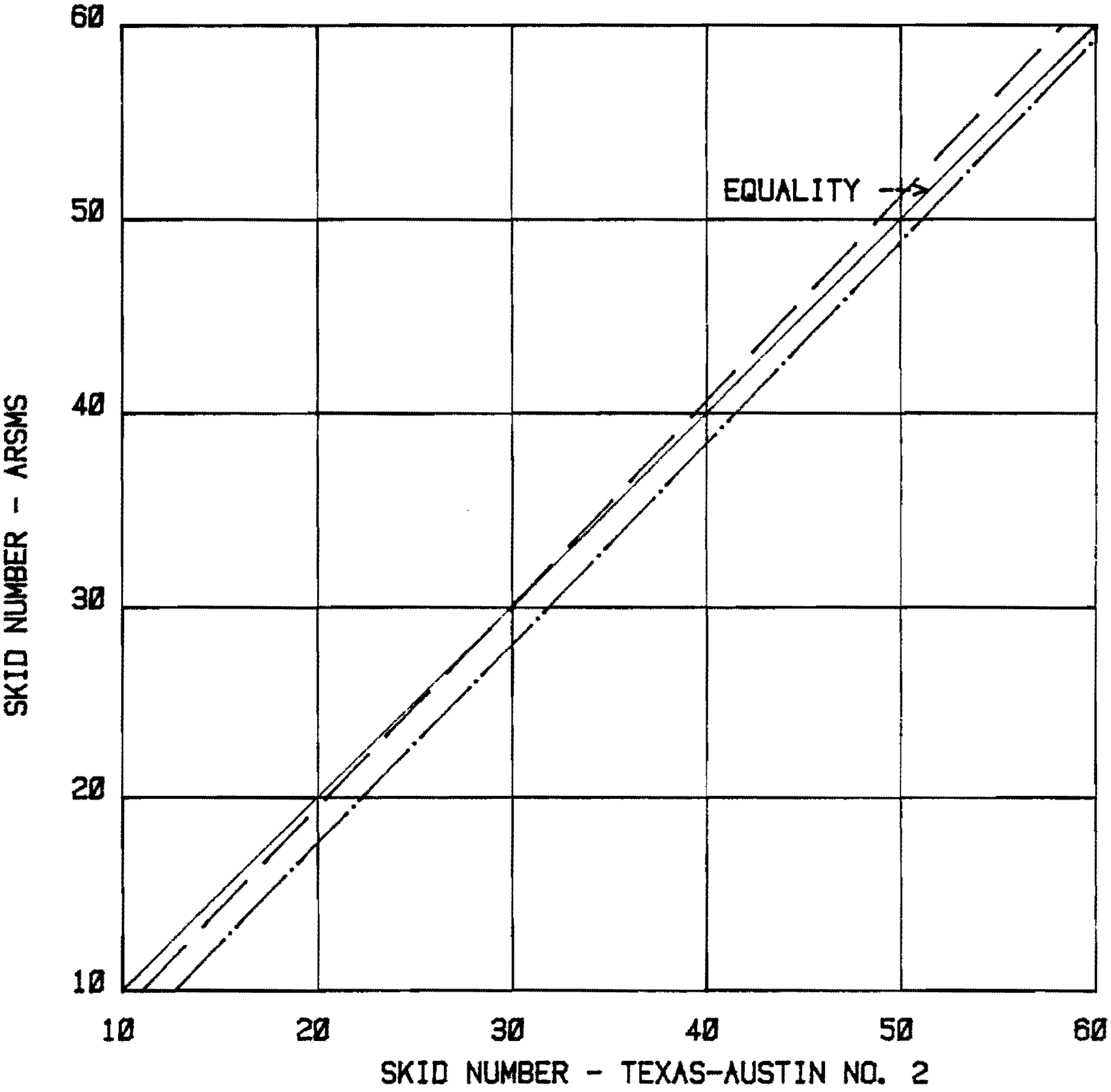


FIGURE C3. COMPARISON OF 1984 AS ARRIVED AND DEPARTING REGRESSION EQUATIONS AT 50 MPH

1984 AS ARRIVED

—— —— SN_{ALL} (ARSMS) = −1.321 + 0.992 SN_{ALL} (TEXAS-AUSTIN NO. 2)

1984 DEPARTING

——·—— SN_{ALL} (ARSMS) = −1.698 + 1.009 SN_{ALL} (TEXAS-AUSTIN NO. 2)

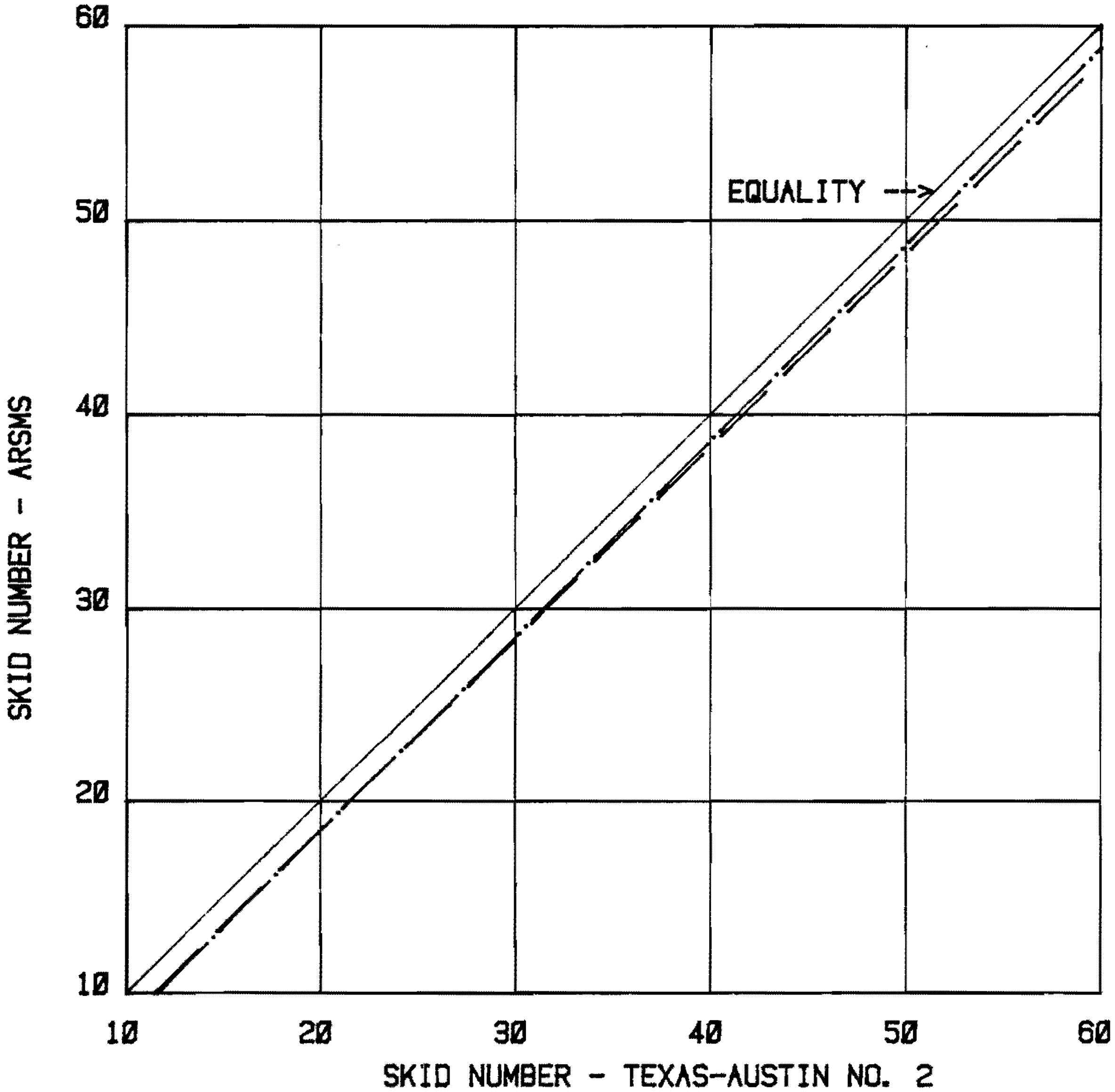


FIGURE C4. COMPARISON OF 1984 AS ARRIVED AND DEPARTING REGRESSION EQUATIONS AT ALL SPEEDS

APPENDIX D

PROCEDURE FOR ESTIMATING SYSTEM VARIABILITY

AND

STATISTICAL INTERPRETATION OF SYSTEM VARIABILITY

PROCEDURE FOR ESTIMATING SYSTEM VARIABILITY

In order to estimate the variability of a skid measurement system defined as Situation I, Figure D2, it is necessary to run a number of skid tests on the same spot or strip of pavement. The operator should make every effort to maintain the same lateral position on the pavement and the same initial starting point of the skid. A suitable pavement section should be selected based on uniformity of skid resistance in both lateral and longitudinal directions. The pavement should have a SN value between 30 and 50. One or more passes should be made to wet the pavement without locking the test tire. At least 20 duplicate tests should be conducted each time the variability of the system is determined. The time between tests should be minimized so that all tests are made under approximately the same environmental conditions. A stoppage of 5 minutes or more will cause this test to be invalid. Experience has shown that twenty tests can be performed in approximately one hour. The same tire should be used on all tests and all tests should be run in the same direction.

The procedure for determining if significant changes in the variability of the skid measurement system occurred is as follows:

(1) Plot the 20 skid numbers versus run number. Construct a straight line through the calculated average (x) of the data points. Determine the deviation of each point from the average.

Variability is computed by the following expression:

$$SD^2 = \frac{\Sigma(d_i^2)}{N - 1}$$

Where: The $\Sigma(d_i)$ should equal 0, within roundoff error.

SD^2 = Variance

d_i = Algebraic value of vertical deviation from the average.

N = Total number of tests.

(2) Investigate possible changes in the variability of the system at a later date by conducting the same number of tests on the same spot on the pavement and comparing the new variability with that previously established. The variability for the second set of tests is computed as shown in step (1). Significant changes in the two values of variance can be established by comparing the ratio of the larger to the smaller with values for this ratio given in Figure D1. If the computed ratio of the variance exceeds that given in Figure D1, it can be concluded that significant changes in the variability of the system have occurred. If the number of tests used to determine the two values of variance are not the same, then Figure D1 is not valid. However, comparison can be made using the appropriate values from the statistical table of F values.

The procedure is illustrated by the following:

Assume twenty tests, on the left wheel, were conducted in this manner by the Texas-Austin No. 2 system. The variance, SD^2, for the system is found to be 1.35 for the left wheel. At a later date, it is desired to check the variability of the system to determine if it has changed significantly. Assume twenty tests are again conducted on the same place on the selected pavement on the left wheel. The new variability computed for the left wheel is 2.27. The ratio of these two variabilities computed for the left wheel is:

$$\frac{SD^2_{max}}{SD^2_{min}} = \frac{2.27}{1.35} = 1.68$$

The value from Figure D1 for 20 tests is 2.15. The computed value of 1.68 for the left wheel from the test data is less than the value given in Figure D1. Therefore, it can be concluded that no significant changes in the variability of the system have occurred.

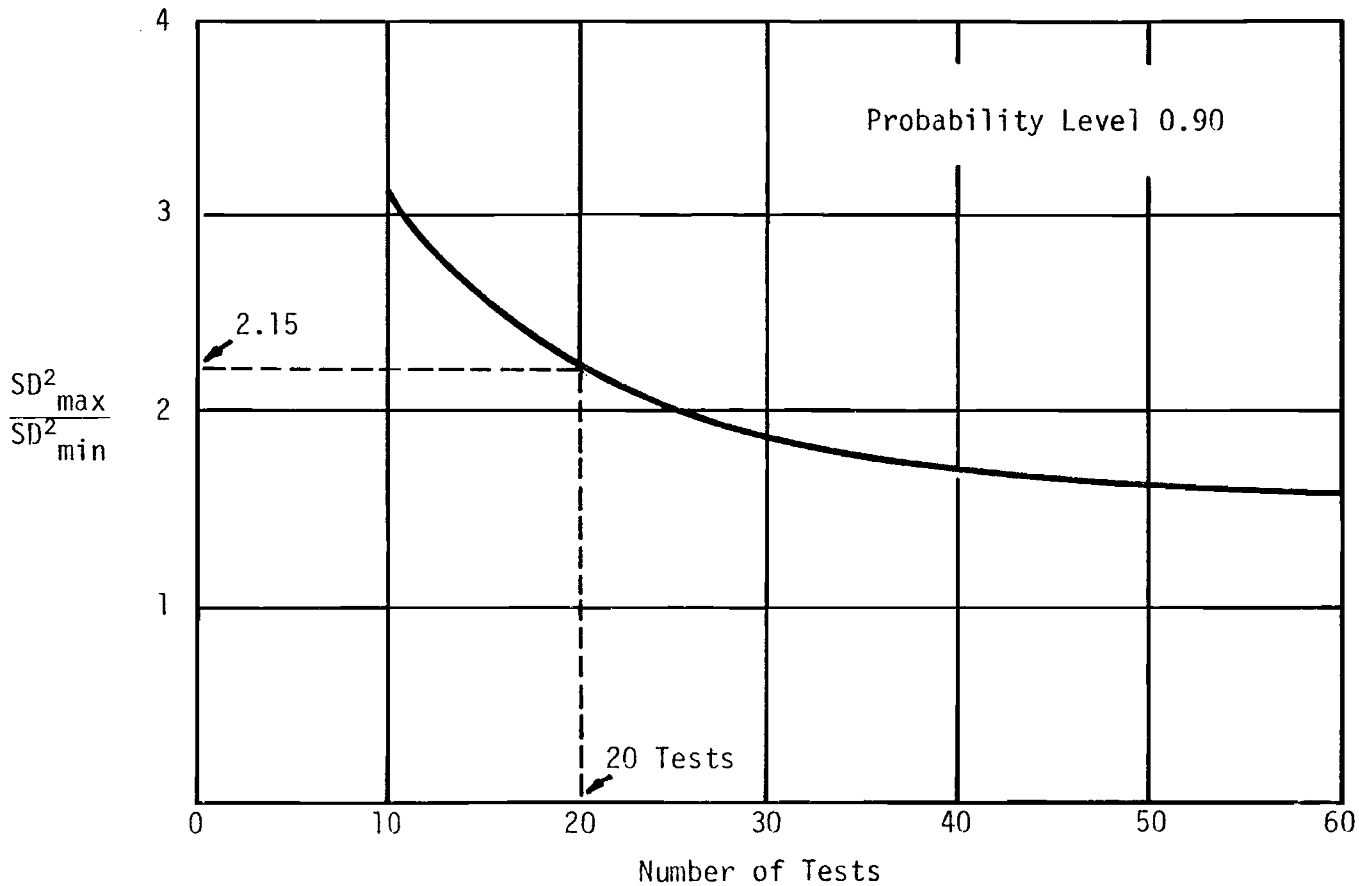


FIGURE D1. DETERMINATION OF CHANGES IN SYSTEM VARIABILITY

STATISTICAL INTERPRETATION OF SYSTEM VARIABILITY

Variability, expressed in terms of standard deviation, must be considered in the interpretation of SN values obtained using any skid number measurement system. Three methods of illustrating the significance of SN variability are shown in Figure D2.

The standard deviation values reported in Table B2 of the previous section include the combined variation effects of the correlation pavement, operator and the skid number measuring system. This condition is defined as Situation II in Figure D2.

Another common method of defining SN variability is illustrated as Situation I in Figure D2. In this case, SN values are obtained on a single strip of pavement. Under perfect test control conditions, the variability of the pavement would approach zero and a good estimate of the skid measurement system variability could be achieved. However, under actual test conditions, a portion of the SN variability will be due to the pavement, as shown in Figure D2, largely caused by: (1) variations in the starting point and lateral displacement of the locked wheel; (2) pavement polishing; (3) variations in water distribution due to changes in wind speed and direction, and changes in the speed of the pumping unit; and (4) the practical necessity of making a number of determinations over a reasonable time period which requires that tests be repeated before the pavement can return to the dry condition. In conclusion, a valid test of the entire skid number measurement is not accomplished under the conditions of Situation I.

As illustrated in Figure D2, Situation III is typical of field surveys in which the total SN variability is unknown until a number of tests have been made and the data analyzed. In general, highways will have a SN variability both

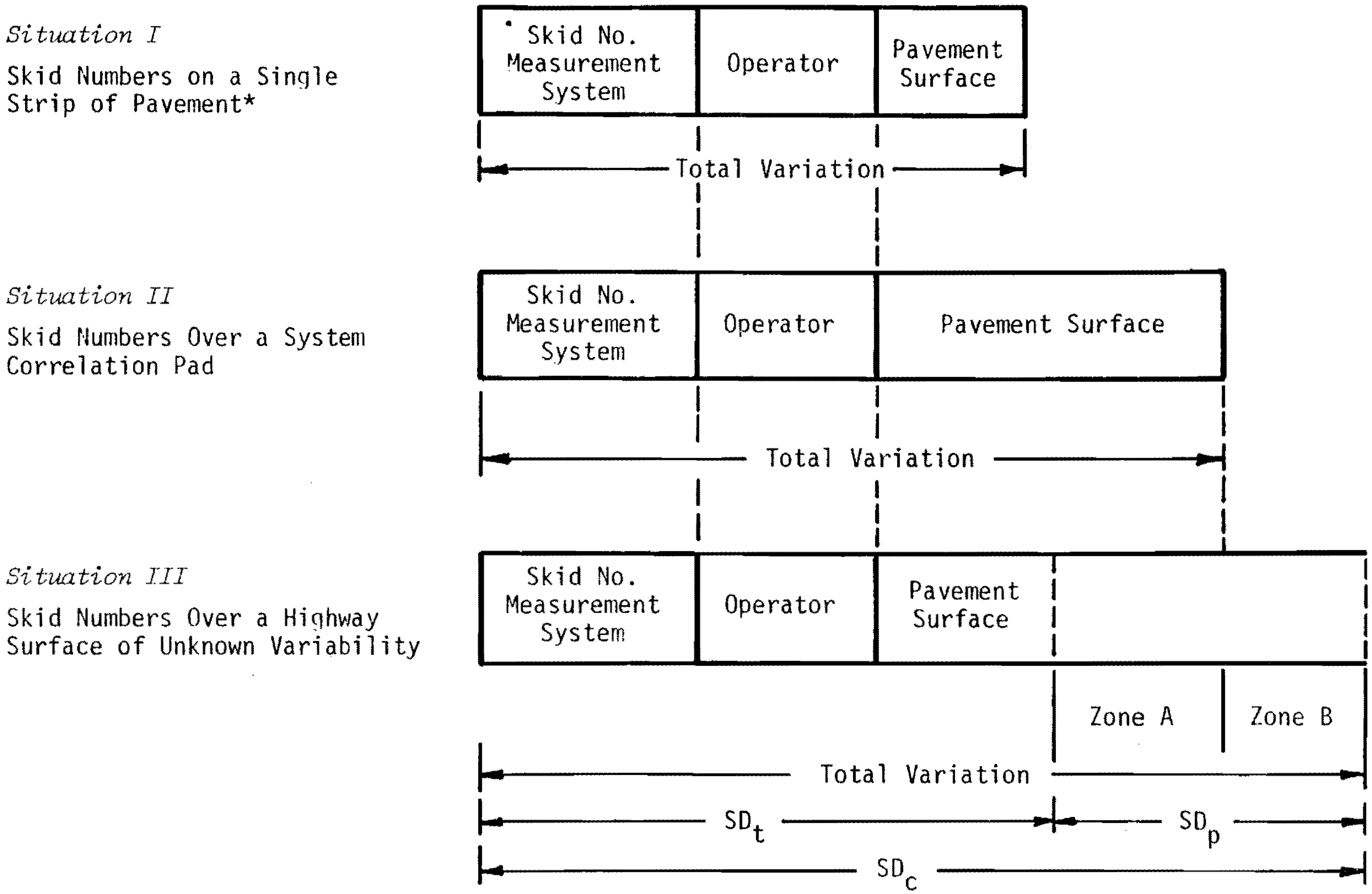


FIGURE D2. SOURCE OF VARIABILITY

* Even with a maximum effort toward repeating a number of skids on the same strip of pavement, there will be some pavement variation due to variations in the starting point and lateral placement.

above and below that of Situation II; and in most cases the variability will be above that of Situation I.

The SN variability obtained under the test condition of Situation I or Situation II can be used to determine the appropriate number of skid tests required to evaluate an actual highway pavement surface. Figure D3 illustrates a graphical relationship available for this purpose. Because of the previously listed influences on variability in Situation I, the SN standard deviation (SD) from Situation II is more useful when using the curves in Figure D3.

Another alternative, which neglects the possibility of variations due to water distribution and other elements discussed above, is the use of a value of SD determined by data taken under Situation I with an approximation of the influence of the pavement SD. An estimate of the composite SD variability corresponding to Situation III is calculated using the following relationship presented by Gillespie.*

$$(SD_c)^2 = (SD_t)^2 + (SD_p)^2$$

Where: SD_t = Standard Deviation of the SN Test System (Corresponding to Situation I)

SD_p = Standard Deviation of the pavement

SD_c = Composite Standard Deviation (Corresponding to Situation III)

Data from NCHRP Report 151 shows that the values of SD_t and SD_p are of the same order of magnitude, and on some of the more uniform highways may be

*Gillespie, T. D., Meyer, W. E., and Hegmon, R. R., "Skid Resistance Testing from a Statistical Viewpoint." Highway Research Record No. 471, presented at the 52nd Annual Meeting of the Highway Research Board, Washington, D. C., January, 1973.

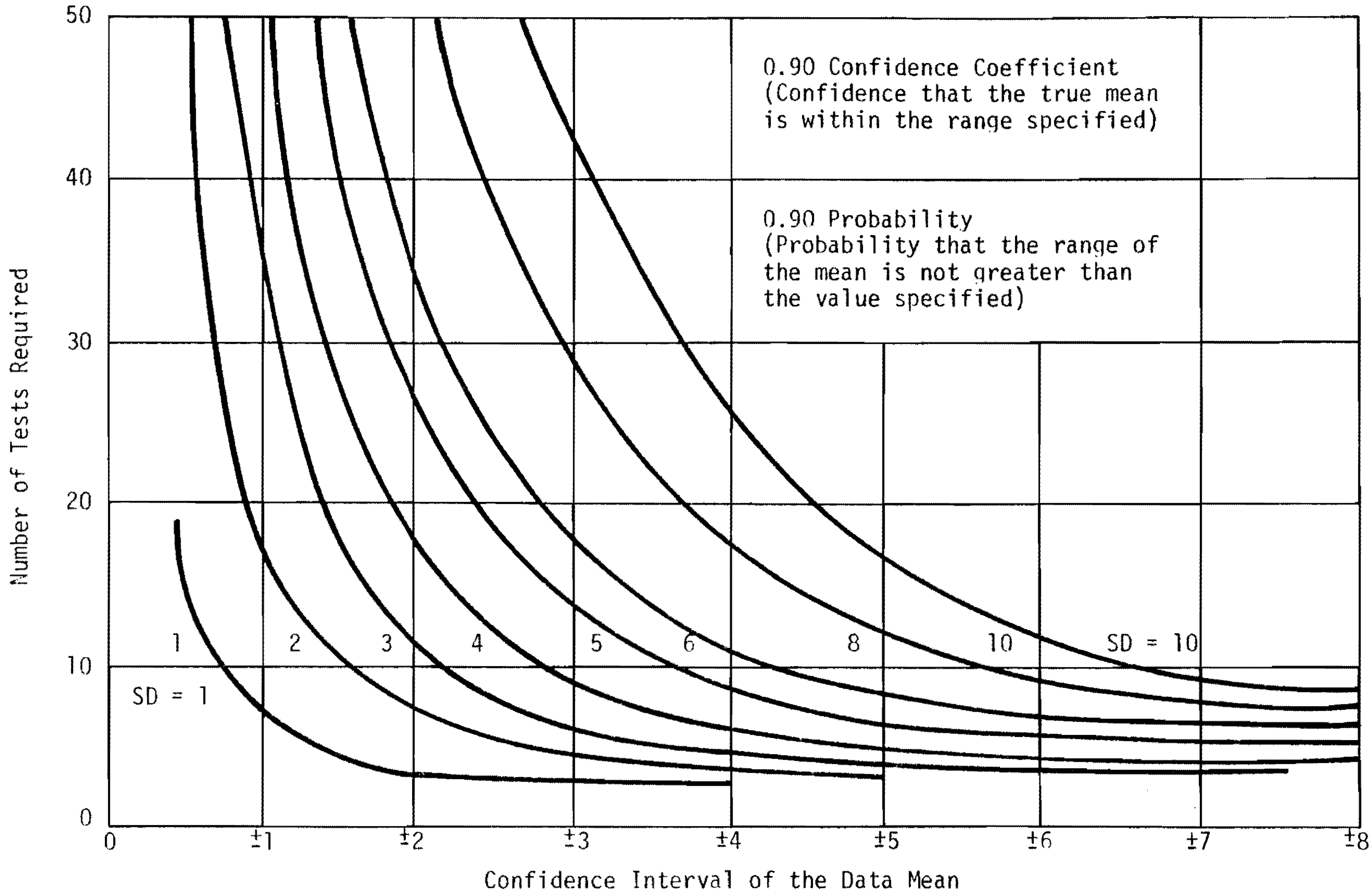


FIGURE D3. RELATIONSHIP BETWEEN THE NUMBER OF SKID TESTS REQUIRED AND THE STANDARD DEVIATION OF THE SKID TEST SYSTEM AND PAVEMENT (after Gillespie, et al) approximately equal. In any case, an estimate of variability is required before a testing program can be planned.

An example is presented to illustrate the use of Figure D3 to determine the number of test required based on an estimate of the SN variability.

> Consider the hypothetical problem of determining the average value of SN on one lane for a one mile section of highway. In order to determine the number of tests that will be necessary, the variability of the combined tester-operator-highway system is required in conjunction with the accuracy of the mean SN value.
>
> The skid number must be determined within ±3. Assume that the SN variability of the highway pavement is approximately the same as the variability of the reference surfaces defined as Situation II in Figure D2.
>
> From Table B2, a value of 1.93 is obtained for pooled standard deviation at 40 mph. Projecting from the ±3 SN range on the abscissa to the SD = 1.93 curve, a value of approximately four required tests can be read from the ordinate of Figure D3.

In order to interpret the values of the mean SN for a section of highway pavement, the use of Figures B1 through B5 is recommended. Figure B1 is a graphical representation of the equations which were statistically derived relating the Texas-Austin No. 2 system and the ARSMS. Figures B2 through B5 give the range of 90 percent confidence limits. These limits provide an estimate of the upper and lower boundaries of the mean SN which would have been determined by ARSMS in performing the same number of tests. The confidence limit boundaries are based on the ratio of variance, SD^2, to the number of skid tests performed, K. An example is presented to illustrate the use of the 90 percent confidence limit graphs.

> On a section of highway, assume ten 40 mph tests were made using the Texas-Austin No. 2 system. The SN values were 41, 42, 41, 45, 42, 48, 47, 45, 42 and 44. The average of these values is 43.7. Using the following equation, the variance is computed to be $SD^2 = 6.23$.

$$SD^2 = \frac{\Sigma(SN_i)^2 - (\Sigma SN_i)^2}{K - 1}$$

Where: SD^2 = Variance

K = Number of Tests

SN_i = Individual Skid Numbers, i = 1 to K

The appropriate equation from Figure B1, can be used to solve for the ARSMS value of SN when the state system SN is 43.7. In this case, the ARSMS skid number is 41.7.

Entering Figure B3 at a point on the abscissa of 43.7, project vertically to the intersection with the 40 mph correlation line. Projecting a line from this point horizontally to the ordinate yields the estimate of the SN for ARSMS of 41.7. This can be used to check the regression equation calculation.

Now entering Figure B3 at the abscissa point of 43.7 and projecting vertically to the position of the $SD^2/K = 0.6$ curve ($SD^2 = 6.23$, $K = 10$), one finds that the range of confidence limits is equal to ±1.5. Thus, the confidence limits of the mean SN lie between 41.7 - 1.5 and 41.7 + 1.5.

The interpretation is as follows: One is now 90 percent confident that the value of the SN mean determined by ARSMS in performing the same number of tests on the same section of highway would lie between 40.2 and 43.2. The best estimate of the SN value is 41.7.

APPENDIX E

WATER DATA

WATER FLOW MEASUREMENT TEXAS-AUSTIN NO. 2						
EQUIVALENT SPEED (MPH)	TOTAL QUANTITY (GAL)	TIME (SEC)	FLOW RATE (GPM)	AVERAGE FLOW RATE (GPM)	TRACE WIDTH (INCH)	GALLONS PER WETTED INCH
20	16.1	60	16.1	15.8	7	2.3
20	15.5	60	15.5			
40	27.0	60	27.0	27.1	7	3.9
40	27.1	60	27.1			
50	20.9	40	31.4	31.4	7	4.5
50	20.9	40	31.4			

TABLE E1

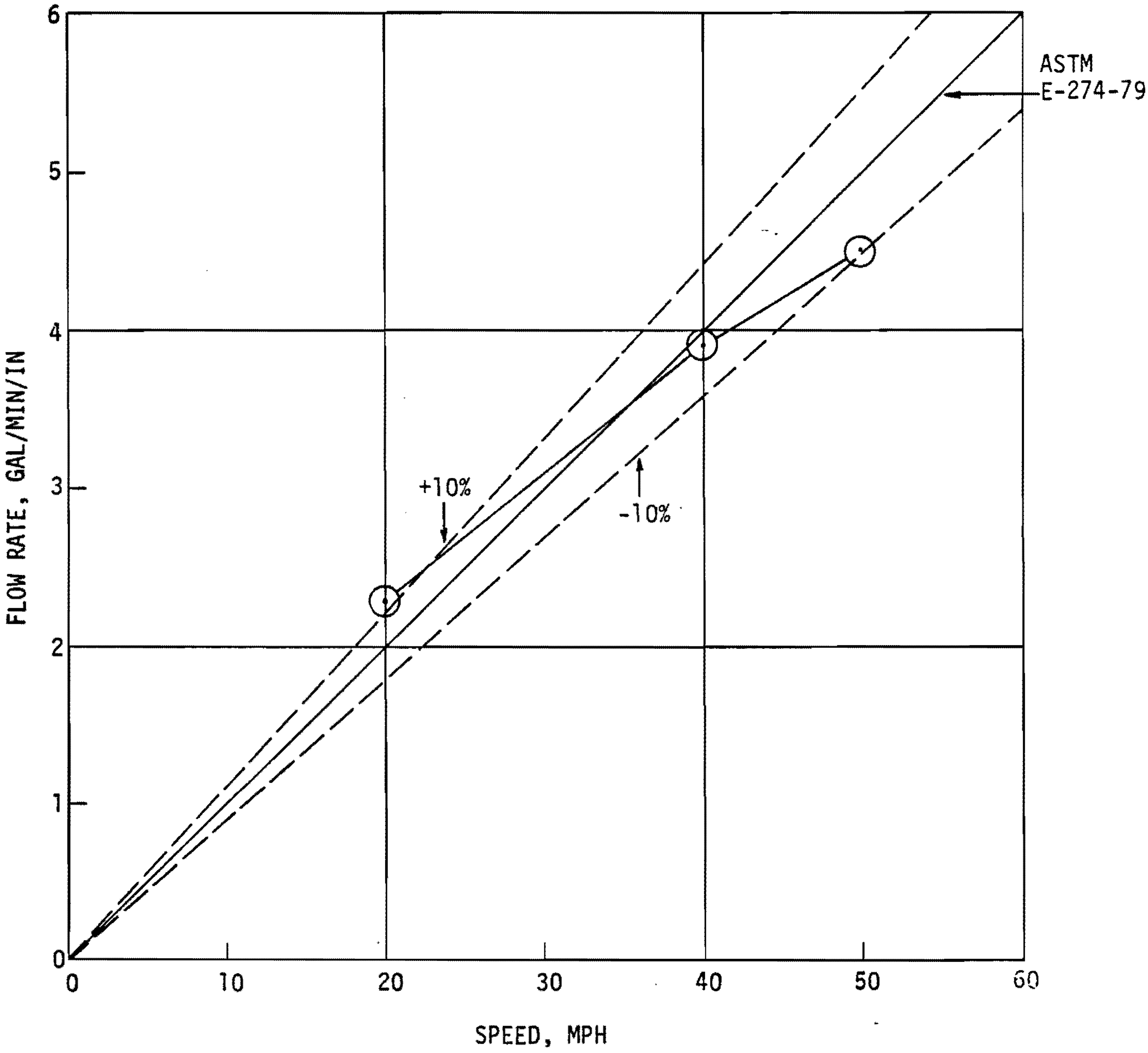


FIGURE E1. FLOW RATE PER UNIT WIDTH - TEXAS-AUSTIN NO. 2

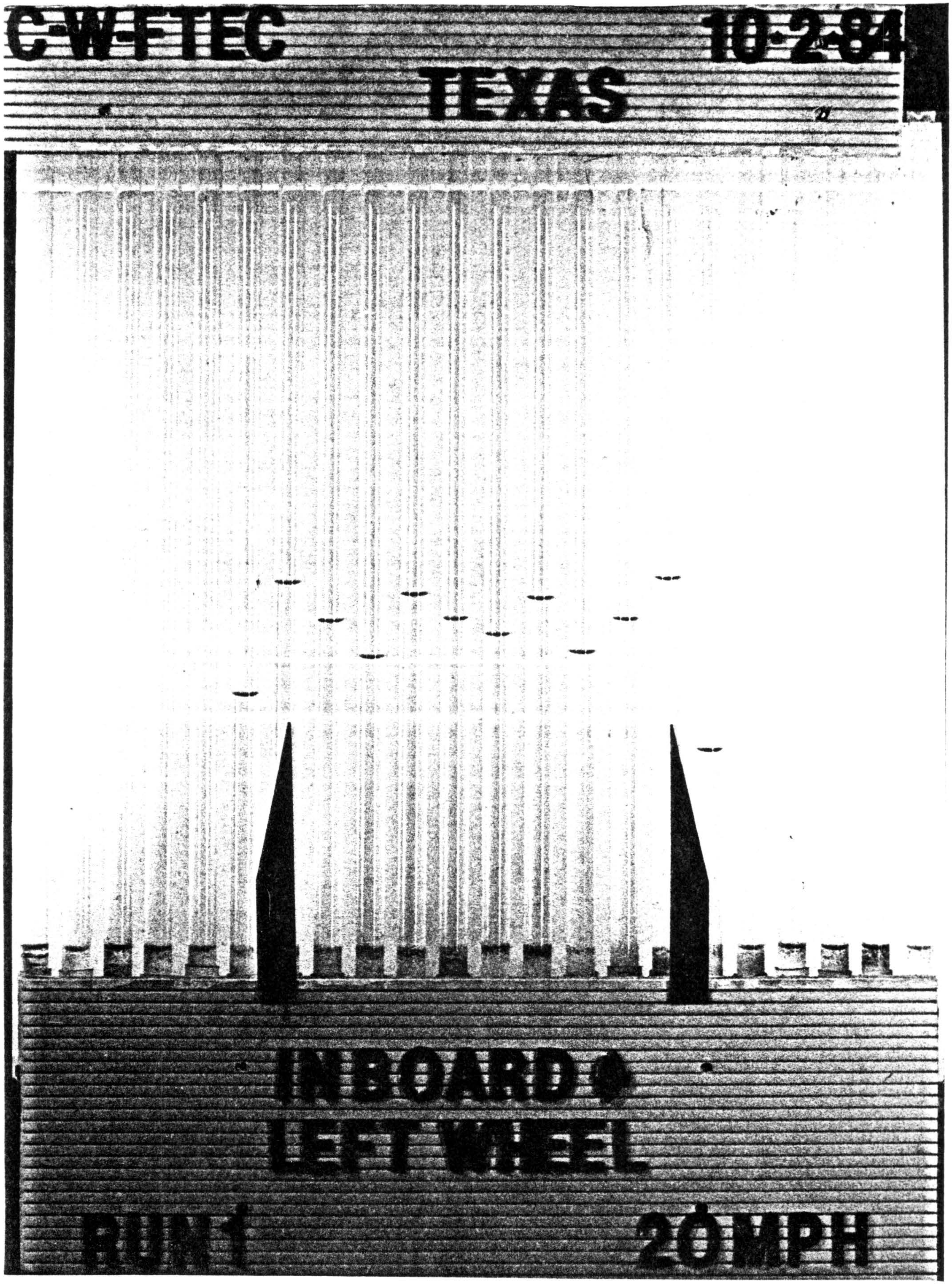


FIGURE E2. TYPICAL RESULTS OF STATIC DISTRIBUTION GAGE
TEXAS-AUSTIN NO. 2, LEFT WHEEL 20 MPH

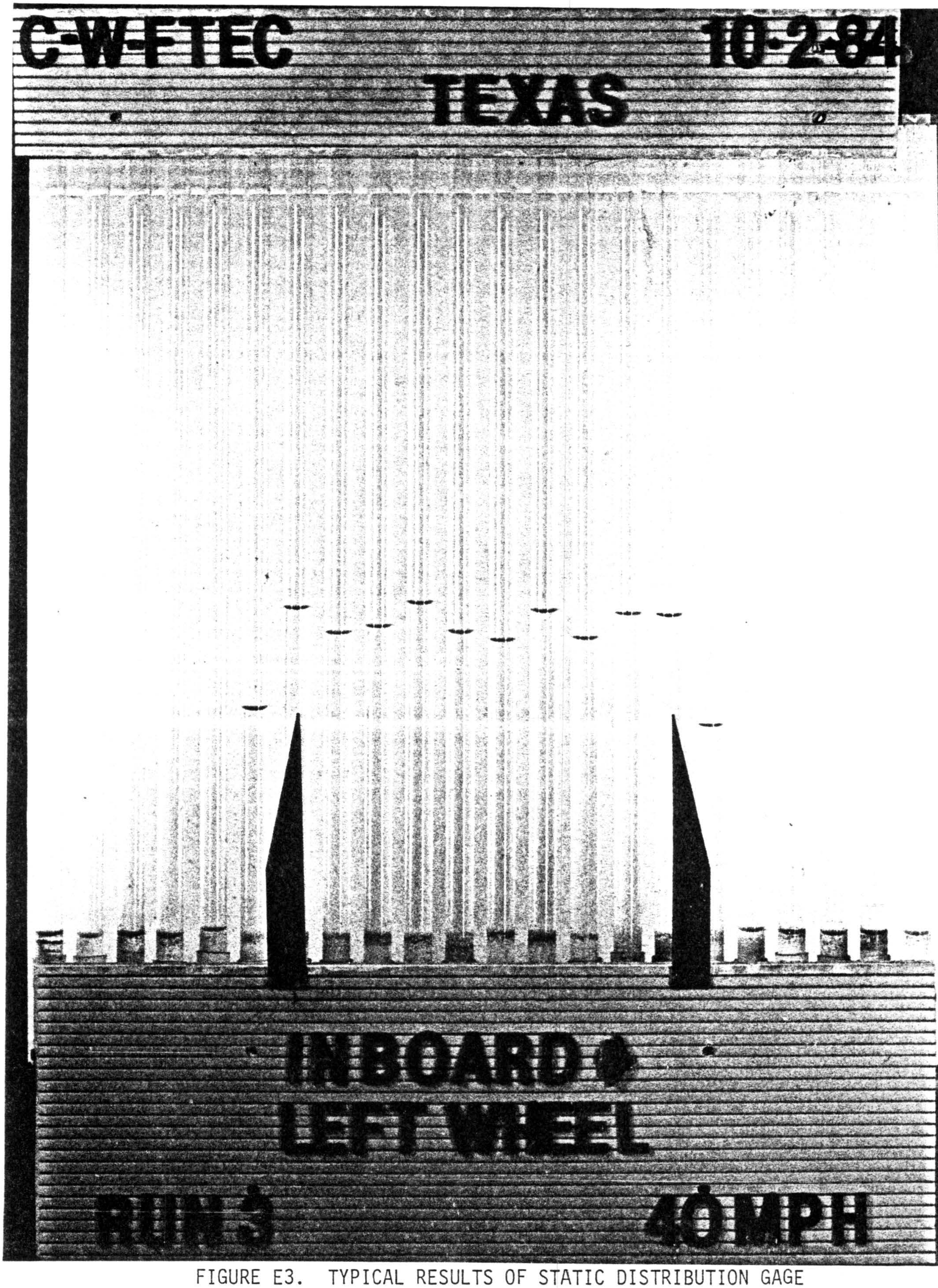


FIGURE E3. TYPICAL RESULTS OF STATIC DISTRIBUTION GAGE
TEXAS-AUSTIN NO. 2, LEFT WHEEL, 40 MPH

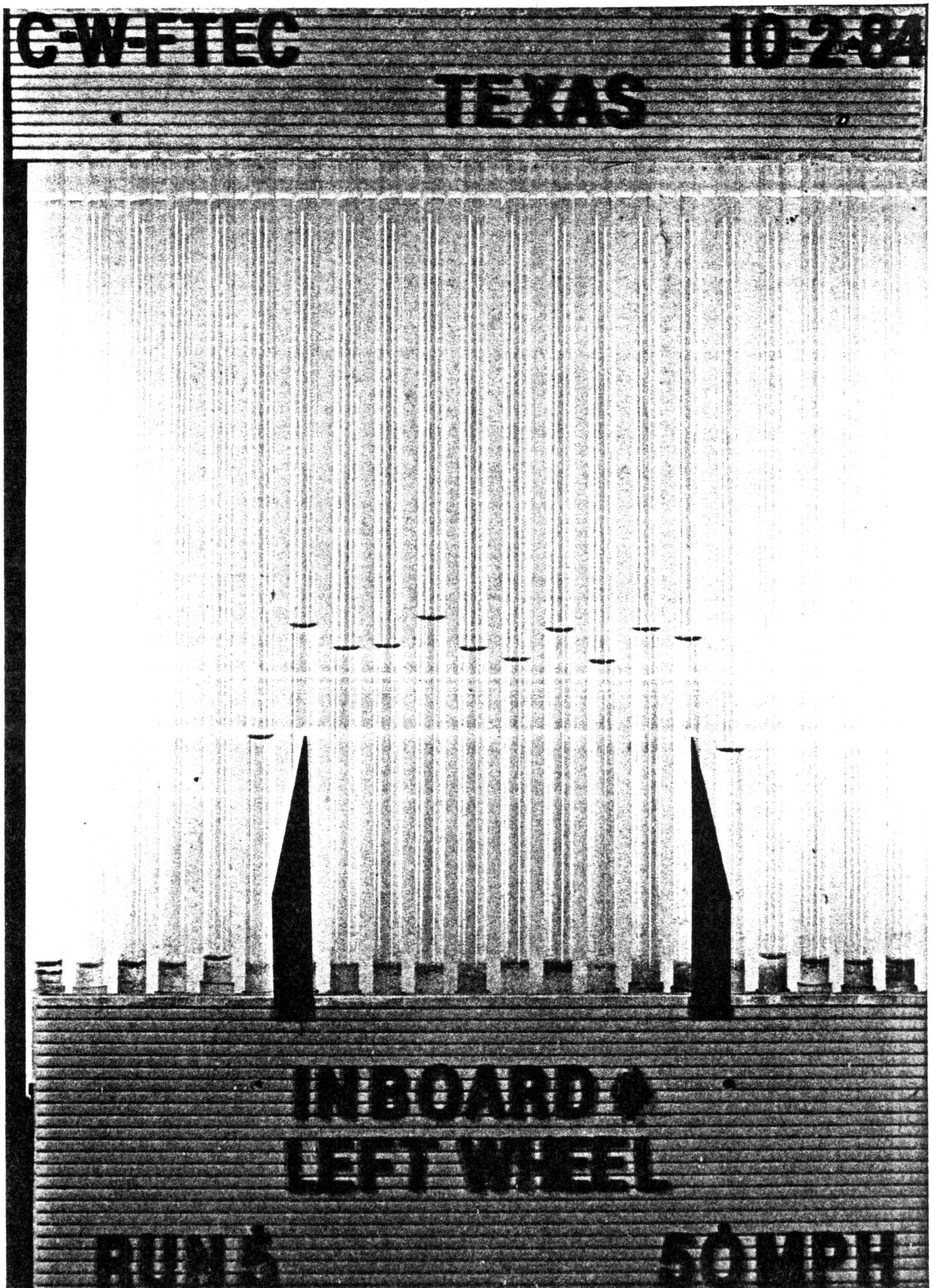


FIGURE E4. TYPICAL RESULTS OF STATIC DISTRIBUTION GAGE
TEXAS-AUSTIN NO. 2, LEFT WHEEL, 50 MPH

APPENDIX F

REPAIRS, MODIFICATIONS, CALIBRATIONS AND MEASUREMENTS

REPAIRS AND ADJUSTMENTS SINCE PREVIOUS
CALIBRATION AT C/W FT&EC
OCTOBER, 1983

Repairs to Tow Vehicle:

Brakes and rear end overhaul
Minor transmission maintenance
General maintenance

Repairs to Skid Trailer:

Replaced flow meter
Replaced speed transducer
Master reset installed for computer

Since last visit to C/W FT&EC:

Skid miles per year	6,000
Skids per year	18,000
Total miles accumulated per year	17,500
Present odometer reading	62,000

TABLE F1

TEXAS-AUSTIN NO. 2 WHEEL TRANSDUCER CALIBRATION LEFT WHEEL TRACTION RUN NO. 1				
FORCE PLATE			VEHICLE INSTRUMENTATION	
HORIZONTAL FORCE	VERTICAL FORCE	SKID NUMBER	HORIZONTAL FORCE*	SKID NUMBER
0	1095	0	0	0
100	1083	9.2	98	9
200	1071	18.7	198	17
300	1059	28.3	299	28
400	1047	38.2	399	38
500	1036	48.3	499	47
600	1024	58.6	602	58
700	1012	69.2	700	68
800	1000	80.0	800	80

*1.5 volts = 500 lbs

TABLE F2

TEXAS-AUSTIN NO. 2 WHEEL TRANSDUCER CALIBRATION LEFT WHEEL TRACTION RUN NO. 2				
FORCE PLATE			VEHICLE INSTRUMENTATION	
HORIZONTAL FORCE	VERTICAL FORCE	SKID NUMBER	HORIZONTAL FORCE*	SKID NUMBER
0	1095	0	0	0
100	1082	9.2	100	9
200	1071	18.7	200	18
300	1059	28.3	300	27
400	1047	38.2	401	38
500	1036	48.3	502	47
600	1024	58.6	604	58
700	1013	69.1	700	69
800	1001	79.9	800	80

* 1.5 volts = 500 lbs

TABLE F3

TEXAS-AUSTIN NO. 2
WHEEL TRANSDUCER CALIBRATION
LEFT WHEEL TRACTION

RUN NO. 3

FORCE PLATE			VEHICLE INSTRUMENTATION	
HORIZONTAL FORCE	VERTICAL FORCE	SKID NUMBER	HORIZONTAL FORCE*	SKID NUMBER
0	1095	0	0	0
100	1083	9.2	96	9
200	1071	18.7	196	17
300	1059	28.3	297	28
400	1047	38.2	398	38
500	1036	48.3	499	47
600	1024	58.6	601	58
700	1012	69.2	697	69
800	1000	80.0	797	79

* 1.5 volts = 500 lbs

TABLE F4

F_H (C/W FTC)	TEXAS-AUSTIN NO. 2	(LBS)	Plate: Law 1275M210-018 Indicator: Texas-Austin	
(LBS)	RUN 1	RUN 2	RUN 3	AVERAGE
0*	0	0	0	0
100	100	100	100	100
200	200	200	200	200
300	299	299	299	299
400	400	399	399	399
500	500	500	500	500
600	599	599	599	599
700	700	699	700	700
800	800	799	799	799

*0 = Slightly preloaded (nulled to zero)
NBS CALIBRATED LOAD CELL
BLH TSP2B - SN 77198 SIDE A

STATED CAL = 500
ACTUAL CAL = 500
FINAL CAL = 500

TABLE F5. FORCE PLATE CALIBRATION-HORIZONTAL

F_V (C/W FT&EC) (LBS)	TEXAS-AUSTIN NO. 2		Plate: Law 1275M210-018 Indicator: Texas-Austin	
(LBS)	RUN 1	RUN 2	RUN 3	AVERAGE
0*	0	0	0	0
200	200	200	199	200
400	400	399	399	399
600	600	599	599	599
700	700	699	699	699
800	800	800	799	800
900	900	900	899	900
1000	1000	1000	1000	1000
1100	1100	1100	1099	1100
1200	1200	1200	1200	1200
1400	1400	1399	1399	1399
1600	1600	1600	1600	1600

*0 = Slightly preload (nulled)
NBS CALIBRATED LOAD CELL
BLH TSP2B = SN 85420 SIDE B

STATED CAL = 700
ACTUAL CAL = 703
FINAL CAL = 700

TABLE F6. FORCE PLATE CALIBRATION-VERTICAL

SPEED CALIBRATION DATA	
TEXAS-AUSTIN NO. 2 SPEED INDICATOR (MPH)	C/W FT&EC READING (MPH)
19	20.0
37	40.0
46	50.0
Average of five runs	

TABLE F7

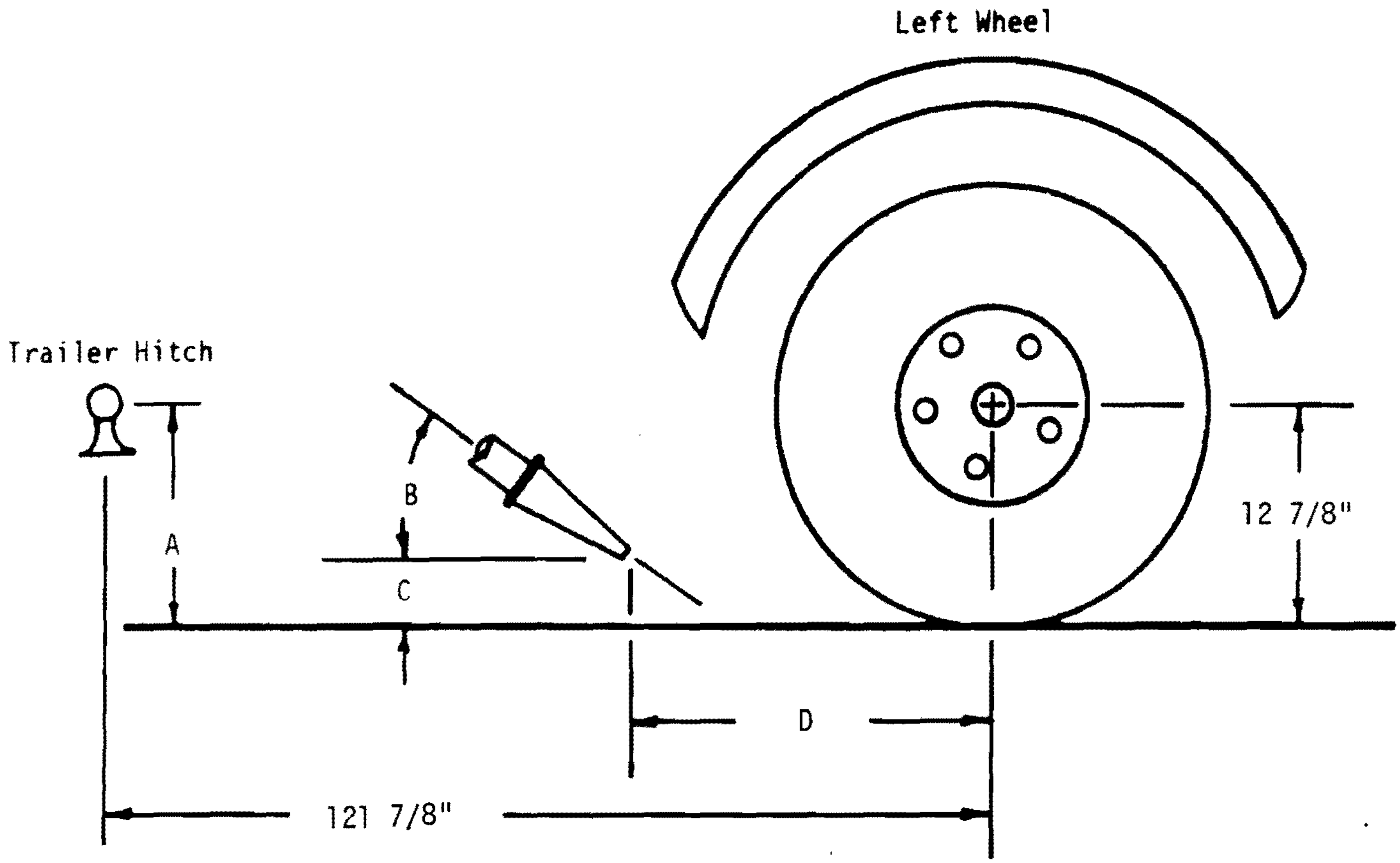
TIRE PRESSURE GAGE CALIBRATION	
REFERENCE GAGE READING (PSI)	TEXAS-AUSTIN NO. 2 GAGE READING (PSI)
10.0	10
20.0	20
22.0	22
24.0	24
26.0	26
28.0	28
30.0	30
Average of 3 runs, gage type - DILL	

TABLE F8

PARAMETERS MEASURED ON
TEXAS-AUSTIN NO. 2 SKID MEASUREMENT SYSTEM

Water	'83 exit	'84 arrival	'84 exit
Total flow, 40 mph, gal/min	29.0	27.1	27.1
Trace width, 40 mph, inches	7	7	7
Flow rate, 40 mph, gal/wetted inch	4.1	3.9	3.9
Nozzle angle, degrees	20	27	27
Nozzle lateral position relative to tire center lines, inches	19 1/4	21	21
Nozzle orifice height above ground, inches	2 3/4	1 1/2	2 1/2
Speed			
C/W FT&EC speed 40 mph - Texas-Austin No. 2 indicates, mph	39.8	37	37
Load			
Test wheel load, pounds			
Left wheel	1095	1095	1095
Right wheel	1031	1031	1031
Tongue load, pounds	127	125	125

TABLE F9



	As Arrived	Departing
Nozzle Type:	ASTM E-274	Same
Dimensions of Nozzle Opening:	18 1/8" holes 19 1/4" holes	Same
℄ to ℄ of Trailer Tires:	64 1/4"	Same
Hitch Height vs. Water Load, A:		
Full	12 1/4"	Same
1/2	12 1/2"	Same
Empty	13"	Same
Nozzle Angle, B:	27°	27°
Nozzle Height, C:	1 1/2"	2 1/2"
Nozzle Distance to Wheel ℄, D:	21"	21"

FIGURE F1. SKID TRAILER AND NOZZLE DIMENSIONS - TEXAS-AUSTIN NO. 2

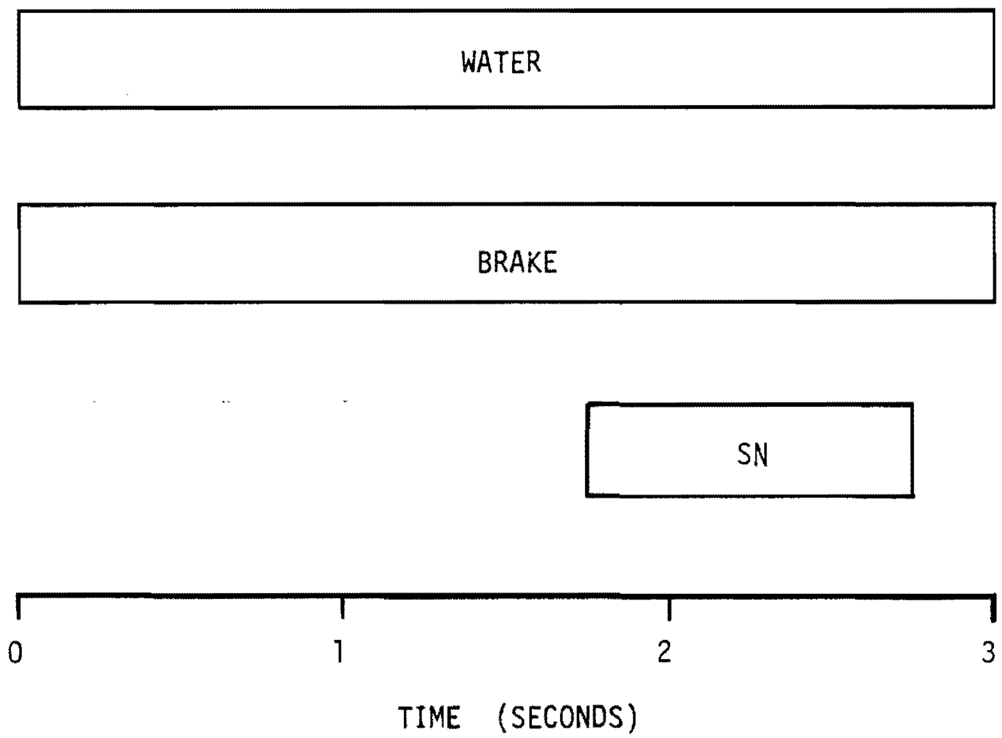


FIGURE F2. SKID CYCLE TIMING SEQUENCE
TEXAS-AUSTIN NO. 2

TOWING VEHICLE DESCRIPTION

1980 Chevrolet

One ton

Vehicle I.D.# 29-5656

454 cu. in. displacement

Crew cab style, dual tires

Two bucket seats, front

Automatic transmission

SKID TRAILER DESCRIPTION

Trailer I.D.# 29-9945-B

Texas State Department of Highways and Public Transportation

BRAKING SYSTEM DESCRIPTION

Hydraulic disc brakes

Skid cycle automatically timed

Left brake locks only

Manual override

WATERING SYSTEM DESCRIPTION

Franklin centrifugal pump

Fiberglass with baffles

Water tank capacity: 300 gallons

MEASUREMENT SYSTEM DESCRIPTION

Recorder: Texas Instruments ASR 733 Micro-processor based system - Pro-Log 2-80

Amplifier: Micro-processor based

PROPERTY OF:

Texas State Department of
Highways and Public Transportation

Operators:

Randy Beck
Douglas Chalman
George Reid
Bill Braddock

FOR FURTHER INFORMATION:

Mr. Curtis Goss
Field Test Coordinator
D-10 Research
P.O. Box 5051
Austin, Texas 78701
512/465-7545

APPENDIX G

C/W FT&EC RECORD OF EVENTS

C/W FT&EC RECORD OF EVENTS
TEXAS-AUSTIN NO. 2

Monday, October 1, 1984

Photography
As arrived correlation

Tuesday, October 2, 1984

Force plate calibration
Calibrated tire pressure gage
Speed calibration
Water calibration
Check automatic skid sequence
Measurements of skid system

Wednesday, October 3, 1984

Wheel transducer calibration
Replace strain gage amplifier and recalibrated wheel transducer
Replace fuel pump on tow vehicle

Thursday, October 4, 1984

Final correlation