# Technical Report Documentation Page

**1. REPORT No.**
633126-7

**2. GOVERNMENT ACCESSION No.**

**3. RECIPIENT'S CATALOG No.**

**4. TITLE AND SUBTITLE**
Skid Tester Correlation Study

**5. REPORT DATE**
October 1971

**6. PERFORMING ORGANIZATION**

**7. AUTHOR(S)**
Mann, G.W. and Svetich, R.R.

**8. PERFORMING ORGANIZATION REPORT No.**
633126-7

**9. PERFORMING ORGANIZATION NAME AND ADDRESS**
State of California
Department of Public Works
Division of Highways
Materials and Research Department

**10. WORK UNIT No.**

**11. CONTRACT OR GRANT No.**

**12. SPONSORING AGENCY NAME AND ADDRESS**

**13. TYPE OF REPORT & PERIOD COVERED**
Interim

**14. SPONSORING AGENCY CODE**

**15. SUPPLEMENTARY NOTES**

**16. ABSTRACT**
A correlation study was conducted between the California Skid Tester and an ASTM Skid Tester. Coefficients of friction were obtained with the California unit at the standard test conditions of locked wheel, smooth tire, wet pavement and a speed of 50 miles per hour. Skid numbers were obtained with the ASTM Skid Trailer operating at ASTM E274-65T standard test conditions of locked wheel, ribbed tire, wet pavement and a speed of 40 miles per hour. The ASTM unit made additional tests with the speed parameter changed to 50 miles per hour. Tests were also made by the ASTM unit with the ribbed tire replaced by a smooth tire at speed of 40 and 50 miles per hour. For the four test conditions investigated, correlations were obtained that indicate that the California coefficient of friction can be used to estimate the ASTM skid number.

A correlation study was also conducted between two makes of ASTM Skid Testers. The correlation was obtained at the standard ASTM test conditions. Correlations were also obtained for skid number conversions for 20, 30, 50 and 60 miles per hour to the standard ASTM test method speed of 40 miles per hour for each ASTM type skid test unit. An analysis of variance was conducted to determine the possible sources of error in this type of testing.

**17. KEYWORDS**
Analysis of variance, correlation, coefficient of friction, skid resistance testing, pavements, surfaces, Portland cement concrete pavements, flexible pavements

**18. No. OF PAGES:**
50

**19. DRI WEBSITE LINK**
http://www.dot.ca.gov/hq/research/researchreports/1971/71-02.pdf

**20. FILE NAME**
71-02.pdf

# HIGHWAY RESEARCH REPORT

# SKID TESTER CORRELATION STUDY

71-02

**STATE OF CALIFORNIA**

**BUSINESS AND TRANSPORTATION AGENCY**

**DEPARTMENT OF PUBLIC WORKS**

**DIVISION OF HIGHWAYS**

**MATERIALS AND RESEARCH DEPARTMENT**

**RESEARCH REPORT**

**NO. M & R 633126-7**

...d in Cooperation with the U.S. Department of Transportation, Federal Highway Administration October, 1971

STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

October 1971

Interim Report
M&R No. 633126-7
FHWA No. B-3-1

Mr. Sam Helwer
Deputy State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

SKID TESTER CORRELATION STUDY

George B. Sherman
Principal Investigator

Melvin H. Johnson
Co-Investigator

Gary W. Mann & Ralph R. Svetich
Analysis & Report

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

REFERENCE: Mann, G. W. and Svetich, R. R., "Skid Tester Correlation Study," State of California, Department of Public Works, Division of Highways, Materials and Research Department, Research Report 633126-7.

ABSTRACT: A correlation study was conducted between the California Skid Tester and an ASTM Skid Tester. Coefficients of friction were obtained with the California unit at the standard test conditions of locked wheel, smooth tire, wet pavement and a speed of 50 miles per hour. Skid numbers were obtained with the ASTM Skid Trailer operating at ASTM E274-65T standard test conditions of locked wheel, ribbed tire, wet pavement and a speed of 40 miles per hour. The ASTM unit made additional tests with the speed parameter changed to 50 miles per hour. Tests were also made by the ASTM unit with the ribbed tire replaced by a smooth tire at speeds of 40 and 50 miles per hour. For the four test conditions investigated, correlations were obtained that indicate that the California coefficient of friction can be used to estimate the ASTM skid number.

A correlation study was also conducted between two makes of ASTM Skid Testers. The correlation was obtained at the standard ASTM test conditions. Correlations were also obtained for skid number conversions for 20, 30, 50 and 60 miles per hour to the standard ASTM test method speed of 40 miles per hour for each ASTM type skid test unit. An analysis of variance was conducted to determine the possible sources of error in this type of testing.

KEY WORDS: Analysis of variance, correlation, coefficient of friction, skid resistance testing, pavements, surfaces, portland cement concrete pavements, flexible pavements.

ACKNOWLEDGMENT

The authors appreciate the contributions of Mr. Gene Stucky and Mr. Lloyd Batham III, operators of the two ASTM Skid Testers, for their assistance in performing the tests and collecting the data. A special note of appreciation goes to Mr. Albert Sequeira, and his personnel, for their work in correcting the electronic problems of the ASTM skid testers. Also, appreciated is the fine work done by the machine shop, under the direction of Mr. Floyd Martin, in building the water nozzles for Skid Tester B, and to Mr. Charles Frazier, in assisting in the ANOVA design and calculations.

This work was performed in cooperation with the U. S. Department of Transportation, Federal Highway Administration, under agreement No. B-3-1.

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## INTRODUCTION

The California Division of Highways has been engaged in skid resistance research for several years. The development of a small skid tester, for field and laboratory use, has previously been reported (1). The California Portable Skid Tester was originally calibrated against the towed trailer unit developed by Professor R. A. Moyer of the University of California. The portable unit was calibrated to read coefficient of friction at the standard test conditions for the towed trailer unit of locked wheel, smooth tires, wet pavement and a speed of 50 miles per hour. This portable skid resistance tester has been used in many research projects for which results have previously been reported (2,3,4 & 5).

In 1969 an ASTM type towed trailer unit (hereafter referred to as Skid Tester A) was purchased by the Division of Highways for use primarily in research work involving the skid resistance of pavements. A correlation was made between Skid Tester A and the California Portable Skid Tester on different pavements at two speeds and with both ribbed and smooth tire. A discussion of the correlation study and resulting charts are included.

Due to the favorable response that Skid Tester A received throughout the Division of Highways and from cities and counties within the State; and after a grant was received from the National Highway Safety Bureau to conduct a statewide skid resistance inventory, a second ASTM type towed trailer unit was needed to handle the work load.

In late 1970 the second ASTM type towed trailer test unit (hereafter referred to as Skid Tester B) was purchased. With the arrival of Skid Tester B it was decided to run an analysis of variance (ANOVA) and a linear regression analysis to determine the source of errors and correlation, if any, between the two ASTM skid testers. Items to be investigated in the ANOVA were to determine the significant difference between operators, significant difference between skid testers, and also investigate the possible sources of errors in this type of testing. Also, during this time, the ASTM skid testers were run at speeds other than the standard ASTM test method speed of 40 miles per hour. Regression analyses were run and charts made that will enable us to convert the skid numbers obtained at speeds other than 40 miles per hour back to the standard 40 miles per hour speed. These charts as well as the discussion of the correlation study between the ASTM skid testers are included in this report.

## CONCLUSIONS

1. Correlations were obtained for the California Portable Skid Tester and the ASTM Skid Tester A for the four test conditions investigated in this study.

2. An excellent correlation between the two makes of ASTM type skid testers was obtained.

3. Excellent correlations were obtained for skid number conversions for 20, 30, 50, and 60 miles per hour to the standard ASTM test method speed of 40 miles per hour for each ASTM type skid test unit.

4. From the results of our study, it is our opinion that ASTM specification E274-65T (Section 3.4 Wetting System) should be revised to include a nozzle design, more stringent installation requirements, and a smaller allowable variation in the water discharge rate or water film thickness.

5. From the results of our study, it is our opinion that ASTM Specification E274-65T (Section 6 Test Section and Number of Tests and Section 10 Faulty Tests) should be revised to take into consideration the variance of the skid test unit being used and the pavement surface type variations.

## FINDINGS

1. The correlation studies between the California Portable Skid Tester and the ASTM Skid Tester indicate the California coefficient of friction can be used to estimate the ASTM skid number.

2. From an analysis of variance it was determined that the repeatability or standard error ($\sigma$) from this study for each ASTM skid tester was as follows:

For Skid Tester A 1.13 SN

For Skid Tester B 1.56 SN

3. From an analysis of variance it was determined that the repeatability or standard error ($\sigma$) of each ASTM skid tester on the different pavement types is as follows:

| Pavement Surface Type | Skid Tester A | Skid Tester B |
|---|---|---|
| Open-Graded Asphalt Concrete | 0.89 SN | 1.47 SN |
| Dense-Graded Asphalt Concrete | 1.03 SN | 1.37 SN |
| New Portland Cement Concrete | 1.33 SN | 1.82 SN |
| Old Portland Cement Concrete | 1.11 SN | 2.04 SN |

4. An analysis of variance also showed the variation between skid tests along the lane for the same pavement surface type for each skid tester and either operator were found to be as follows:

| Pavement Surface Type | Skid Tester A | Skid Tester B |
|---|---|---|
| Open-Graded Asphalt Concrete | 1.17 SN | 1.94 SN |
| Dense-Graded Asphalt Concrete | 1.42 SN | 1.83 SN |
| New Portland Cement Concrete | 2.59 SN | 3.72 SN |
| Old Portland Cement Concrete | 2.30 SN | 3.28 SN |

## IMPLEMENTATION

With the excellent correlation obtained, either ASTM type skid tester can now be used in our statewide skid test program. Also, when our districts request special skid resistance studies, Table IV of this report will be used to determine the number of skid tests required to adequately calculate the skid resistance of that particular pavement surface type.

When participation is requested of the Federal Highway Administration in surface correction work, one of the test results that must be submitted is the skid resistance measured at the standard ASTM test speed of 40 miles per hour. In locations where the standard speed cannot be maintained it has been requested that all skid numbers be converted to the standard test speed values. This can now be accomplished by means of the conversion charts obtained in this study for each of our ASTM type skid testers.

From this study the portable skid tester can be used to predict the skid number obtained with the ASTM type skid tester at locations where length of testing is limited. From test patches a good indication can be obtained of the skid number that would result from a full scale project.

## Discussion of Skid Testers

### California Portable Skid Tester

The portable skid tester was developed and built in the late 1950's by the California Division of Highways, to measure skid resistance of various types of pavement surfaces under both laboratory and field conditions. The portable tester was

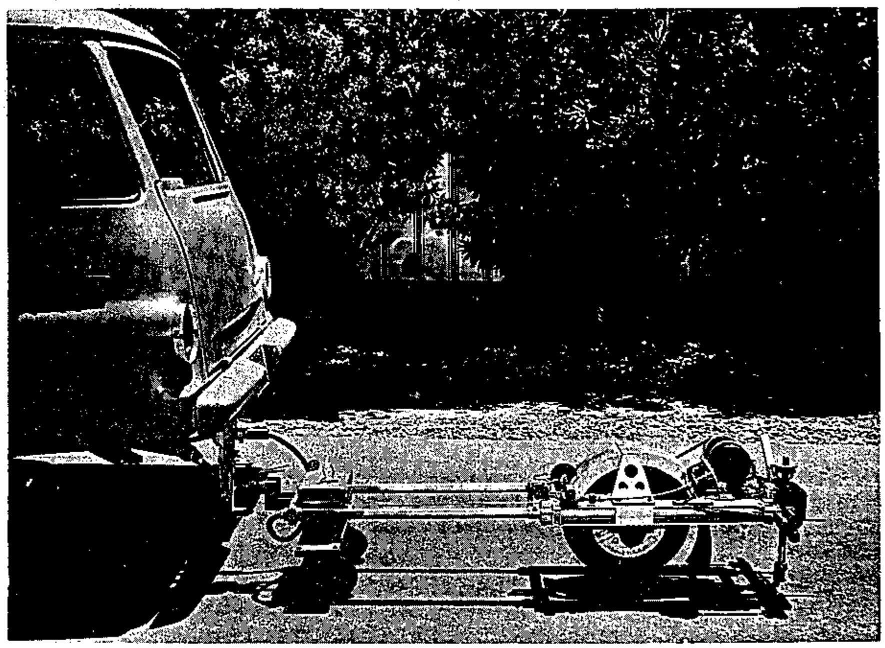

Figure 1

CALIFORNIA PORTABLE SKID TESTER

correlated against a towed trailer skid test unit (forerunner of presently used ASTM devices) developed by Professor Moyer of the University of California. The standard test conditions of Moyer's unit were locked wheel, smooth tire, wet pavement and a speed of 50 miles per hour.

The design of the portable apparatus was based on the following concept: A wheel equipped with a smooth tire is mounted on a carriage which is free to move on ball bearings along two guide bars. The tire is suspended just above the pavement surface and revolved by driving it with an electric motor. After the designated speed has been attained, the entire carriage is dropped allowing the tire to contact the surface. If unrestrained, the guide bars would have to be too long for practical transportation of the device. Therefore, a restraining spring of constant tension was employed between the carriage and rear cross bar. If the surface has a low friction value, the tire will slip and the forward movement of the carriage will be low. A greater forward movement will be attained on a high friction value surface for equivalent conditions of test (1).

During the original development period, it was noted that the small water film thickness was insufficient to maintain a wet pavement condition under the small spinning wheel. This was overcome by the use of glycerine, with its viscosity higher than water, as the wetting agent. Glycerine, of course, will not give the same results as water, and we would not consider such an agent for use with a primary skid test unit such as the towed trailer unit, or in conjunction with the stopping car method. However, the point to emphasize is that our portable unit was being correlated against a primary friction factor measuring device and any system or method that would achieve a high degree of correlation could be used. A complete discussion of the development and correlation of this unit is included in reference 1.

Presently new portland cement concrete pavements and bridge decks are tested with this unit in order to check for conformance to California's present minimum coefficient of friction requirements in accordance with Test Method No. Calif. 342. These portable units can be used on very short sections and will not be replaced by ASTM type units for contract control skid resistance measurements.

## ASTM SKID TEST UNIT - A

The ASTM type skid resistance tester consists of a two wheeled towed trailer and an automotive towing vehicle. These can be of almost any design so long as they meet the criteria of ASTM Test Method E274-65T (9). The towing vehicle contains the operating console, a water supply tank, a drive-shaft driven water pump and data recording instrumentation. The trailer is equipped with special test tires (ASTM E249), water laying system, and a strain gauged braking system. The load on each test wheel is 1085 ± 25 pounds.

For testing, the unit is brought to the desired test speed (standard test speed is 40 miles per hour), water is applied ahead of the test tire (.020 ± .005 in.), and the left, right, or both brakes are locked. The drag force at the interface between the tire and pavement surface is recorded. The skid resistance value of the pavement is then calculated.

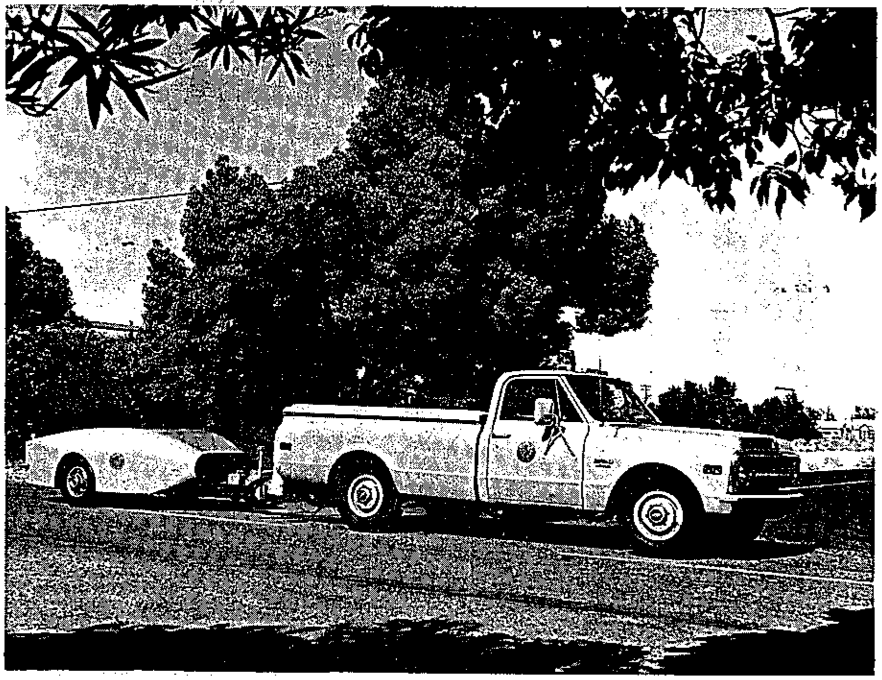

Figure 2

ASTM SKID TEST UNIT-A

The above pictured unit was purchased in the summer of 1969. As received the unit required several minor corrections before the unit functioned properly. These included removing foreign matter from within the brake line, replacing a broken copper brake line on the trailer with a flexible line, rebuilding the mounting bracket for the air compressor on the truck and replacing the inverter after several attempts failed to determine the cause of its malfunctioning. This unit was originally intended for research work on pavement surface materials and dynamic testing of sections of highway suspected of being a skid problem.

The towing unit is a Chevrolet 3/4 ton Custom Sport Pickup supplied with bucket seats, air conditioner, and a 396 cubic inch, 310 H.P. engine. Mounted between the seats is the operating console and an 8 channel oscillograph (Figure 3). The device above the steering wheel is the electrical speed indicating unit driven by a fifth wheel attached to the trailer. Shown facing the operator is the analog-to-digital converter and printer. This equipment was only recently installed and was not used during the correlation testing period. With this equipment the skid number is printed out immediately after each skid test. The

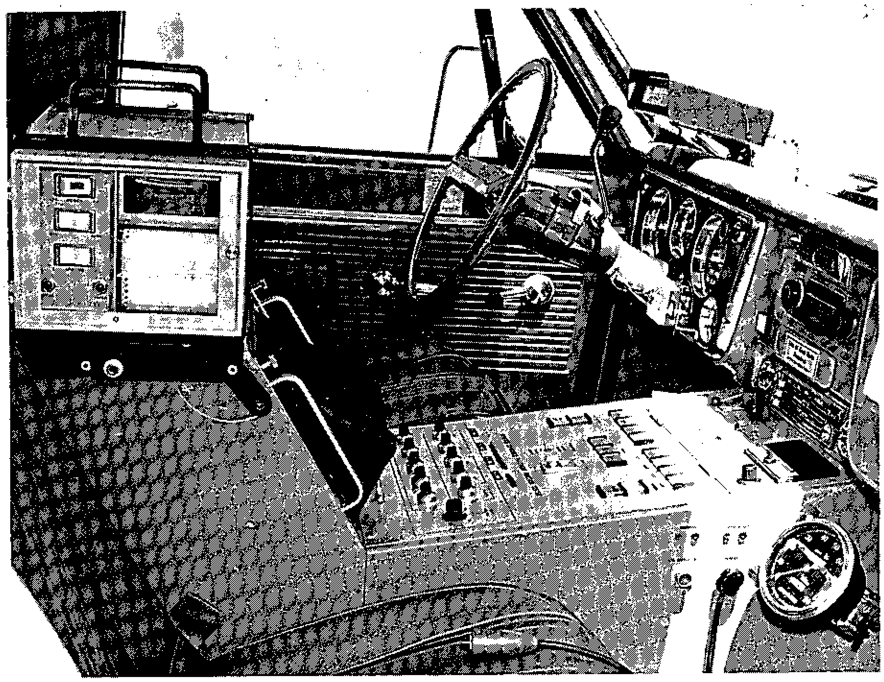

Figure 3

INTERIOR OF SKID TESTER A

survey odometer was added to aid the operator in recording test locations. Under the fiberglass covered truck bed is an internally baffled 230 gallon water tank.

The specially built trailer is constructed of rectangular steel box sections. The suspension system consists of coil springs and the trailer is equipped with air over hydraulic disc brakes.

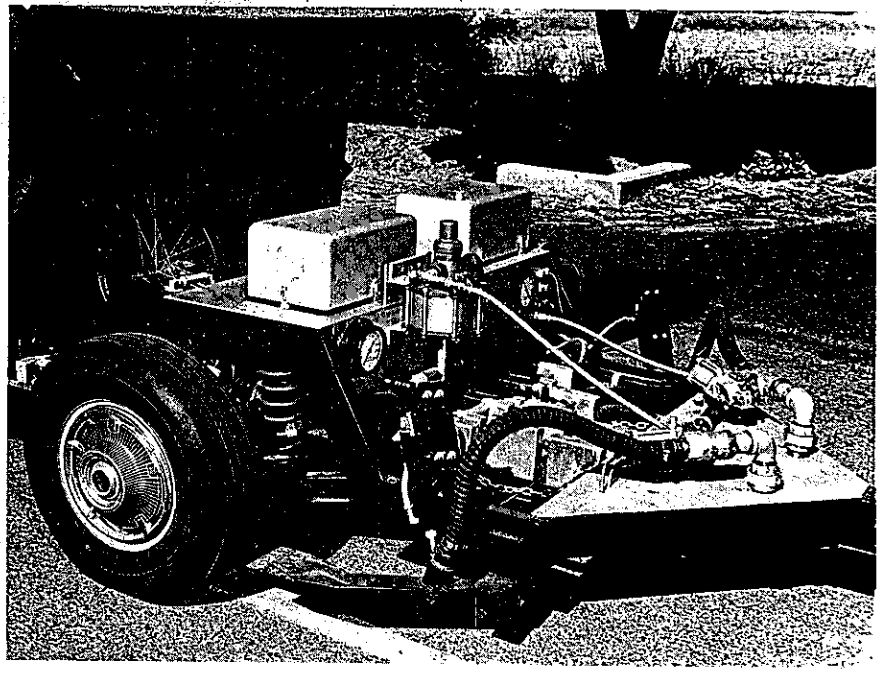

Figure 4

INTERIOR VIEW OF TRAILER-SKID TESTER A

The water nozzle shown in the picture is internally baffled for equal distribution of the water. The baffles run from approximately the circular water inlet to the nozzle outlet. Force transducers for each test wheel are gauged for both horizontal and vertical load measurements. An aerodynamically designed fiberglass cover has been provided for protection.

ASTM Skid Test Unit - B

Our second skid test unit was received in late 1970. A grant from the National Highway Safety Bureau to conduct a statewide skid resistance inventory necessitated the purchasing of the second ASTM type skid tester. It was thought this unit should be equipped with a larger capacity water tank and storage capacity to increase the efficiency of conducting skid measurements on the 45,000 lane miles of the California Highway System. The result of our specification was the unit shown in Figure 5. As received the unit was not operational and required several corrections and modifications before the unit functioned properly.


Figure 5

ASTM SKID TEST UNIT-B

Briefly, these were: replacement of torque tubes, replacement of defective pre-amplifier, correction of noise problem with recorder, modifications to strain gauge circuit design, and correction to pressure relief valve on water delivery system. Before beginning tests for the correlation series, and after all corrective work had been completed, the unit was checked and found to comply with all requirements of the ASTM test method.

The towing unit is a Ford truck, 6-passenger cab equipped with air conditioner and a 361 cubic inch engine. Mounted between the front seats is the operating controls and a two channel ink pen recorder (Figure 6). An electronic speed indicating device driven by the transmission was supplied. Again, a survey odometer was added for recording test locations. Also shown in the picture (Figure 6) is the digital printer, recently added but not used in this correlation test program, identical to the one in Skid Tester A. The rear of the truck contains an internally baffled 500 gallon water tank.

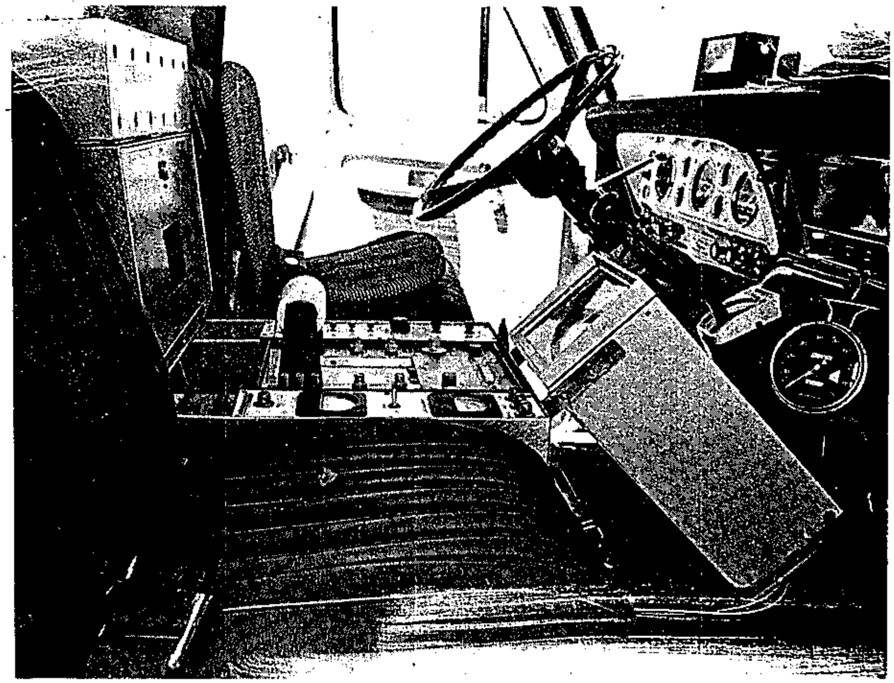

Figure 6

INTERIOR OF SKID TESTER B

Figure 7

WATER NOZZLE SUPPLIED BY MANUFACTURER-SKID TESTER B

The trailer is constructed of structural steel and equipped with leaf spring suspension. The success with tester A convinced us to again specify air over hydraulic disc brakes. The water nozzle type initially supplied is shown in Figure 7. This nozzle design meets the present ASTM specification. After our first attempt to correlate the skid testers, new internally baffled nozzles (See Figure 8) were manufactured based on the dimensions of those in use on skid tester A. (See Discussion, page 16.) Torque developed by braking is sensed by strain gauged metal torque tubes placed concentrically around the trailer axle inboard of each wheel.

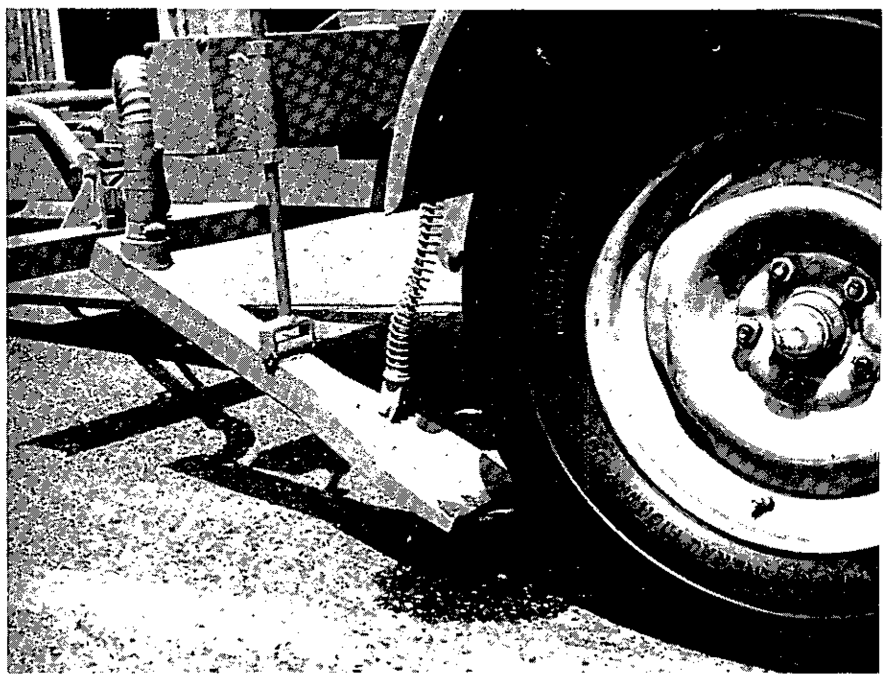

Figure 8

WATER NOZZLE NOW IN USE-SKID TESTER B

## DISCUSSION

### Correlation Between California Portable Skid Tester and ASTM Skid Tester A.

In 1969 a correlation study was made between ASTM Skid Tester A and the California portable skid tester. The method of operation for conducting the correlation study between the two skid testers was as follows: Skid Tester A would run three skid tests as rapidly as possible, attempting to get the middle skid test at a specified location or post mile marker. The three skid tests would then be averaged and considered as one test. This was done both at 40 miles per hour and 50 miles per hour, and also with the skid tester using standard ribbed tires and smooth tires. After the tests by Skid Tester A were made, the California portable skid tester would test the site in accordance with California Test Method 342 (10). Briefly, this consists of a series of five tests, 25 feet apart, at the specified location or post-mile marker. These five tests are then averaged and considered as one test. This same procedure for testing was repeated on test sites selected to provide a large range in skid resistance values and included both portland cement concrete pavements and asphalt concrete pavements. The correlation testing was conducted in this manner to comply with the requirements of the test method governing each skid test unit. Section 6 of ASTM E274-65T states a minimum of three values should be obtained for each test section, and for the portable skid test unit an average of 5 skid determinations for each test section is required. A linear regression analysis was then made on these average results, and the plots of the best-fit lines are shown on Figures 10 through 13.

Previous reports (2,3) have explained correlation studies between the California portable skid tester and other skid testers. In report 2, the coefficient of friction value of 0.25 was established as a minimum value for pavement evaluation. In report 3 this value of 0.25 was further verified, as it corresponded quite well to the tentative minimum skid number for main rural highways (37 SN) recommended by Kummer and Meyer (11). The purpose of this correlation study was to further determine the adequacy of the California tentative minimum coefficient of friction for pavement evaluation in conjunction with our own ASTM type skid tester. From Figure 10, this value of .25 is confirmed when compared with ASTM Skid Tester A with ribbed tires run at the standard speed of 40 miles per hour. Again using Kummer and Meyer's tentative minimum skid number ($SN_{40}$) for main rural highways of 37, this corresponds to a California coefficient of friction value of .27.

In Figure 11 the parameters are essentially the same except that the speed of the ASTM skid tester was increased to 50 miles per hour. From Kummer and Meyer a skid number of 37 obtained at 40 miles per hour would correspond to a skid number of 32 measured at 50 miles per hour. As can be seen in Figure 11, this value of 32 corresponds exactly to the California tentative minimum of .25.

In Figures 12 and 13, Skid Tester A ran the tests using smooth tires, instead of the standard ribbed tires, at 40 miles per hour and 50 miles per hour, respectively. In Figure 13, the parameters are exactly the same (50 miles per hour, smooth tire, wet pavement) as used during the original calibration of the California Portable Skid Tester against Professor Moyer's skid trailer unit. The probable reasons why better correlation wasn't obtained with these parameters are that there were large differences on the weight of the test wheels (1820 pounds for Professor Moyer's, and 1085 pounds for Skid Tester A), and the water film thicknesses used with the two towed trailer devices. With Professor Moyer's skid trailer, water was applied to the pavement by use of spray bars attached to the truck. The trailer then passed over the wetted pavement, and the skid tests were performed. We suspect this type of water application gives less water film thickness and, therefore, higher skid values than the procedure used by ASTM Skid Tester A. Figure 13 confirms this, as Skid Tester A's results are less than the California coefficient of friction. Also, Figure 12 shows data for tests performed at 40 mph, which increased the skid number obtained by Skid Tester A, giving almost perfect correlation to the results obtained from the California portable skid tester.

Correlation of ASTM Type Skid Test Units

In April 1971, a correlation study was made between our two ASTM skid testers. In order to determine where the sources of error, if any, might exist between the two ASTM skid testers and to correct for them, if possible, it was decided to use an analysis of variance. A computer program was used that calculates for a two by five factorial analysis of variance. That analysis of variance (ANOVA) was written to test for significance of the difference between operators, skid testers, pavement types, and different areas within a pavement type. Briefly the ANOVA (ANOVA I) was as follows:

4 different pavement types (Open-Graded AC, Dense-Graded AC, new PCC and old PCC)

4 separate locations within each pavement type

6 tests at each location (one test every 0.1 mile) by each operator and skid tester

2 operators

2 repetitions at each location

2 skid testers

A total of 768 individual skid numbers were obtained.

Some of the variables not considered in our ANOVA were errors due to reading the chart and temperature effects. In a report by the Texas Highway Department (6), they concluded that there was only a slight variation produced by reading the force values from the chart. For this reason it was decided to ignore this possible source of variance to reduce the complexity of the ANOVA.

The variation due to temperature is a well-known possible source of error, and has been reported as such by other researchers (6,7). The total temperature variation is the summation of ambient, pavement and tire variances. The magnitude of these variances is unknown, and, therefore, had to be minimized by having the two ASTM skid testers perform the same series of tests on the same pavement within minutes of each other. By doing this we were confident that any possible source of variation due to temperature was kept to an absolute minimum.

Before the collection of data for the ANOVA began, the test sites to be used in the study were selected to provide a wide range in skid resistance values and included both portland cement concrete and asphalt concrete pavements. From the ANOVA it was found that there was a highly significant difference between skid testers (as high as 10 skid numbers), but not between the operators. It was also found that the standard error between repetitions on any pavement type, with either skid tester or operator, was 1.71 SN. A regression analysis was run and a linear function of $Y=11.26 + 0.98X$ with a correlation coefficient of 0.85 was determined. At this point we began to look for variables between the two skid testers that might be correctable.

Prior to the ANOVA study both skid testers had been calibrated using the same loading platform (air-floating, near frictionless device, which was supplied with skid tester A) (See Figure 9). The load cell of the platform had also been calibrated with a universal testing machine and was found to be functioning properly and in calibration. The torque tubes on each skid tester during calibration were checked for linearity. The weight of the trailers and water discharge rates were also checked and found to be within the ASTM specification.

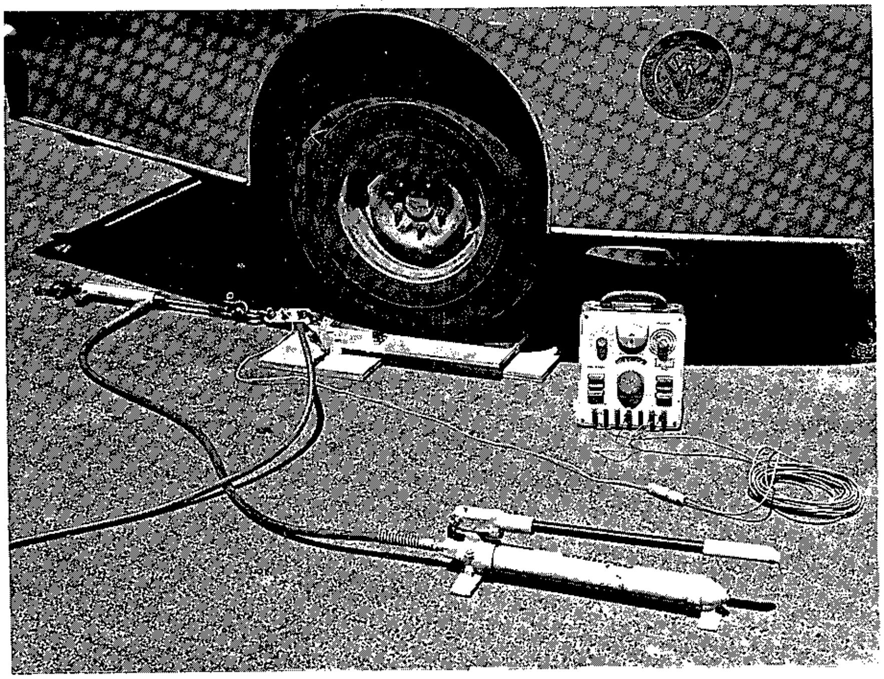

Figure 9

CALIBRATION PLATFORM AND FORCE READOUT EQUIPMENT

During the ANOVA testing it was noticed that Skid Tester A appeared to be gaining on Skid Tester B while both were supposedly traveling at the same rate of speed. One of our first efforts was to recheck the calibration of the electrical tachometer driven by the "fifth" wheel of Skid Tester A and this was found to be correct. Skid Tester B's electrical speed meter was then reset by driving the two units side by side on a newly constructed section of freeway near Sacramento. The speed error of Skid Tester B was approximately 3 miles per hour slower than Skid Tester A.

The survey odometers used by the operators to locate the test locations were then rechecked and Skid Tester A's was found to need recalibration.

Even though the water discharge rates for both skid testers were within the ASTM specification (E274) for water layer thickness (0.020 + 0.005 in.) it was visually apparent that there was a significant difference between the two discharge rates. It was then decided to recheck the two units, and more accurately determine the discharge rates. From the following formula as found in the ASTM Test Method:

$$h = 0.22 \frac{Q}{w \times V}$$

Where: H = water layer thickness in.

Q = nozzle discharge rate, gpm

V = test speed, mph

w = width of water trace, in.

We found that Skid Tester B had a water layer thickness of approximately 0.020 in. with a width of water trace of 7.0 in., and a nozzle discharge rate of 26 gpm. Skid Tester A had a water layer thickness of approximately 0.025 in. with a width of water trace of 6.5 in., and a nozzle discharge rate of 30 gpm. Since Skid Tester A had already been testing pavements in California for over a year, and results were in apparent agreement with experience, it was decided to modify Skid Tester B to match as closely as possible Skid Tester A. With this as a criteria the nozzle from Skid Tester B was taken off, and a new nozzle was built, which closely matched Skid Tester A's nozzle. It was then found that an incorrectly sized belt was on Skid Tester B's water pump pulley. By replacing with the correct size pulley belt, the discharge rate was increased to about 30 gpm, which is the same rate as discharged by Skid Tester A's water pump.

Because of this experience and the resulting correlation, we feel that the ASTM specification section for the water wetting system should be revised to include a nozzle design, more stringent installation requirements, and a smaller allowable variation in the water discharge rate.

It was brought to our attention that another possible source of variance could be in the tires used during the skid tests. As the wheel rims for Skid Tester A and Skid Tester B trailers are not interchangeable, there was not an easy, fast method available of changing tires. Therefore, it was decided not to interchange the tires, but merely to begin testing with tires with the same amount of wear on them. While this may not be a desirable solution, it was felt that since all tires used during the testing met ASTM specifications, no workable solution could be developed if an error was found to exist between tires. Also, extreme care was taken to make sure that the tires used did not wear past the protrusion ring. This procedure was in compliance with ASTM Specification E249, and a report by the Texas Highway Department (6) which cautioned against wearing beyond this protrusion ring.

With these modifications, a new ANOVA (ANOVA II) was started similar to the previous one except that a separate ANOVA was run for each pavement type. Again, no significant difference was found between the two operators. Before the regression analysis was completed, it was decided as a further check, to recalibrate the ASTM skid testers, with the load platform device, to assure the validity of their results. For some inexplicable reason, Skid Tester B was found to be out of calibration and had to be readjusted. Due to the time element involved, the ANOVA approach was dropped in favor of a regression analysis by the least squares method. In this analysis, pavements covering a wide range of SN's (skid numbers) were selected. The same two operators as used in the ANOVA's were used. In this analysis 192 skid tests were run on pavements ranging in SN from 25 to 65 (as based on Skid Test A's results). The correlation coefficient was found to be 0.98 with a best-fit line as follows:

$$A = 0.947 + 0.941\ B \quad \text{(See Figure 14)}$$

The next question to be answered was what is the average standard error, or repeatability of the two units [a standard error is a term of precision and is defined as a deviation of $\pm\ \sigma$ (8)]. To determine this ANOVA II was used, even though the $S\bar{N}$'s were not completely correct, due to the calibration error of the Skid Tester B. This error was a constant type error that would not affect the difference between the repeated tests. From ANOVA II the following standard errors were found to be:

For Skid Tester A - 1.13 SN

For Skid Tester B - 1.56 SN

These values tell how closely each unit can repeat its values, when run by the same operator, at the same location with very little time lapse between tests.

From ANOVA II it was also possible to determine whether or not there was any significant difference between operators, since the operators ran tests in both skid trailers, and even though Skid Tester B was not properly calibrated. The repeatability error of the operator is independent of the magnitude of the skid number. Again, as was found in ANOVA I, there was no significant difference between the operators.

However, it was not possible to check for significance between skid testers, as Skid Tester B's results did get closer to Skid Tester A's results after the calibration error was corrected, but this was not shown in ANOVA II.

For further analysis of the two skid testers yet another ANOVA was written. This ANOVA (ANOVA III) was written based on the data from ANOVA II, except that now the data from the two skid testers was separated, meaning that eight separate ANOVA's were written for each skid tester and each pavement type. The main reason for ANOVA III was to answer the following questions: What is the repeatability of each skid tester, and the standard error involved when a skid tester performs skid tests on the same type surface?

From ANOVA III the repeatability or standard error of each ASTM skid tester on the different pavement types is shown in Table I.

Table I

Skid Tester Repeatability

| Pavement Type | Skid Tester A | Skid Tester B |
|---|---|---|
| Open-Graded Asphalt Concrete | 0.89 SN | 1.47 SN |
| Dense-Graded " " | 1.03 SN | 1.37 SN |
| New Portland Cement Concrete | 1.33 SN | 1.82 SN |
| Old " " " | 1.11 SN | 2.04 SN |

With this information, it was now possible to determine the standard error between the six skid tests along the lane on the same type of pavement. The Appendix lists the computations involved in determining the variance, and hence, standard deviation, of the skid tests along a lane.. These values are listed in Table II.

Table II

Standard Error Along Pavement Lane

| Pavement Type | Skid Tester A | Skid Tester B |
|---|---|---|
| Open-Graded Asphalt Concrete | 1.17 SN | 1.94 SN |
| Dense-Graded " " | 1.42 SN | 1.83 SN |
| New Portland Cement Concrete | 2.59 SN | 3.72 SN |
| Old " " " | 2.30 SN | 3.28 SN |

According to section 10.1 of ASTM Test Method E274-65T, tests that give values greater than 5 SN on the same test section from the average values of all tests of a test section shall be treated in accordance with ASTM Recommended Practice E 178, for Dealing with Outlying Observations (9). Not being sure where ASTM got its data to arrive at this figure of 5 SN, and not being certain of its confidence limits, we have taken the data from ANOVA III, and set up a table (Table III), listing the values of skid numbers that could be suspected of being erroneous. These values are based on the use of the 5 percent significance level (95% probability for a normal distribution).

Table III

Suspect Values From Skid Tests on Same Test Section

| Pavement Type | Skid Tester A | Skid Tester B |
|---|---|---|
| Open-Graded Asphalt Concrete | 3 SN | 4 SN |
| Dense Graded " " | 3 SN | 4 SN |
| New Portland Cement Concrete | 6 SN | 8 SN |
| Old " " " | 5 SN | 7 SN |

Any skid numbers that exceed the values given in the above table from the average values of all tests are to be treated in accordance with ASTM Recommended Practice E 178.

Based on the standard error of each skid tester on the four pavement types, the number of tests to determine within ± 2 SN of the "true" mean value of a test section *, based on a 5 percent significance level, will be as shown in Table IV.

Table IV

Number of Tests to Determine Within 2 SN of True Mean Value

| Pavement Type | Skid Tester A | Skid Tester B |
|---|---|---|
| Open-Graded Asphalt Concrete | 2 | 4 |
| Dense-Graded " " | 2 | 4 |
| New Portland Cement Concrete | 7 | 14 |
| Old " " " | 6 | 11 |

This information was obtained from the following equation:

$$\sigma_x = \frac{\sigma}{\sqrt{n}}$$

Where: $\sigma_x$ = standard error of the mean (arbitrarily set at 2 SN)

$n$ = number of tests

$\sigma$ = known standard deviation

* "A test section shall be defined as a section of pavement of uniform age and general composition which has been subjected to essentially identical wear throughout. Sharp curves and steep grades should not be included in the same test section with level tangents, nor should passing lanes be included with traffic lanes." (9)

It is felt that ASTM should use a procedure similar to the one used in determining the values of Table IV in lieu of paragraph 6.1 of ASTM Test Method E274 (Test Section and Number of Tests). By utilizing the procedure of Table IV, the variances of the skid tester and the different pavement types are taken into account, resulting in a table of skid number determinations which is much more realistic and practical than using an arbitrarily set number of skid tests to determine the mean value of a test section.

The question may arise as to what is considered a new PCC pavement. We define a new PCC pavement, for skid resistance study, as being pavement that has been tested using an ASTM skid tester, after being constructed but prior to having been opened to traffic. Normally, very few new PCC pavements would have any skid resistance problems, therefore, most portland cement concrete pavements that need skid resistance evaluation are considered as old PCC pavements. With this in mind it can be seen from Table IV that reasonably few tests are needed for pavement evaluation.

Often times it is desirable to run the skid testers at speeds other than 40 mph. For this reason tests were run at different speeds, on the same pavements, by the same operator with both testers. A linear regression analysis was performed at each speed as related to the 40 mph standard speed. The charts showing the best-fit line, along with the coefficient of correlation and the equation for the line, are attached as Figures 15 through 24.

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4. Zube, E., Skog, J. B. and Kemp, G. R., "Field and Laboratory Studies on Skid Resistance of Pavement Surfaces," State of California, Department of Public Works, Division of Highways, Materials and Research Department, Research Report 633126-3, February 1968.

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10. State of California, "Materials Manual," Test Method No. Calif. 342-C, State of California, Department of Public Works, Division of Highways.

11. Kummer, H. W. and Meyer, W. E., "Tentative Skid-Resistance Requirements for Main Rural Highways," NCHRP Report 37, 1967, Highway Research Board, Washington, D. C.

Figure 10

# CALIF. COEFFICIENT OF FRICTION VS ASTM SKID NUMBER

(SKID TESTER A WITH RIB TIRE AT 40 MPH)

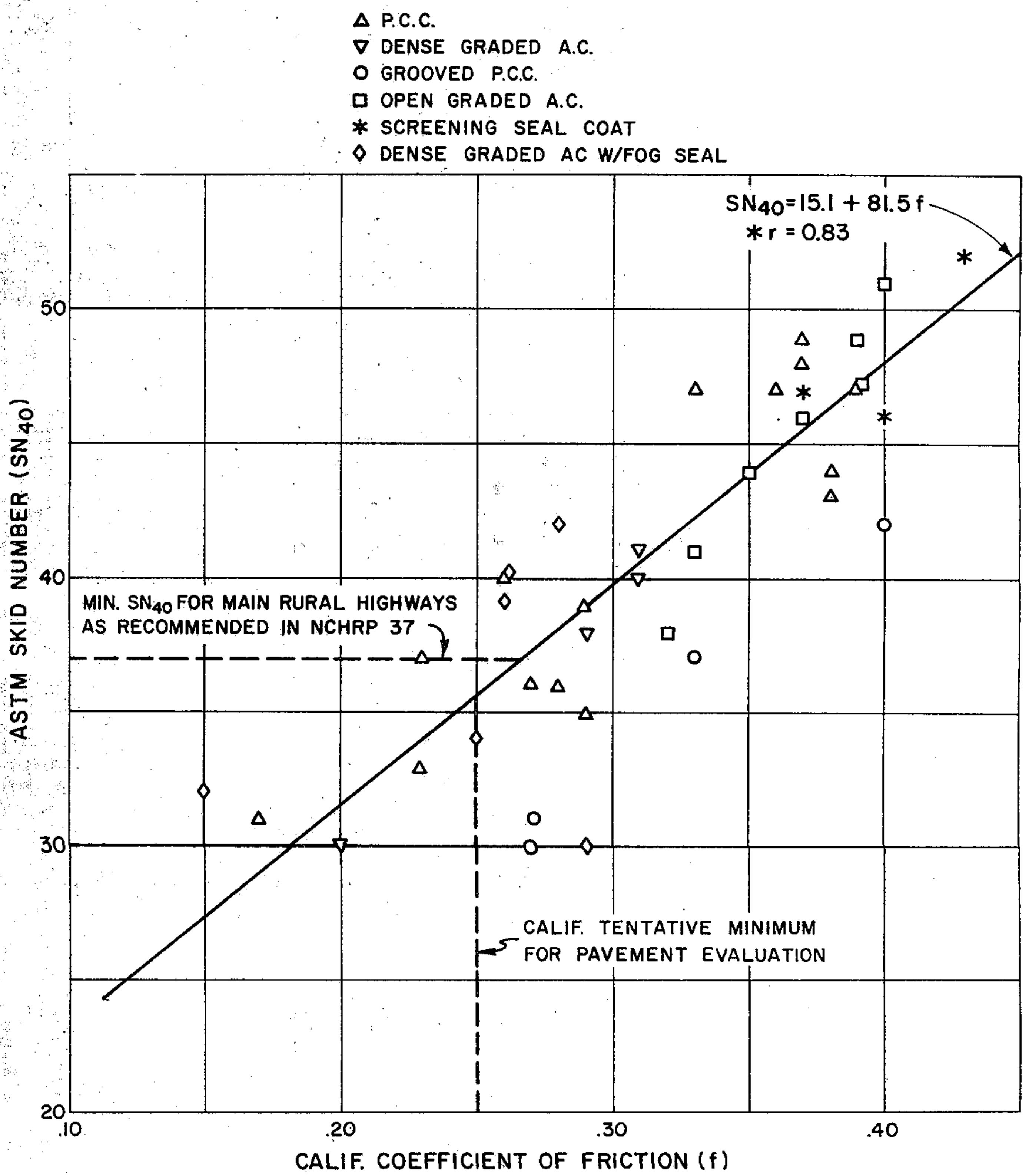




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Figure 11

# CALIF. COEFFICIENT OF FRICTION VS ASTM SKID NUMBER

(SKID TESTER A WITH RIB TIRE @ 50 MPH)

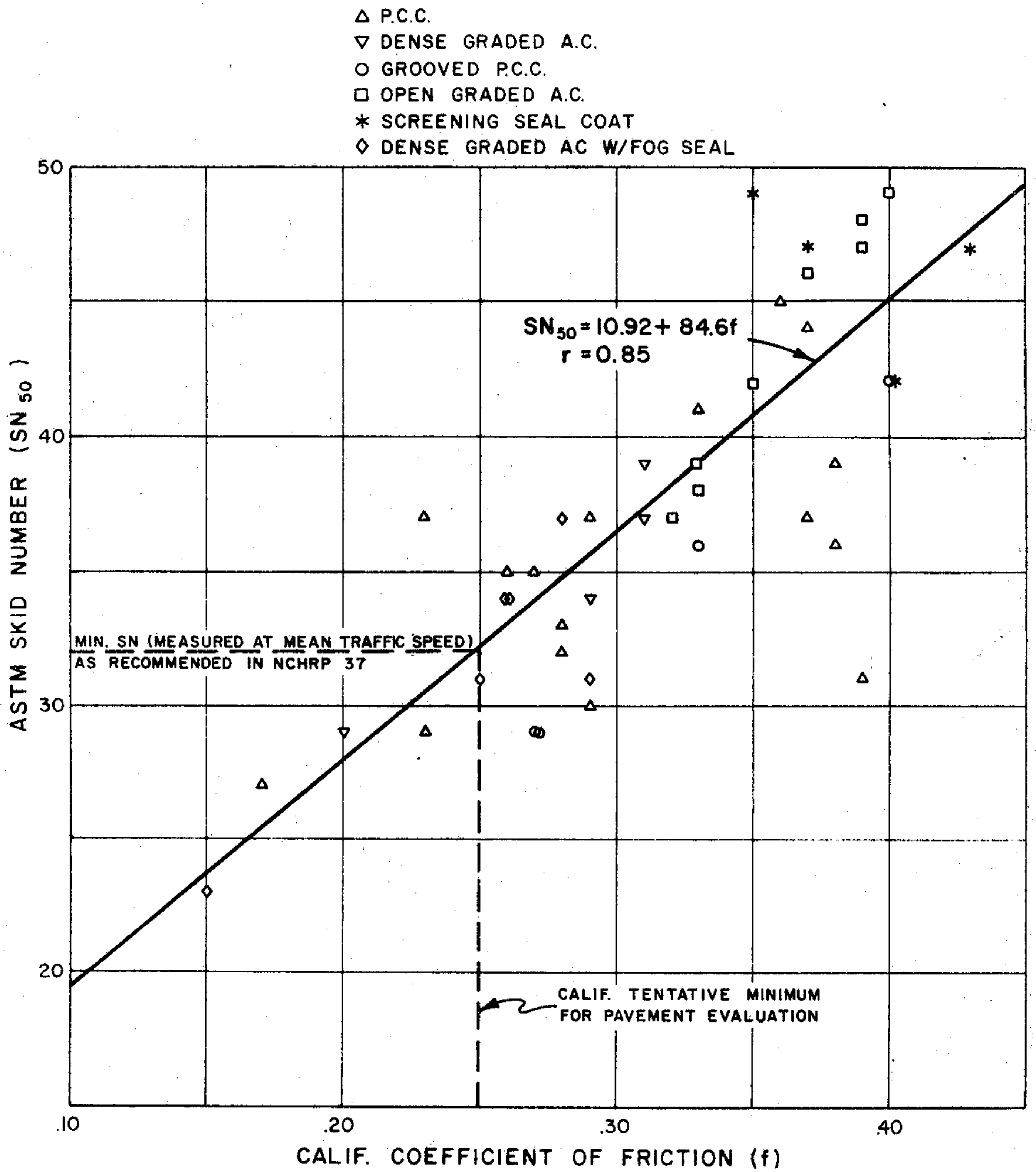


Figure 12

# CALIF. COEFFICIENT OF FRICTION VS ASTM SKID NUMBER

(SKID TESTER A WITH SMOOTH TIRE @ 40 MPH)

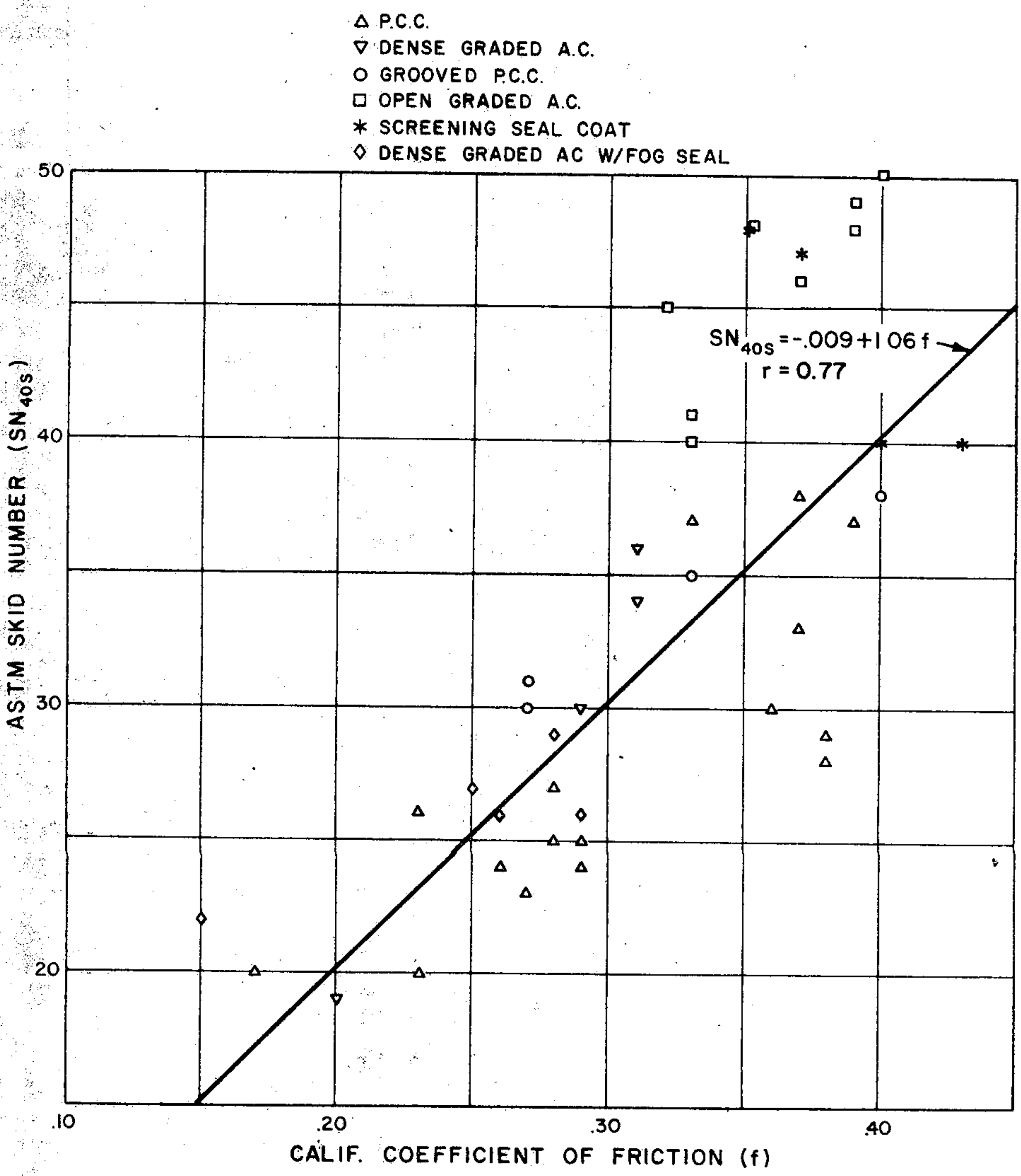


Figure 13

# CALIF. COEFFICIENT OF FRICTION VS ASTM SKID NUMBER

(SKID TESTER A WITH SMOOTH TIRE @ 50 MPH)

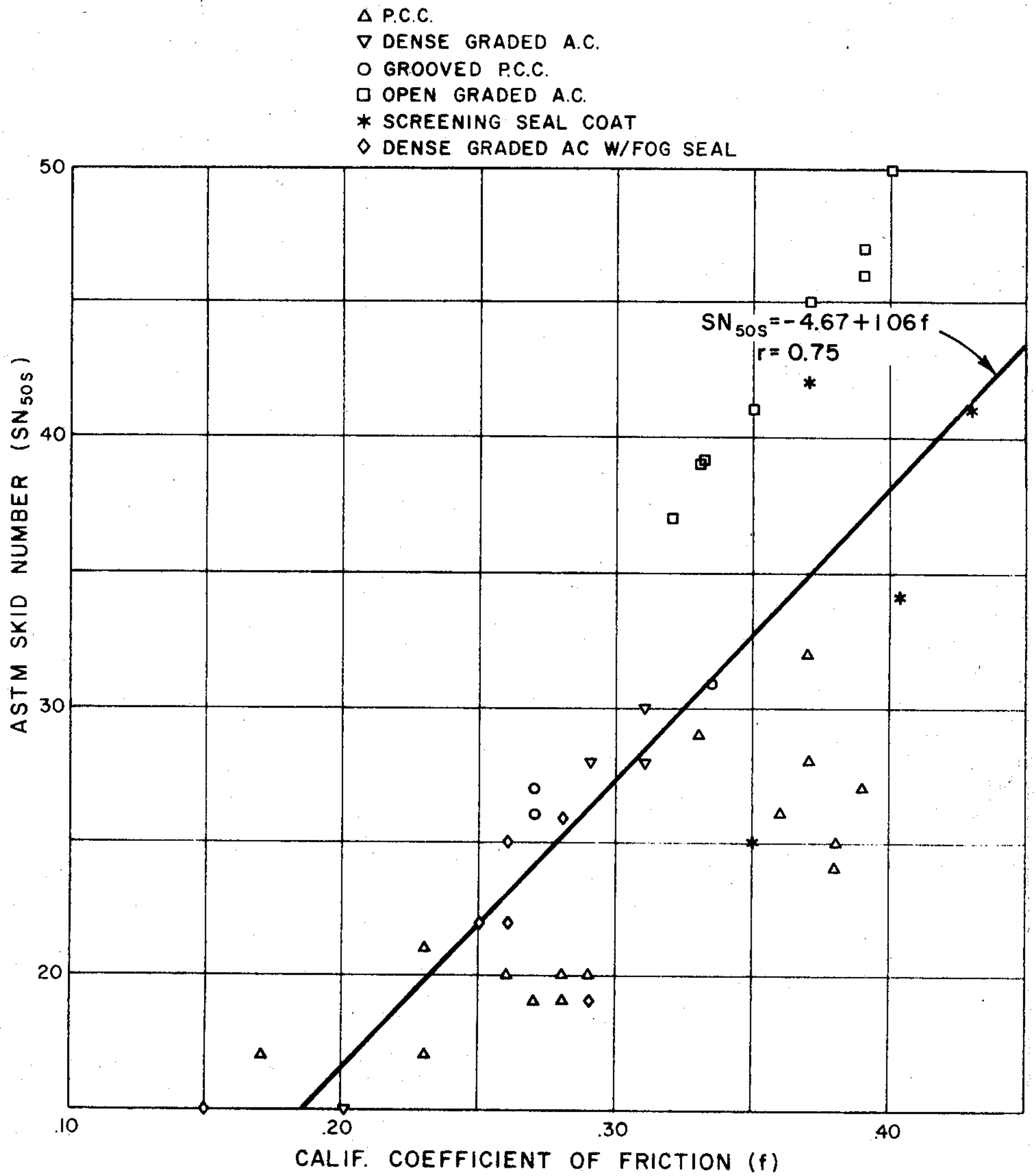
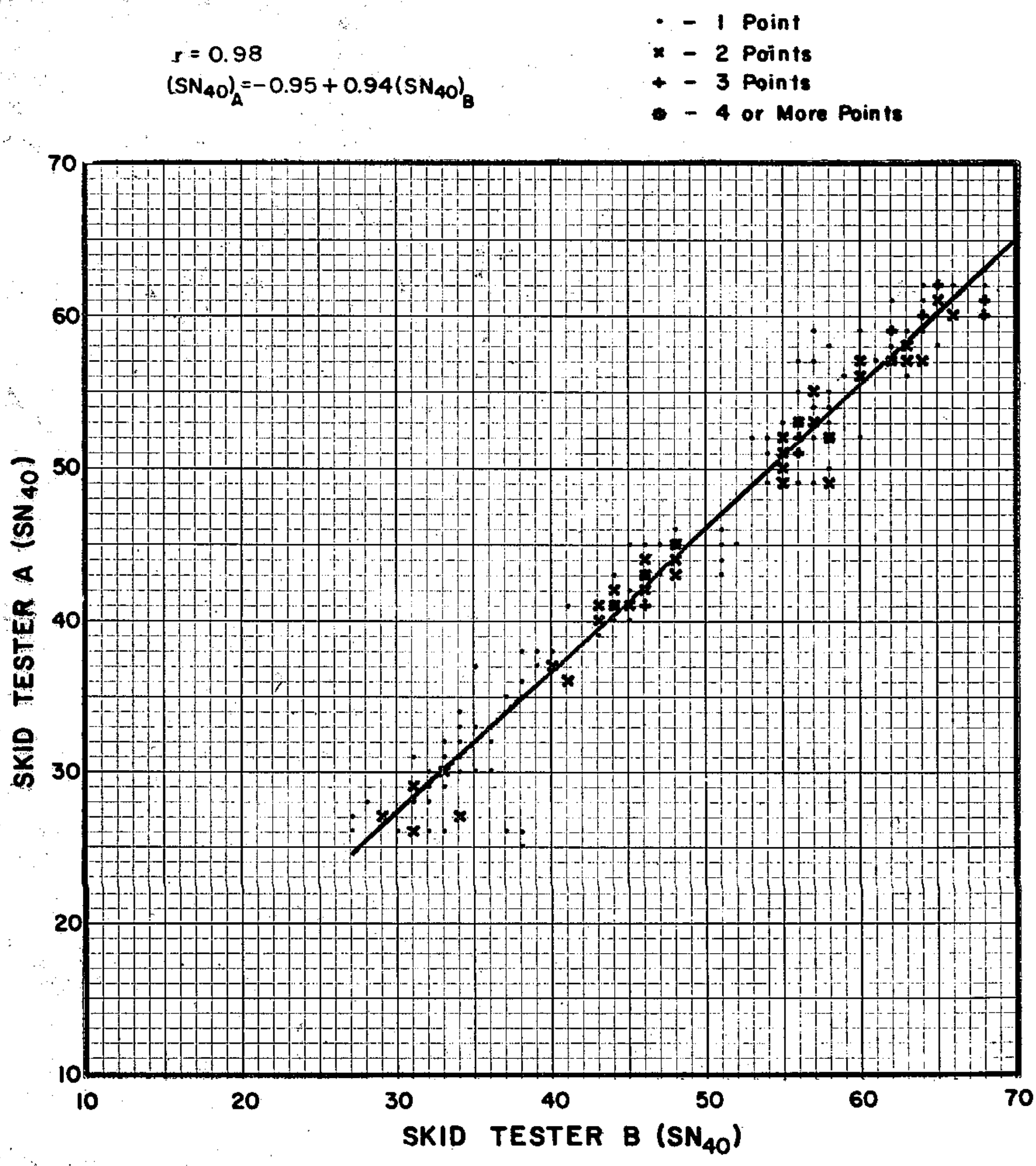


Figure 14

# CORRELATION CURVE
## SKID TESTER A VS SKID TESTER B
### RIBBED TIRE AT 40 MPH



# SKID TESTER A

## SKID NUMBER CONVERSION FOR VARIOUS SPEEDS ($SN_i$) TO SKID NUMBER AT 40 MPH ($SN_{40}$)

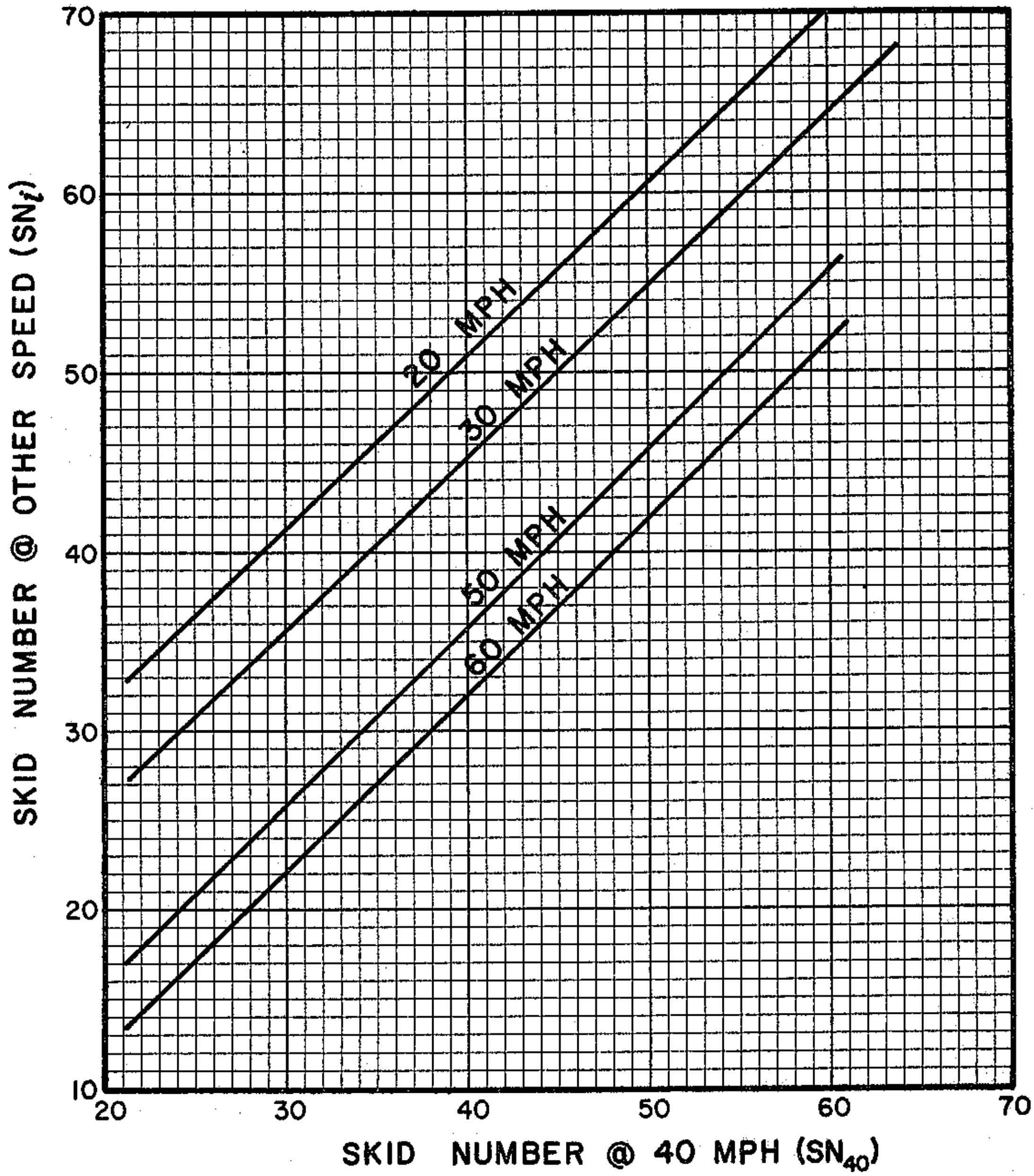


Figure 16

# SKID TESTER A

## SKID NUMBER CONVERSION FOR 20 MPH ($SN_{20}$) TO SKID NUMBER AT 40 MPH ($SN_{40}$)

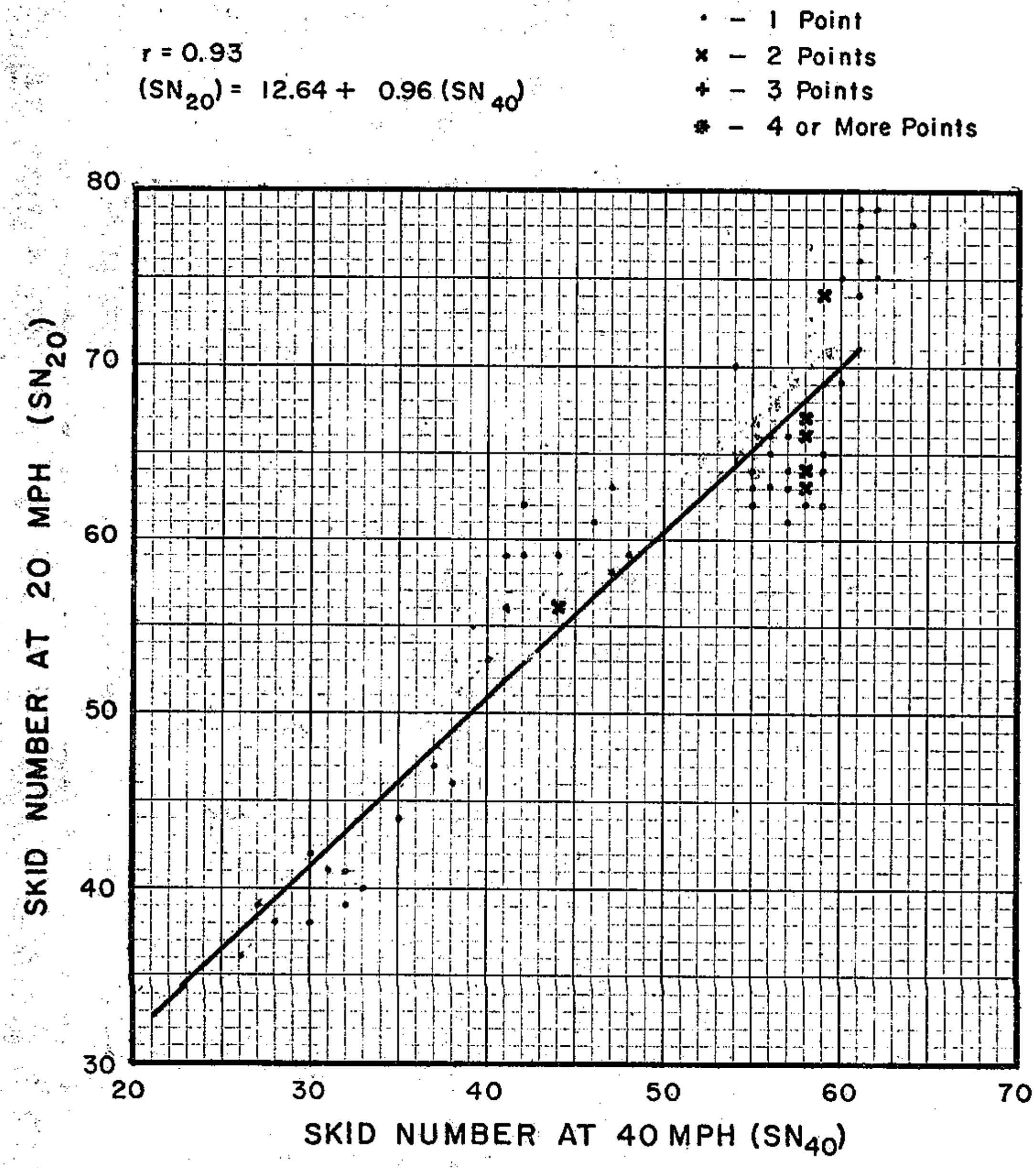


Figure 17

## SKID TESTER A

### SKID NUMBER CONVERSION FOR 30 MPH ($SN_{30}$) TO SKID NUMBER AT 40 MPH ($SN_{40}$)

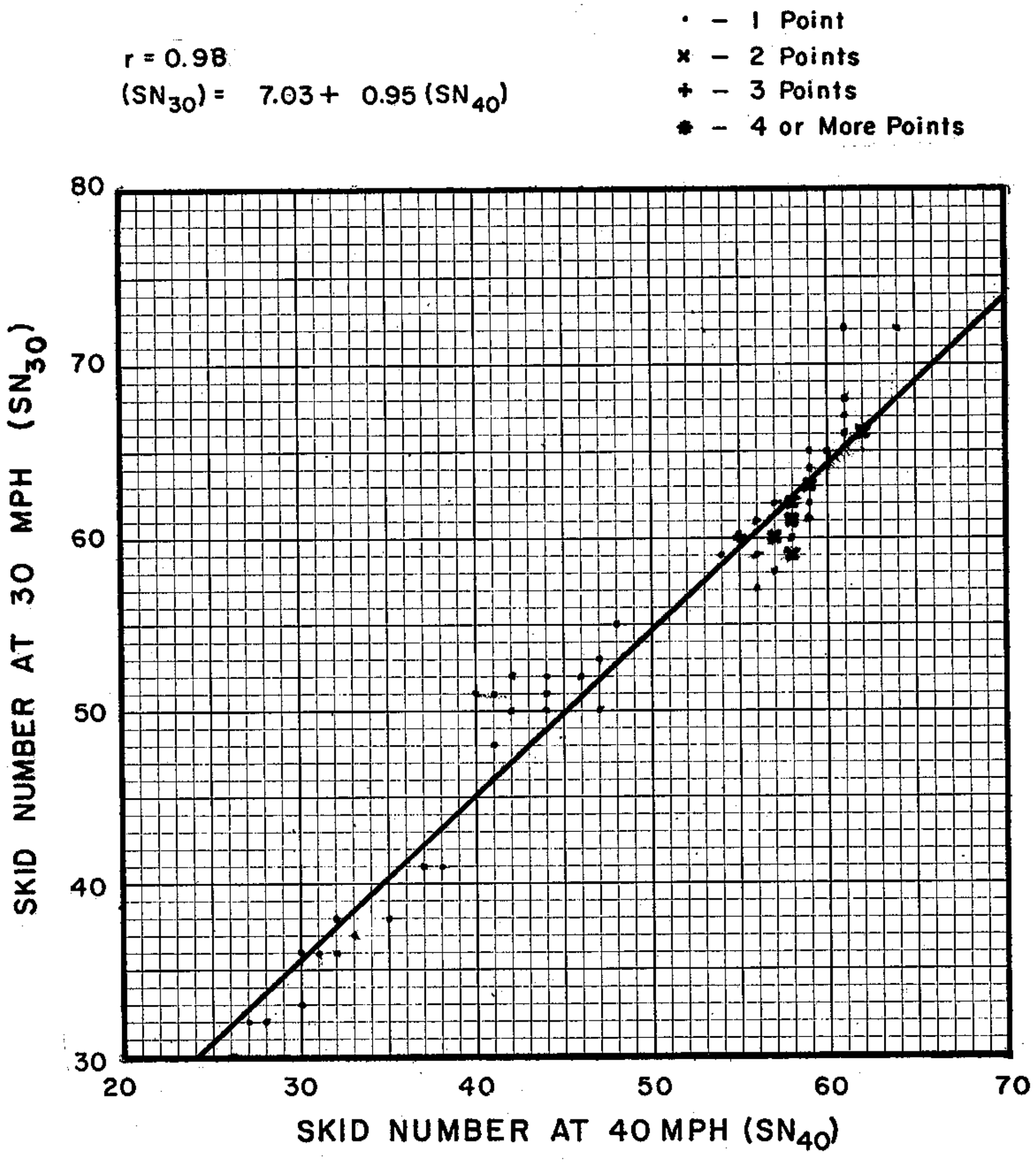
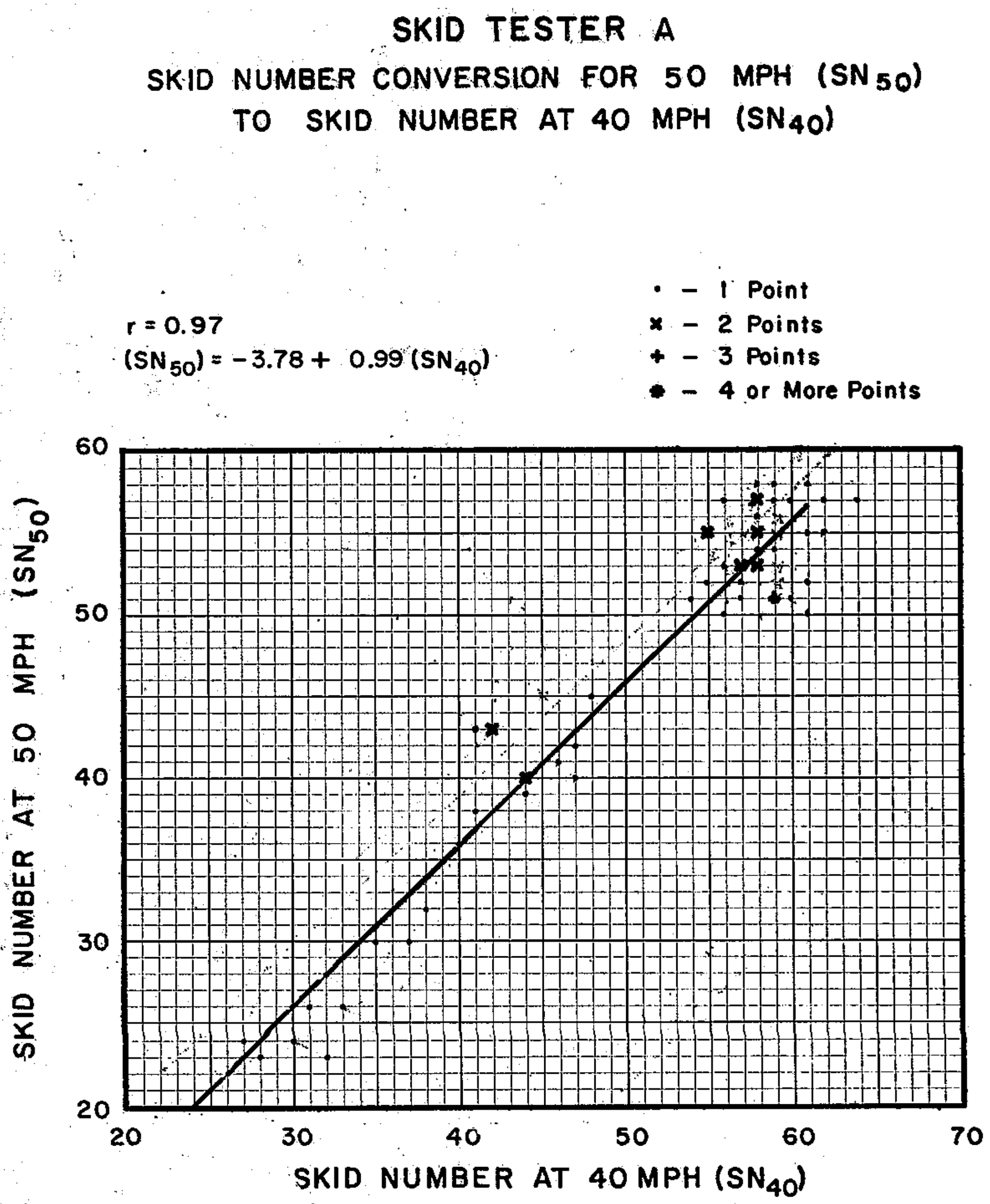


Figure 18



SKID TESTER A
SKID NUMBER CONVERSION FOR 50 MPH ($SN_{50}$)
TO SKID NUMBER AT 40 MPH ($SN_{40}$)
r = 0.97
($SN_{50}$) = −3.78 + 0.99 ($SN_{40}$)
• – 1 Point
✖ – 2 Points
✚ – 3 Points
✱ – 4 or More Points
60
50
40
30
20
20
30
40
50
60
70
SKID NUMBER AT 50 MPH ($SN_{50}$)
SKID NUMBER AT 40 MPH ($SN_{40}$)

Figure 19

## SKID TESTER A

### SKID NUMBER CONVERSION FOR 60 MPH ($SN_{60}$) TO SKID NUMBER AT 40 MPH ($SN_{40}$)

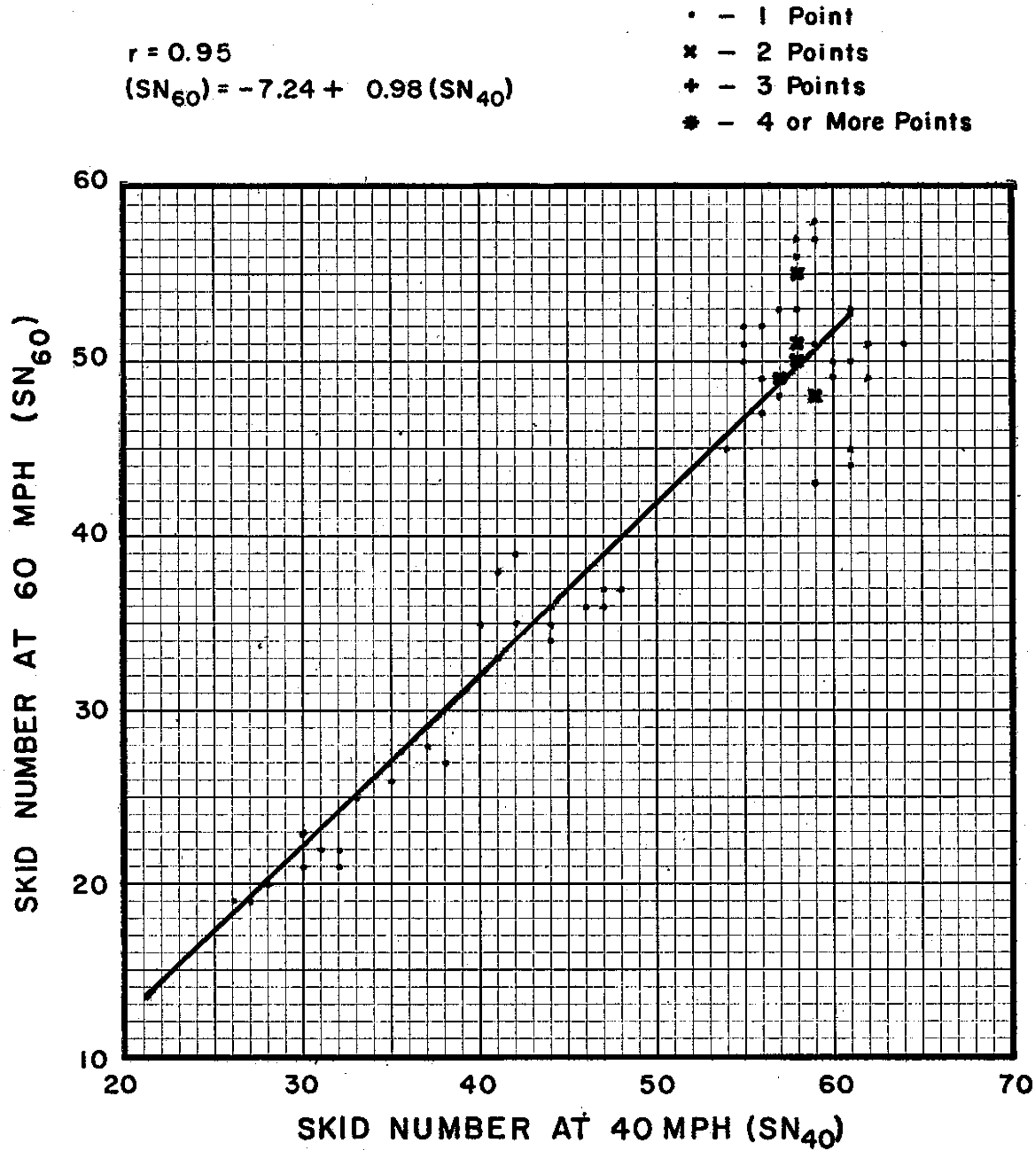


Figure 20

# SKID TESTER B

## SKID NUMBER CONVERSION FOR VARIOUS SPEEDS ($SN_i$) TO SKID NUMBER AT 40 MPH ($SN_{40}$)

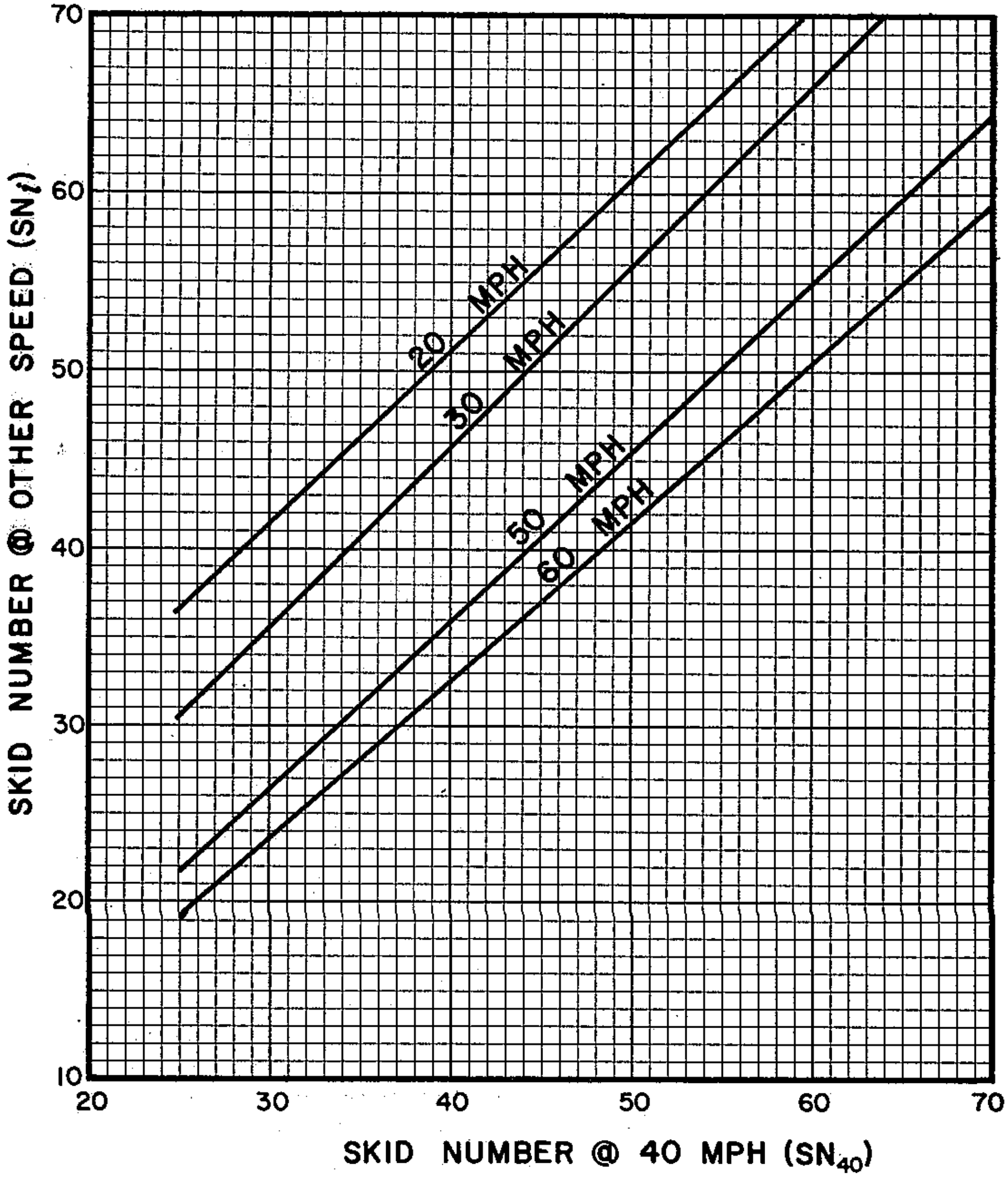


Figure 21

## SKID TESTER B

### SKID NUMBER CONVERSION FOR 20 MPH ($SN_{20}$) TO SKID NUMBER AT 40 MPH ($SN_{40}$)

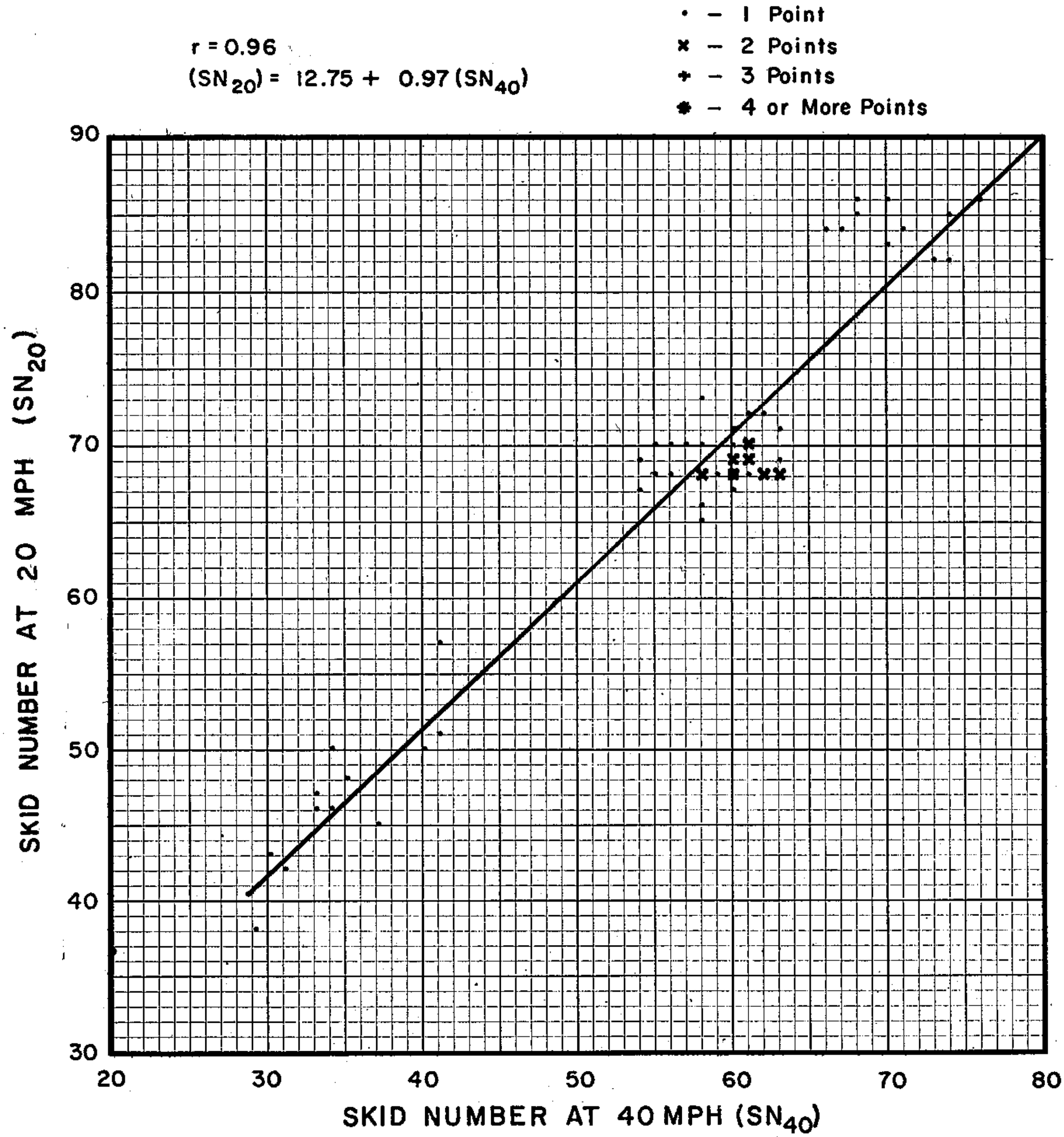


Figure 22

# SKID TESTER B

## SKID NUMBER CONVERSION FOR 30 MPH ($SN_{30}$) TO SKID NUMBER AT 40 MPH ($SN_{40}$)

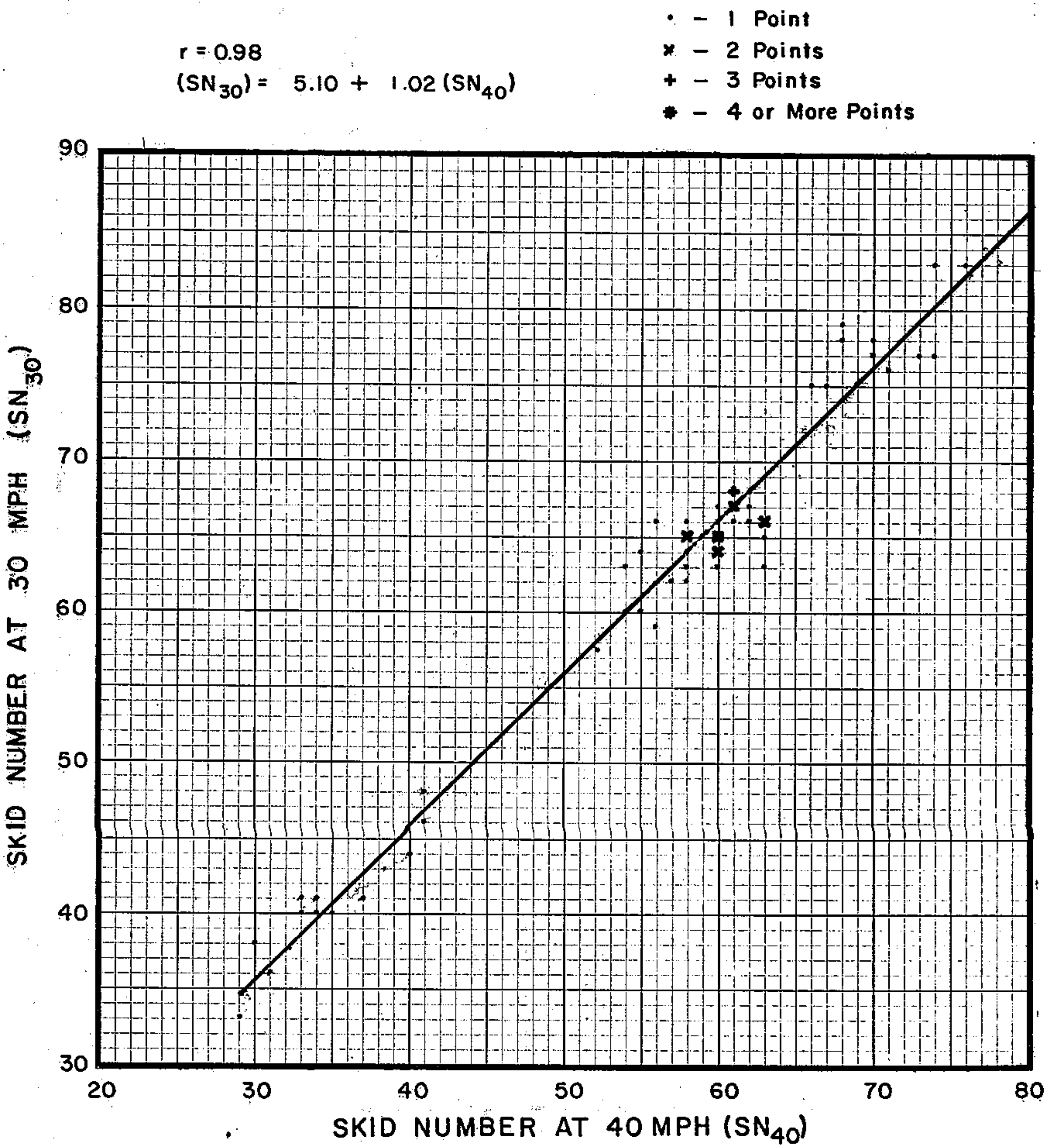


Figure 23

# SKID TESTER B

## SKID NUMBER CONVERSION FOR 50 MPH ($SN_{50}$) TO SKID NUMBER AT 40 MPH ($SN_{40}$)

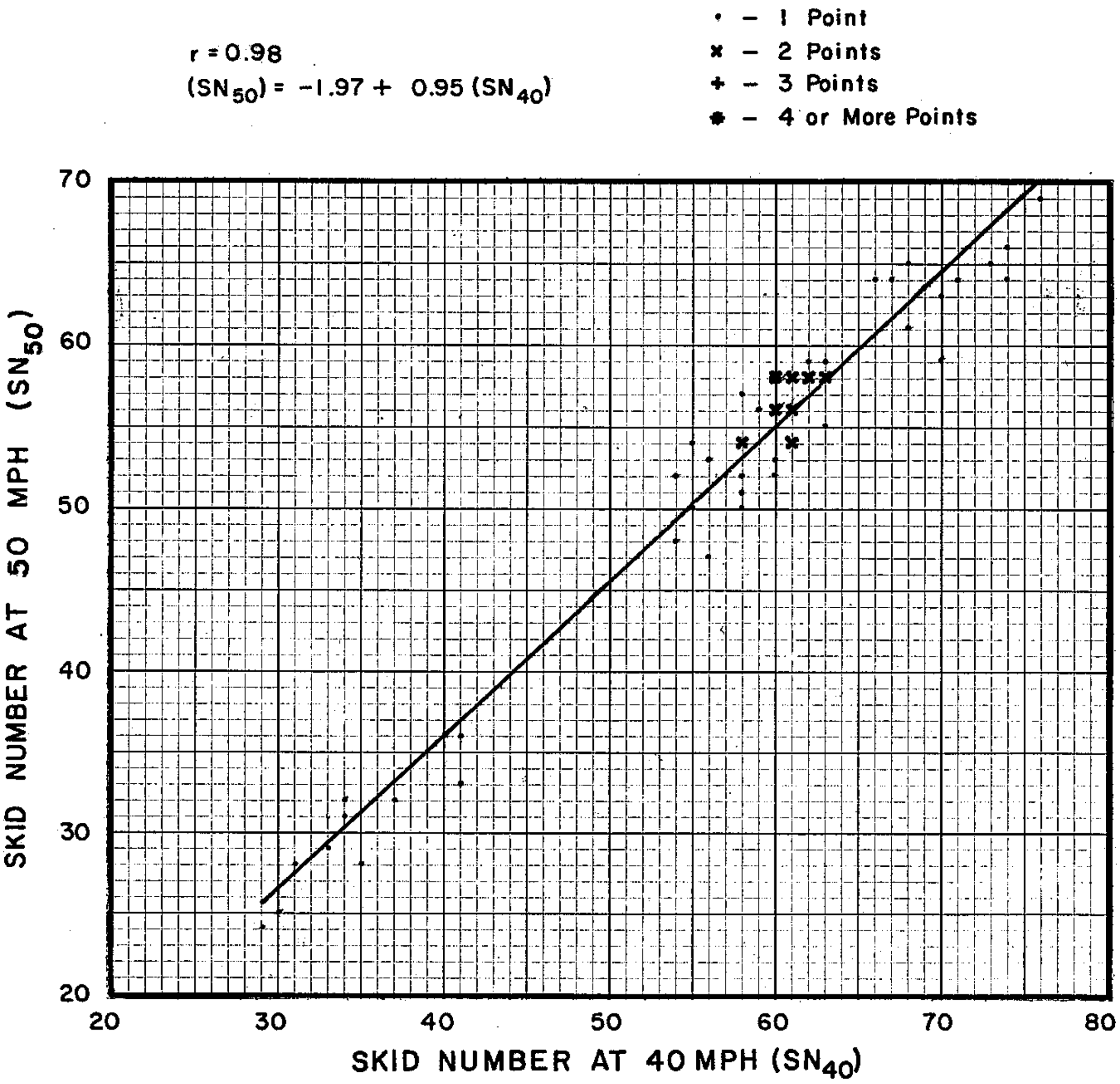
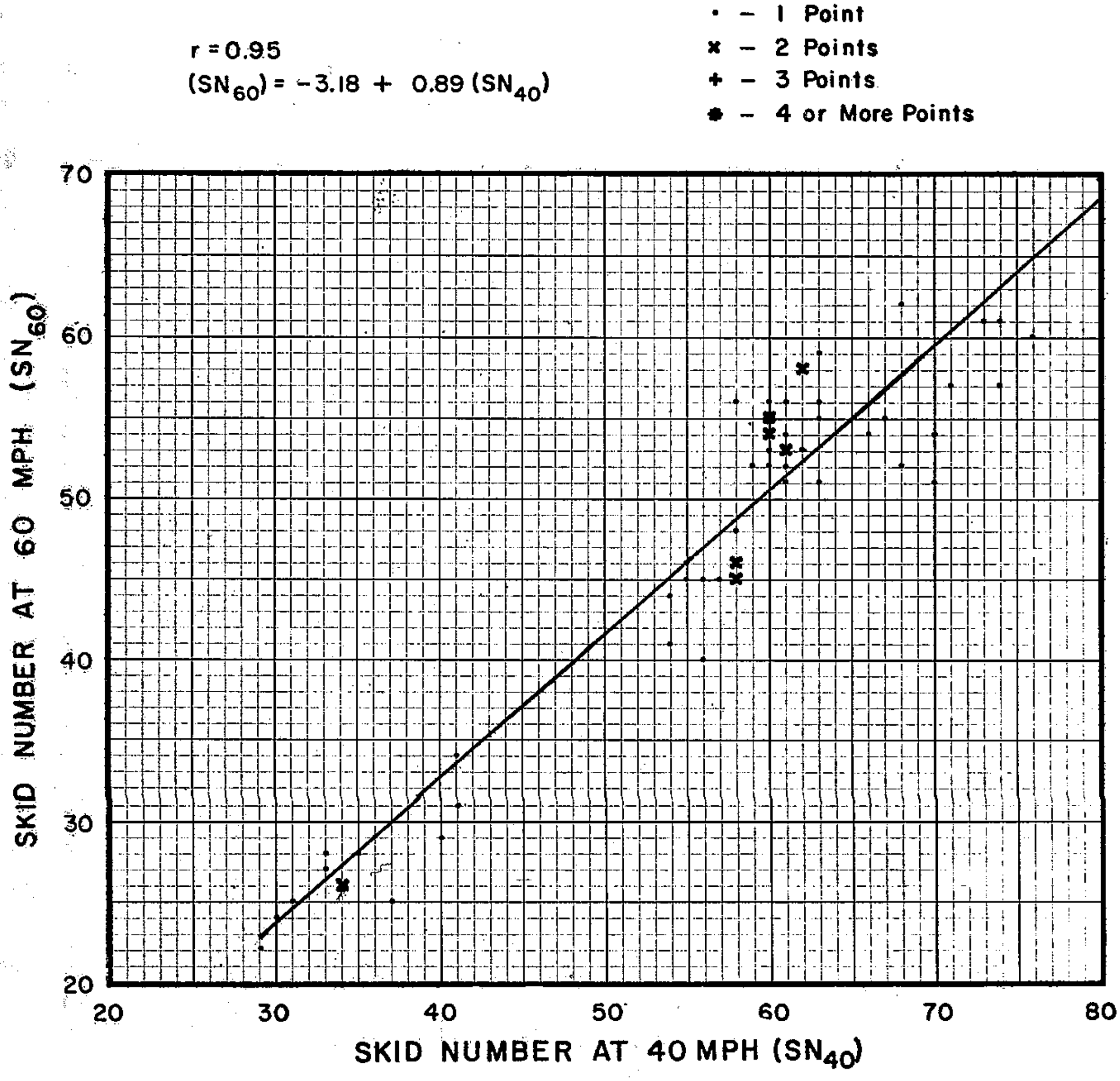


Figure 24

## SKID TESTER B

### SKID NUMBER CONVERSION FOR 60 MPH ($SN_{60}$) TO SKID NUMBER AT 40 MPH ($SN_{40}$)



APPENDIX

The Analysis of Variance (ANOVA II) for both skid testers on any one of the four different pavement types was calculated using the following variables:

$L_i$ = 4 = locations of tests, (R)

$O_j$ = 2 = operators, (F)

$T_{k(i)}$ = 6 = test sites within the locations, (R)

$S_l$ = 2 = skid testers, (F)

$\varepsilon_m$ = 2 = repetitions or error term,

Where, the letters R and F after the description of terms, stands for either a random or fixed variable. The operators are considered a fixed variable, as these two particular operators were selected among all the operators available because of their past experience, and the fact that they will be doing most of the future testing.

| | L<br>i<br>4 | O<br>j<br>2 | T<br>k<br>6 | S<br>l<br>2 | ε<br>m<br>2 | DF | EMS |
|---|---|---|---|---|---|---|---|
| $L_i$ | 1 | 2 | 6 | 2 | 2 | 3 | $\sigma^2(\varepsilon)+8\sigma^2(T)+48\sigma^2(L)$ |
| $O_j$ | 4 | 0 | 6 | 2 | 2 | 1 | $\sigma^2(\varepsilon)+4\sigma^2(OT)+24\sigma^2(LO)+96\sigma^2(O)$ |
| $LO_{ij}$ | 1 | 0 | 6 | 2 | 2 | 3 | $\sigma^2(\varepsilon)+24\sigma^2(LO)+4\sigma^2(OT)$ |
| $T_{k(i)}$ | 1 | 2 | 1 | 2 | 2 | 20 | $\sigma^2(\varepsilon)+8\sigma^2(T)$ |
| $OT_{jk(i)}$ | 1 | 0 | 1 | 2 | 2 | 20 | $\sigma^2(\varepsilon)+4\sigma^2(OT)$ |
| $S_l$ | 4 | 2 | 6 | 0 | 2 | 1 | $\sigma^2(\varepsilon)+4\sigma^2(TS)+24\sigma^2(LS)+96\sigma^2(S)$ |
| $LS_{il}$ | 1 | 2 | 6 | 0 | 2 | 3 | $\sigma^2(\varepsilon)+4\sigma^2(TS)+24\sigma^2(LS)$ |
| $OS_{jl}$ | 4 | 0 | 6 | 0 | 2 | 1 | $\sigma^2(\varepsilon)+2\sigma^2(OTS)+12\sigma^2(LOS)+48\sigma^2(OS)$ |
| $TS_{kl(i)}$ | 1 | 2 | 1 | 0 | 2 | 20 | $\sigma^2(\varepsilon)+4\sigma^2(TS)$ |
| $LOS_{ijl}$ | 1 | 0 | 6 | 0 | 2 | 3 | $\sigma^2(\varepsilon)+2\sigma^2(OTS)+12\sigma^2(LOS)$ |
| $OTS_{jkl(i)}$ | 1 | 0 | 1 | 0 | 2 | 20 | $\sigma^2(\varepsilon)+2\sigma^2(OTS)$ |
| $\varepsilon_{m(ijkl)}$ | 1 | 1 | 1 | 1 | 1 | 96 | $\sigma^2(\varepsilon)$ |

Variance between locations of tests:

$$T_{k(i)} = \sigma^2(\varepsilon)+8\sigma^2(T)$$

subtracting the error variance and dividing by 8 leaves $\sigma^2(T)$. This has to be added to error variance $[\sigma^2(\varepsilon)/96]$ to arrive at the total error between test sites, which is:

$$\sigma^2(T) = (T_{k(i)} - \sigma^2(\varepsilon)/96)/8 \quad +\sigma^2(\varepsilon)/96$$

ANOVA III

For both skid testers on the four different pavement types:

$L_i$ = 4 = locations of tests, (R)

$T_{j(i)}$ = 6 = test sites within the locations, (R)

$O_k$ = 2 = operators, (F)

$\varepsilon_{l(ijk)}$ = 2 = repetitions, (R)

| | L<br>i<br>4 | T<br>j<br>6 | O<br>k<br>2 | R<br>l<br>2 | DF | EMS |
|---|---|---|---|---|---|---|
| $L_i$ | 1 | 6 | 2 | 2 | 3 | $\sigma^2(\varepsilon)+4\sigma^2(T)+24\sigma^2(L)$ |
| $T_{j(i)}$ | 1 | 1 | 2 | 2 | 20 | $\sigma^2(\varepsilon)+4\sigma^2(T)$ |
| $O_k$ | 4 | 6 | 0 | 2 | 1 | $\sigma^2(\varepsilon)+2\sigma^2(TO)+12\sigma^2(LO)+48\sigma^2(O)$ |
| $LO_{ik}$ | 1 | 6 | 0 | 2 | 3 | $\sigma^2(\varepsilon)+2\sigma^2(TO)+12\sigma^2(LO)$ |
| $TO_{jk(i)}$ | 1 | 1 | 0 | 2 | 20 | $\sigma^2(\varepsilon)+2\sigma^2(TO)$ |
| $\varepsilon_{l(ijk)}$ | 1 | 1 | 1 | 1 | 48 | $\sigma^2(\varepsilon)$ |

In order to determine the average error between test sites we have:

$$T_{j(i)} = \sigma^2(\varepsilon)+4\sigma^2(T)$$

The contribution to variance caused by the test sites ($T_{j(i)}$) is:

$$[T_{j(i)} - \sigma^2(\varepsilon)/48]/4$$

this has to be added to the variance of the repetitions ($\varepsilon_{l(ijk)}$)

$$\text{Variance } \varepsilon_{l(ijk)} = \sigma^2(\varepsilon)/48$$

Therefore the total variance between test sites is:

$$(T_{j(i)} - \sigma^2(\varepsilon)/48)/4 \quad + \sigma^2(\varepsilon)/48$$