

SKID RESISTANCE STUDY

Phase Report

POLISH RESISTANCE OF
SELECTED NEW JERSEY AGGREGATES

by

Kathleen T. Diring

Principal Engineer

February, 1987

Prepared by

New Jersey Department of Transportation
Division of Research and Demonstration

In Cooperation with

U. S. Department of Transportation
Federal Highway Administration

DISCLAIMER STATEMENT

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the New Jersey Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

1. Report No. FHWA/NJ-86-016-7711	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Skid Resistance Study - Phase Report Polish Resistance of Selected New Jersey Aggregates		5. Report Date February, 1987	
		6. Performing Organization Code	
7. Author(s) Kathleen T. Diring, Principal Engineer		8. Performing Organization Report No.	
9. Performing Organization Name and Address Division of Research and Demonstration New Jersey Department of Transportation 1035 Parkway Avenue Trenton, NJ 08625		10. Work Unit No. (TRAIS) 86-016-7711	
		11. Contract or Grant No. NJ HPR Study 7711	
12. Sponsoring Agency Name and Address New Jersey Department of Transportation 1035 Parkway Avenue Trenton, NJ 08625		13. Type of Report and Period Covered Interim Report	
		14. Sponsoring Agency Code	
15. Supplementary Notes Prepared in cooperation with the Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.			
16. Abstract This report documents the laboratory portion of the Skid Resistance Study, which was devoted to the testing of New Jersey surface course aggregates using the British Polishing Wheel and Pendulum Tester. Analysis of the data indicated that the polishing rate for each aggregate could be characterized by an exponential function, where the minimum polish value was represented by the function's asymptote. The report presents the development of these models and recommends a field test program to relate SN ₄₀ to the polish values reported herein.			
17. Key Words Skid resistance, polish resistance, aggregates, polish value		18. Distribution Statement Copies available on request.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price

ACKNOWLEDGMENTS

The author would like to express her appreciation to Mr. John Salt for his assistance throughout this study. Mr. Salt's contributions in the laboratory, as well as in the field, were invaluable to the success of this project.

TABLE OF CONTENTS

	<u>Page</u>
1.0 OBJECTIVE	1
2.0 BACKGROUND	1
2.1 Study Needs	1
2.2 Laboratory Polishing Tests: State of the Art.....	3
3.0 SCOPE	7
3.1 Sampling	8
3.2 Preparation of Test Specimens	8
3.3 Accelerated Polishing Procedure	10
3.4 British Pendulum Test	10
3.5 Data Analysis.....	12
4.0 ANALYSIS OF FINDINGS	13
4.1 General	13
4.2 Model I	13
4.3 Model II.....	17
4.4 Comparison of Models	17
5.0 DISCUSSION OF RESULTS	21
6.0 CONCLUSIONS	26
7.0 RECOMMENDATIONS FOR FUTURE RESEARCH	27
7.1 Refine Laboratory Procedure	27
7.2 Define Relationship Between Laboratory Polish Value and Skid Number	27
7.3 Check Seasonal Adjustment	28
7.4 Develop Specification	28
8.0 REFERENCES	29
9.0 APPENDIX	A-1

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Polish Value Requirements	6
2	Model I Correlations	16
3	Model II Sum of Squared Residuals	19
4	Comparison of Models - Sum of Squared Residuals	22
5	Comparison of Models - Ultimate Polish Value Range at 95% Confidence Level	23
	PSV(n) for Carbonate Rocks	A-1
	PSV(n) for Gneiss	A-1
	PSV(n) for Trap Rocks	A-1
	PSV(n) for Argillites	A-2
	PSV(n) for Crushed Gravels	A-2

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	Preparation of Test Specimens	9
2	British Polishing Wheel	11
3	British Pendulum Tester	11
4	Typical Plot of Data	14
5	Conceptualized Model of Polishing Rate	15
6	Typical Model I Polish Curves	18
7	Typical Model II Polish Curves	20
8	Ultimate Polish Values at 95% Confidence Level	24

NOMENCLATURE

a	constants for Model I
b	
A	
B	constants for Model II
C	
$b_0, b_1, b_2,$	coefficients for Equation 2 (Reference 2)
b_3, b_4, b_5	
exp	exponential function (e)
SN_v	skid number measured at velocity V
SN_{40}	skid number measured at 40 mph (64 km/hr)
BPN	British Pendulum Number, a relative measure of skid resistance
V	vehicle speed in km/hr.
D	Texture depth in mm.
ADT	Average daily traffic, vehicles/day/lane
JDAY	Julian calendar day
DSF	Dry spell factor (days) = $\ln(R + 1)$; R is the number of days since the last rainfall of 0.1 inch or more.
AIRT	Air temperature at time of test, F.
T	Accumulated traffic/lane
LA	Los Angeles Abrasion Value
MTD	Mean texture depth, inches
n	hours of polishing
PSV(n)	Polished stone value in BPN at n hours
PVt	Texas Polish Value
PV	New Jersey Polish Value

1.0 OBJECTIVE

The ultimate goal of this study is to develop and implement a laboratory acceptance procedure to prequalify aggregates used in the Department's bituminous surface course mixes, based on their long-term skid resistant qualities. The first (laboratory) phase of the study is designed to achieve the following intermediate goals:

1. Refine method of accelerated polishing of aggregates.
2. Develop historical data base for New Jersey aggregates.
3. Develop a generalized model describing New Jersey aggregate polishing rates.

This phase report documents the work undertaken to achieve these goals.

2.0 BACKGROUND

2.1 Study Needs

The New Jersey Department of Transportation has been involved in the study of skid resistance continuously since 1967. Initial research efforts were concerned with the in-situ measurement of skid resistance on bituminous and concrete pavements. This work led to the identification of poor quality aggregate types, and subsequent restrictions on their use in surface course mixes. From 1973, research concentrated on the development of mix design gradations which would produce a greater surface texture, thereby increasing skid resistant characteristics. This work resulted in the I-4 mix, the open-graded mix, and the crushed gravel friction course. Monitoring into the 1980s of bituminous pavements using these mix designs led to further understanding of the complex relationships between microtexture, macrotexture, and skid resistance.

As part of the Department's continuing commitment to promote the highest standards in highway safety, this phase of the Skid Resistance Study has

been devoted to identifying high quality aggregates which enhance the skid resistance of bituminous surface course mixes. Currently, the New Jersey Department of Transportation's Bureau of Maintenance conducts a Pavement Skid Resistance Inventory Program which monitors skid resistance on the state highway system, using locked wheel skid test trailers in accordance with ASTM E-274. In New Jersey a skid number (SN_{40} ; 100 times the coefficient of friction between the locked test tire and the pavement measured at 40 mph) of less than 35 is considered to offer marginal protection to the average motorist under wet weather conditions. When a roadway exhibits this skid resistance level, together with other indicators of pavement slipperiness such as number of wet weather accidents or ratio of wet-to-total accidents, major rehabilitative measures are considered; i.e., surface treatment or friction course overlay. Thus, by increasing the skid resistant life of surface course mixes, maintenance and construction costs can be reduced, wet weather accident rates can be reduced, and highway safety preserved.

There are two generally accepted strategies for improving the long-term skid resistance of the roadway. The first technique -- one traditionally used in New Jersey -- is to modify the surface course mix design so as to provide the optimum macrotexture in the riding course. The second is to require the use of high quality, polish resistant aggregates which will provide durable aggregate texture in the riding course.

Although New Jersey is fortunate to have good quality aggregates available for pavements at present, previous work has identified some aggregates to be substandard in this regard. After many years of field testing, one class of aggregates, "carbonate rock", have been shown to yield less than acceptable skid resistant characteristics. Subsequently, aggregate sources have changed and relative skid resistance values have not been quantified. As new aggregate sources develop, it becomes less effective to rely on costly, time-consuming field tests to determine the polish resistance of aggregates.

This phase of the Skid Resistance Study focuses on the development of a laboratory test method which can be used to determine the polish resistance of aggregates at an accelerated rate. This method can be used to examine new aggregate sources and/or aggregate blends cost-effectively. This report presents the results of this laboratory work to date, as well as presenting a synthesis of the background information needed to discuss the relationships between laboratory and field parameters.

2.2 Laboratory Polishing Tests: State of the Art

The skid resistance of a pavement is dependent upon a number of factors, notably accumulated traffic, the surface texture, and the polish susceptibility of the aggregate. A simplistic explanation of the inter-relationship between these variables is that as the pavement is abraded by traffic, the aggregate becomes exposed and polished, and the skid resistance consequently deteriorates.

Research conducted at Texas Transportation Institute⁽¹⁾ indicates that this decline in skid resistance may be described mathematically in terms of accumulated traffic, polish value after nine hours of polishing, and LA Abrasion factor, as follows:

$$\text{Eqn 1: } \log SN_{40} = 1.526 - 0.0569 \log T + 0.0135 PV - 0.0030LA$$

Unfortunately, the coefficient of determination (R^2) reported for this relationship, 0.40, is indicative of a poor correlation and hence, a weak ability to predict losses in skid resistance. The coefficient of determination suggests that this model explains only 40% of the total variation in observed skid resistance values. The poor correlation with this model is attributed to the variety of factors which influence the measurement of SN_{40} , most notably seasonal variations and day-to-day weather conditions.

Importantly, research recently completed by Nittany Engineers and Management Consultants, Inc. for the FHWA holds considerable promise in accounting for these variations⁽²⁾. The cited study has resulted in a procedure for correcting skid resistance measurements made on any given day to an end-of-season minimum skid number, $SN_{40}(F)$, based on ADT, Julian calendar day (JDAY), dry-spell factor (DSF), and air temperature (AIRT).

$$\text{Eqn 2: } SN_{40}(F) = 1/b_1 (\ln SN_{40} - b_0 - b_2 \text{ ADT} - b_3 \text{ JDAY} - b_4 \text{ DSF} - b_5 \text{ AIRT})$$

A very good correlation, $R^2 = 0.86$ was obtained. As will be subsequently discussed, application of this type of analysis will be crucial to the development of a skid resistance model in New Jersey. (See Section 7.0.)

It is instructive at this point to briefly review other skid resistance models developed in New Jersey and elsewhere. Much of this research was directed at quantifying the relationship between microtexture, macrotexture, and skid resistance. Microtexture is defined as the surface roughness of individual aggregate particles, which depends largely on the mineral composition of the aggregate. The British Pendulum Test is the standard method used to measure microtexture. Macrotexture is a function of the aggregate gradation in the surface course mix and is measured in New Jersey using the modified sandpatch method. Two models relating these variables have been proposed^(3,4).

$$\text{Eqn 3: } SN_v = (1.38 \text{ BPN} - 31) \exp(-.0045 V(D)^{-0.47})$$

Where SN_v is the skid number measured at velocity, V, BPN is the British Pendulum Number and D is the macrotexture depth measured in millimeters.

Eqn 4: $SN_{40} = -16.87 + 0.54 \text{ BPN} + 0.50 \text{ MTD}$

Where SN_{40} is the skid number measured at 40 mph, BPN is the British Pendulum Number and MTD is the mean texture depth measured in inches.

New Jersey's model for skid resistance and texture (Eqn 5) is similar to that in Equation 4. A high degree of correlation was found for this relationship ($R^2 = 0.85$).

Eqn 5: $SN_{40} = 0.798 \text{ BPN} + 162.54 \text{ MTD} - 10.98$

It was expected that this regression model would be of value in relating laboratory measurements of aggregate texture to field measurements of overall pavement texture, but at present it is believed that the texture provided by the surface course matrix cannot be approximated by a laboratory measurement of aggregate microtexture over time. In other words, the influence of the aggregate on skid resistance is not paramount over the life of the pavement. Only after an initial period of service (measured by cumulative traffic), when the aggregate reaches maximum exposure does it become the controlling factor. Prior to this point, the macrotexture of the pavement surface controls skid resistance.

Once the surface course aggregate has been exposed by the wearing action of traffic, the polish resistance of the aggregate is essential to maintain the long term skid resistance of the pavement. The susceptibility of the aggregate to polishing may depend on its chemical composition, crystalline structure and geologic formation, or a variety of other factors too numerous or complex to test and/or specify. In order to identify the polishing characteristics of aggregates, an end-result type test has been used.

The British Polishing Wheel and Pendulum Tester, respectively, simulate and measure the polishing action of traffic on surface course aggregates at an accelerated rate. ASTM Specifications D-3319 and E-303 outline the procedures to be followed. According to a survey⁽⁵⁾ conducted in 1985 by ASTM Subcommittee D04.35, four states (Alabama, Louisiana, Texas, and West Virginia) currently use this method to prequalify polish resistant aggregates for use in surface course mixes. Table 1 shows the polish value requirements specified in these states.

TABLE 1
POLISH VALUE REQUIREMENTS

<u>STATE</u>	<u>MINIMUM POLISH VALUE</u>	<u>AVERAGE DAILY TRAFFIC</u>
TEXAS	NONE	0 - 749
	30	750 - 1999
	33	2000 - 4999
	35	5000 - OVER
	35	ALL INTERSTATE HIGHWAYS
ALABAMA	28	750 - 1500
LOUISIANA	35	ALL PAVEMENTS
WEST VIRGINIA	30	ALL PAVEMENTS

Generally, the procedure used to set these polish value requirements is to polish the aggregate samples on the British Polishing Wheel, making British Pendulum tests at periodic intervals, 0, 1, 2, 4 ... hours until the minimum BPN has been reached. In Texas and Louisiana, this value is defined as that measured after nine hours of accelerated polishing. It was anticipated that New Jersey aggregates would require a longer exposure to accelerated polishing in order to reach the ultimate polish value. Regional and geological factors which

determine the types of aggregates available are important in setting limitations on the polish resistance achievable. Fortunately, New Jersey has historically had a number of high quality aggregate sources available.

The previously cited Texas Transportation Institute study reports that:

"...it has been found that a reliable correlation does exist between the ultimate polish value of the aggregate reached in the laboratory test and the stable value of skid resistance reached in the field after several years of traffic (one million traffic applications)." (1)

Earlier work conducted in New Jersey, noting the decline in skid resistance over time, indicates that a stabilized skid resistance level, exclusive of seasonal variations and weather, is reached after approximately two million vehicle passes. These field studies (6, 7, 8) also revealed the relative skid resistance performance of carbonate rock, traprock, and crushed gravel.

This relationship between skid resistance, traffic, and polish value will prove helpful in applying the laboratory models to field conditions. For now, it is useful to keep in mind that accuracy in determining ultimate polish values for New Jersey aggregates is essential to the next step in the program.

3.0 SCOPE

The laboratory phase of the skid resistance study followed a five step program:

1. Sampling
2. Preparation of samples
3. Accelerated Polishing and Pendulum Testing
4. Data Analysis
5. Selection of Model

3.1 Sampling

Aggregate samples of #57 and #67 stone were gathered at each approved quarry in accordance with ASTM D75 and AASHTO No. T2. The aggregate samples were then assigned serial numbers for ease of reference; recording quarry sampled, date sampled, type of aggregate and Materials lab serial number (referencing an LB-9 "Report of Analysis of Aggregate"). Each sample was then sieved to produce a sample composed of a specified size aggregate (passing 1/2 inch, retained on 3/8 inch sieve). The aggregate sample was then washed, dried and stored for future test specimen preparation.

3.2 Preparation of Test Specimens

Polishing wheel test specimens were prepared in accordance with ASTM D3319 which entails the production of polyester resin-aggregate molds, which fit around the periphery of the accelerated polishing wheel. The molds (see Figure 1) are precoated with silicon spray, then wiped clean, so as not to contaminate the aggregate. A single layer of dry aggregate is placed by hand into each mold, so as to leave as few gaps between aggregates as possible.

A polyester resin material is then mixed according to the following formula:

Polyester Resin	300 grams
Wollastonite (CaSiO ₃)	90 grams
Aerosil (Colloidal Silica)	19 grams
6% Cobalt Naphthenate Solution	1.5 grams
MEK (OH) ₂ in Plasticizer	2.8 grams
Anhydrous Glycerol	1.0 ml.

This bonding agent is then spread over the aggregates, filling the mold. When the resin has cured properly (6-8 hours), the specimen is removed from the mold and the edges are dressed with a belt sander.

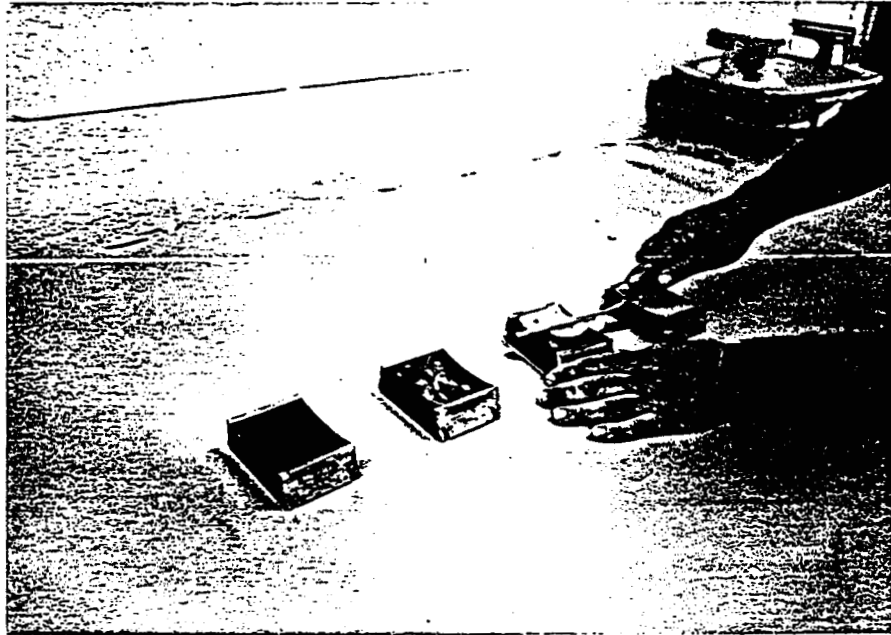


FIGURE 1: Preparation of Test Specimens

For each quarry, seven samples were prepared in this manner. Two sets of samples were polished at one time.

3.3 Accelerated Polishing Test Procedure

The British Polishing Wheel, manufactured by Wessex Engineering and Metalcraft Co. of Somerset, England is designed to simulate the polishing action of vehicular tires under conditions similar to those occurring on the surface of the roadway. The polishing wheel induces a polishing action by feeding a slurry of silicon carbide grit and water at the contact point between a hard solid rubber tire and the specimen wheel. (See Figure 2.) The specimen wheel rotates at a constant 320 rpm. The slurry is fed at a rate of 50 - 75 milliliters per minute with silicon carbide grit at 25 grams per minute. Specimens were removed from the polishing wheel at set intervals (1, 2, 4, 6, 8, 10 hrs., etc.) for testing with the British Pendulum Tester. Difficulty was encountered with test specimens breaking so that often the full complement of seven samples was reduced to four or five.

3.4 British Pendulum Test

The British Pendulum Tester is a dynamic pendulum impact tester which measures the energy loss when a rubber slider edge is propelled by gravity over the aggregate test specimen. (See Figure 3.) The values measured in the laboratory, PSV(n), describing the polished stone value after n hours of polishing, is a relative number which relates to the skid resistance of the exposed aggregates in a roadway surface at a given point in time.

After removal from the polishing wheel, each test specimen is cleaned thoroughly of all grit, then is locked into the specimen base. The pendulum tester is leveled and zeroed, the height of the pendulum is adjusted so as to

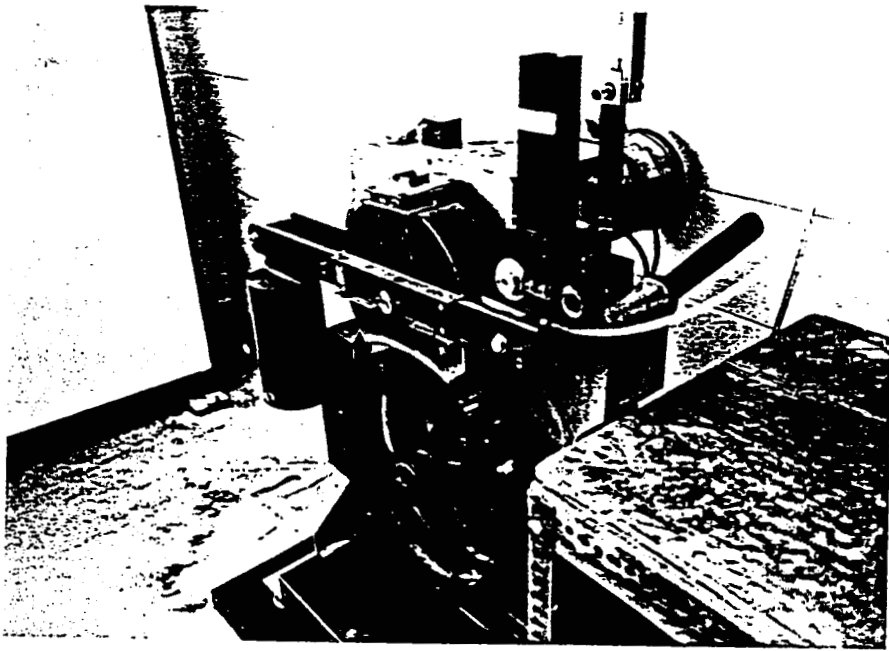


FIGURE 2: The British Polishing Wheel

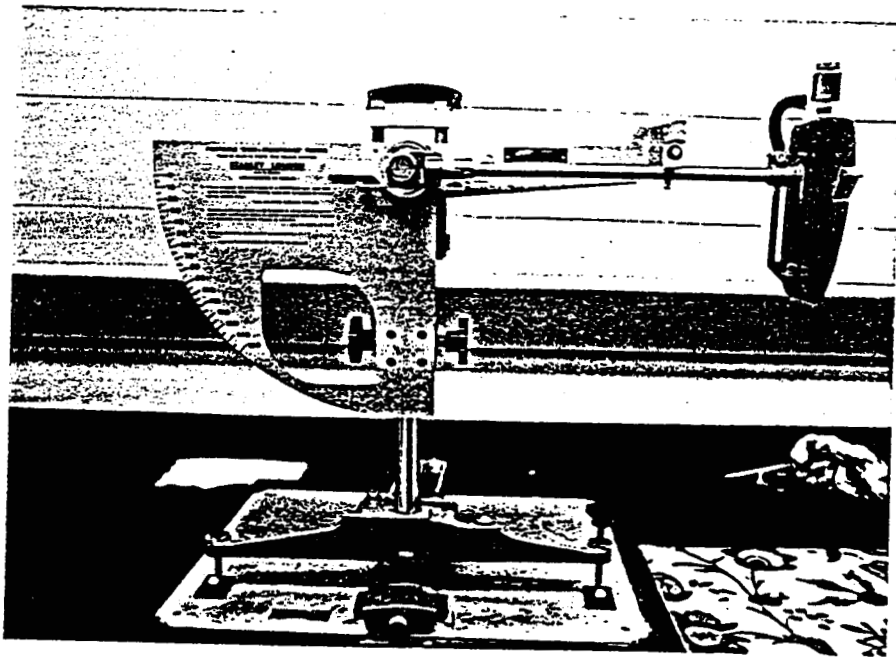


FIGURE 3: The British Pendulum Tester

impact the same area of the test specimen at each test, and a thin film of water is applied to the specimen. The pendulum is then released. The value obtained from the first swing of the pendulum is not recorded, to allow the rubber slider to self-adjust so that it will strike flush with the test specimen. Five swings are then made, and their values recorded. Temperature of the slurry and of the water film are recorded. Number of polishing wheel revolutions, hours of polishing, and initials of operator are recorded.

3.5 Data Analysis

The average of the five pendulum swings were calculated and the average of the seven samples were calculated. This value is designated as the PSV(n) where n equals hours of polishing. Originally, the samples were polished and tested at two-hour intervals until the polishing curve appeared to level off. Midway through collection of data, repeatability tests indicated that values obtained from the British Pendulum Tester were precise within a standard deviation of approximately 0.50 BPN, including operator-to-operator error. On the basis of this, a decision rule was developed that the samples would be polished and tested at two-hour intervals for ten hours, after which testing would continue until the difference between three successive readings was less than or equal to 0.5 BPN. Since two quarries were polished at one time, the test was continued until both met this criteria. These data are then used as input to various model regression equations in order to determine a mathematical relationship with acceptable correlations. For a given geologic type of aggregate, it was anticipated that similar curves would be developed.

4.0 ANALYSIS OF FINDINGS

4.1 General

Five different aggregate types were examined in this phase of the study; carbonate rock, traprock, argillite, gneiss, and crushed gravel. The results of the accelerated polishing test are presented in the Appendix. A preliminary examination of the data (see Figure 4) indicated that exponential mathematical models should be examined, as well as, a transformed linear model, in order to establish the form which best describes the relationship between PSV(n) and n. Each model examined describes a function which at $n = 0$, PSV(n) equals the intercept (the unpolished value) and as n becomes infinitely large, PSV(n) becomes asymptotic to the minimum polish value, PV. This conceptualized model is graphically depicted in Figure 5.

Analyses of the data were undertaken, using the Statistical Analysis System's (SAS) linear regression (GLM) and non-linear regression (NLIN) procedures. After a number of models were tested, two were found to be the best, having the greatest correlation coefficients and/or the least sum of the squared residuals.

4.2 Model I

Model I was developed as a linear regression of PSV(n) versus a simple transformation of the variable, n. Transformation of a variable to its inverse is a common technique used to promote regression analysis. In this case, in order to avoid dividing by zero, 1 is added to n, so that when $n = 0$, $\frac{1}{n + 1} = 1$.

$$\text{Model I: } \text{PSV}(n) = a + b (1/n + 1)$$

Application of this generalized model to each of the aggregates shows good correlation and is presented in Table 2. As shown in the table, the correlation coefficient for each aggregate source is high, on the average, greater than 0.90.

FIGURE 4

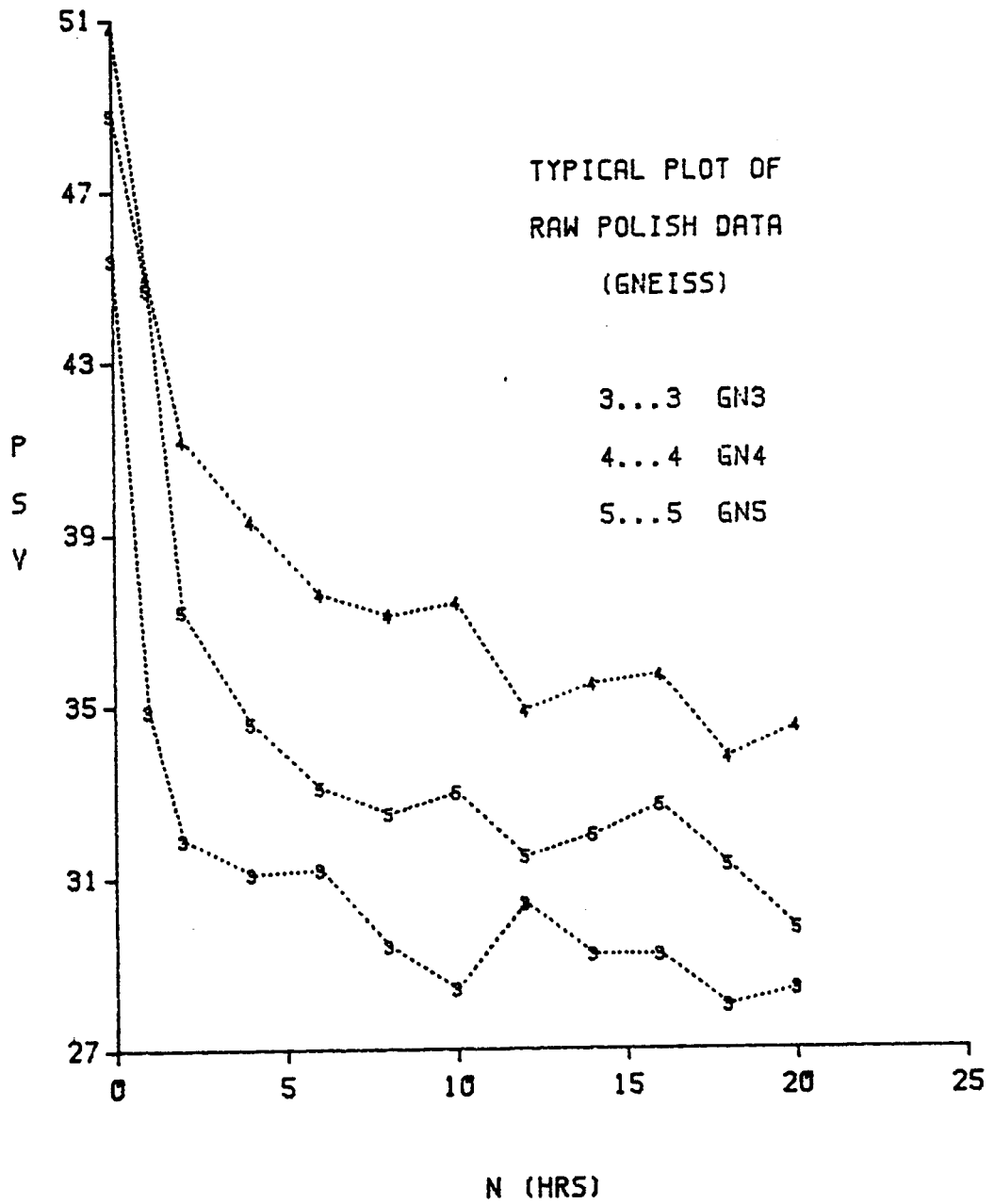


FIGURE 5

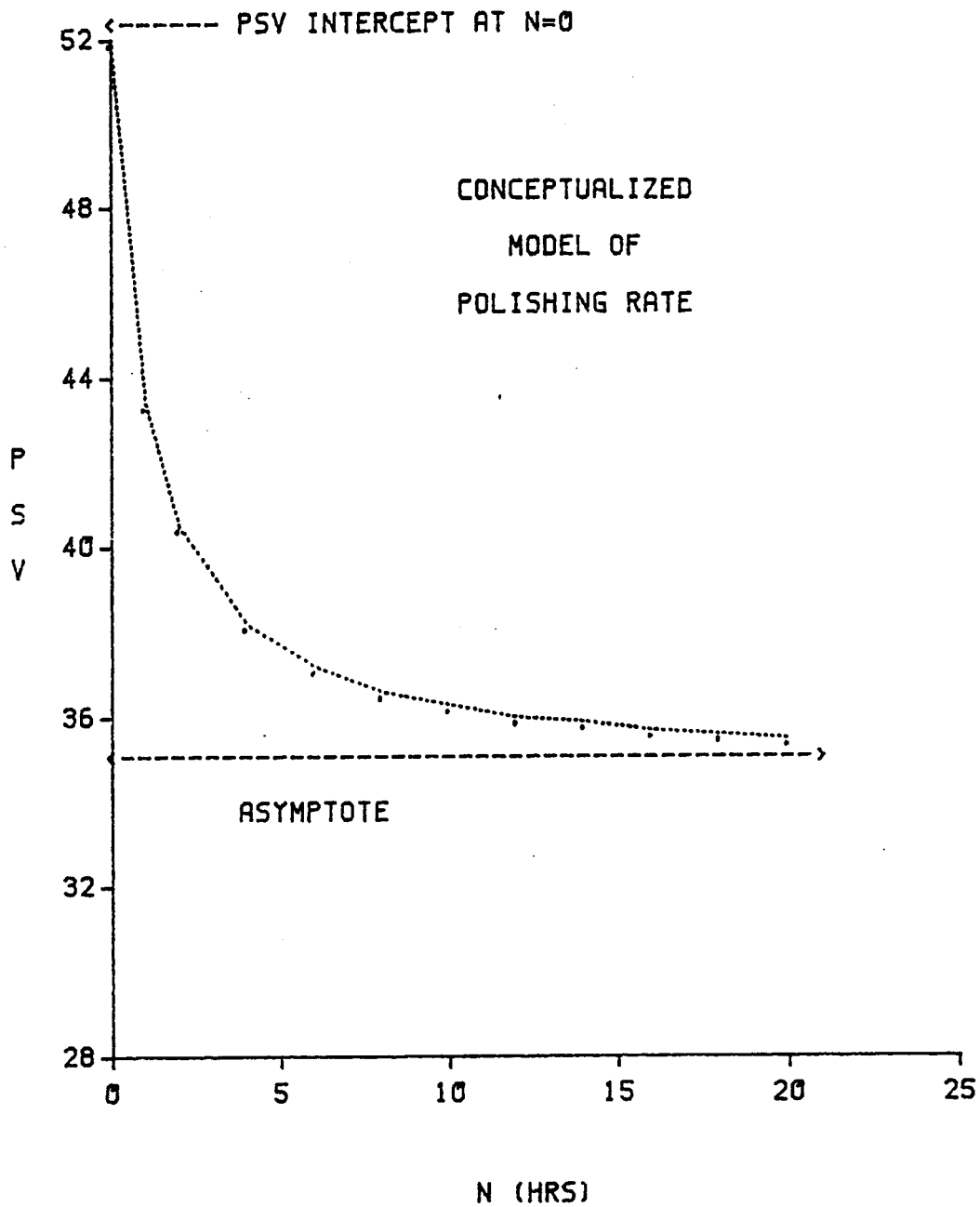


TABLE 2

MODEL I: $PSV(n) = a+b*(1/n+1)$

SAMPLE	a	b	R-SQUARE
CR1	24.0	20.7	.97
CR2	20.2	21.3	.91
CR3	19.1	22.8	.99
CR4	19.1	22.5	.99
GN1	27.5	17.8	.93
GN2	27.9	15.6	.98
GN3	27.7	16.8	.96
GN4	34.7	17.4	.95
GN5	30.6	20.0	.93
TR1	30.3	14.8	.98
TR2	25.9	18.7	.97
TR3	31.3	13.6	.95
TR4	30.3	16.4	.96
TR5	29.9	15.2	.86
TR6	29.7	16.9	.98
TR7	26.9	12.3	.93
ARG1	29.1	13.4	.93
ARG2	31.6	13.8	.96
ARG3	30.1	14.3	.86
ARG4	35.9	8.9	.96
ARG5	28.5	15.3	.96
CG1	34.8	12.6	.99
CG2	35.0	14.1	.81
CG3	34.0	13.1	.91
CG4	32.7	13.8	.94
CG5	34.4	16.2	.90
CG6	38.6	10.7	.83

The value of the constant, a, representing the asymptote of the curve and the minimum polish value, PV, for each aggregate indicates a similarity for aggregates of the same type. Figure 6 shows typical Model I polish curves for aggregates of the same type.

4.3 Model II

Model II represents a more conventional form for data of this type. This model required the use of non-linear regression techniques on the equation:

$$\text{Model II: } \text{PSV}(n) = B + (A - B) \exp(Cn) \quad C < 0$$

The SAS non-linear regression procedure requires that estimates be made for each of the constants, A, B, and C. In this model, A represents the value for PSV(n) when $n = 0$, B represents the value for PSV(n) when n is infinitely large (the asymptote), and C represents the rate of decline of PSV(n) versus n . The SAS program modifies each constant by small increments, testing the sum of the squared residuals (the difference between the observed and the predicted values) for a minimum value. Correlation coefficients are not available in this type of analysis, so it is more difficult to analyze the computer generated output. However, in this type of analysis, the sum of the squared residuals were compared with those of other models. Model II represents the best exponential form for these data. The similarity between the asymptote, B, for each aggregate type is noticeable, as shown in Table 3. Figure 7 shows typical Model II polish curves for aggregate of the same type.

4.4 Comparison of Models

Two techniques were employed to compare Models I and II in order to determine which model best describes the data for each aggregate type. The first technique used compares the sum of the squared residuals from each model.

FIGURE 6

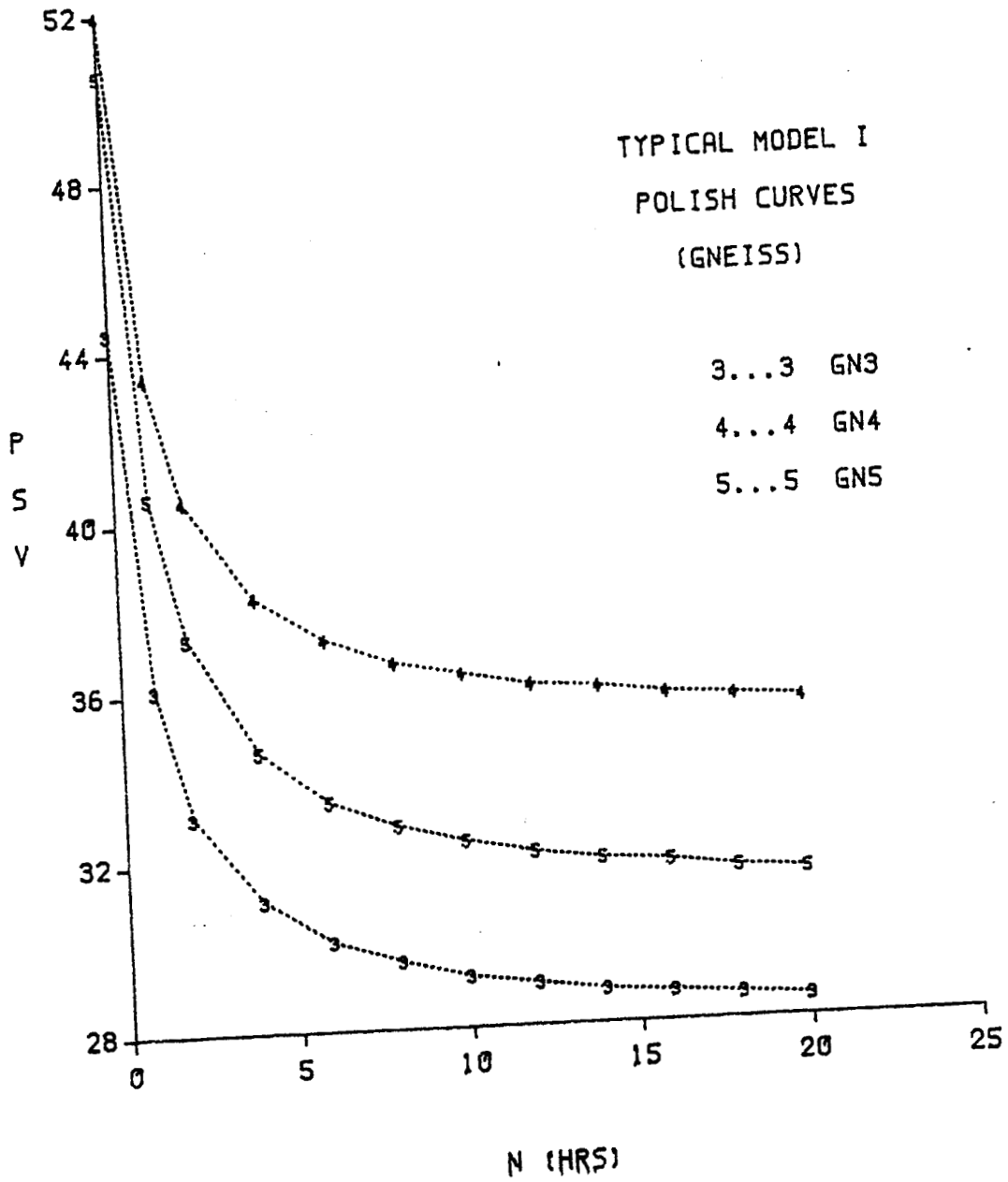
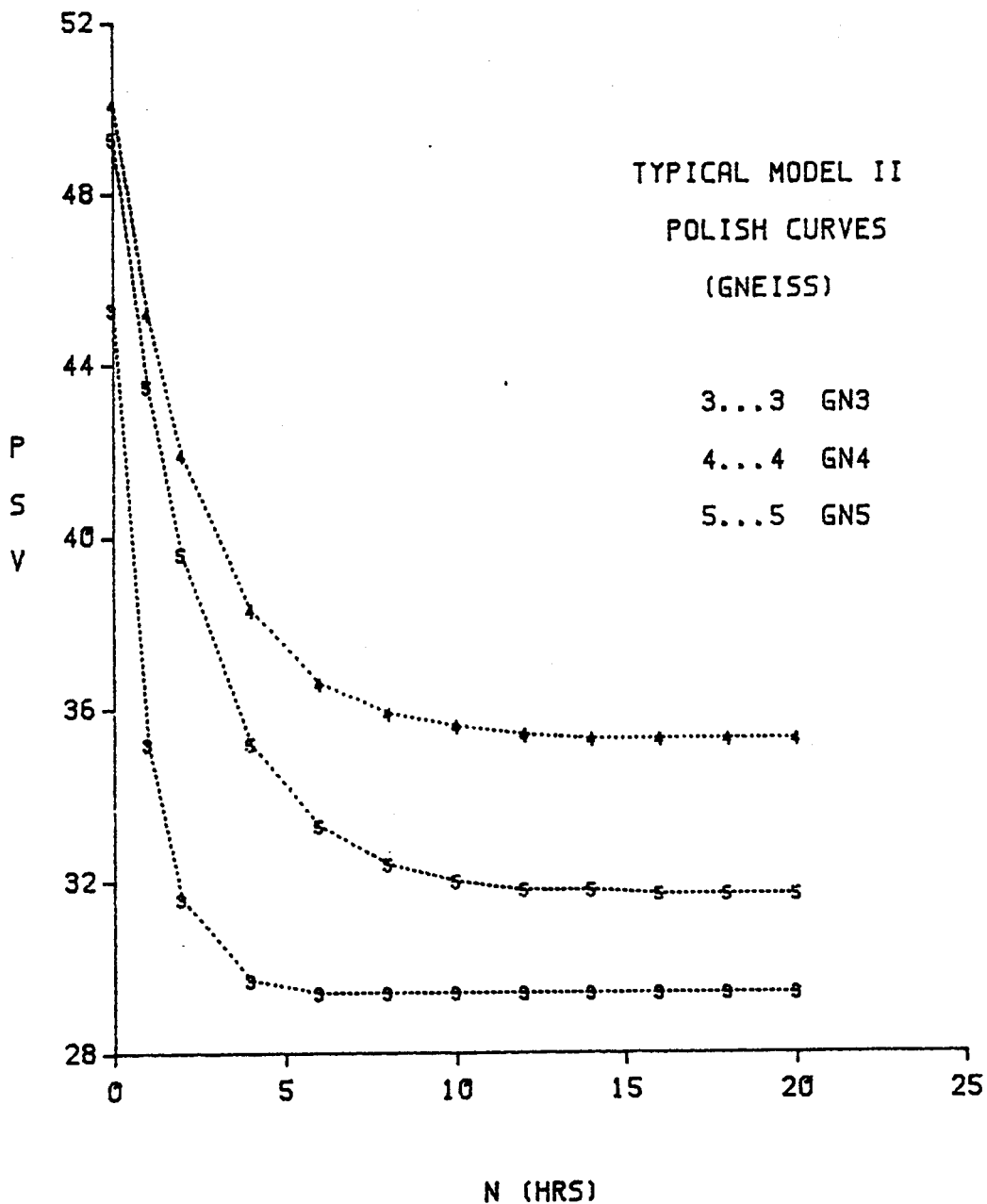


TABLE 3

$$\text{MODEL II: } \text{PSV}(n) = B + (A - B)\exp(Cn)$$

SAMPLE	A	B	C	SUM OF SQUARED RESIDUALS
CR1	45.6	26.9	-1.1	8.47
CR2	43.2	23.3	-1.4	22.73
CR3	42.0	21.8	-0.8	5.81
CR4	41.3	21.6	-0.7	8.56
GN1	43.6	28.5	-0.5	32.89
GN2	43.5	29.2	-0.8	9.47
GN3	45.3	29.4	-1.0	10.33
GN4	50.1	35.3	-0.4	10.45
GN5	49.3	31.7	-0.4	12.42
TR1	45.3	31.8	-0.8	7.20
TR2	43.5	27.4	-0.6	20.65
TR3	43.4	32.0	-0.4	10.91
TR4	46.2	31.7	-0.6	12.42
TR5	42.6	30.0	-0.3	33.88
TR6	46.8	32.1	-0.9	7.04
TR7	37.5	26.8	-0.3	4.83
ARG1	43.2	30.6	-1.0	10.25
ARG2	45.6	33.0	-0.9	9.48
ARG3	44.9	31.9	-1.0	27.01
ARG4	44.5	36.7	-0.6	3.94
ARG5	44.8	30.9	-1.3	5.56
CG1	47.6	36.6	-0.9	2.45
CG2	45.9	33.8	-0.2	24.55
CG3	46.6	35.2	-0.6	18.48
CG4	45.2	33.5	-0.4	12.17
CG5	52.1	36.7	-1.3	9.91
CG6	47.8	37.0	-0.2	6.59

FIGURE 7



In order to make a comparison of this type, the data was manipulated so that for each aggregate type, a constant sample size was chosen. The results of this comparison is shown in Table 4. On the average, there is no significant difference in the sum of the squared residuals between the two models.

The second technique used was to determine the 95 percent upper and lower confidence limits about the asymptote given for each of the two models. The models with the narrowest confidence limit band (within two standard deviations) would seem to be that which is more accurate to use for values of $PSV(n)$ when n is infinitely large; i.e., the "true" minimum polish value, PV. These results are presented in Table 5.

The results shown in Table 5 indicate that Model II more accurately defines the PV, minimum polish value, for each aggregate source. For the aggregate types tested, the PV has been pinpointed within an average of ± 1.7 BPN, at the 95% confidence level.

5.0 DISCUSSION OF RESULTS

Having selected Model II as that which most accurately describes the polishing curves under study, the aggregate sources can be ranked according to their polish resistance. The range for the minimum polish value, PV, at the 95% confidence level is illustrated in Figure 8. The overall ranking of PV for each aggregate type is as follows:

<u>Aggregate Type</u>	<u>Polish Value Range</u>
Carbonate Rock	20 - 28
Traprock	25 - 34
Gneiss	27 - 36
Argillite	30 - 37
Crushed Gravel	30 - 43

TABLE 4
 COMPARISON OF MODELS: SUM OF SQUARED RESIDUALS

SAMPLE	n	MODEL I: SUM OF SQUARED RESIDUALS	MODEL II: SUM OF SQUARED RESIDUALS
CR1	12	8.52	8.47
CR2	12	31.35	16.12
CR3	12	2.50	5.81
CR4	12	3.23	8.56
GN1	20	20.05	32.27
GN2	20	4.39	9.47
GN3	20	8.87	10.33
GN4	20	13.41	10.45
GN5	20	25.07	12.42
TR1	14	2.78	7.20
TR2	14	9.33	18.91
TR3	14	6.43	9.54
TR4	14	8.00	12.20
TR5	14	21.60	27.18
TR6	10	8.36	4.83
TR7	14	3.86	7.04
ARG1	12	6.88	4.92
ARG2	12	5.83	7.41
ARG3	12	6.95	0.95
ARG4	12	2.34	3.94
ARG5	12	7.59	5.56
CG1	10	1.40	2.45
CG2	16	31.80	24.00
CG3	16	13.24	18.48
CG4	16	9.06	12.17
CG5	14	21.91	9.91
CG6	10	14.88	6.59

TABLE 5
COMPARISON OF MODELS: ULTIMATE POLISH VALUE RANGES

SAMPLE	MODEL I: POLISH VALUE AT 95% CONFIDENCE	MODEL I: POLISH VALUE RANGE	MODEL II: POLISH VALUE AT 95% CONFIDENCE	MODEL II: POLISH VALUE RANGE
CR1	21.0-27.5	6.5	25.4-28.5	3.1
CR2	14.8-26.0	11.2	21.3-25.2	3.9
CR3	17.6-21.1	3.5	20.5-23.2	2.7
CR4	17.3-21.4	4.1	19.9-23.3	3.4
GN1	24.5-30.8	6.3	27.0-30.0	3.0
GN2	26.4-29.6	3.2	28.5-30.1	1.6
GN3	25.6-30.1	4.5	28.6-30.2	1.6
GN4	32.1-37.6	5.5	34.3-36.4	2.1
GN5	27.1-34.6	7.5	30.6-32.7	2.1
TR1	28.9-32.0	3.1	30.9-32.6	1.7
TR2	23.6-28.6	5.0	25.9-28.9	3.0
TR3	28.9-33.8	4.9	30.5-33.4	2.9
TR4	27.9-32.9	5.0	30.4-33.0	2.6
TR5	25.6-34.5	8.9	27.2-32.8	5.6
TR6	-----	---	30.1-34.1	4.0
TR7	24.1-29.8	5.7	25.2-28.5	3.3
ARG1	26.5-31.9	5.4	29.6-31.5	1.9
ARG2	29.7-33.7	4.0	32.1-33.9	1.8
ARG3	25.4-35.1	9.7	29.7-34.1	4.4
ARG4	34.3-37.7	3.4	35.5-38.0	2.5
ARG5	25.6-31.8	6.2	29.7-32.1	2.4
CG1	33.4-36.5	3.1	35.4-37.8	2.4
CG2	30.6-39.7	9.1	31.1-36.6	5.5
CG3	30.9-37.4	6.5	33.6-36.9	3.3
CG4	30.2-35.5	5.3	32.0-35.0	3.0
CG5	30.0-39.1	9.1	35.4-37.9	2.5
CG6	33.6-43.8	10.2	30.1-43.9	13.8

FIGURE 8

ULTIMATE POLISH VALUES(PV) AT 95% CONFIDENCE LEVELS

SAMPLE	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	
CR1						XXXXXXXXXXXX																				
CR2		XXXXXXXXXXXXXXXXXXXXXXXXXXXX																								
CR3	XXXXXXXXXXXX																									
CR4	XXXXXXXXXXXX																									
GN1								XXXXXXXXXXXXXXXXXXXX																		
GN2									XXXXXXXXXXXX																	
GN3										XXXXXXX																
GN4																	XXXXXXX									
GN5												XXXXXXX														
TR1												XXXXXXX														
TR2							XXXXXXXXXXXX																			
TR3												XXXXXXXXXXXX														
* TR4												XXXXXXXXXXXX														
TR5								XXXXXXXXXXXXXXXXXXXXXXXXXXXX																		
* TR6												XXXXXXXXXXXXXXXXXXXX														
TR7						XXXXXXXXXXXX																				
** ARG1												XXXX														
ARG2													XXXXXXX													
ARG3													XXXXXXXXXXXXXXXXXXXX													
ARG4																							XXXXXXX			
** ARG5													XXXXXXXXXX													
*** CG1																								XXXXXXXXXXXX		
*** CG2													XXXXXXXXXXXXXXXXXXXXXXXXXXXX													
*** CG3														XXXXXXXXXXXX												
*** CG4													XXXXXXXXXXXX													
*** CG5																								XXXXXXXXXXXX		
*** CG6																										XX

* Samples from the same quarry(TR4 extracted, TR6 stockpiled)
 ** Samples from the same quarry(ARG1 sampled 1983, ARG5 sampled 1984)
 *** Multiple samples from the same stockpile

Immediately evident is that on the average, the crushed gravel samples exhibit high PVs and the carbonate rock samples exhibit low PVs. Traprocks, gneiss, and argillites are distributed within the intermediate ranges.

These results are not surprising. Drawing on New Jersey's experience with skid resistance, it is well documented that crushed gravel mixes yield superior skid resistance, while carbonate rock mixes provide marginal skid resistance over the long term^(7,8). Currently, New Jersey Standard Specifications require that either open graded mix or crushed gravel (containing no more than 10% total carbonates) be used when bituminous concrete friction course is specified. In general, carbonate rock is excluded from use as coarse aggregate in surface course mixes⁽⁹⁾. Therefore, the results obtained in this phase of the study support New Jersey's current specifications.

However, the range of PVs obtained for each aggregate type is rather broad. Looking at each aggregate sample individually, it appears that in particular, GN4 and ARG4 are superior, and that TR2 and TR7 may be inferior in terms of polish resistance. It does not seem that any definitive conclusions can be drawn on the basis of the polish resistance of aggregate types as a group. Each aggregate source must be treated individually.

At this point, it is instructive to briefly discuss the effect of material variations on the results of this test method. As noted in the footnotes of Figure 8, TR4 and TR6 are two samples of the same material; TR4 is an extracted core sample, whereas TR6 is a stockpile sample. Both materials originate from a single source. ARG1 and ARG5 are both stockpile samples from the same quarry, taken approximately one year apart. All of the crushed gravel samples, CG1 through CG6, were taken from one stockpile. These samples were stored, test specimens were prepared and tested at intervals over a two-year period.

Although these similar samples did not yield identical results, the range of polish values are very close for the corresponding samples. Small variations in

materials or specimens preparation would probably account for variability in polish values.

In the next phase of this study, the relationship between ultimate polish value and the stabilized skid number will be investigated. Further refinements will be made on the model developed in this report. Accordingly at this time, only generalized statements referring to polish value requirements can be made.

Figure 8 indicates three categories for the aggregate samples tested. Applying "historical perspective" to the data, i.e., crushed gravel yields good skid resistance and carbonate rocks generally yield the lowest skid resistance, limits are tentatively set as follows:

<u>PV</u>	<u>QUALITY</u>
24 or Less	POOR
25 to 30	MARGINAL
31 or More	GOOD

These initial limits are offered only as a starting point for future refinement. The development of critical or "cutoff" values for PV must await statistical correlation with skid resistance values measured in the field.

6.0 CONCLUSIONS

1. Phase I of this study has successfully resulted in the application of a laboratory test to identify the polish resistance of aggregates. The model developed,

$$PSV(n) = B + (A - B) \exp (Cn)$$

statistically enables us to determine the minimum polish value, within a given confidence level.

2. Generalized statements of polish resistance based on aggregate type cannot be made. Individual sources must be tested.

3. More work is needed to relate polish value to skid resistance and to develop polish value requirements for surface course aggregates.

7.0 RECOMMENDATIONS FOR FUTURE RESEARCH

7.1 Refine Laboratory Procedure

Laboratory work should continue in order to further refine the procedure for determining the ultimate polish value, PV. Work should also continue on identifying a meaningful relationship between n , hours of polishing and T , cumulative traffic. The Texas Transportation Institute has included the LA Abrasion factor into this relationship. This data is available and will be used in the next phase of this study.

7.2 Define Relationship Between Laboratory Polish Value and Skid Number

The next phase of this study must be directed toward determining the relationship between ultimate polish value and stabilized skid number. The work conducted by the Texas Transportation Institute⁽¹⁾ suggests that this relationship is linear. In order to test this hypothesis in New Jersey, it will be necessary to:

1. Skid test pavements with cumulative traffic in excess of two million vehicle passes.
2. Correct the skid test value, SN_{40} , to an end-of-season minimum value⁽²⁾.
3. Core the skid test site, identify the aggregate from the core, extract the unexposed surface course aggregate.
4. Polish the extracted aggregate and determine polish value.
5. Determine the relationship between the end-of-season minimum skid number and the minimum polish value.

7.3 Check Seasonal Adjustment of Skid Number

As an adjunct to this study, it will be necessary to set up a field test to verify or modify (based on New Jersey specific conditions) the seasonal adjustments for skid numbers developed by Nittany Engineers; skid tests, macro and micro texture measurements will be made over a one-year period. Weather data (temperature and precipitation) and accumulated traffic will be recorded. Multiple regression analyses of these data should result in a seasonal adjustment equation similar to that developed by Nittany Engineers.

7.4 Develop Specifications

The final step in this study will be to set definitive limits for the polish value of aggregates to be used in surface course mixes and to write up a quality control test method to be used as a specification to prequalify surface course aggregates.

8.0 REFERENCES

1. Gandhi, P. M. and Fred C. Benson, "Design of Skid Resistant Asphalt Pavements", Texas Transportation Institute, June 1984.
2. Anderson, D. A., W. E. Meyer, and J. L. Rosenberger, "Data Collection Procedure for Use with Skid Resistance Measurements, Volume I: Comprehensive Report", Nittany Engineers and Management Consultants, Inc., September 1984.
3. Balmer, G. G. and R. R. Hegmon, "Recent Developments in Pavement Texture Research", Transportation Research Record 788, July 1981.
4. Yeh, E. C., J. J. Henry, and J. C. Wambold, "Methodology for Analyzing Texture and Skid Resistance Data for Use in Pavement Management Systems", Transportation Research Record 893, 1982.
5. Jenson, Paul A., ASTM Subcommittee D04.35, "Questionnaire Responses - Criteria Used to Provide Good Frictional Properties for Bituminous Systems", November 1985.
6. Afferton, K. C., "Further Evaluations of Skid Resistance Characteristics of Carbonate Rock Aggregates", New Jersey Department of Transportation, 1978.
7. Quinn, J. J., "Evaluation of Skid Resistant Thin Bituminous Overlays", New Jersey Department of Transportation, 1972.
8. Quinn, J. J., "Skid Resistant Characteristics of Carbonate Rock Aggregates", New Jersey Department of Transportation, May 1975.
9. New Jersey Department of Transportation Standard Specifications for Road and Bridge Construction, 1983.

APPENDIX

TABLE A-1

PSV(n) for CARBONATE ROCKS

n(hrs)	CR1	CR2	CR3	CR4
0	45.7	43.2	42.2	41.6
1	32.7	28.4	30.0	30.4
2	29.7	23.8	26.3	26.4
4	28.9	25.7	23.3	23.8
6	27.6	25.5	23.3	23.8
8	26.2	24.4	22.2	21.4
10	27.3	22.3	20.4	20.2
12	25.0	21.3	21.1	20.7
14	---	20.9	---	---

TABLE A-2

PSV(n) for GNEISS

n(hrs)	GN1	GN2	GN3	GN4	GN5
0	45.3	44.0	45.4	50.8	48.8
1	34.3	34.2	34.9	45.0	44.7
2	35.2	33.6	31.9	41.2	37.2
4	32.8	31.4	31.1	39.3	34.6
6	31.4	29.8	31.2	37.6	33.1
8	28.0	29.4	29.4	37.1	32.5
10	29.0	29.0	28.4	37.4	33.0
12	30.0	29.8	30.4	34.9	31.5
14	29.4	29.6	29.2	35.5	32.0
16	27.4	28.6	29.2	35.7	32.7
18	27.0	28.2	28.0	33.8	31.3
20	27.8	28.6	28.4	34.5	29.8
22	27.8	---	---	---	---

TABLE A-3

PSV(n) for TRAPROCKS

n(hrs)	TR1	TR2	TR3	TR4	TR5	TR6	TR7
0	45.6	44.5	44.3	46.6	44.7	47.1	38.3
1	36.4	34.7	38.6	38.6	36.5	36.5	33.6
2	35.2	32.3	35.5	34.9	37.2	35.7	32.1
4	33.5	30.8	35.3	35.4	32.8	33.7	30.3
6	32.5	31.0	34.8	33.3	36.2	32.0	29.6
8	32.4	28.0	32.7	30.7	31.0	32.0	28.4
10	31.8	27.3	32.5	30.7	31.7	30.8	27.1
12	31.3	26.3	31.8	32.1	30.7	---	26.1
14	30.5	26.3	31.0	31.3	30.5	---	27.1
16	31.0	26.8	31.0	31.3	28.7	---	---
18	31.9	26.5	---	---	29.3	---	---

TABLE A-4

PSV(n) for ARGILLITES

n(hrs)	ARG1	ARG2	ARG3	ARG4	ARG5
0	43.4	46.0	45.0	44.7	44.9
1	34.0	36.7	36.3	40.5	33.9
2	33.4	36.9	34.1	38.5	33.1
4	31.9	34.0	33.2	38.5	32.1
6	30.6	34.4	32.8	38.0	31.4
8	30.3	32.3	32.2	36.7	30.7
10	30.0	33.2	32.9	36.3	30.0
12	31.7	33.0	33.5	35.8	29.8
14	29.2	32.5	27.3	---	---
16	29.2	32.8	---	---	---
18	31.5	32.0	---	---	---

TABLE A-5

PSV(n) for CRUSHED GRAVELS

n(hrs)	CG1	CG2	CG3	CG4	CG5	CG6
0	47.8	47.9	46.9	46.1	52.0	48.3
1	40.3	41.5	40.8	39.5	41.5	45.0
2	39.3	42.5	37.7	38.5	36.0	44.0
4	37.5	40.8	37.3	35.9	38.0	41.3
6	36.8	38.5	36.3	34.9	37.5	39.5
8	35.8	37.0	37.2	36.1	36.0	40.8
10	36.5	35.5	35.7	34.1	37.0	36.8
12	---	38.8	36.0	32.9	35.0	---
14	---	35.5	33.8	32.8	---	---
16	---	33.3	32.2	32.0	---	---
18	---	34.3	---	---	---	---
20	---	34.5	---	---	---	---
22	---	33.8	---	---	---	---