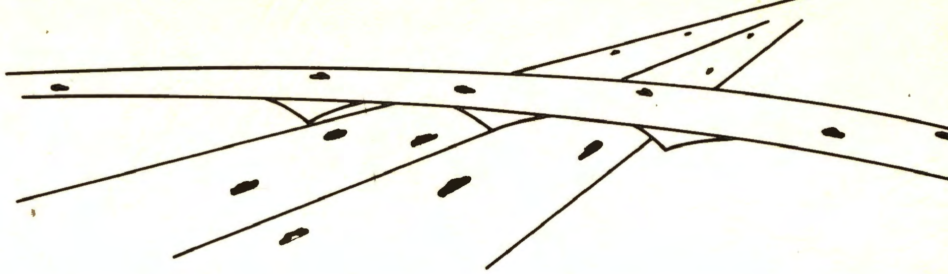

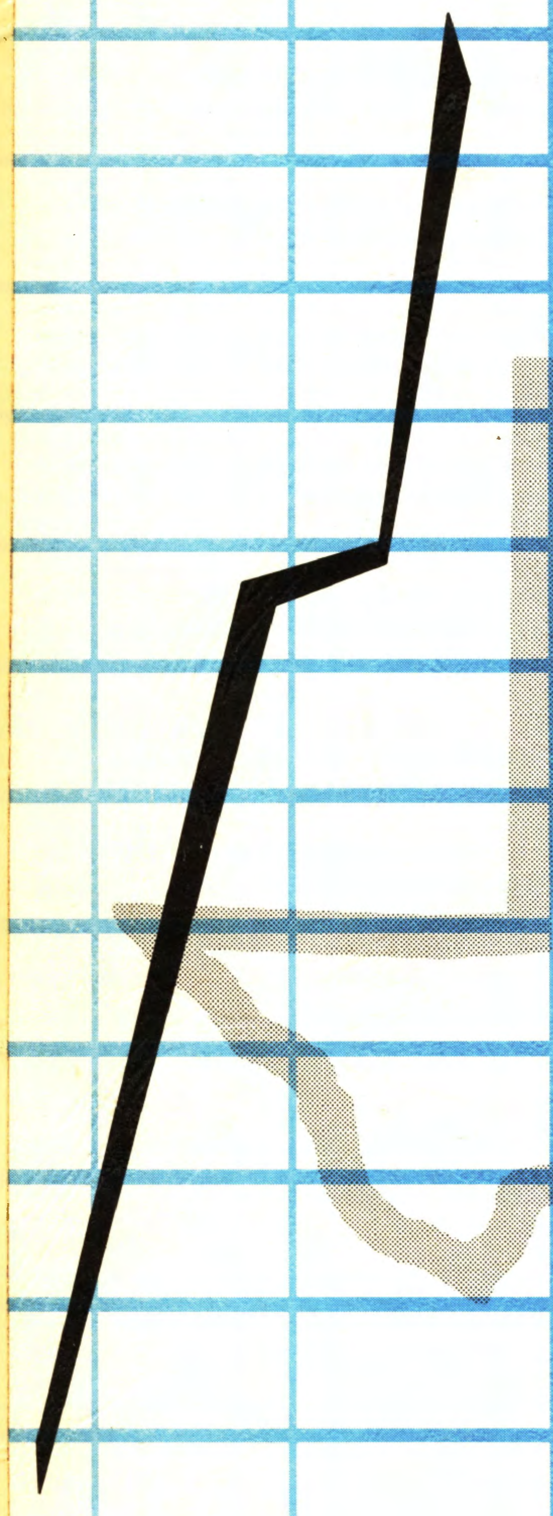

DEPARTMENTAL RESEARCH

Report Number : 126 - 2

AGGREGATE POLISHING CHARACTERISTICS: THE BRITISH WHEEL TEST AND THE INSOLUBLE RESIDUE TEST

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AGGREGATE POLISHING CHARACTERISTICS: THE BRITISH WHEEL TEST AND THE INSOLUBLE RESIDUE TEST

by

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and

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Research Report 126-2
A Laboratory and Field Evaluation of the Polishing Characteristics of Texas Aggregates

Research Study 1-8-68-126

Conducted by
Highway Design Division, Research Section
Texas Highway Department
In Cooperation with the
U.S. Department of Transportation
Federal Highway Administration

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

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ABSTRACT

Aggregate Polishing Characteristics: The British Wheel and The Insoluble Residue Test

Project Number	:	HPR - 1(10), 1-8-68-126
Investigators	:	Underwood, Hankins, Garaña
Research Agency	:	Texas Highway Department
Sponsor	:	Texas Highway Department and Federal Highway Administration
Date	:	January 1971
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Key Words	:	Aggregate Polish Characteristics British Wheel Insoluble Residue Test Polish Value Aggregate Rate of Polish Pavement Friction Measurement British Portable Tester

This report describes an attempt to implement research work which was conducted in England. A British Wheel and a British Portable Tester were purchased. The British Specification BS:812 was modified for use in Texas. The Insoluble Residue Test was also studied and compared to the British Wheel Test. Research effort was directed toward obtaining the variations expected in performing the tests, variations expected in the sources, obtaining the polish characteristics of a sample of approximately 100 sources in Texas, and studying the "rate of polish"

by comparing field polish to laboratory polish characteristics. Recommendations were made to specify the British Wheel "Polish Value" in construction contracts, and an experimental construction job was reported.

IMPLEMENTATION

Implementation of this phase of study has developed through the use of the suggested specifications and test procedure for the British Wheel "Polish Value" on construction projects. The use of the "Polish Value" on construction projects has been experimental in nature and, at present, the "Polish Value" has been used on two projects. The construction of one of the two projects has been completed and bids have been received on the second project. Both projects have occurred in District 17 (Bryan, Texas); however, at least two additional Districts are contemplating the use of a "Polish Value" specification.

It is recommended that further implementation be divided into three phases:

Phase I: Additional work could be advanced from the research stage to that of testing. British Wheel equipment should be provided to Materials and Tests Division (File D-9). D-9 should be provided with sufficient time to study the polishing equipment and devise (or revise the proposed) a tentative test procedure.

The Specification Committee and the Districts could develop pertinent specifications.

Phase II: Other construction projects of an experimental nature could be constructed. During this time D-9 could revise the test procedure as necessary and the Districts and Specification Committee could revise specifications as necessary.

Phase III: Tentative Test Procedures could be advanced to a standard and the "Polish Value" specification could be used on a state wide basis as proposed by the Districts.

It should be noted that the "Polish Value" should be used only for the coarse aggregate for the surfacing material of flexible pavements at this time.

SUMMARY

Recommendations have been made to implement the results of this study by using the British Wheel "Polish Value" in construction specifications. It is believed that the British Wheel Test does order the friction characteristics of the coarse aggregate material used in the surface of flexible pavements. Therefore, the specification can be used to advantage on seals or surface treatments unless the asphalt has flushed to the surface. Even with a flushed surface, there is evidence that certain aggregates provide high friction until the aggregate is completely inundated. Since vehicular friction is related to the pavement surface which the tire contacts, coarse aggregate in an asphaltic concrete does not greatly contribute to vehicular friction during the initial stages of polish. A thin film of asphalt and fines are available to the tire. However, during the latter stages of wear (at times after 30 to 50 thousand vehicle applications) the coarse aggregate continues to provide some measure of friction throughout the remaining structural life of the surface.

The maximum range of "Polish Values" (BPN_m) of the several materials which were studied varied from 20 to 56 or a difference of 36. These values are somewhat less than that reported by the British. This is probably due to the single grit size recommended herein as compared to the two grit sizes used in England. The range of 36 is somewhat disappointing in view of the variation summary listed below:

Variation Summary

I. Variance in British Portable Tester and Operator

The greatest range found in BPN_m values using different operators (that is, the operator and laboratory friction equipment).. ± 2

II. Variance Between Three Specimens in a Sample

A. The greatest range found between three specimens of a sample.. 9

B. The average range found between three specimens of a sample.. 3.6

III. Variance Between Samples From a Given Source

A. The greatest range found between samples from a given source.. 12

B. The average range found for a given source in repeat tests for 12 sources studied........................ 5.1

This would mean that some of the sources with extreme friction variation could range in "Polish Values" from day to day with a value of at least 12 or 1/3 the total average range of values found between the sources (36). However, in considering the average range of a given source (5.1), less than 1/6 the total average range of values found between the sources occurs. It is believed that the average day to day variance which is expected in any given source (5.1) is acceptable; however, increased test sensitivity could be achieved through the use of two grits in the test or through the use of a single very small grit size. The use of two grit sizes would allow the test to be performed in less time with a larger spread in the "Polish Values" (however, the last grit should be very small - probably around a 600 grit size). The use of one grit of very small size would make the test time longer but would provide a greater range in the final "Polish Values." Eventually, the "rate of polish" might be used as a design or specification factor, and it would be advantageous to use only one grit size. Again, it is believed that the 150 grit size is optimum (time-wise) for use in this state and continued effort should be given toward the study of a "rate of polish" test procedure and specifications.

I. INTRODUCTION

Kummer and Meyer in NCHRP Report #37 indicate that the two principal components of rubber friction are adhesion and hysteresis.[1] With reference to the pavement surface, the adhesion component is principally concerned with the contact area of the tire-pavement interface and the "shearing strength" developed between the tire and the surface as the tire slides across the surface. It is obvious that the "shearing strength" depends, in part, upon the micro-texture of the pavement surface.

The hysteresis component is concerned with energy absorption; and with reference to the pavement surface, textures of all types and sizes are important. However, the macro-texture is particularly important.

The hysteresis component does not depend greatly upon (tire) pressure, or the wet or dry pavement condition, but is heavily dependent upon the rubber damping characteristics of the tire. Adhesion on the other hand is dependent upon (tire) pressure and pavement contaminants such as water and road film.

This report is concerned with one portion of the friction characteristics of the pavement surface; that is, the friction performance of the aggregate in the pavement surface which is exposed to the vehicle tire. Aggregate polish or performance depends, to a large extent, on the adhesion component of friction and therefore performance depends on obtaining and maintaining micro-texture on the surface of the individual aggregate particles.

The state of the art in aggregate friction performance has been steadily increasing during the past years. For example, A.J.P. Vander-Burgh and D.H.F. Obertop in the Netherlands attempted to decrease the macro-texture height of a man-made surface under study by filling around the macro-texture with Plaster-of-Paris.[2] This procedure increased the friction to such an extent that a microscopic investigation of the Plaster-of-Paris was performed. The investigation revealed that the plaster had very minute sharp crystals, and this indicated: (1) the micro-texture was an important ingredient in friction and (2) the micro-texture could be very small-observed with a microscope.

Later, England, while performing the initial experimentation with the British Wheel, observed a fluctuation in friction values which was proportional to the size of grit used in the accelerated polish.[3] In this test, an aggregate sample was polished with a rubber tire, and the polishing was accelerated by inserting grit and water between the aggregate and the tire. When a small grit size was used, low friction resulted; however, if the sample was then induced to polish using a larger grit size, higher friction resulted. In essence, Gallaway confirmed this phenomena in the field with the use of a skid trailer.[4] In Gallaway's work, several test pads were being prepared for skid test work with a stopping distance vehicle. Attempts were being made to provide a variety of friction levels (each pad containing a certain friction but different from a neighboring pad). One of the test pads consisted of an asphaltic concrete in which limestone coarse aggregate was used. Tests obtained with a skid trailer indicated the SN of the limestone asphaltic concrete to be approximately 69. The test pad was then polished with a terrazzo machine. The terrazzo machine left a smooth surface in which the natural macro-texture had been removed in the grinding process. The machine utilized an 80 grit stone, and when friction tests were obtained after grinding, the SN was found to still be in the middle sixties. Using a rubber float, Gallaway then polished the surface with fine sand and fly ash. After the fly ash polish, the SN was lowered to the low forties. The grit size of the fly ash was unknown, but it was considerably smaller than the 80 grit size used in the grind stone.

The conclusions of the above studies are that an aggregate can be polished by grit, and that the grit must act in a micro abrasion manner. As the grit is forced to scratch across the surface, part of the surface is removed; however, small abrasions (or micro-texture) are left on the aggregate surface. These facts have been known by lapidary artists (and metal machine operators) for many years. For example, in lapidary work, a gem is formed from a hard stone by:

1. Bringing the stone to the desired shape with a coarse grit grind stone (possibly 80 to 100 grit size)
2. Sanding the scratch marks left by the coarse grit grindstone with a smaller grit (possibly a 200 to 400 grit size)
3. Sanding the scratch marks left by the 200 to 400 grit with an even smaller grit (possibly a 600 grit size)
4. And finally buffing with a very small grit (possibly rouge on a leather or cloth buff)

At this point research into the tire polish of aggregate is still confusing. The exact polishing effect of the tire is unknown. It is not known whether the tire is the grind stone, the sander, or the buffer mentioned in the above 4 steps. Also, the effect of tire pressure is unknown. It is possible to effect deeper scratches in a gem stone by simply pressing the gem to the grind stone with more pressure. Probably, the most confusing of all is the micro structure of the stone or aggregate which is being polished. The hardness, flakiness, and density of the stone must be considered.

Presently, the American Society for Testing And Materials is attempting to develop test methods for four mechanical devices and one chemical procedure which reflect the polish characteristics of aggregate or the pavement surface. Many investigators in almost every state are involved in producing information which is directed toward providing safer highways, and much of this information is related to the friction characteristics of the material which composes pavement surfaces.

Background

The study of the polishing characteristics of Texas aggregates was developed because of the need for skid resistant surfaces. Obviously, newly constructed surfaces should provide good friction characteristics, and just as obvious is the fact that friction deteriorates rapidly on certain surfaces when they are exposed to even moderate traffic. In the past, because of the cost considerations of local materials in certain areas, the Department has been forced into renewing the friction of pavement surfaces with aggregates which were literally "slick to start with".

A review of literature and experience in the Department indicated the coarse aggregate to be one of the most important constituents in providing and maintaining friction on flexible pavement structures. Therefore, it was believed that some method of specifying a non-polishable coarse aggregate was needed. After again resorting to a literature search, it was found that there was only one test which was being continually used for job control. This was a British Test described in British Specification BS:812.[5] Since there was an urgent need in this state for a suitable test, a decision was made to purchase equipment from England, develop or adopt a test procedure, and provide the equipment for Departmental use.

Also, it appeared that the Insoluble Residue Test (which was being prepared by ASTM and studied by others) would provide a test with a moderate "first cost" which might possibly be adapted for District use. Therefore, it was decided to study the Insoluble Residue Test and to perform tests on aggregates from several sources.

Object

The object of this study was to develop or adopt a method of providing this state with a means of selecting a coarse aggregate for a pavement surface with sufficient and lasting friction properties.

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II. DESCRIPTION OF EQUIPMENT

British Wheel Test

In the first phase of this study, the polishing characteristics of aggregate were observed by the use of an accelerated polish machine (which is termed the "British Wheel"), and friction properties were determined by the use of a British Portable Skid Tester.

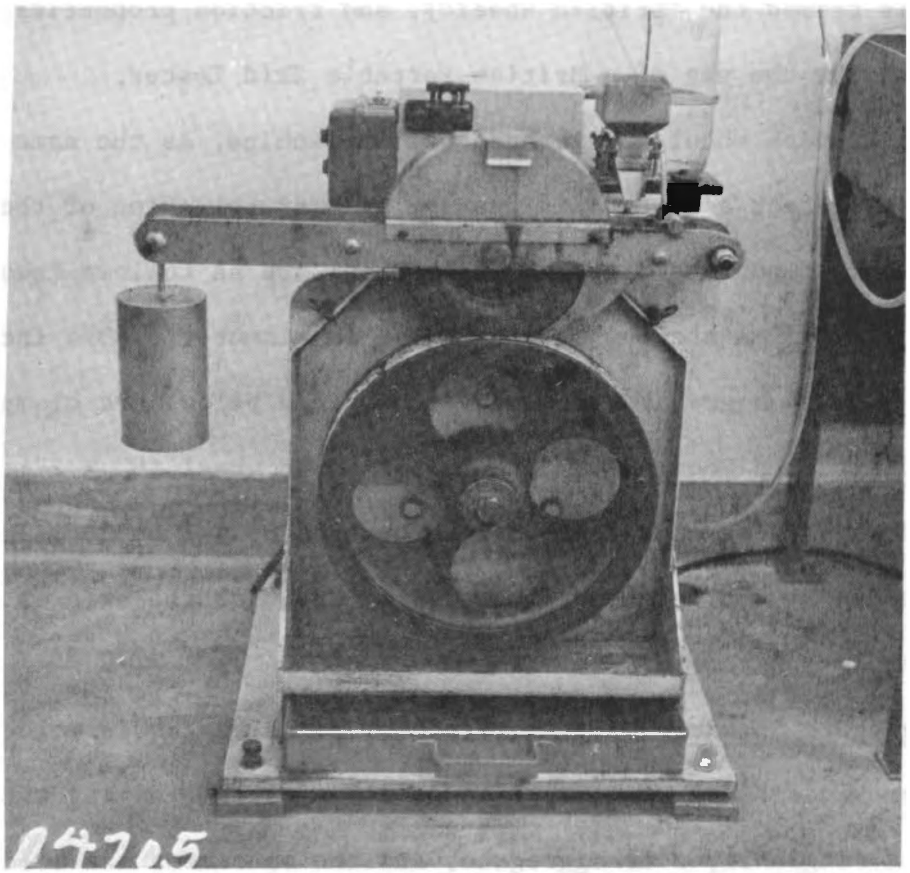
The British Wheel accelerated polish machine, as the name implies, is used to effect a more rapid wearing away or polishing of the aggregate. Major components of the British Wheel are as follows (see Figure 1):

Road Wheel A steel wheel 16 inches in diameter, 1-3/4 inches wide, around which 14 aggregate specimens (described below) are clamped.

Rubber Tired Wheel A smooth rubber tired wheel (8" X 2") rests on the Road Wheel/test specimens with a force of 88 $\pm$ 1 pounds. This force is developed by the weighted lever system in which the axle of the Rubber Tired Wheel is fixed.

Aggregate Specimen The aggregate(s) to be tested is molded in a polyester binder. The specimen size is 3.5" X 1.75", having the thickness of a single layer of aggregate; and the specimens are molded to the same radius of curvature as the Road Wheel, around which they are then attached.

Grit Feed System Accelerated wearing or polishing is induced by the continuous, uniform application of No. 150 silicone carbide grit between the Rubber Tire and the Road Wheel. The grit is vibrated from a small hopper to a chute at a specified rate. Water is applied (also



Accelerated Polish Machine
(British Wheel)
Figure 1

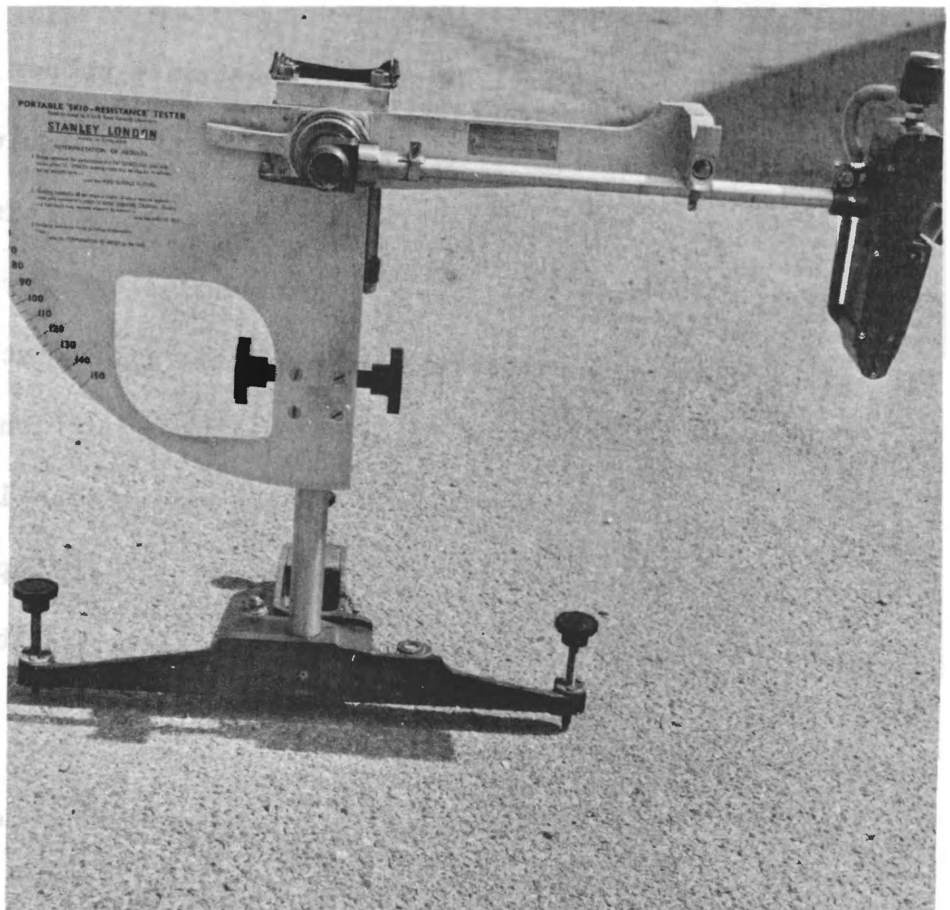
at a specified rate) into the chute. Thus, the grit is washed onto the Road Wheel near the point of contact of the Road Wheel and the Rubber Tire.

The Road Wheel is rotated (by an electric motor) to a speed of 315 to 325 revolutions per minute or 18,900 to 19,500 tire applications per specimen per hour.

ASTM describes the British Portable Tester as "...a dynamic pendulum impact-type tester used to measure the energy loss when a rubber slider edge is propelled over a test surface" (see Figure 2).[6] Pendulum length is an established 20 inches, while height of the pivot point (pinned end) from the test specimen is adjustable. This adjustment allows for a specified length of slider contact path to be maintained on different sizes and types of specimens. The pendulum is placed in a near horizontal position as it is cocked, and release by the trigger mechanism allows the arm to swing freely. A pointer "rides" the arm to the maximum upswing, and then it remains in place to indicate the BPN (British Portable Number).

Insoluble Residue Test

It is probably not necessary to describe the equipment which is used in the Insoluble Residue Test since the equipment is that which is generally found in the laboratory (such as screens and flasks). However, the test method and the equipment which are used are found in the Appendix. The aim of the Insoluble Residue Test is to establish a relationship between the friction properties exhibited by an aggregate and the physical characteristics of carbonate aggregates. The theory is based on the concept that the skid resistance of carbonate aggregates is related to the differential hardness of the minerals that comprise the structure of the



British Portable Tester
Figure 2

aggregate. According to this concept, when a carbonate aggregate is subjected to polish, the softer minerals will wear away at a faster rate than the harder particles and/or there will be some attrition of the aggregate caused by the loss of the softer particles. The result will leave the wearing surface of the aggregate with a rough, uneven texture which increases or maintains the friction properties of the carbonate aggregate.

In order that the minerals could be examined and analyzed, a method was developed which chemically separates the non-carbonate particles from the carbonate particles. The method which was developed acts only on the carbonate portion of the aggregate since it is imperative that the non-carbonate minerals not be destroyed or altered in any manner.

The non-carbonate minerals cannot be analyzed until they have been separated from the matrix of the aggregate. This analysis involves a determination of the amount of carbonate present in the total aggregate and a grain size distribution of the non-carbonate particles.

The National Crushed Stone Association (NCSA) uses the following definition to qualify an aggregate as a carbonate aggregate:(7)

> "A carbonate aggregate is a sedimentary rock in which the carbonate fraction exceeds the non-carbonate fraction."

Note that this definition does not mention the composition of the non-carbonate fraction nor differentiate between aggregates that are non-carbonate in nature (such as silicious river gravels).

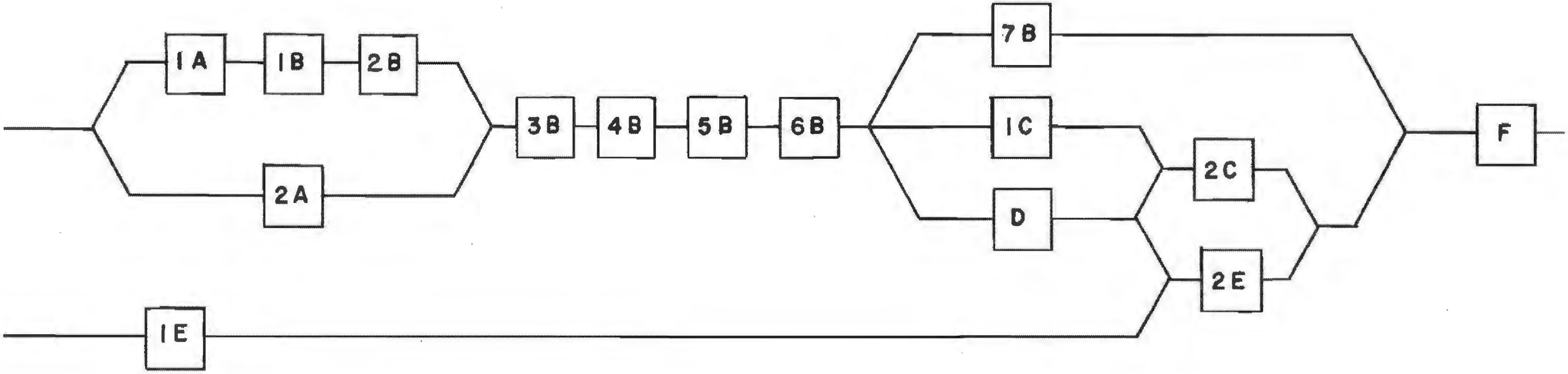
The procedure used to separate the aggregate into a carbonate fraction and a non-carbonate fraction is based on the chemical reaction that occurs when dilute hydrochloric acid is allowed to react with the carbonate portion of the aggregate. The leaching process dissolves the carbonate fraction leaving the non-carbonate fraction in the form of a residue.

III. METHOD AND RESULTS OF ANALYSIS

The method of analysis conforms to the flow chart in Figure 3. The reporting is of two sub-studies which are tests with the British Wheel and the Insoluble Residue Tests. First the necessary equipment was obtained and calibrated. Introductory studies were performed on several sources in order to determine the effect of grit size, sample variation, pit variation, test repeatability, and day to day variation. The introductory studies permitted equipment debugging and also allowed operating technicians to become familiar with equipment. At the end of this period a tentative test procedure was developed which established guidelines for further testing. Samples of aggregate from several sources in Texas were collected and the "Polish Value" was found for each source. Attempts were made to correlate field friction performance and accelerated polish friction performance on four aggregate sources. Also, toward the end of the subject study, Insoluble Residue Tests were performed on aggregates from several sources for which "Polish Values" had been determined. The relationship between the "Polish Value" and the results of the Insoluble Residue Test were then studied. Finally, specifications were developed to be used experimentally in construction work.

Calibration of the British Portable Tester

Upon receipt, the British Portable Tester was calibrated by the tentative test method described in ASTM designation E303-66T.[6] No correction was found to be necessary and the equipment seemed to conform to the requirements established in the ASTM method.



1A Obtain the British Portable Tester
2A Obtain the British Wheel Accelerated Polisher
1B Calibrate the British Portable Tester
2B Check operator variance in the British Portable Tester
3B Check the effect of grit sizes on polish specimens
4B Analyze variations within single pit
5B Analyze variation between specimens of a sample
6B Develop a Modified Wheel Test Method
7B Analyze repeatability between samples of a source(s) collected at different times
1C Perform and analyze acid leaching for carbonate aggregates
2C Analyze the relationship between acid leaching for carbonate aggregates and polish values
D Obtain polish values for 97 sources
1E Obtain field friction performance record for pavement surfaces under actual traffic conditions
2E Analyze relationship between field friction performance and British Wheel Polishing
F Develop suggested specifications for experimental job

FLOW CHART OF STUDY METHOD

Figure 3

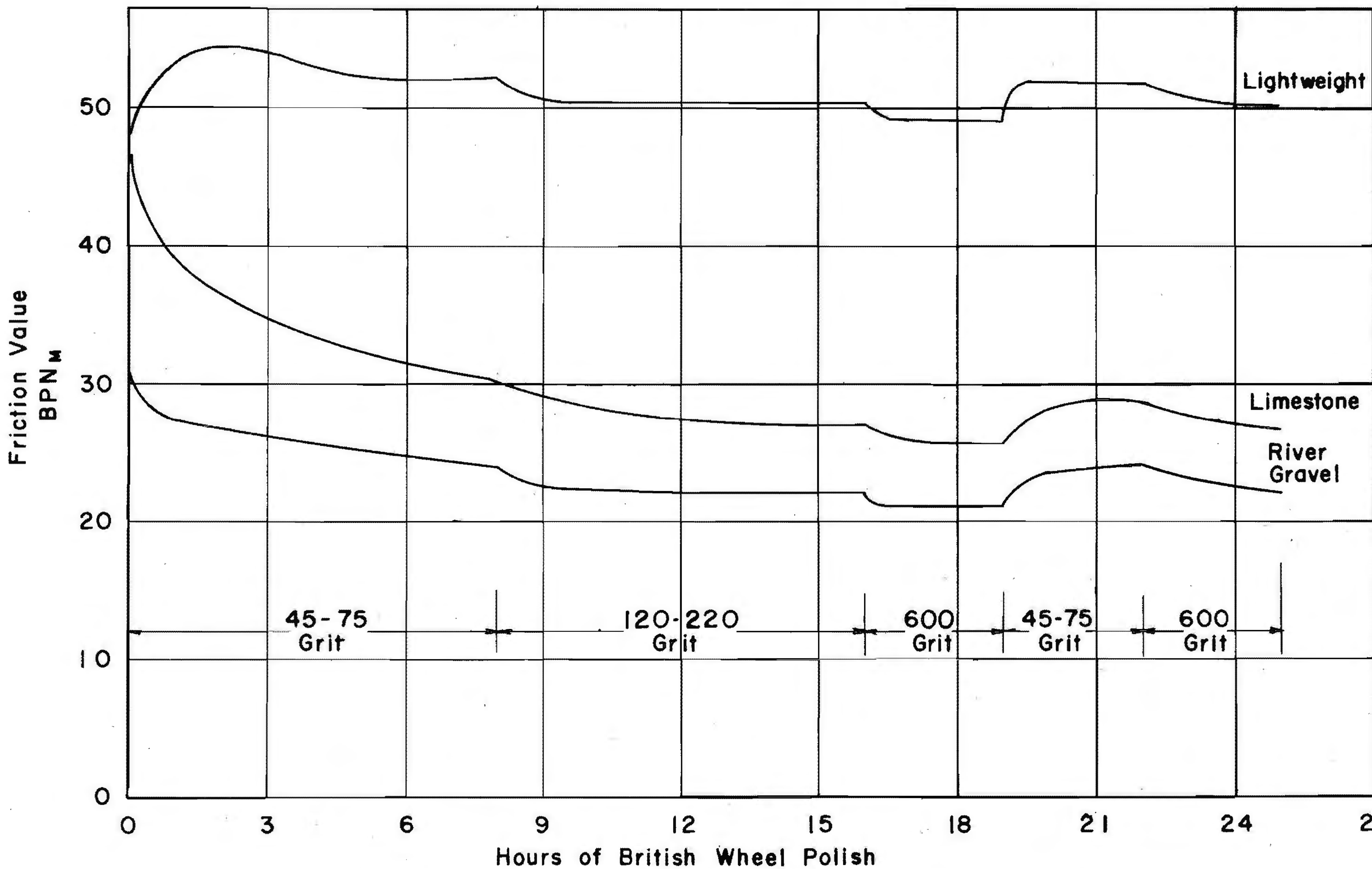
Operator Variation Using The British Portable Tester

Operator variation, while using the British Portable Tester, was determined by two operators obtaining repeat tests on the same specimen. Each operator was required to set up the instrument on a given specimen, adjust the slider length, and read the values from the scale. All testing was done while the surface was in a wet condition. Four specimens with varying friction values were used. The greatest BPN range, using different operators, was found to be 2. There was also a range of 2 for one operator (with repeat tests) where the operator was required to set the instrument up between tests. It is believed that most of the variance can be attributed to adjusting the slider length.

The Effect of Grit Size and Hardness

England, in developing the British Wheel Test, performed several experiments concerning grit size.(3) The researchers did not feel that the exact grit used by the British could be imported because of the excessive cost. Therefore, attempts were made to develop a modified test procedure using different grit. Originally, attempts were made to find two grit sizes which would closely conform to the British test. Also, it appeared that silicone carbide would closely approximate the hardness of emory flour used by the British.

The first testing was performed on 3 samples consisting of 4 specimens per sample. Attempts were made to duplicate British work by polishing the specimens with various grit sizes as shown in Figure 4. The silicone carbide grit, which was obtained locally, consisted of three sizes. The largest ranged from a 45 to a 75 size; the medium ranged from a 120 to a 220 size; the smallest was a 600 size. The aggregates which were used



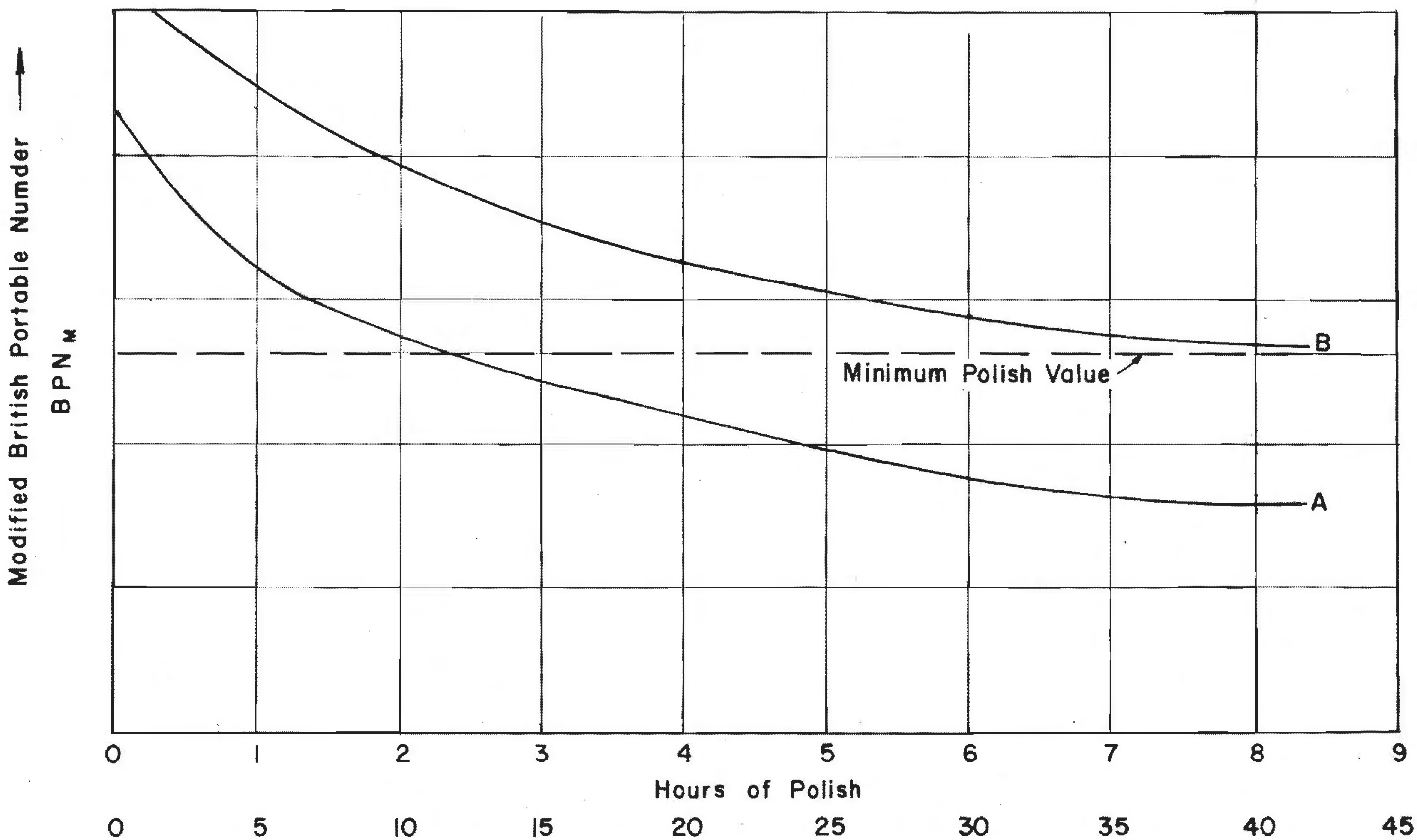
EFFECT OF POLISHING AGGREGATE WITH VARIOUS GRIT SIZES

Figure 4

were a synthetic, a limestone and a river gravel. The results were essentially the same as that reported by the British.[3] The specimens decreased in friction with consecutive applications of smaller grit sizes and increased in friction when the larger grit size was again used. In the haste of getting started, the limestone was not polished to the lowest level with the application of the 45-75 grit. Also, the lightweight synthetic aggregate increased in friction during the first stages of polish with the 45-75 grit. It is believed that the coarse grit abraded through the "rind" (or the dense outer layer) of the lightweight aggregate exposing the blib (or small holes) structure in the interior. As the remainder of the rind wore away the friction was lowered slightly.

At this time, a close review of the available literature was performed. It appeared that most of the past work had been pointed toward obtaining one value; the lowest friction value (the "Polish Value" or the point at which friction does not decrease even with continued polishing). It also appeared that the "rate of polish" would be important in future applications. The postulation was that many of the highways in Texas do not receive enough traffic applications to polish to a low friction level before resurfacing or maintenance must be performed for structural reasons.

It was believed that it would be possible to specify a Polish Value for all highways, but the Polish Value would be determined after a specified number of hours of accelerated polish. An example of this postulation is given in Figure 5. Source "A" will eventually polish below a minimum allowable Polish Value. However, the aggregate would withstand approximately 1.3 million vehicle applications before attaining the minimum value. The 1.3 million vehicle applications is equivalent to eight years



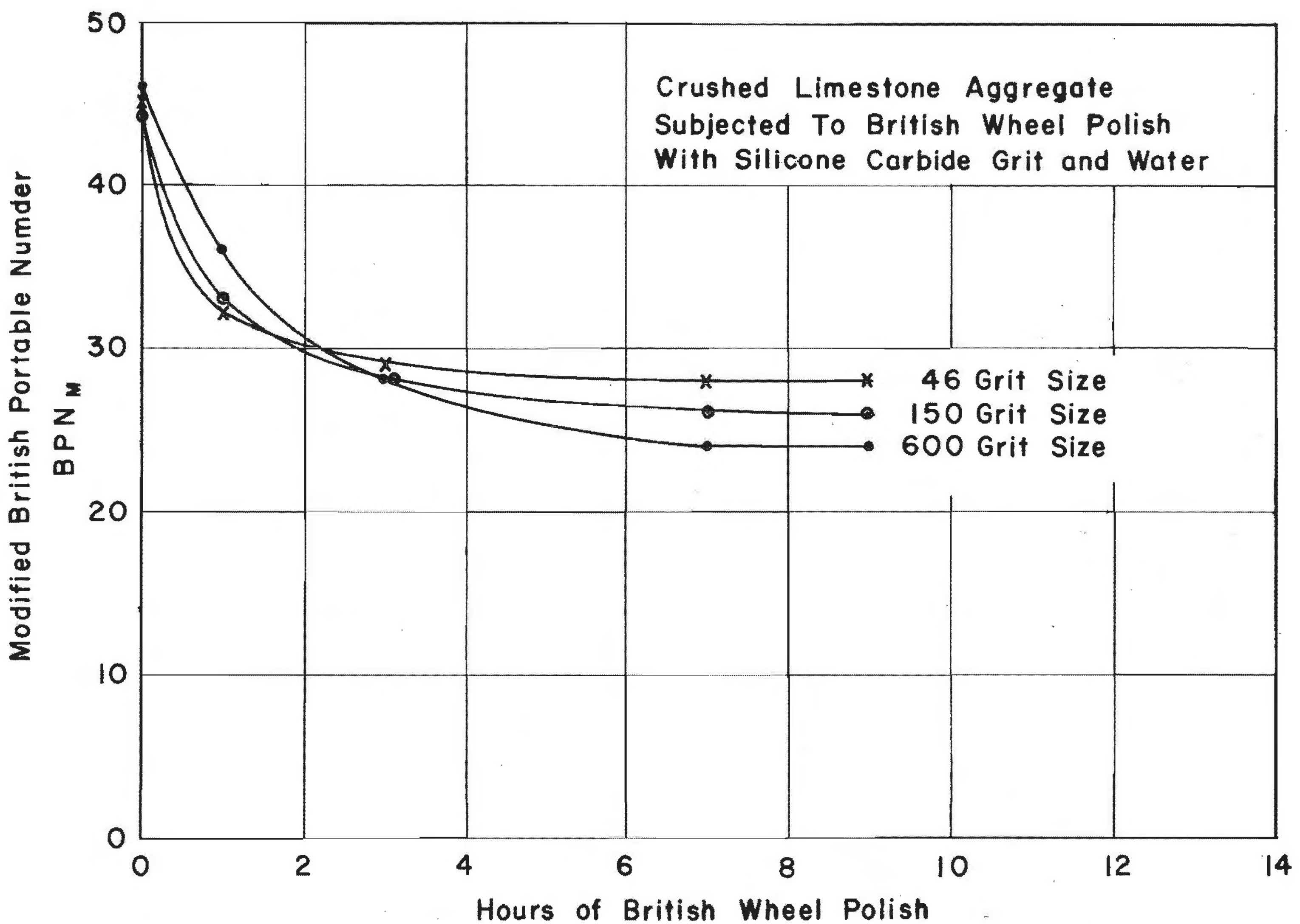
EQUIVALENT VEHICLE APPLICATIONS ($X 10^5$)

SCHEMATIC OF AGGREGATE RATE OF POLISH

Figure 5

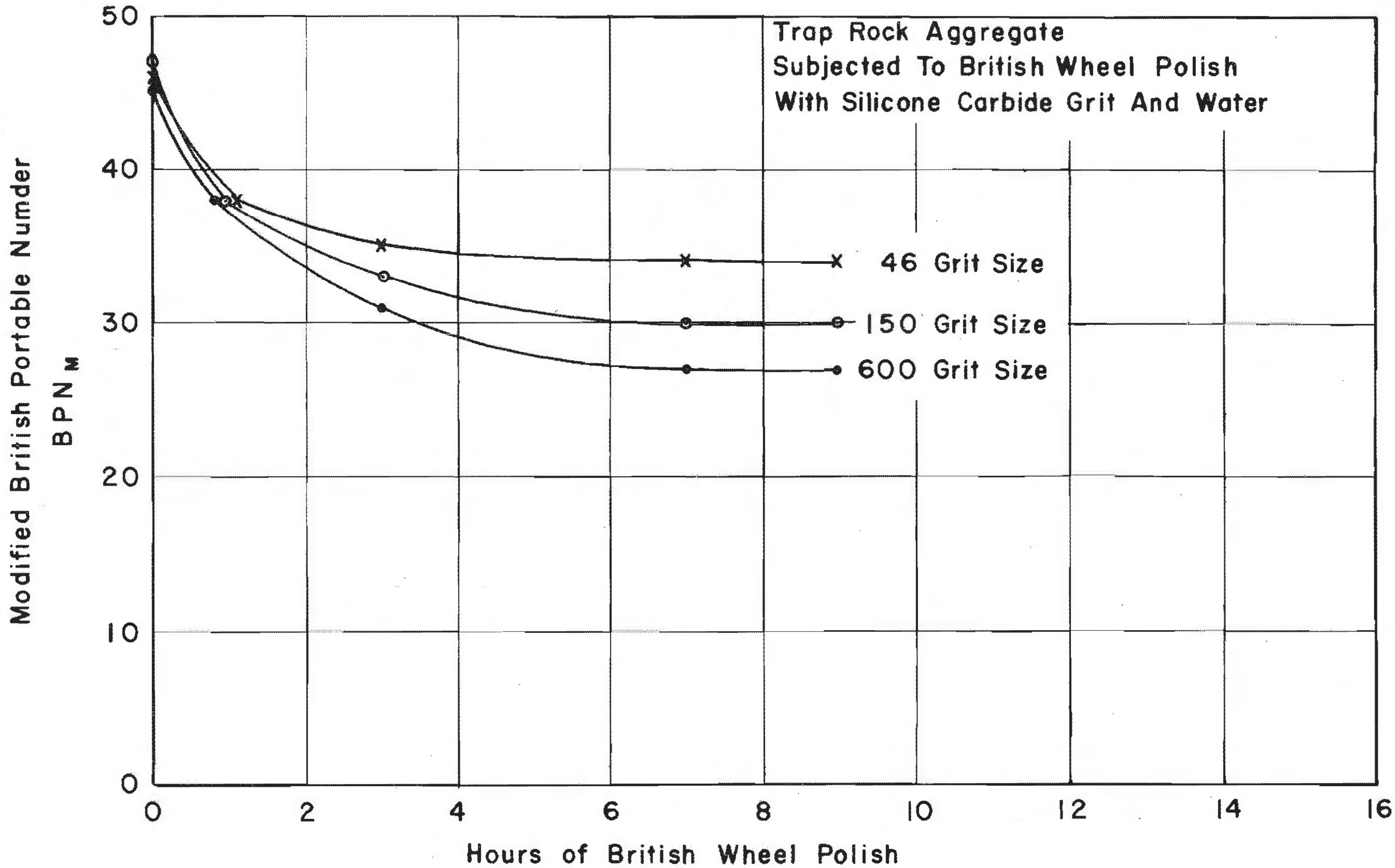
of traffic on a two lane rural highway which has an ADT of approximately 900. Therefore, for this highway, a minimum Polish Value would be specified after 2-1/2 hours of accelerated polish. Of course, Source "B" would be more satisfactory for a roadway with heavy traffic. It was believed that this approach would possibly allow the use of local materials for certain highways with less cost to the state.

It was difficult to obtain a rate of polish when two grit sizes were used during the test because of the "stair-step" formed in the polish rate when the smaller grit was applied. Therefore, a decision was made to polish with only one grit size. The next decision concerned the grit size to use. Figures 6 and 7 reveal the results of testing two sources with three grit sizes. Duplicate samples were prepared from each source and polishing was performed beginning with a new series of samples when the grit size was changed. That is, specimens were polished to the lowest extent with the larger grit size; then the specimens were removed and duplicate specimens were polished with the intermediate grit size, etc. A comparison with field polish was available since the sources for the specimens had been under study for some time in field tests. The field tests consisted of periodic measurements with a skid test trailer on the subject aggregates which had been placed as Surface Treatments on an experimental test section (IH 35 South of Austin; described in Interim Report 126-1). The results of the grit size study indicated that no grit exactly duplicated the field tests. The samples which were polished with the larger grit size revealed the greatest initial rate of polish but the final polish (British Portable Number - modified) value was the highest. The samples which were polished with the 600 grit had the smallest rate



EFFECT OF POLISHING LIMESTONE AGGREGATE WITH 3 GRIT SIZES

Figure 6



EFFECT OF POLISHING TRAP ROCK AGGREGATE WITH 3 GRIT SIZES

Figure 7

of polish but the lowest BPN_m. When the intermediate grit size was used, the rate of polish and final Polish Value was between those mentioned with the coarse and fine grit. From these results, a decision was made to use the intermediate (150) grit size because of the following facts:

1. Even though no grit exactly duplicated field wear, it appeared that it would be possible to correlate any one of the polish rates by simply adapting an accelerated polish time scale corresponding to traffic applications. This would mean that the larger grit size would have the smallest polish time and the smallest grit size would have the largest polish time, but either rate of polish could be adjusted to fit the field rate of polish.
2. The 150 grit gave a larger range of BPN_m values between initial and final polish than the 46 grit size.
3. The use of the 600 grit was disliked because of the difficulty associated with the grit feed system. During any test the grit feed must be continually monitored. However, during the tests with the 600 grit, the grit application rate appeared to fluctuate erratically.

It should be stated that during the testing with the 600 grit, a sample of grit was obtained from the rubber tired wheel; and it was observed under a microscope. A large percentage of 600 grit was found; however, there were traces of 150 and 46 grit. Apparently, the larger grit sizes were retained in the surface of the tire throughout the testing with the smaller grit sizes. This fact could have caused some error in the above tests; however, it was believed that this error was small. Before changing grit sizes on subsequent tests, the tire was briskly rubbed with a cloth.

The next series of tests dealt with the relative hardness of the grit which was used for polishing. It was postulated that if grit were present during the actual polishing of the pavement surface, much of the grit must have come from the parent aggregate. Also, if the grit were wind or water deposited, the grit would have come from fields, etc. which bordered the highway. This grit would not have the same hardness as silicone carbide; therefore, four material sources were selected and samples from each source were prepared for polish tests. Also, aggregate from each of the four sources was crushed to pass a 100 mesh screen, and be retained on a 200 mesh screen. The crushed aggregate was used as the grit instead of the silicone carbide, and accelerated polish tests were performed.

The four sources were numbered, and information concerning each source follows:

Source No.	Aggregate Type	L.A. Abrasion No. "C Wear"
264	Crushed Limestone (Fossilized Matrix)	32
6	River Gravel	25
108	Trap Rock	11
99	Crushed Limestone (Dense Matrix)	29

The method of testing is as follows:

A.

1. Seven specimens of Source 264 and seven specimens of Source 6 were placed on the road wheel and polished with Source 264 grit (100-200 screen size) and water for nine hours.
2. Seven specimens of Source 264 and seven specimens of Source 6 were placed on the road wheel and polished with Source 6 grit (and water) for nine hours.

B.

1. Seven specimens of Source 108 and seven specimens of Source 99 were polished with Source 108 grit (and water) in a manner similar to "A" above.

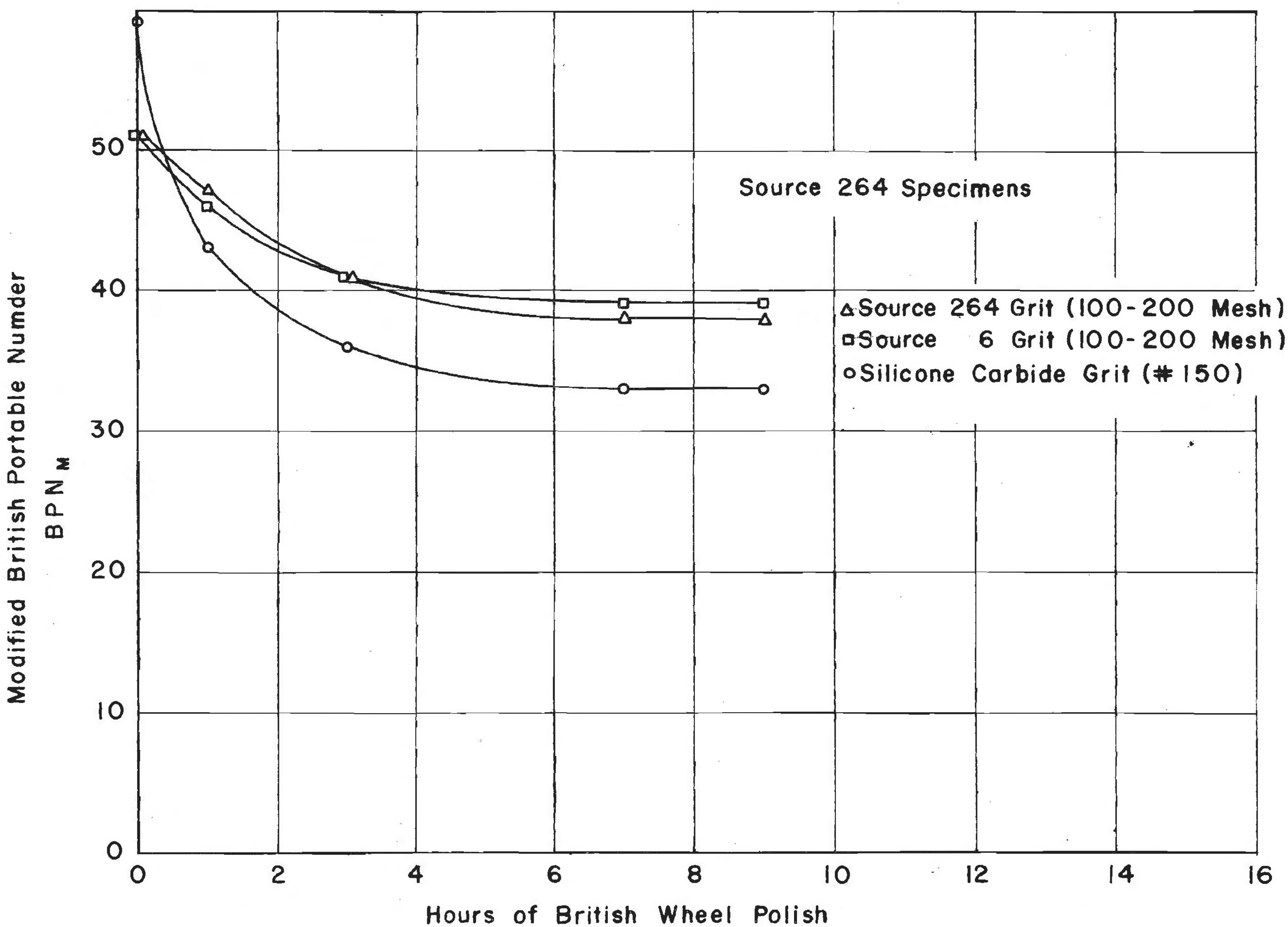
2. Seven specimens of Source 108 and seven specimens of Source 99 were polished with Source 99 grit (and water) for nine hours.

C.

A sample (three specimens per sample) of each of the four sources was polished for nine hours using silicone carbide grit (150 grit size) and water.

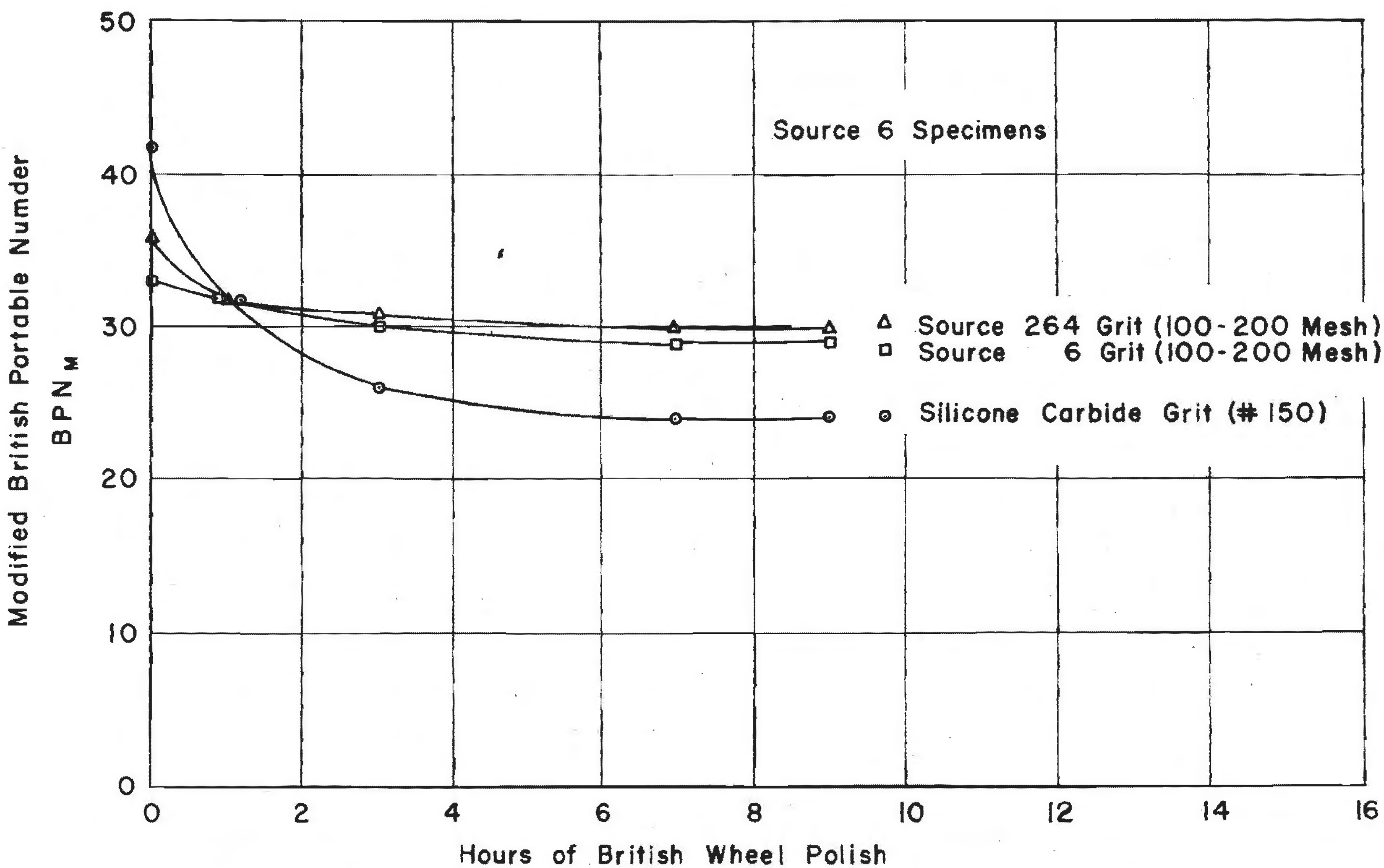
The results of these tests are shown in Figures 8 through 11. The L.A. Abrasion values were used as a method of determining a hardness number for the natural grit. The usual loss in friction occurred with increased polish effort and in each case the specimens polished to a lower level when silicone carbide was used. When considering the results of the specimens which were polished with natural grit, it would appear that the lower friction values resulted from either (1) the harder grit or (2) specimens being polished in their own grit. However, it would appear that lower friction values were obtained as a harder grit was used (Only in Figure 8 was disorder found. The BPN_m difference was only one unit, possibly the result of an error in testing.) The variation in the lower friction values (Polish Values) which was caused by grit hardness (or type) was found to be approximately 5 or 6 BPN_m.

There would appear to be some variation due to grit type or hardness; however, a method of correction was not known because the actual traffic polishing mechanism was not known. A decision was made to use <u>150 size silicone carbide grit</u> for future tests.



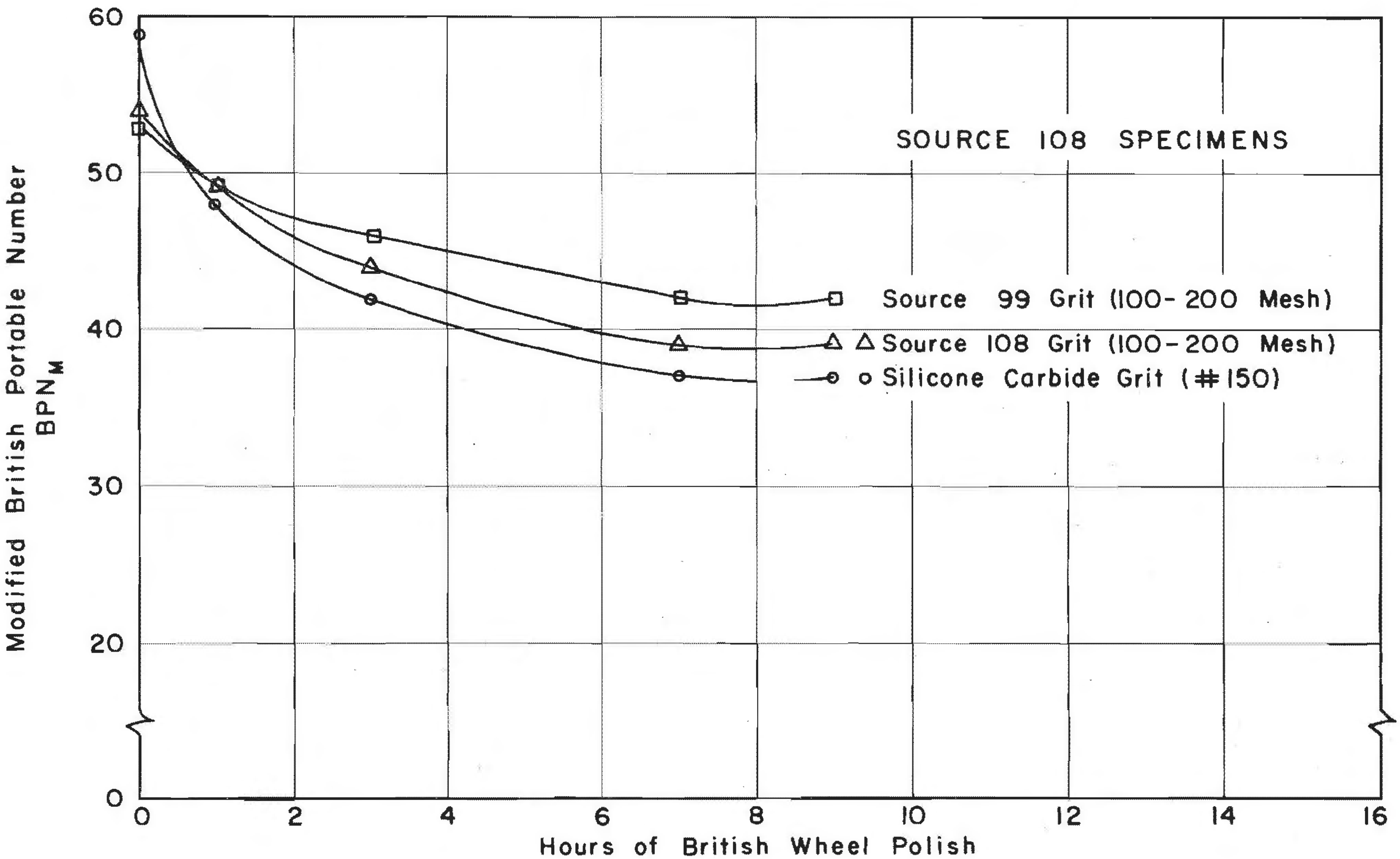
EFFECT OF GRIT HARDNESS WHEN USING THE BRITISH WHEEL TEST ON FOSSILIZED LIMESTONE

Figure 8



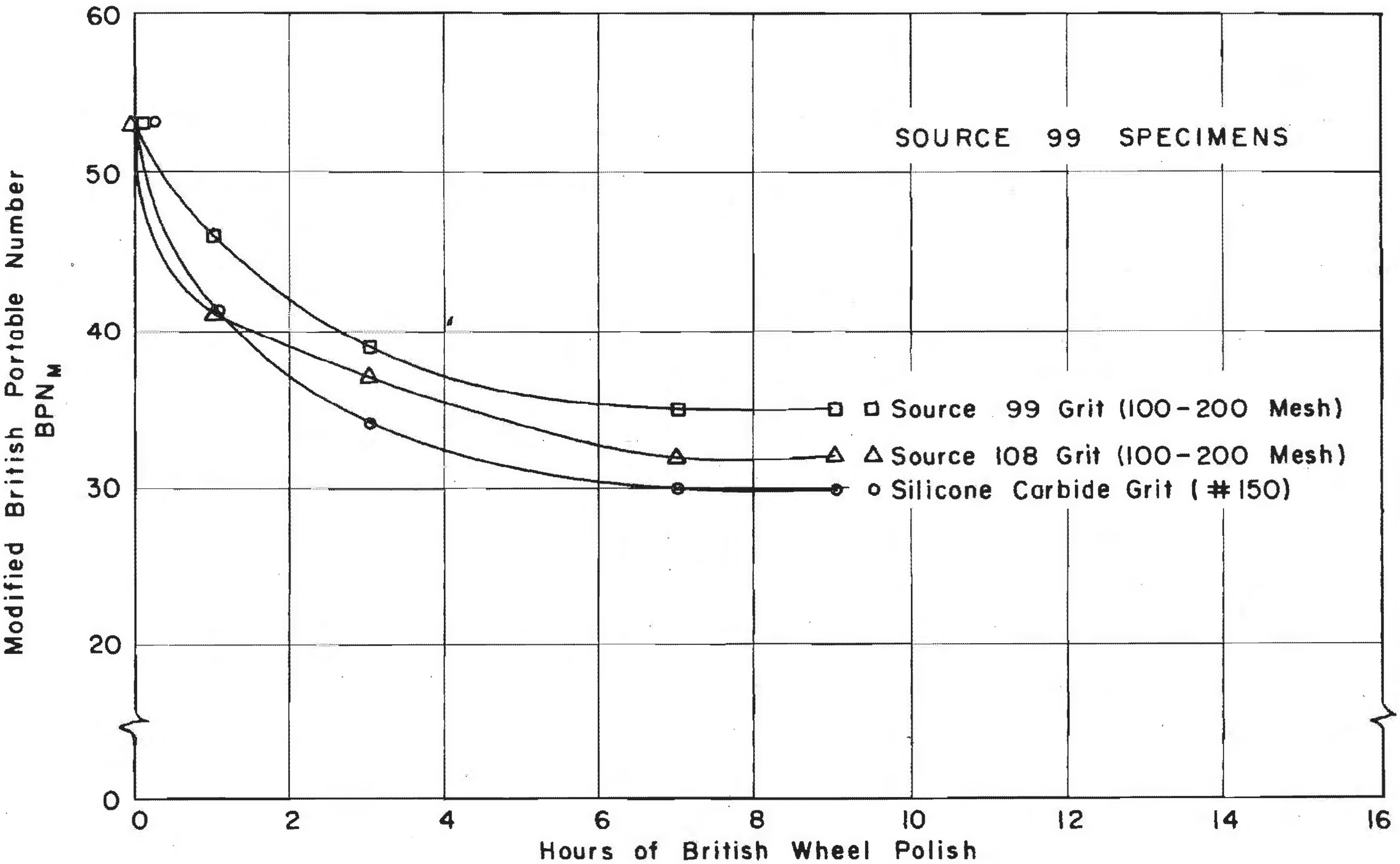
EFFECT OF GRIT HARDNESS WHEN USING THE BRITISH WHEEL TEST ON RIVER GRAVEL

Figure 9



EFFECT OF GRIT HARDNESS WHEN USING
THE BRITISH WHEEL TEST ON TRAP ROCK

Figure 10



EFFECT OF GRIT HARDNESS WHEN USING THE BRITISH WHEEL TEST ON DENSE LIMESTONE

Figure 11

Within Pit Variation

Pit variation is a problem which is associated with the polish test as well as all other aggregate material testing. Certain limestone sources contain layers which are dense, crystalized and even highly fossilized. River gravel sources have extreme variation in material type, and this variation will be discussed later in this report.

The pit variation was studied by obtaining a rock sample from four widely different areas of four different source pits. One dolomitic limestone source, one trap rock source, and two calcareous limestone sources were selected for study. Different areas of each pit were selected for wide variation in polish characteristics; however, acceptable aggregate must have been produced from the area selected. In other words, no attempt was made to obtain material from poor areas or the strippings. Personnel of The Materials and Tests Division crushed the material to the desired size. The results of the study were recorded in Table I. The letters were used to indicate directional locations in the pit with S. being South, N.E. being Northeast, etc. "Avg." was used as the average Polish Value of the four samples which were obtained in the four areas of the pit, and "Var." was used to represent one Standard Deviation. The "% Var." was presented to illustrate the extent to which different areas of the pit vary about the average value. The "% Var." is the percent of variation and is found by dividing the variation (Standard Deviation) by the average (Mean). The variation was found to range from 0.7 (2.6%) to 2.6 (7.2%). The average Polish Values ranged from 26.5 to 37.3.

The Polish Value which is referred to is defined in this chapter under The Effect of Grit Size. The testing actually conformed to the

Table I

Within Pit Variation
(Polish Value)

Crushed Limestone #264		Trap Rock #108	
S.	32.7	S.E.	37.0
S.E.	37.3	W.	39.3
N.E.	36.0	S.	35.7
N.W.	39.7	N.	37.3
Avg.	36.4	Avg.	37.3
Var.	2.6	Var.	1.3
% Var.	7.2%	% Var.	3.5%

Dolomite #110		Crushed Limestone #99	
N.W.	27.6	N.	29.7
S.E.	26.3	W.	33.7
N.E.	26.0	N.E.	28.7
W.	26.0	S.E.	30.3
Avg.	26.5	Avg.	30.6
Var.	0.7	Var.	1.9
% Var.	2.6%	% Var.	6.1%

tentative test procedure which has been described later in this chapter.

Variation Between Specimens of a Sample

Table II reveals the results of the study of specimen variation. In this study, 66 samples were prepared in which each sample consisted of 3 specimens. Table II gives the smallest and largest Polish Values obtained on the specimens of a given sample and the value found for the range in the sample. The largest range in the 66 samples was 9, and the average range was 3.64. The smallest Polish Value was 20, and the largest was 48. Again, the Polish Value which is referred to conforms to the tenative test method which is described below.

Development of a Modified Test Method

At this point, it was believed that a test procedure should be developed to reduce operator variance in the British Wheel test, especially since a study of several sources was contemplated. The test method which was developed, a modified British version, has been placed in the appendix. Attempts were made to duplicate BS:812 with exceptions encountered in, the British Portable Tester, the type of grit, the size of grit, and a calibration exercise which was associated with the British Portable Tester.(5)

The British Portable Tester conformed to and was calibrated by use of ASTM E303-66T. The tester was then modified with a 1-1/4 inch wide slider to conform to BS:812, and it was further modified to use ASTM E249 rubber (American rubber rather than British).(6)

The grit which was used was silicone carbide because it could be easily obtained from commercial sources. The single size used was 150 grit.

Table II

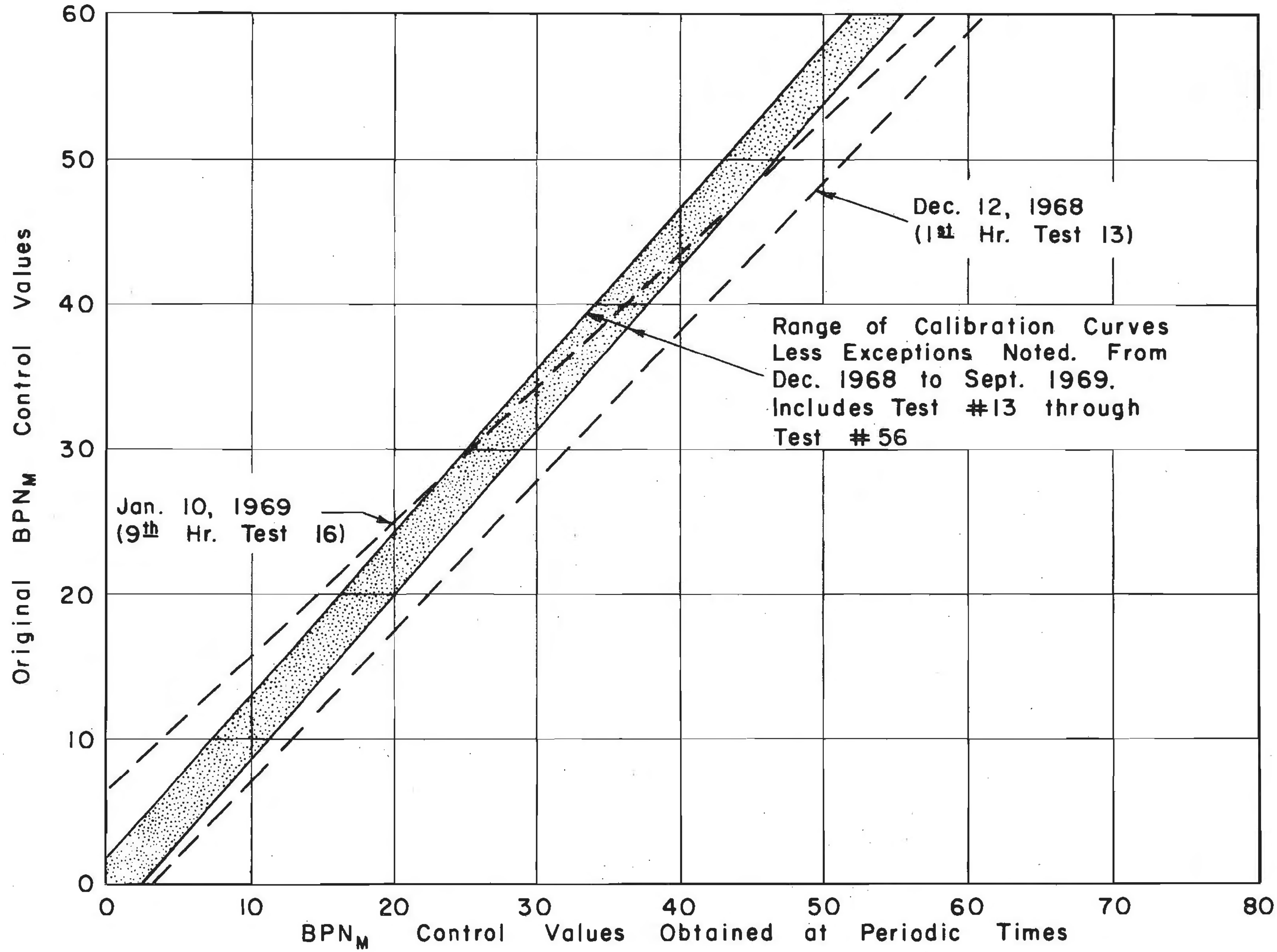
Specimen to Specimen Variation Within a 3 Specimen Sample (Polish Value)

27-30 - 3	26-27 - 1
29-32 - 3	23-27 - 4
37-38 - 1	24-30 - 6
23-29 - 6	23-27 - 4
29-31 - 2	24-27 - 3
37-39 - 2	40-45 - 5
34-39 - 5	37-45 - 8
38-40 - 2	22-24 - 2
37-40 - 3	23-32 - 9
28-31 - 3	23-28 - 5
38-41 - 3	27-29 - 2
26-27 - 1	27-29 - 2
26-33 - 7	26-27 - 1
23-29 - 6	20-26 - 6
22-25 - 3	26-27 - 1
33-38 - 5	33-34 - 1
31-36 - 5	27-35 - 8
32-39 - 7	27-29 - 2
23-26 - 3	34-37 - 3
24-28 - 4	34-38 - 4
26-31 - 5	27-29 - 2
26-32 - 6	29-32 - 3
33-34 - 1	23-28 - 5
26-32 - 6	26-33 - 7
33-34 - 1	31-35 - 4
36-41 - 5	37-42 - 5
35-37 - 2	28-30 - 2
25-26 - 1	28-30 - 2
28-37 - 9	37-39 - 2
23-28 - 5	30-33 - 3
26-28 - 2	26-28 - 2
45-48 - 3	26-32 - 4
27-28 - 1	
26-27 - 1	

Largest Range - 9
Average Range - 3.64

The calibration exercise (Test Control) which was used consisted of testing four previously polished control specimens. This calibration exercise was performed prior to all testing of actual polished specimens, and the friction of the control specimens varied from low to high. If "day to day" variations existed in the control specimens, a correction was obtained by correcting the "day to day" value back to the original value which had been obtained on the control specimens. This correction was obtained by plotting the original values of the control specimens v.s. the daily value for the control specimen. A "best fit" line was drawn between the four points, and if it did not conform to a 45 degree line (1:1), the correction value was obtained by measuring the distance between lines. This correction was expressed in terms of the modified BPN values. The values for the polished specimens were then corrected in the same manner. Hopefully, all values were corrected to be representative of the BPT after it had been calibrated according to ASTM E303-66T. The researchers realized that the friction of the control specimen could change with repeated applications of the slider, but it was believed that this change would be small and discernable only with time and experience.

The reasons for adopting the test control were: the lack of prior experience with operating the British Portable Tester, the lack of experience in obtaining temperature corrections, and the lack of experience in obtaining texture corrections. The experience which was gained in using the "Test Control" indicated that the method was satisfactory. As illustrated in Figure 12, a series of calibrations were performed at different times. Having obtained some 209 (reported) calibration exercises (from December, 1968 to September, 1969), the calibration curve varied only



STUDY OF DAILY VARIATION IN BPT VALUES

Figure 12

$\pm$ 2 BPN_m; this amount of variation did not appear to be significant. On two occasions extreme variance was noted, both near the initial stages of testing. It should be stated that (except for vacation and sick leave) only one technician performed the tests. Some of the research personnel who had been assigned to this project had a feeling of unease or distrust toward the British Portable Tester when using or observing the equipment. However, it was believed that the performance (as indicated in Figure 12) was satisfactory and that the equipment produces usable results without the calibration control mentioned in the suggested test procedure. But the calibration control is recommended, especially with personnel who are unfamiliar with the British Portable Tester.

Daily Variance of Samples From A Source

The daily variance study was actually a continuation of the Pit Variation study which was reported above. The pit variance study provided a means by which the researchers could determine the significance of the values which were being obtained; this also provided continued familiarization and experience with the equipment. However, the following information was also desired:

1. Whether there was difference between laboratory crushed material and material which was produced commercially
2. The variation in the overall, day to day test repeatability
3. Pit variation from a greater number of sources

The data was actually obtained while information was being gathered on a sample of sources from throughout the state; this data will be introduced later in this report. The dates of test, Polish Values, and the range in Polish Values for a particular source have been recorded in

Table III. In general, the material for any one source was collected at one time; however, material for sources 99, 108 and 297 was collected at different times. The material for Source 99 (which was tested in June, 1969) was obtained from a stockpile at the construction site. The average range for daily variance of samples was found to be 5, with the smallest range being 2 and the largest 12.

The Insoluble Residue Test and Its Relationship With the Polish Value

During the literature search, it was found that the National Crushed Stone Association (NCSA) had studied the Insoluble Residue Test in detail. NCSA was consulted and a test procedure, along with several helpful comments, was obtained. The following outline is the procedure which was used in this study:

1. Samples are washed, dried, graded and weighed.
2. Samples are then leached until all available soluble carbonates have been dissolved.
3. The remaining insoluble residue is filtered, washed, dried, and weighed.
4. The resulting amounts of carbonates and insoluble residue are reported as percentages of the total aggregate.
5. Grain size distribution results are reported as percentages of the total aggregate.

The acid leaching test was performed on several different commercially produced aggregates. In selecting the sources, no distinction was made between limestone sources and non-carbonate sources in an effort to correlate the Insoluble Residue Test results with the friction test results for all materials. Actually, the tested sources were selected from

Table III

Day to Day Variation of Source Samples

Pit No.	Material Type	Date Tested	Polish Value	Range In Source
6	River Gravel	1-30-69	25	
6	" "	12- -68	22	4
6	" "	12- -68	21	
6	" "	12-16-68	24	
21	River Gravel	4-15-69	28	2
21	" "	4-8-69	26	
31	River Gravel	4-10-69	28	5
31	" "	4-15-69	33	
83	Crushed Calcareous Limestone	3-11-69	26	3
83	" " "	2-17-69	29	
99	Crushed Calcareous Limestone	6- -69	37	
99	" " "	12- -68	28	12
99	" " "	12- -68	28	
99	" " "	12-16-68	25	
108	Trap Rock	12- -68	34	
108	" "	12- -68	31	5
108	" "	12-16-68	29	
110	Crushed Dolomitic Limestone	12- -68	25	
110	" " "	12- -68	24	5
110	" " "	12- -68	20	
142	Limestone Rock Asphalt	2-12-69	40	2
142	" " "	3-11-69	38	
262	River Gravel	2-7-69	25	7
262	" "	1-30-69	32	
266	River Gravel	3- -69	30	4
266	" "	2-27-69	34	
268	River Gravel	3-28-69	29	9
268	" "	3- -69	38	
297	Lightweight	12- -68	39	
297	"	12- -68	42	3
297	"	12-16-68	40	

Largest range found in one source = 12

Average range found in sources tested more than once = 5 the "stockpile" of materials which had been obtained for the British Wheel Test. The selection was arbitrarily made but was believed to form a sample of materials which was representative of the state. The sample consisted of 31 sources of which 16 were found to be calcareous in nature.

The Insoluble Residue Test Procedure is found in the Appendix and a summary of results is listed in Table IV. The results of the Insoluble Residue Test are basically a knowledge of the percent of the carbonate fraction and a screen analysis of the non-carbonate fraction or residue. The 8 and the 200 mesh screens were used.

As stated previously, the test was developed for use on limestone materials. The portion of the residue which is most critically examined by most researchers is the amount (or percent) found which passes the 8 mesh screen and is retained on the 200 mesh screen.[7] This portion is frequently referred to as the "sand size" portion. The "sand size" portion is believed to have the most influence on friction (for limestones, the greater the quantity of sand size residue, the higher the friction value).[7]

The analysis consisted of comparing the results of the Insoluble Residue Test with the results of the British Wheel Test. Actually, a comparison was made of the Polish Value to each item from the leaching test. A comparison was obtained for all materials which were selected, and also, a comparison was made for only limestone materials (that is, the materials containing more than 50% carbonates). Of the above analyses, only the relationship of the 8-200 portion (sand sized) of the limestone materials appeared significant and it is shown in Figure 13. For information purposes, a plot of the relationship between the British Wheel Polish Value

Table IV

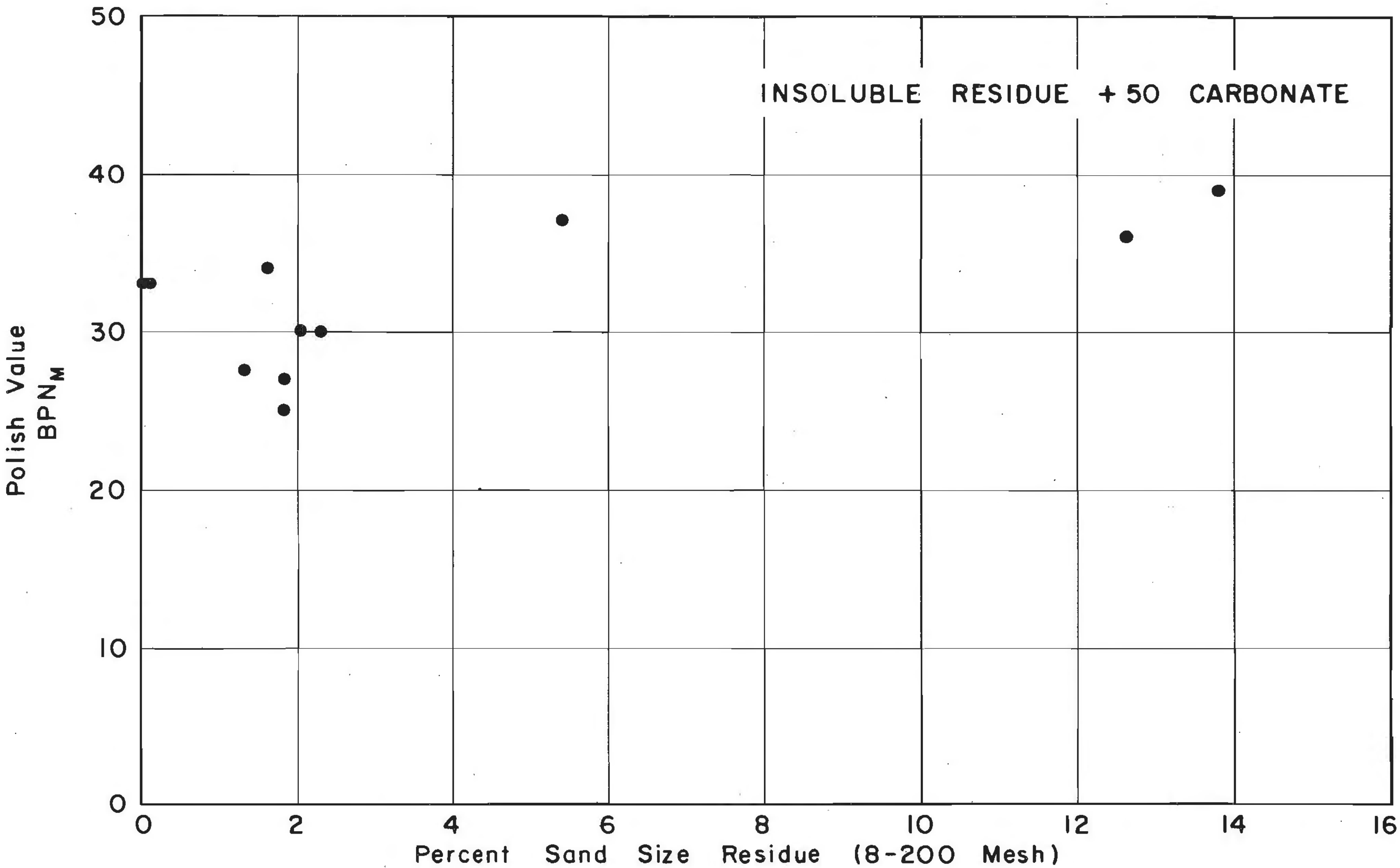
Summary of Insoluble Residue Test Results

Sample Pit	Carbonate Fraction	-200	8-200	+8	Total Residue Non-Carbonate	Polish Value	Material Description
1 - 142	87.51				14.05	39	Limestone Rock Asphalt
2 - 60	37.69	1.1	0.3	87.5	88.8	25	River Gravel
3 - 110	95.96					23	Dolomitic Limestone
4 - 285	97.51	1.3	0.1	0.9	2.3	33	Limestone
5 - 284	23.57	2.2	0.9	81.4	84.4	36	River Gravel
6 - 79	60.10	2.5	12.6	31.1	46.1	36	Limestone
7 - 291	87.82	3.6	1.6	5.0	10.19	34	Limestone
8 - 296	97.81					38	Limestone
9 - 290	68.30	1.3	1.9	42.6	46.2		River Gravel
10 - 295	95.38	2.5	0.0	0.0	2.4	33	Limestone
11 - 19	61.36	2.9	1.8	47.8	52.46	25	River Gravel
12 - 42	6.75	0.3	0.1	96.9	97.26	44	Silicious
13 - 20	35.89	0.1	1.2	91.6	92.9	25	Trap Rock
14 - 292	86.33	3.4	2.0	11.5	16.9	30	River Gravel
15 - 293	9.20	0.0	0.0	99.8	0.95	24	River Gravel
16 - 68	81.63	2.4	1.3	17.8	21.47	28	River Gravel
17 - 61	77.52	2.9	2.3	33.4	38.63	30	River Gravel
18 - 259	92.44	3.2	1.8	2.9	7.87	27	Limestone
19 - 282	77.92	7.2	13.8	0.9	21.91	39	Limestone
20 - 50	4.48	0.3	0.7	97.8	98.77	36	River Gravel
21 - 278	7.71	0.1	0.6	95.7	96.43	39	River Gravel
22 - 42	4.34	0.1	0.1	97.7	97.88	44	Repeat Test
23 - 273	7.04	0.3	0.6	91.9	92.84	39	River Gravel
24 - 303	6.99	0.6	0.1	95.9	96.61	53	Lightweight
25 - 66	66.41	6.0	5.4	41.6	52.98	37	River Gravel
26 - 279	8.90	0.2	0.3	94.8	95.32	39	River Gravel
27 - 312	1.90	0.1	0.1	99.2	99.41	56	Lightweight

Table IV (Continued)

Summary of Insoluble Residue Test Results

Sample Pit	Carbonate Fraction	-200	8-200	+8	Total Residue Non-Carbonate	Polish Value	Material Description
28 - 287	20.85	0.4	4.6	86.5	91.48	38	River Gravel
29 - 95	4.18	0.1	0.0	99.1	99.20	39	Silicious (Igneous Origin)
30 - 28	38.65	4.0	57.4	2.9	64.31	44	Sandstone
31 - 131	90.81					42	Limestone Rock Asphalt
32 - 296	97.83					38	Repeat Test
33 - 290		1.45	1.74	45.92	49.11		Repeat Test
34 - 19		2.67	1.93	50.28	54.88	25	Repeat Test
35 - 79		4.28	10.52	33.55	48.35	36	Repeat Test
36 - 68		2.4	1.4	20.2	23.97	28	Repeat Test



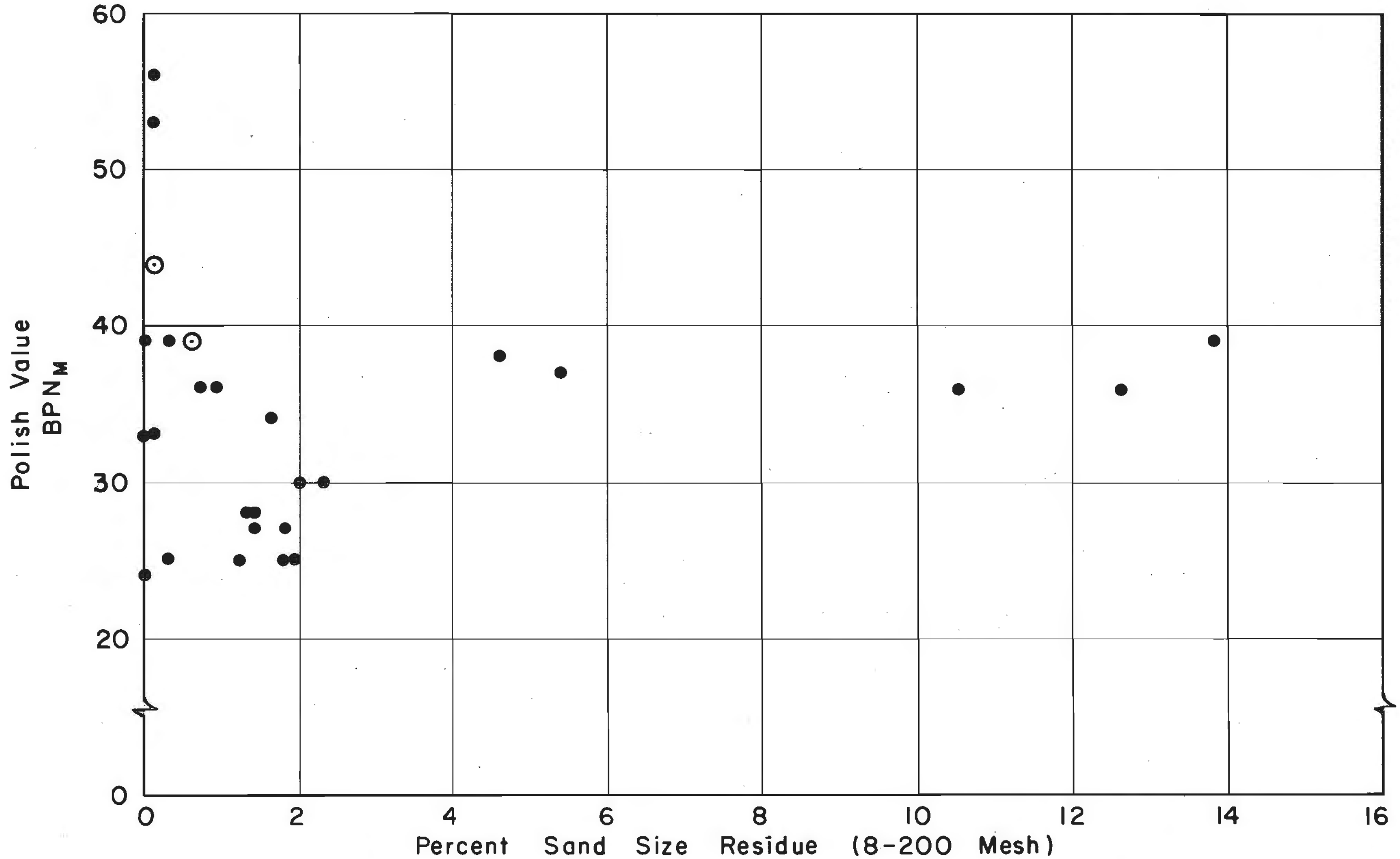
COMPARISON OF THE INSOLUBLE RESIDUE TEST RESULTS AND THE BRITISH WHEEL TEST RESULTS LIMESTONE

Figure 13

and the 8-200 portion of the residue for all materials (which were studied) is found on Figure 14. Generally, the carbonate fraction was found to be the matrix of the aggregate; however, one unusual material was found in which the matrix was believed to be non-carbonate. After the leaching process, several aggregates were found in which a skeleton of non-carbonates remained. Also, rock asphalt was tested by first attempting to extract the asphalt, but the results of leaching the remaining rock asphalt material were believed to be inaccurate.

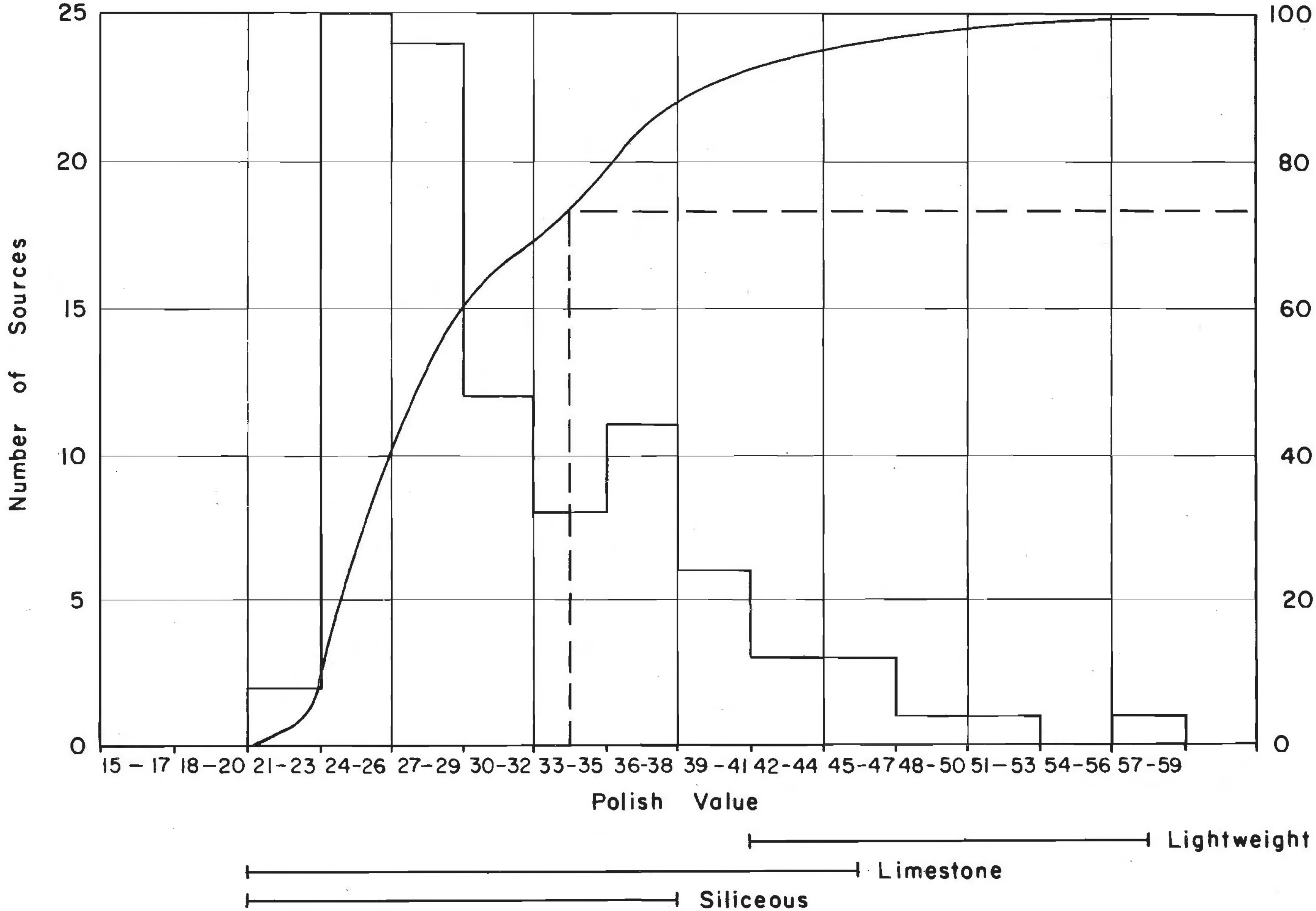
Polish Values from A Sample of Texas Sources

After the preliminary work and the establishment of a tentative test procedure, a sample of various aggregate sources (which have been used throughout the state) was collected. The sample consisted of aggregate from 97 producers. In many cases, the Districts were asked to supply material which has been used for surface aggregate or from sources of special interest. The results from testing the sample were plotted and have been shown in Figure 15. Figure 15 is a frequency distribution which shows the number of sources which were found for selected Polish Value ranges. The group having the largest number of sources was found to be between the Polish Values of 24 and 26, where 25 sources occurred. In the cummulative distribution found on the right side of the plot, some 73 percent were found to have Polish Values below 34. There is a definite spread or range in Polish Values for a certain aggregate type. For example, synthetic lightweight aggregate ranges from approximately 41 to 58 depending on the source. The Polish Value for a source probably depends on the size of the holes in the blib structure (bloated voids) and the rate of attrition of the synthetic aggregate. The Polish Values for the



COMPARISON OF THE INSOLUBLE RESIDUE TEST RESULTS AND THE BRITISH WHEEL TEST RESULTS ALL MATERIAL TYPES

Figure 14



FREQUENCY DISTRIBUTION OF POLISH VALUES

Figure 15

limestone sources ranged from about 20 to 46, and silicious sources (generally river gravels) ranged from approximately 19 to 38.

<u>Relationship Between Laboratory and Field Friction Measuring Instruments</u>

An item which had to be considered when studying the relationship between field and laboratory friction performance was the correlation of the British Portable Tester and the skid test trailer. As noted previously, the British Portable Tester (BPT) was modified by using a 1-1/4 inch rubber pad rather than the usual 3 inch pad. The test on the British Wheel specimens utilizes a 3 inch swing rather than the 5 inch swing ordinarily used. Using these modifications, correlation data was obtained on several sections of pavement surface. Two skids were obtained with the skid test trailer on each section of pavement surface, and two British Portable tests were obtained in these skid paths. Figure 16 is a plot of the information which was collected. It should also be noted that similar correlations were performed, each on different days, and the correlation equations were essentially the same. For information, the equations for the three correlation exercises is given as follows:

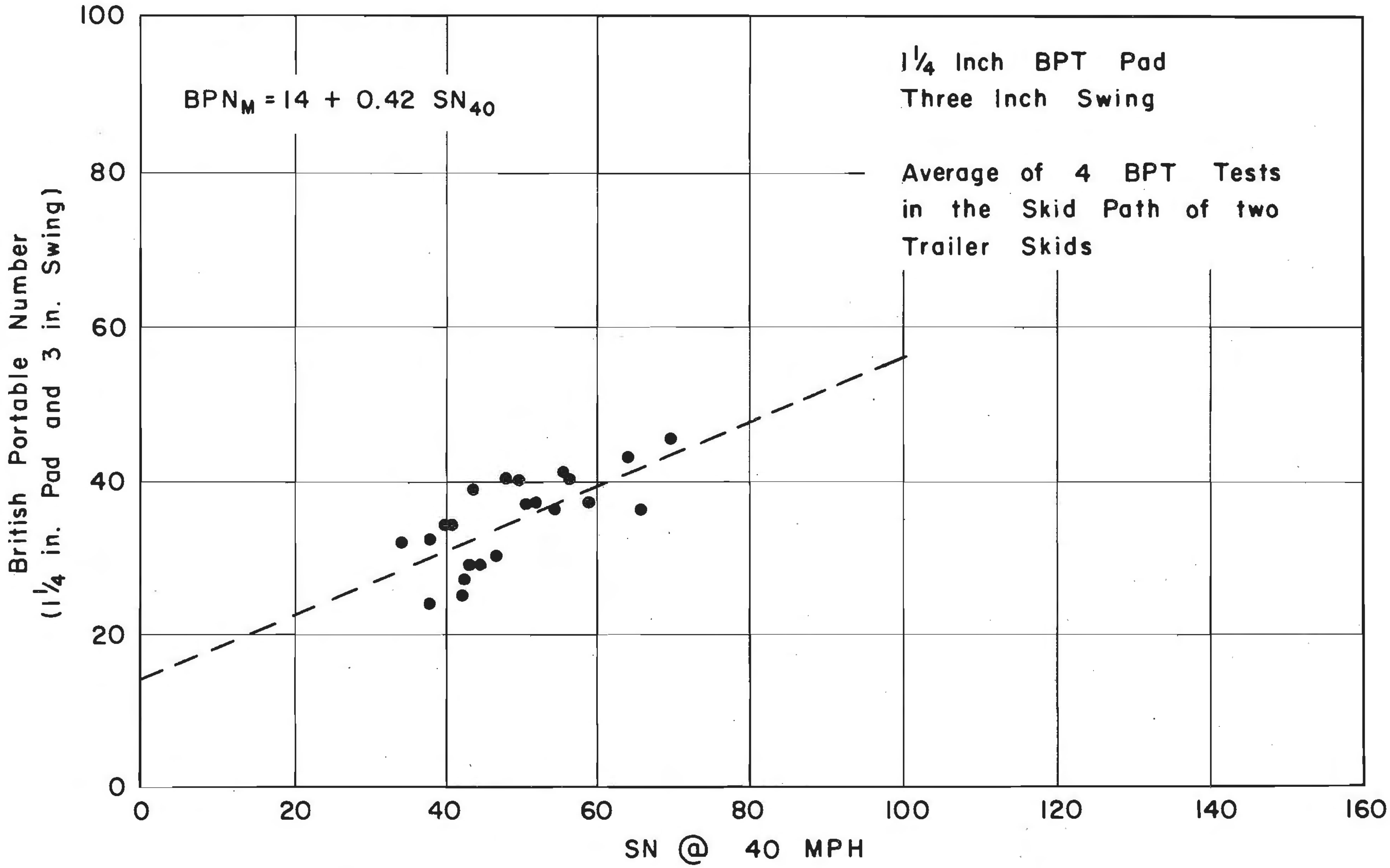
a. $BPN_m = 14 + 0.44\ SN_{40}$

b. $BPN_m = 11 + 0.52\ SN_{40}$

c. $BPN_m = 14 + 0.42\ SN_{40}$

where BPN_m = Modified BPN and SN_{40} = SN at 40 mph

The equation in "a" was derived from data from only eight different sections of highways and the equation in "b" was derived from the BPT data which was obtained with a 3 inch rubber pad and a 5 inch swing. The BPT data in equation "b" was adapted for comparison to the trailer data by multiplying by a factor of 0.6. The 0.6 factor was derived by obtaining



RELATIONSHIP BETWEEN THE BRITISH PORTABLE TESTER AND TRAILER

Figure 16

the ratio of the lengths of swing (that is 3/5). The equation in "c" was selected for use because of the planned and consistant method in which the data was collected. American rubber conforming to ASTM specification E 249 was used on the BPT.

Relationship Between Field and Laboratory Friction Performance

The greatest inconsistancy between comparing field and laboratory friction performance is the lack of field friction performance data. This drawback was noted several years ago, and attempts were made to establish test sections on certain highways in order to study the friction performance of several coarse aggregate types under varying traffic conditions.[11] Unfortunately, most of the experimental test section surfaces were composed of asphaltic concrete. Since this phase of the study was concerned with the coarse aggregate only, it was believed that the asphaltic concrete test sections should not be included because of the lack of knowledge concerning the friction characteristics of the fine aggregate. One test section remained on which four aggregate types were used as a seal or surface treatment. Periodic friction measurements had been maintained on this section using a skid test trailer; therefore this test section was selected for the study of the relationship between field and laboratory friction performance.

Aggregates from the four material sources used on the selected test section were subjected to the British Wheel test. Friction measurements were obtained before polish, after 1 hour, after 3 hours, after 7 hours and after 9 hours of polish (in almost every case no further polishing was necessary because friction could not be lowered with additional polish effort). The four material types used in the study were a synthetic lightweight, a trap rock, a dolomitic limestone and a calcareous limestone.

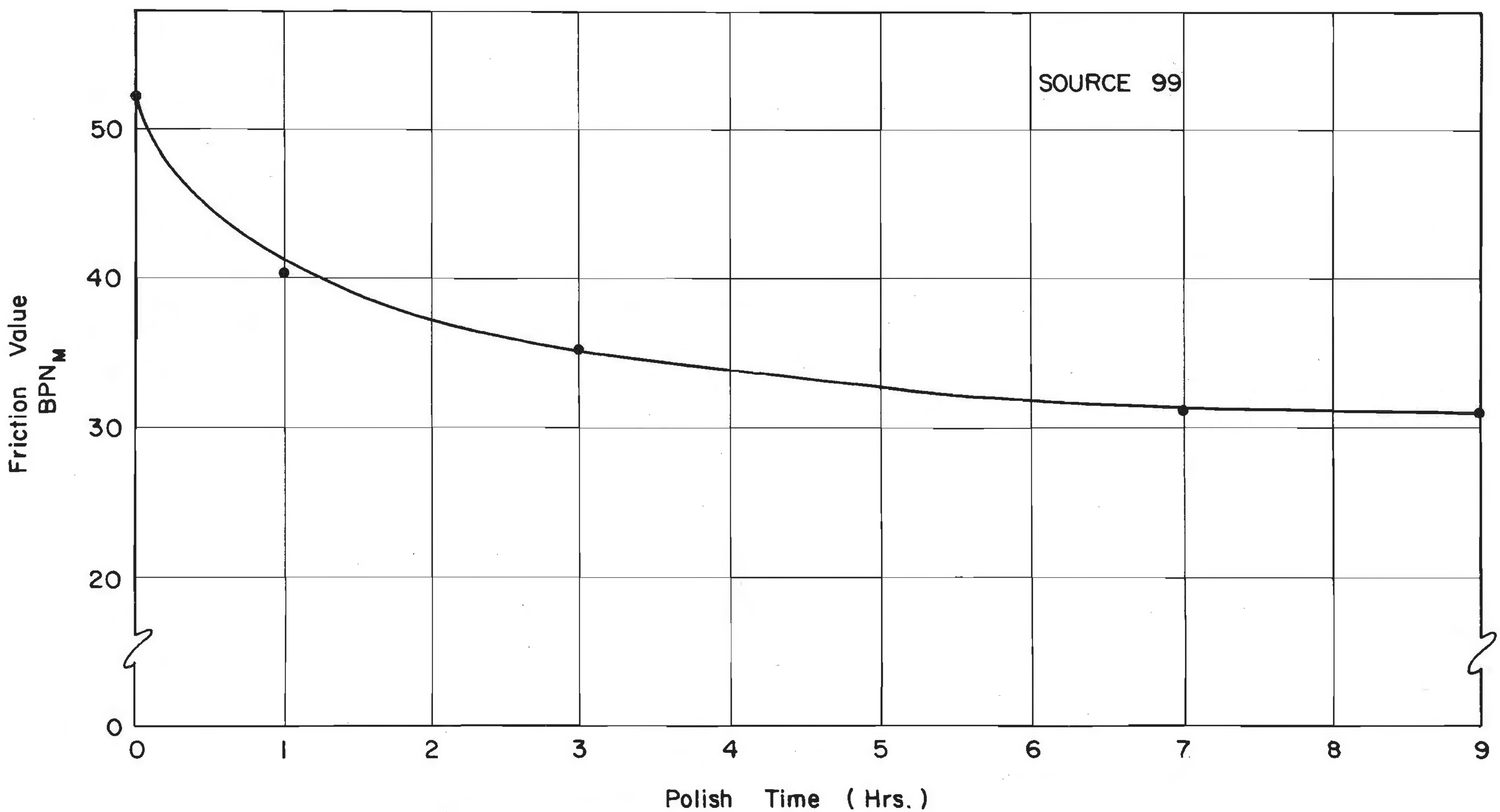
The results of the British Wheel tests are given in Figures 17 through 20 and the results of the field tests are given in Figures 21 through 24. It should be stated that the curves shown in the field tests were obtained by the placement of a best fit line by visual means. (There was considerable scatter in the individual periodic friction plots which was of much concern until agencies from other states were consulted.) The other states were having the same trouble. The scatter appeared to be worse near the earlier stages of field wear and much less near the latter stages of polish. Total variation around the "eye balled" curve fit was as much as ± 5 SN near the early stages of polish. The cause is still unknown; however, the larger variation of points is undoubtedly caused by seasonal variation. Possibly, some of the remaining scatter was caused by day-to-day trailer variation, but it was believed that most of the unexplained variation was caused by some sort of material property or micro-texture change occurring on the roadway surface. The possible seasonal variation resulted in higher friction values in the winter months with the total seasonal variation - winter to summer - being approximately 10 skid numbers. All skid trailer data was corrected for road film and temperature as explained in Research Report 45-3. Full data for the experimental test sections is given in Research Report 126-1.

After working with several curve forms, further analysis was formed using log-log or exponential curves:

$$f_T = T_T^{\frac{1}{b_T}} \quad \text{and} \quad f_B = T_B^{\frac{1}{b_B}}$$

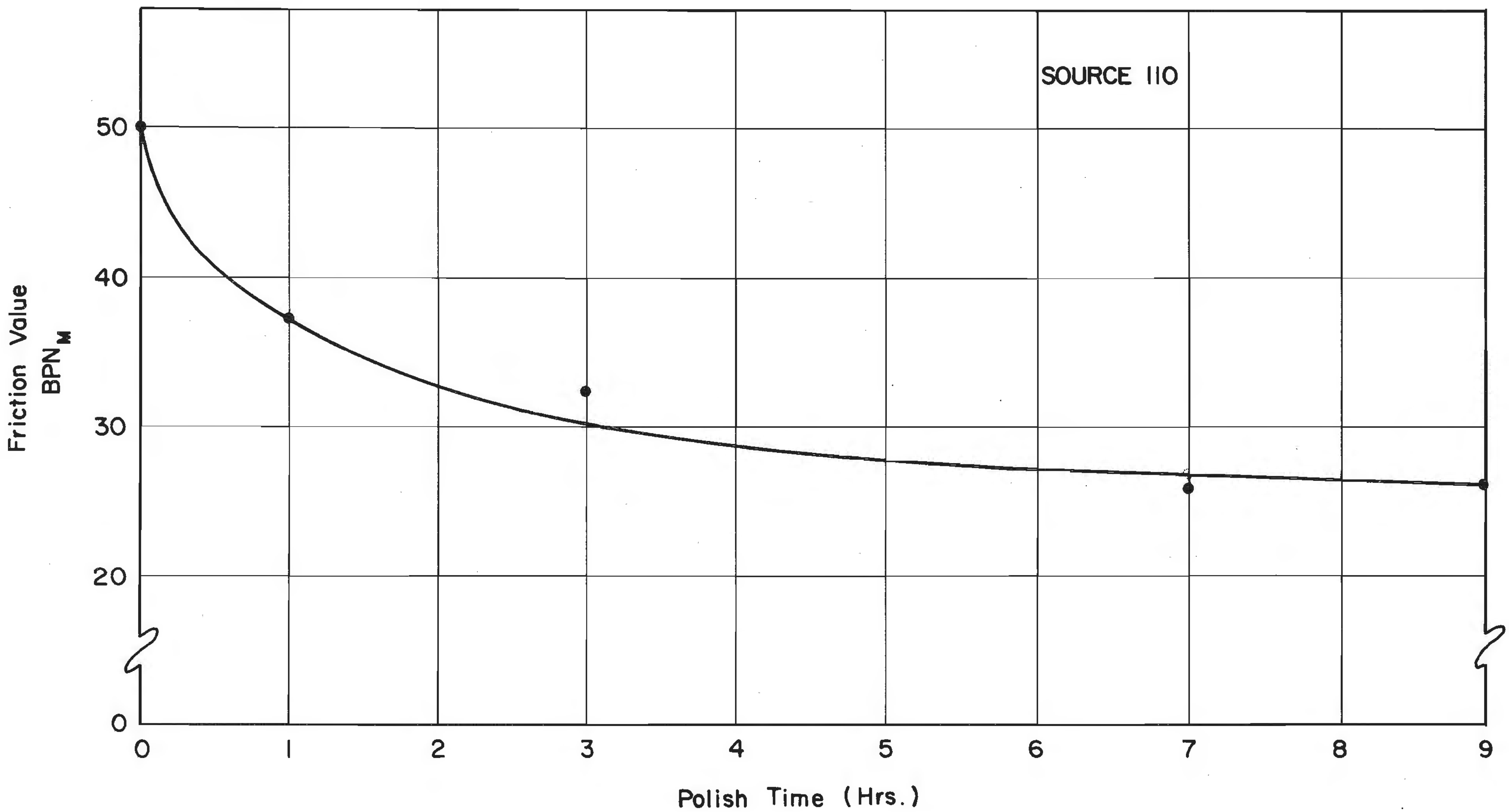
or

$$\log f_T = \frac{1}{b_T} (\log T_T) \quad \text{and} \quad \log f_B = \frac{1}{b_B} (\log T_B)$$



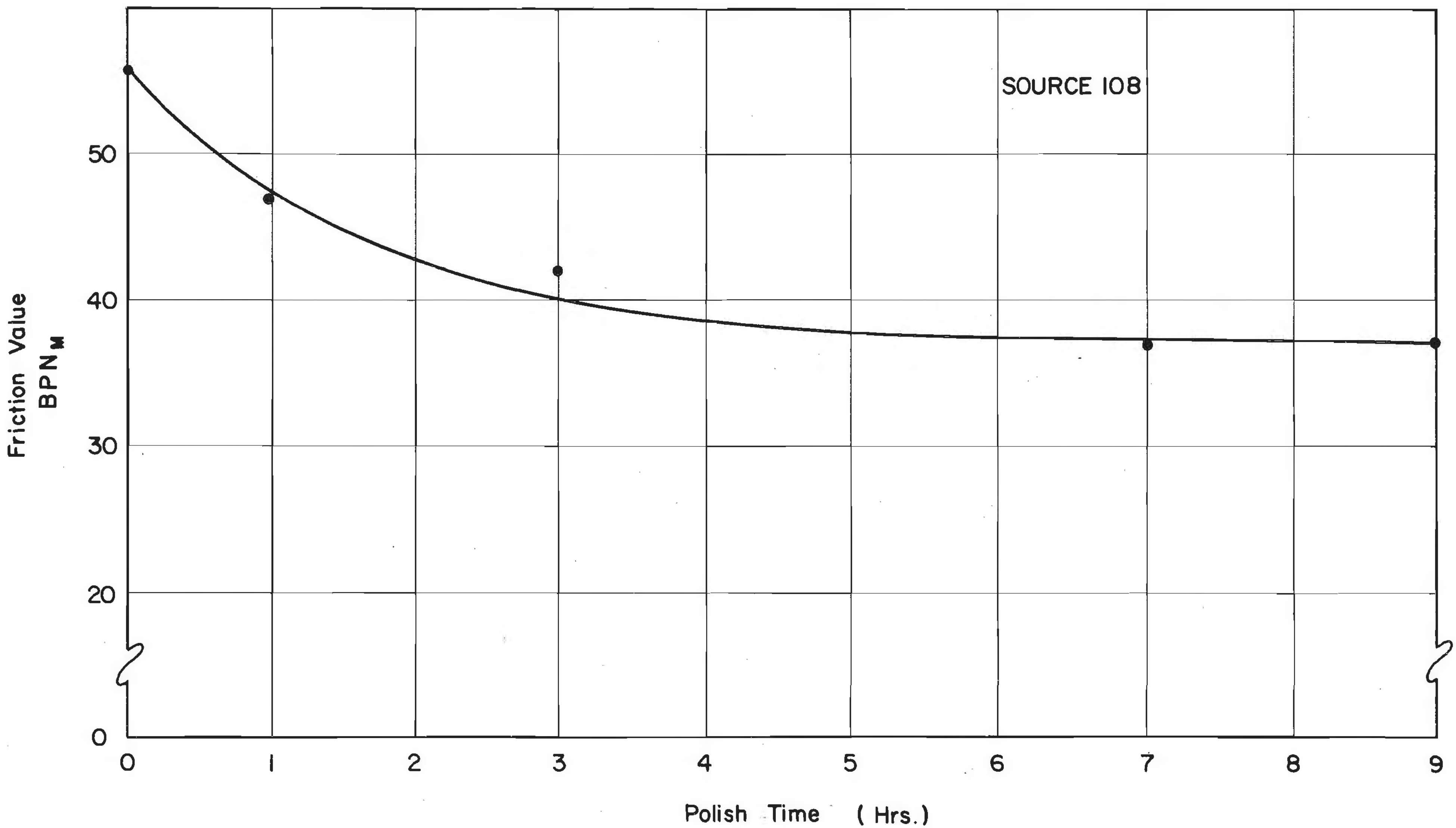
LABORATORY FRICTION PERFORMANCE OF LIMESTONE

Figure 17



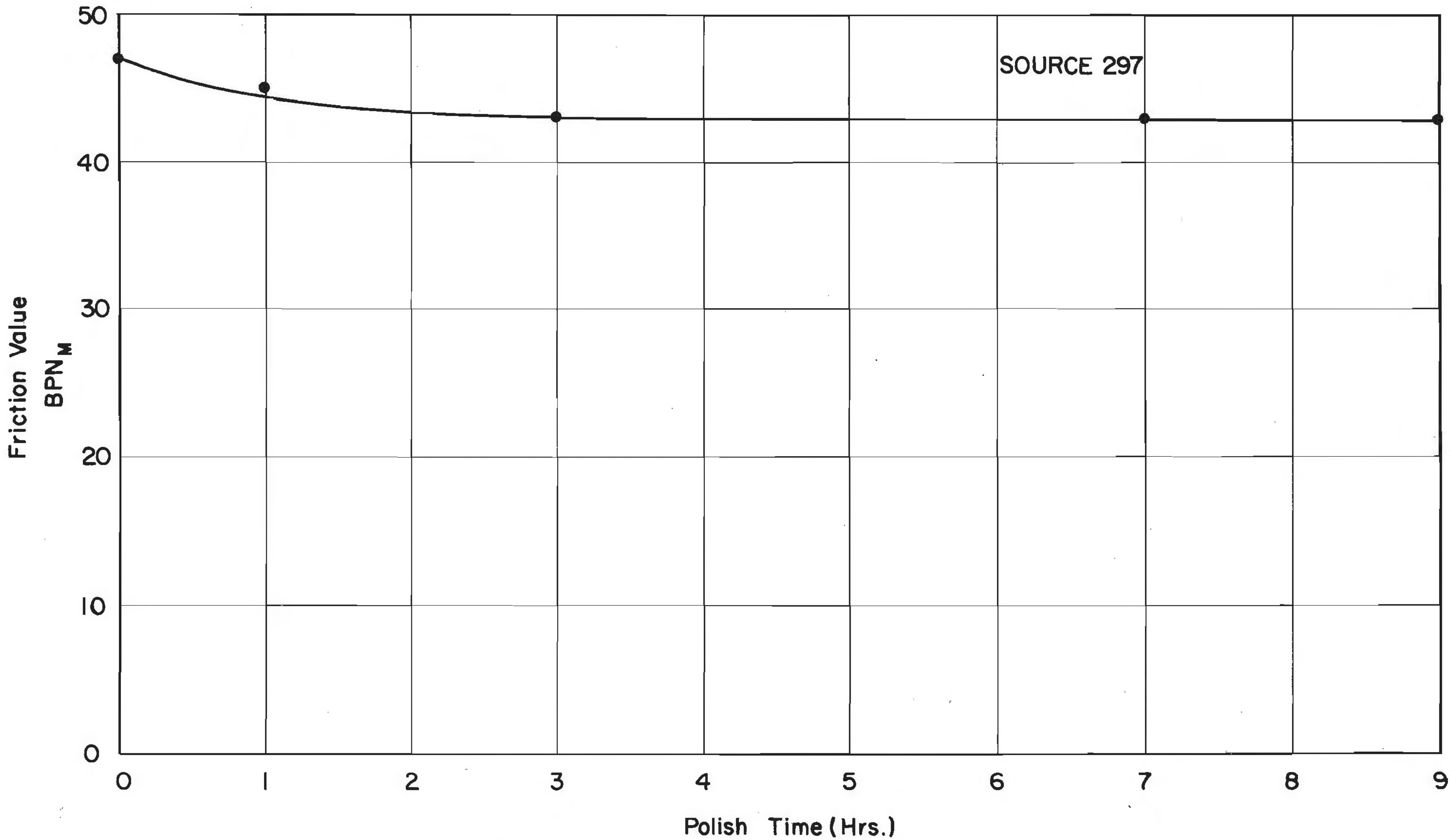
LABORATORY FRICTION PERFORMANCE OF DOLOMITE

Figure 18



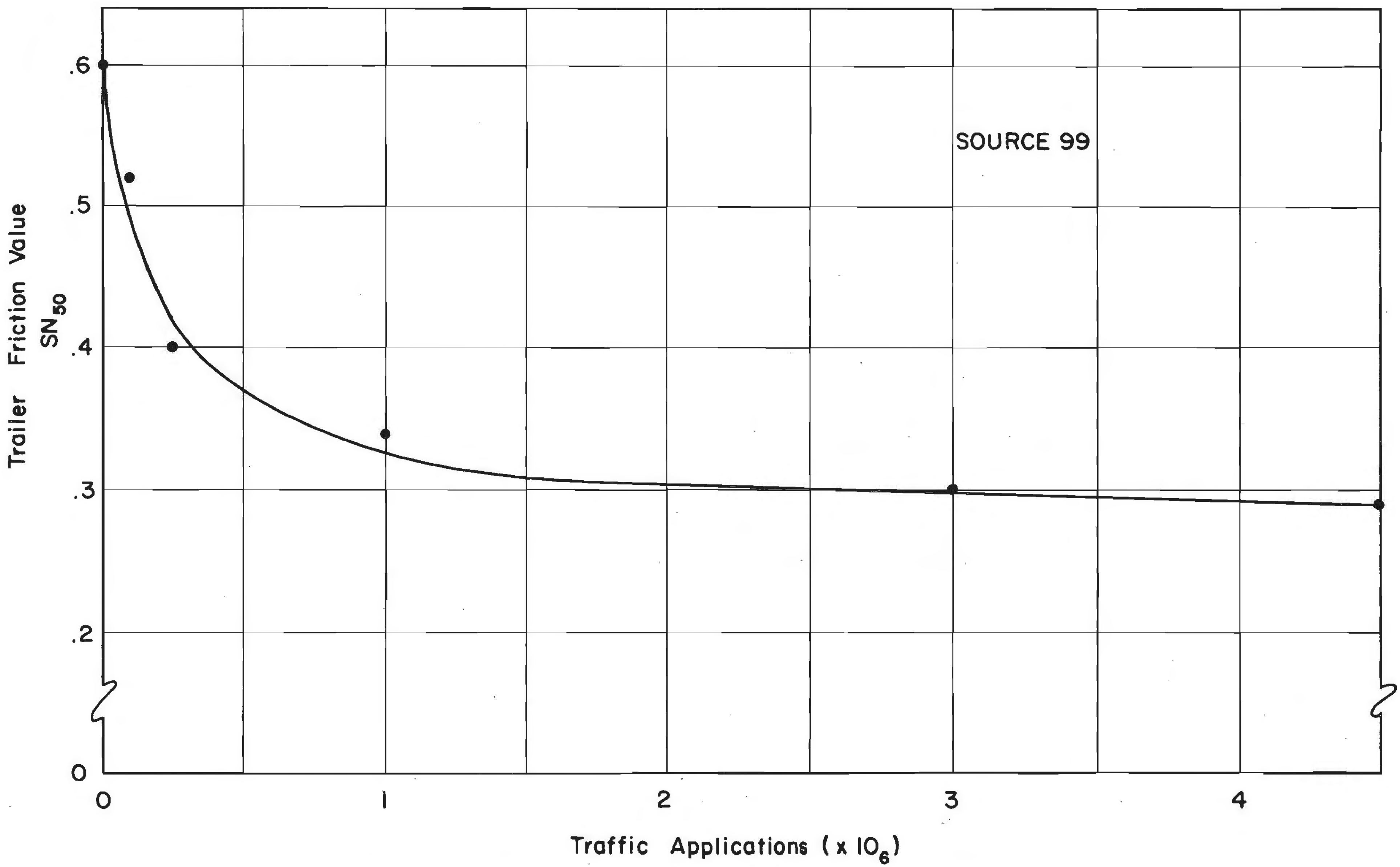
LABORATORY FRICTION PERFORMANCE OF TRAP ROCK

Figure 19



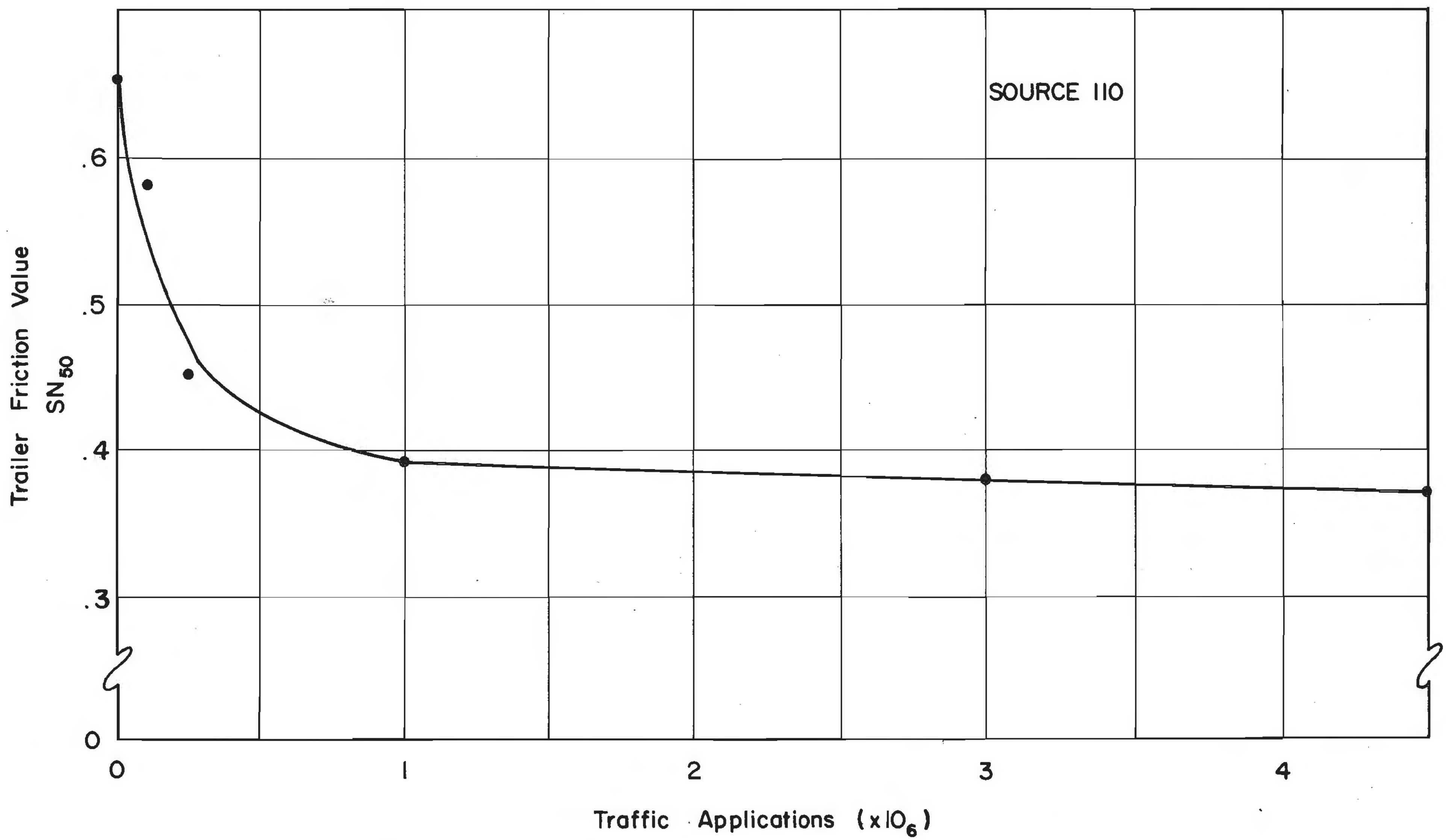
LABORATORY FRICTION PERFORMANCE OF LIGHTWEIGHT

Figure 20



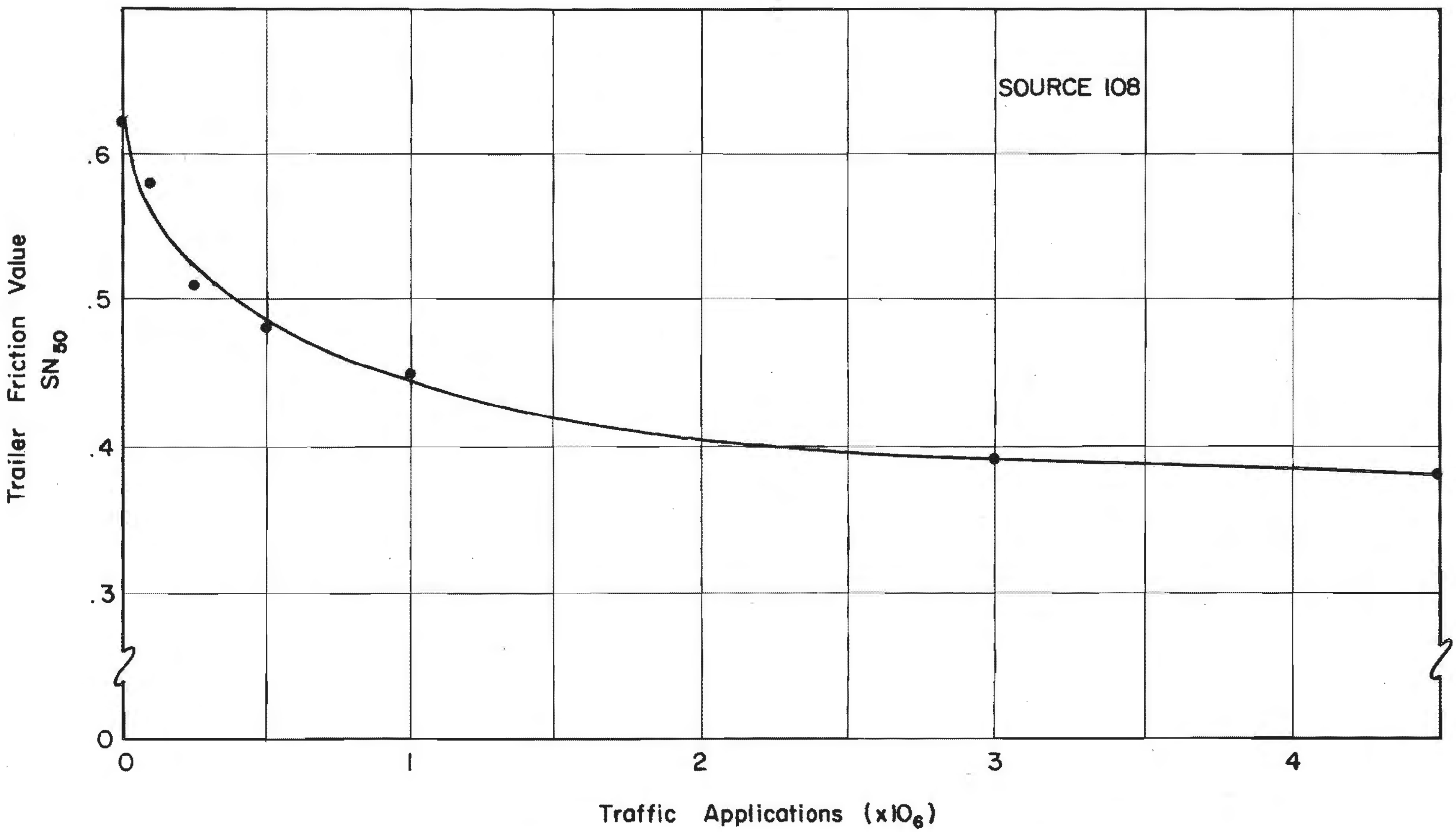
FIELD FRICTION PERFORMANCE OF LIMESTONE

Figure 21



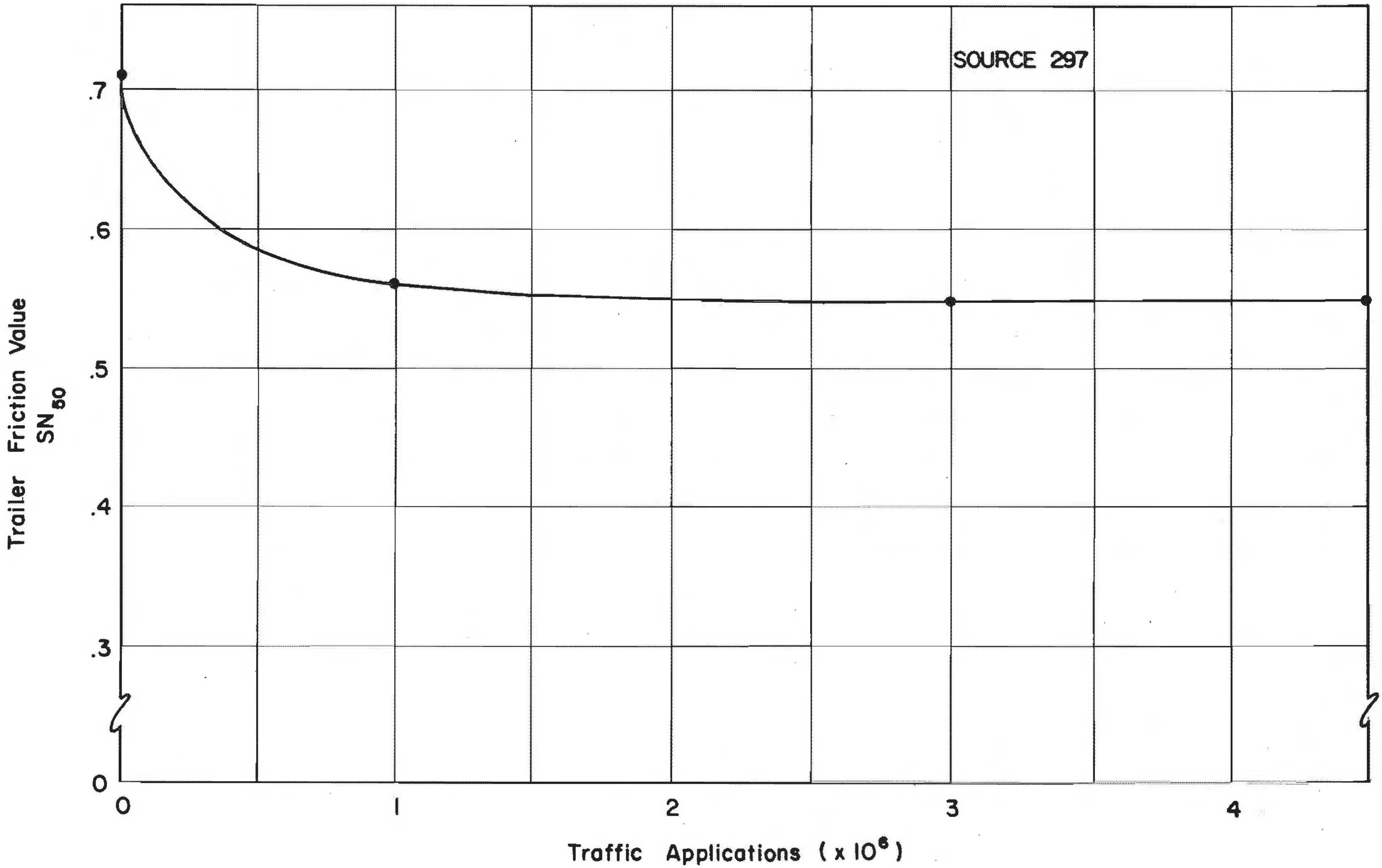
FIELD FRICTION PERFORMANCE OF DOLOMITE

Figure 22



FIELD FRICTION PERFORMANCE OF TRAP ROCK

Figure 23



FIELD FRICTION PERFORMANCE OF LIGHTWEIGHT

Figure 24

where f_T = the skid trailer value or SN at 50 mph

f_B = BPN measured with the British Portable Tester

T_T = the number of traffic applications (actual one lane traffic)

T_B = the number of hours of polish with the British Wheel

b_T = the log-log slope or rate of polish of the trailer friction and traffic field wear

b_B = the log-log slope or rate of polish of the BPN and British Wheel (Laboratory wear)

Several points were selected from the field wear plots found in Figures 21 through 24, and the common logarithmic values were found for the data. These values were listed in Table V. Note that a liberty was taken in that the value of "one" was added to each selected traffic application number in order that the following data may more readily fit the analysis procedure which was selected.

Several points were also selected from the laboratory wear plots found in Figures 17 through 20, and the same procedure mentioned above was used. Note that the BPN was transformed to a SN_{40} value by use of the plot shown in Figure 16. (Experience in obtaining friction values at various speeds using a Texas skid trailer indicates little difference in 40 mph values and 50 mph values for a particular surface; therefore, the friction values found in the plot in Figure 16 are considered to be the same as SN_{50}.) The laboratory values are found in Table VI, and Figure 25 indicates a plot of the log values of the field tests. Likewise, Figure 26 indicates the plot of the log values of the laboratory tests. There is a significant difference in log-log slopes of the linear curves which were fitted to the points for each plot. The lightweight aggregate was found to have the least slope or rate of polish;

Table V

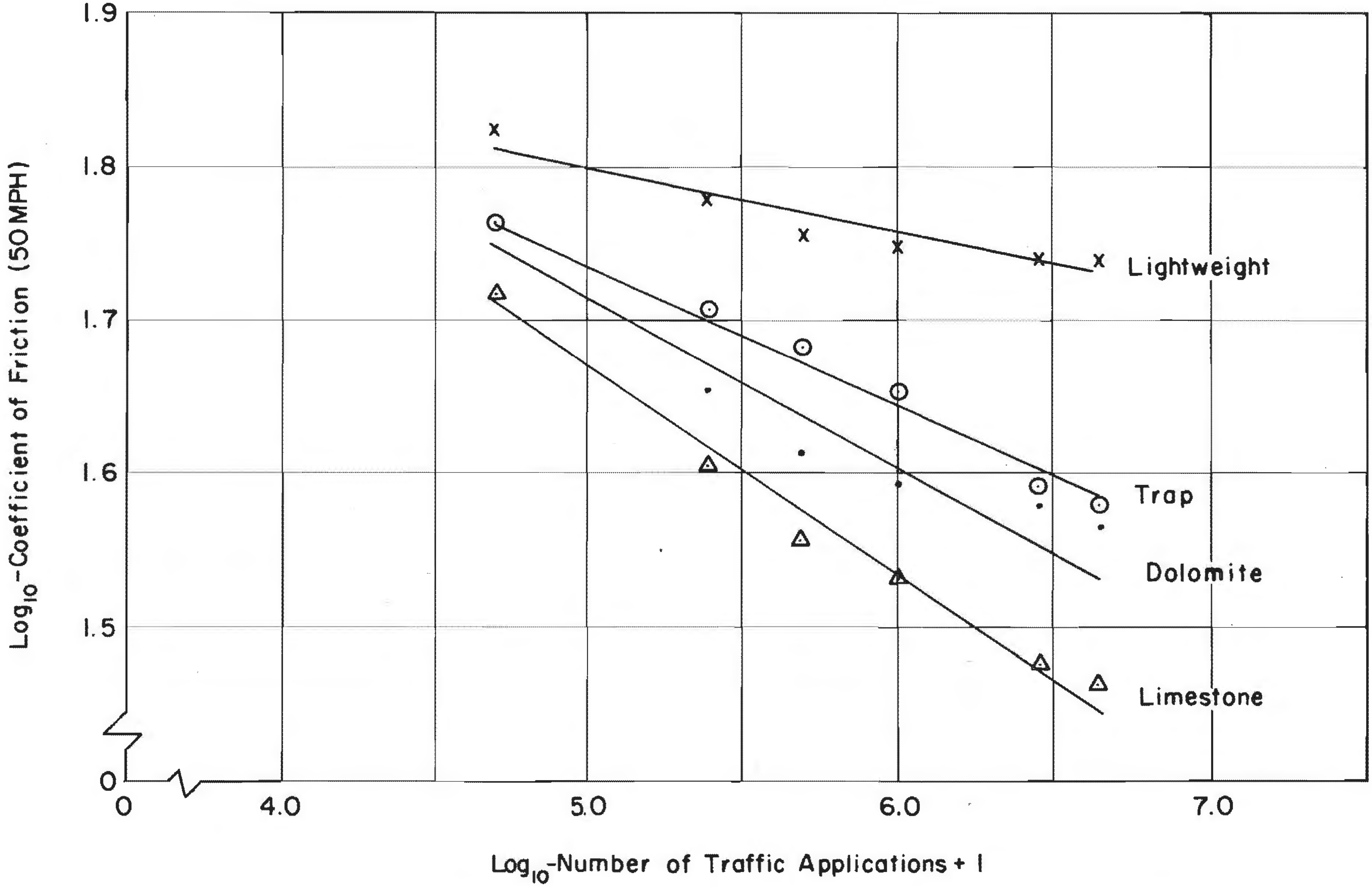
TABLE OF TRAFFIC POLISH RATES

	TRAFFIC APPLICATIONS + 1					
Actual Traffic	50,001	250,001	500,001	1,000,001	3,000,001	4,500,001
Log_{10} of Traffic	4.699	5.398	5.699	6.000	6.477	6.653
Dolomite						
SN @ 50 mph	58	45	41	39	38	37
Log_{10} SN @ 50 mph	1.763	1.653	1.613	1.591	1.580	1.568
Lightweight						
SN @ 50 mph	67	60	57	56	55	55
Log_{10} SN @ 50 mph	1.826	1.778	1.756	1.748	1.740	1.740
Trap Rock						
SN @ 50 mph	58	51	48	45	39	38
Log_{10} SN @ 50 mph	1.763	1.708	1.681	1.653	1.591	1.580
Limestone						
SN @ 50 mph	52	40	36	34	30	29
Log_{10} SN @ 50 mph	1.716	1.602	1.556	1.531	1.477	1.462

Table VI

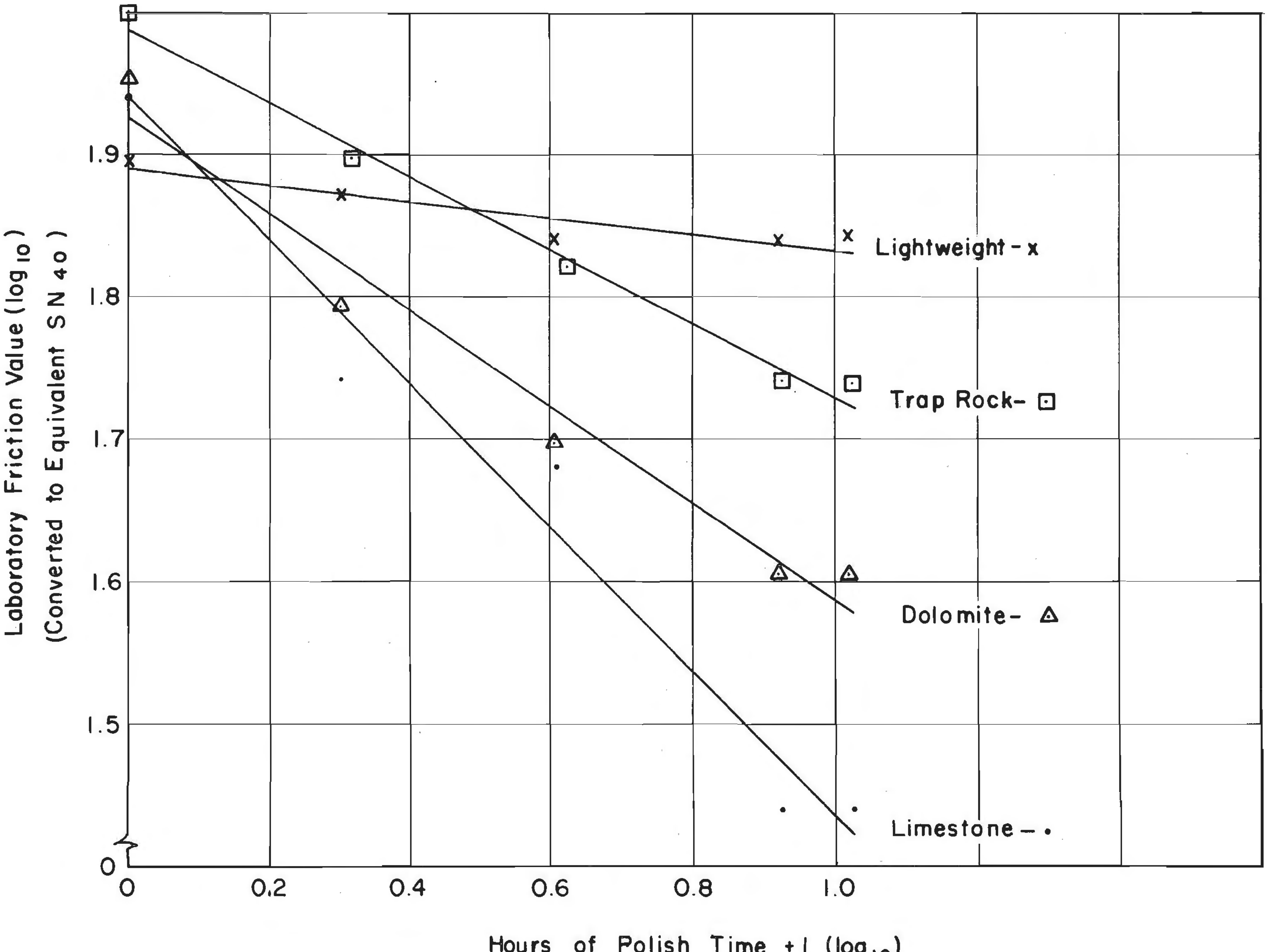
TABLE OF LABORATORY POLISH RATES

	HOURS OF POLISH + 1				
Hours + 1	1	2	4	8	10
Log_{10} Hours + 1	0.000	0.301	0.602	0.903	1.000
Dolomite					
Average Polish Value All Tests	51	37	32	26	26
Polish Value Converted to SN	88	55	48	28	28
Log_{10} Converted Polish Value	1.944	1.740	1.681	1.447	1.447
Lightweight					
Average Polish Value All Tests	47	45	43	43	43
Polish Value Converted to SN	78	74	69	69	69
Log_{10} Converted Polish Value	1.892	1.869	1.839	1.839	1.839
Trap Rock					
Average Polish Value All Tests	56	47	42	37	37
Polish Value Converted to SN	100	78	66	55	55
Log_{10} Converted Polish Value	2.000	1.892	1.819	1.740	1.740
Limestone					
Average Polish Value All Tests	52	40	35	31	31
Polish Value Converted to SN	90	62	50	40	40
Log_{10} Converted Polish Value	1.954	1.792	1.699	1.602	1.602



FIELD POLISH RATES OF FOUR AGGREGATE MATERIALS

Figure 25



LABORATORY POLISH RATES OF FOUR AGGREGATE TYPES

Figure 26

the trap rock was ordered in the next position. The dolomitic limestone and calcareous limestone slopes varied with the calcareous material having the greatest rate of polish in the field tests and the dolomitic material the greatest rate of polish in the laboratory tests. The rates of polish (slopes) which are found in Figures 25 and 26 are listed in Table VII. Next, a plot was formed showing the relationship between the field and laboratory rates of polish (see Figure 27).

With only four points in the plot in Figure 27 there was difficulty in drawing conclusions. However, there is a possibility that there is a relationship between the rate of polish of the laboratory British Wheel Method and the traffic applications in the field for the one particular test section studied. If so, the approximate relationship is as follows:

British Wheel Rate of Polish = -0.12 + 4.4 (Field Rate of Polish)
(log-log slope) (log-log slope)

Also, scatter around the curve is evident which means there will be variation in the results when using the equation.

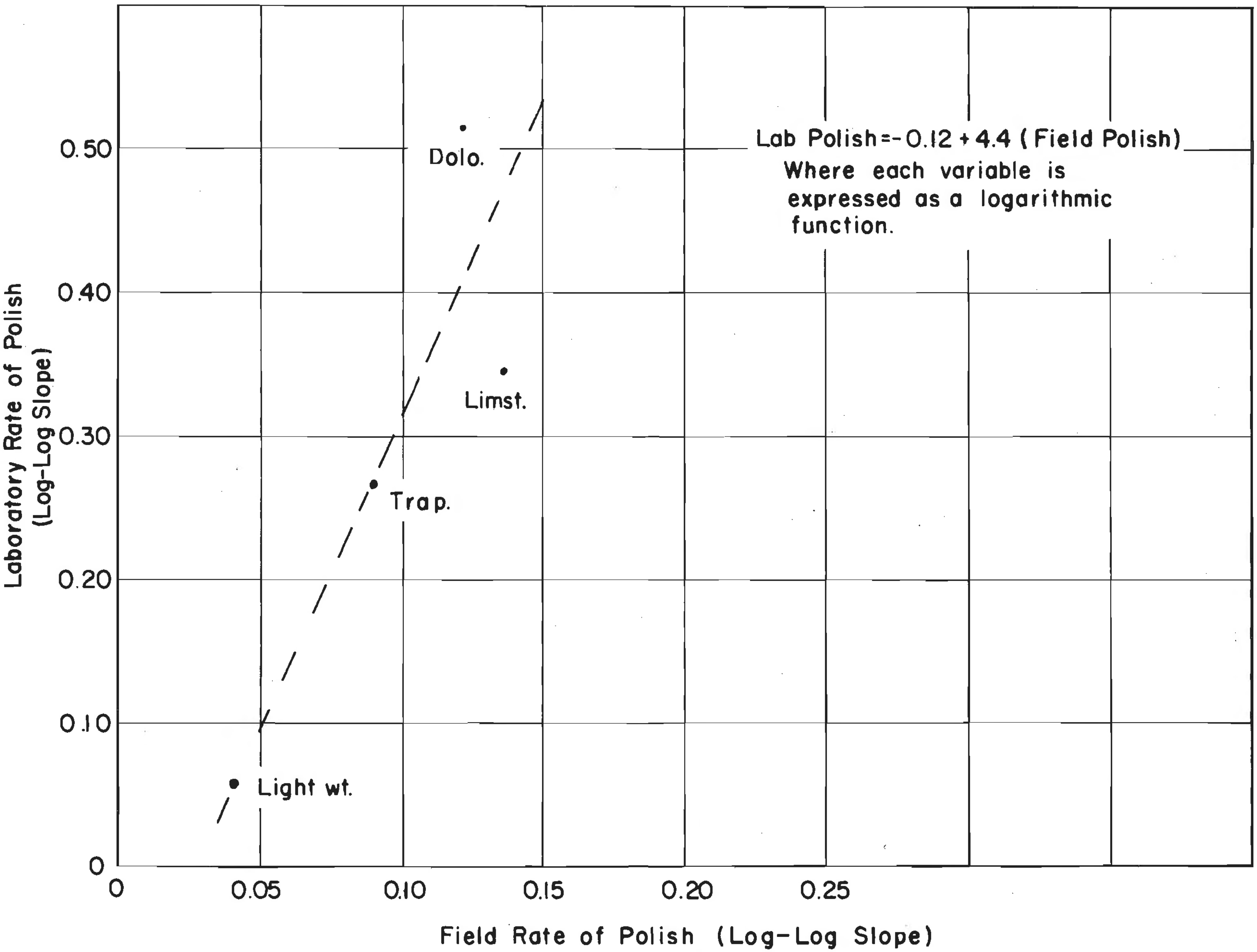
At this point the reader should remember that the above equation was developed using only four data points (four materials) and only one test surface. Therefore, the equation should not be used in practice. Other materials could perform differently, and other highways with other types and amounts of traffic could perform differently. The point is that there is a possible relationship between the rates of polish of materials which receive the same traffic, and this leaves the doorway open to speculate that the rate of polish could be predicted in the future (employing a similar procedure) after sufficient data and experience have been collected.

Figure 28 is a plot which indicates the relationship of the Polish Value and the lowest trailer friction value (predicted) from the field

Table VII

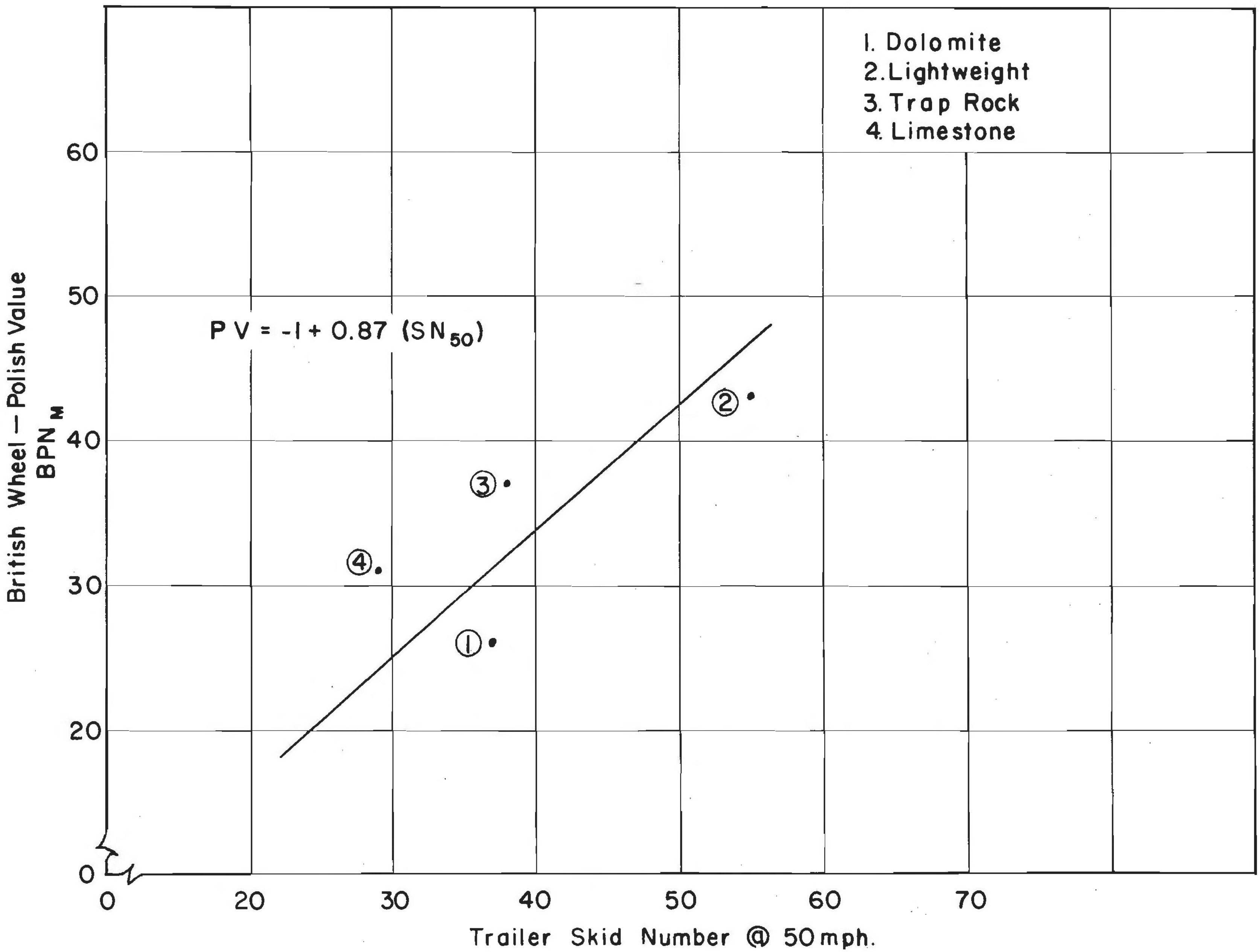
RATES OF POLISH FOR FIELD AND LABORATORY

	Field	Laboratory
Dolomite	0.121	0.513
Lightweight	0.041	0.058
Trap Rock	0.089	0.265
Limestone	0.136	0.346



COMPARISON OF LAB AND FIELD RATES OF POLISH

Figure 27



FIELD WEAR - (AFTER 4.5×10^6 TRAFFIC APPLICATIONS)

RELATIONSHIP OF POLISH VALUE AND ESTIMATED LOWEST FIELD POLISH VALUE

Figure 28

polish of the materials in the test sections mentioned above. The information for the plot points was obtained from Tables V and VI. Again, there appears to be a relationship between the ultimate (or lowest) friction values for the four materials studied on one test section. There is considerable scatter of the data points around the linear best fit curve; however, the resulting equation was found to be:

$P.V. = -1 + 0.87\ SN_{50}$ where P.V. = Polish Value (British Wheel) and SN_{50} (in this case) = Estimated Lowest Field Polish Value

Development of a Polish Value Specification

The following information is related to the implementation of the findings of this project (which is discussed in another chapter), and the events are listed so that the chronological order may be continued. After presenting a summary of the above data to the administrative personnel of the Highway Design and the Materials and Tests Divisions, a decision was made to develop specifications concerning the Polish Value for use on an experimental basis for construction jobs. It was believed that the Polish Value should be used and that the rate of polish should not be considered until more data has been collected and analyses have been performed to develop a valid procedure.

The actual format of the specification was developed by the Specification Committee and personnel from the District which was involved in the experimental construction job (District 17, Bryan, Texas). However, a Polish Value of 29 was recommended for the specification by research personnel. The Polish Value of 29 was derived from a correlation of the BPT and the skid test trailer. The skid trailer value selected was $SN_{40} = 32$. (At that time a correlation existed which equated a SN_{40} of 32 to a BPN_m of 29. The equation has since been revised as shown in this chapter; BPN_m of 28 = SN_{40} of 32.) The experimental job was constructed, and subsequent field studies, coupled with the experience gained by District personnel, indicated that the choice of the 29 Polish Value was poor. The 29 Polish Value actually represented the average value and did not account for the day to day variation of the material from a particular source. (It was possible that approximately half of the material which was received could have had a Polish Value less than 29.) Consequently, a reevaluation of the suggested Polish Value was made. Using the information shown in Table III (Day to Day Variation of Source Samples) it was found that the average variation (the average standard deviation) was approximately 2 BPN_m. This value was multiplied by 3 (three standard deviations) to include almost all of the random variation (a higher probability of success). The resulting value of 6 was added to the revised Polish Value of 28 (mentioned above), and at the present time the revised Polish Value of 34 is recommended for specifications.

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IV. DISCUSSION

Of the two test methods studied, the British Wheel is suggested for use on coarse aggregate because practically all material types can be tested with the British Wheel. However, this statement does not condemn the use of the Insoluble Residue Test because it is useful for testing limestones. There is one item of concern which is related to the Insoluble Residue Test: some limestones contain small fossils or calcite crystals. One specimen, of which the material was composed of a mass of calcite crystals, revealed a relatively small amount of sand size residue when subjected to the Insoluble Residue Test. The small amount of sand size residue would normally indicate low friction properties; however, the British Wheel test indicated a high Polish Value or good friction. Because of the good micro-texture of the material (determined by visual inspection), the authors suspect that the British Wheel more accurately predicted the friction characteristics. It is believed, however, that the material would fail the L.A. Wear test which is required in this state.

There is some doubt that grit and water duplicate the polishing action of vehicle tires. On the other hand, it is also doubtful that any method of accelerated polishing will exactly duplicate vehicle polishing. It can be postulated that there are as many polishing rates and final (field) polish values as there are highways. Every highway section is unique in that it has different quantities of loads, varying types of loads, different precipitation present at varying times, different types and amounts of grit present on the roadway or in the tires, etc. The question is, does the variation caused by these variables result in great errors in predicting the rate of polish or in the final Polish Value? Or, is it possible to live with this variation and/or obtain corrections for the variables to the extent that reasonably accurate predictions can be made?

It is believed that this study proves that the adhesion friction characteristics of materials can be ranked and even ordered. It is further believed that this ordering of materials, combined with the use of materials with good friction characteristics, is the first step in obtaining and maintaining friction on highway surfaces.

There are other steps which can be studied. One of the foremost is the friction characteristics which, at present, are a result of construction practices. District 17 personnel (Bryan, Texas) are presently involved in studying the friction variation found in the experimental job mentioned in this report.(8) The District has found that large friction variations can exist in one days placement of the same asphaltic concrete material. After an exhausting check of the records, the mixing and materials proportioning were found to not significantly vary. However, higher friction values were observed where the lay-down machine "pulled" the surface, and lower friction values were found where the mix was dense or compacted in a close, "tight-knit" manner. The "pulled" surface is undesirable structurally, but it is possible that placement procedures or even a different type of roller could be used to improve friction properties.

The experimental construction job involved the placement of asphaltic concrete at 10 separate locations. The objectives of the placement of the experimental construction were (1) to overlay sections of highway in need of structural support, (2) to design, test and pay for the mix on a volumetric control basis, and (3) to specify and bid the coarse aggregate based on a Polish Value. The constructed overlay would, in turn, provide sections for periodic tests with a skid trailer to verify field polish with the laboratory polish predicted from the British Wheel. Three different (weight-batch) mixing plants were used and two different coarse aggregate materials meeting the (original) Polish Value specification were used. Three combinations of fine aggregates were used (one variety at each mixer) in conjunction with the coarse aggregate. At present, on the most heavily traveled site, only some 200,000 vehicle applications have cumulated so the polish plots will not be shown. However, it should be stated that in no case has the "as measured" field friction value (SN_{40}) been as large as that predicted by the British Wheel test (determined by observing the initial phases of the laboratory rate of polish). The bid prices reflected a "new" occurrence in that asphaltic concrete was bid higher than ordinary. The contractor receiving the job at the lowest bid, priced asphaltic concrete aggregate at $22.50/cu. yd., whereas approximately $13.00/cu. yd. is usual. (It should be stated that at the time of the preparation of this report a second experimental job specifying a Polish Value of 34 has been bid in the same District. The bid prices for asphaltic concrete were less than the ordinary bid price. Also, the asphaltic concrete material for both jobs was designed, bid and constructed on a volumetric control basis which is new in Texas.)

There are several items which occur as the result of the study reported herein. Of these, two items regarding the economy of asphaltic concretes arise. The first is concerned with the blending of aggregates, especially the coarse aggregates. It is possible to blend a local material having poor friction qualities with an imported material having good friction qualities. The result would be a mixture which (hopefully) would maintain a friction value above a desired level. There are certain items which must be considered. Foremost among these is "differential wear." It would be undesirable to blend a soft (highly abrading) material having good friction characteristics such as a lightweight aggregate with a hard slick rounded material such as a silicious river gravel. In this event, it is postulated that the lightweight aggregate would abrade at a more rapid rate than the river gravel leaving the slick rounded river gravel exposed to the vehicle tire. It is believed that low friction would result.

Tentative tests with the British Wheel indicated that a linear relationship of Polish Values existed in blended combinations of two materials. Figure 29 reveals an example plot of the tentative tests. Several British Wheel specimens were prepared in which the percentages of two aggregate materials were varied. The materials represented in Figure 29 are a lightweight aggregate with a Polish Value of 56 and a crushed limestone material with a Polish Value of 27. The percentages of the two materials were varied in the specimens in the following manner:

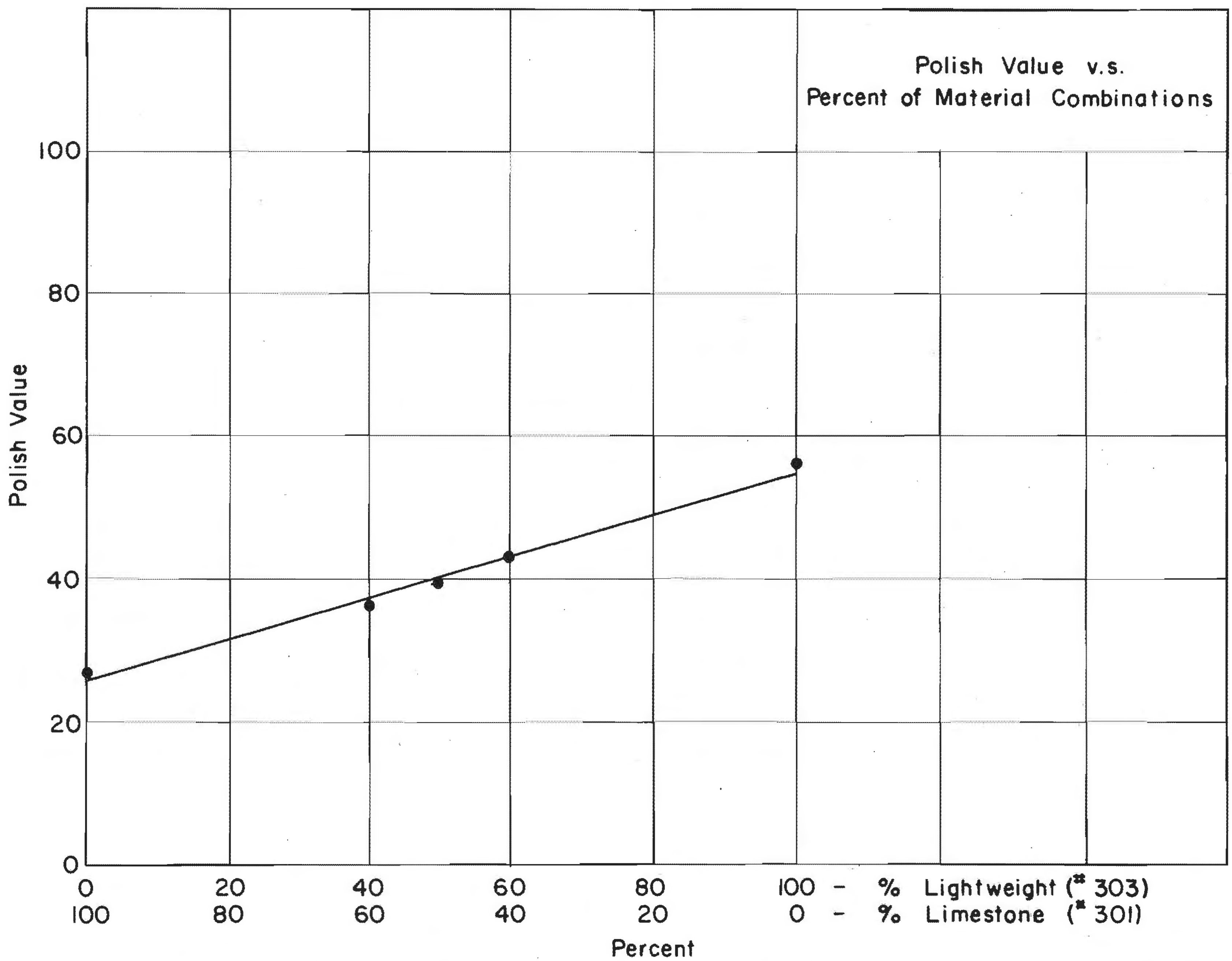
a. specimens containing 100% of the selected material

b. specimens containing 60-40 blends of the two materials

c. specimens containing 50-50 blends of the two materials

The blending could be considered to be by volume; however, the simple method of counting and placing the correct number of individual aggregate particles was used to form the blends. The aggregate types were placed in the molds in a random manner. The specimens were then polished according to the test procedure given in the appendix, and the resulting Polish Value of each blend appeared to be in linear proportion to the 100% or parent material. That is, if it is desired to determine the Polish Value of a 50-50 blend of the limestone and lightweight material, the Polish Value of both materials would be determined, added, and halved.

A study of blending occurred on one other occasion: during the testing



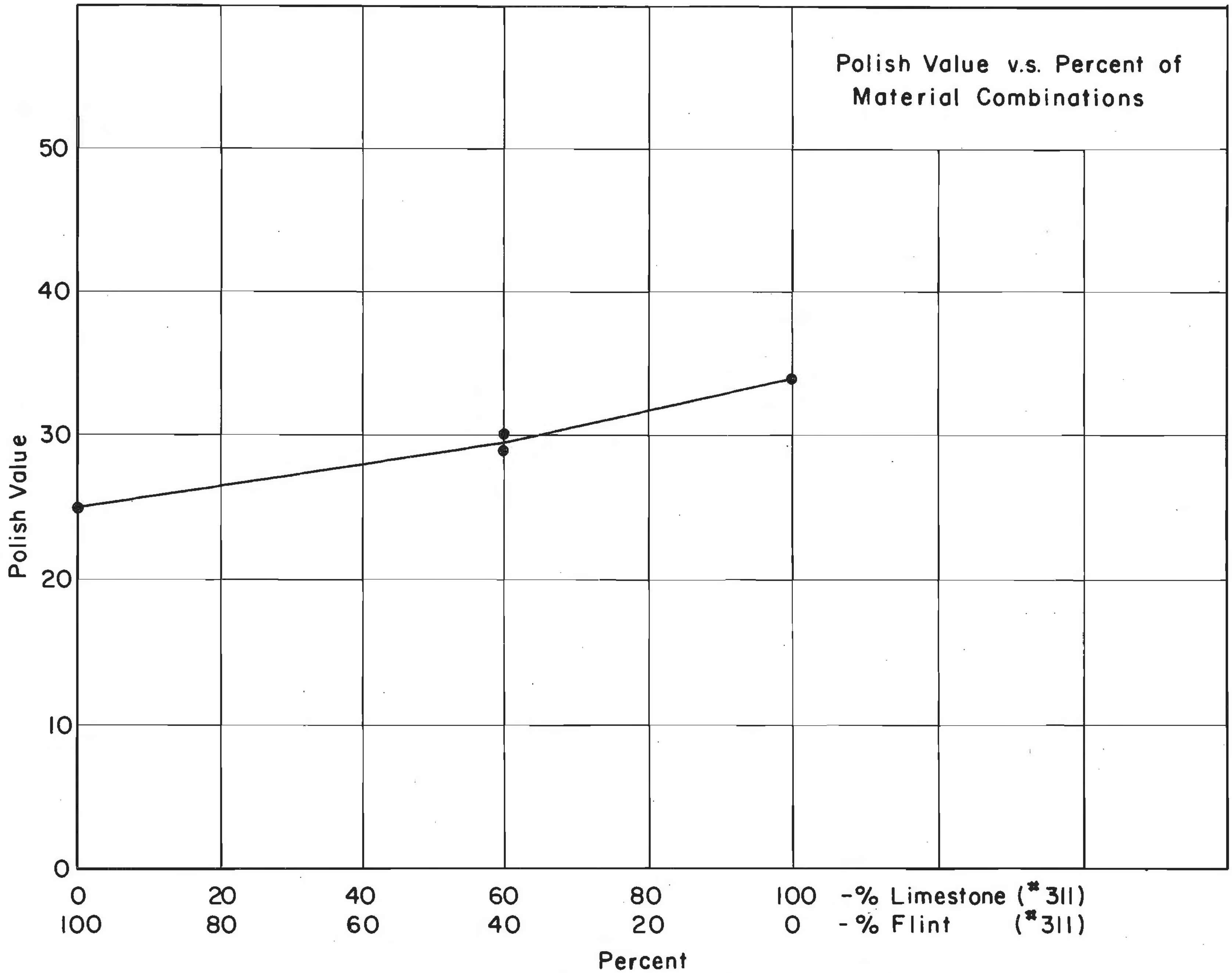
POLISH VALUES AS A RESULT OF COMBINING LIGHTWEIGHT AND LIMESTONE

Figure 29

of one of the materials selected for use by the contractor on the experimental construction job mentioned previously. The contractor elected to use a river gravel which in preliminary tests was found to have a Polish Value of 29 (the original suggested minimum). After stockpiling, the material was sampled and found to have a Polish Value below the required 29. During the sampling process, District personnel indicated that the river gravel could be separated into two basic materials - flint and a rather hard limestone (both materials were rounded to some extent by the tumbling action which had occurred in the stream bed). The District personnel further stated that the material which had been sampled before stockpiling contained more limestone than the stockpiled sample. As a result, the stockpiled material was visually separated into two parts - flint and limestone. British Wheel tests were conducted on each of the separate (100%) parts and also on a 60% limestone, 40% flint combination which the stockpile was thought to contain. The results are shown in Figure 30. The figure reveals that the Polish Value of the material could vary from 25 (all flint) to 34 (all limestone), and it would be possible to have a Polish Value at any point between depending on the percent combination of the two parent parts.

It is believed that the above tests further prove that the adhesion friction characteristics of aggregate materials can be ordered and that the British Wheel test is reasonably accurate. In any event, there is a strong possibility that aggregate types can be blended for optimal economic benefit. Further studies are needed.

The second theory regarding economic benefit (which was mentioned previously) is related to the amount and frequency of traffic applica-



POLISH VALUES AS A RESULT OF COMBINING LIMESTONE AND FLINT (BOTH FROM ONE SOURCE)

Figure 30

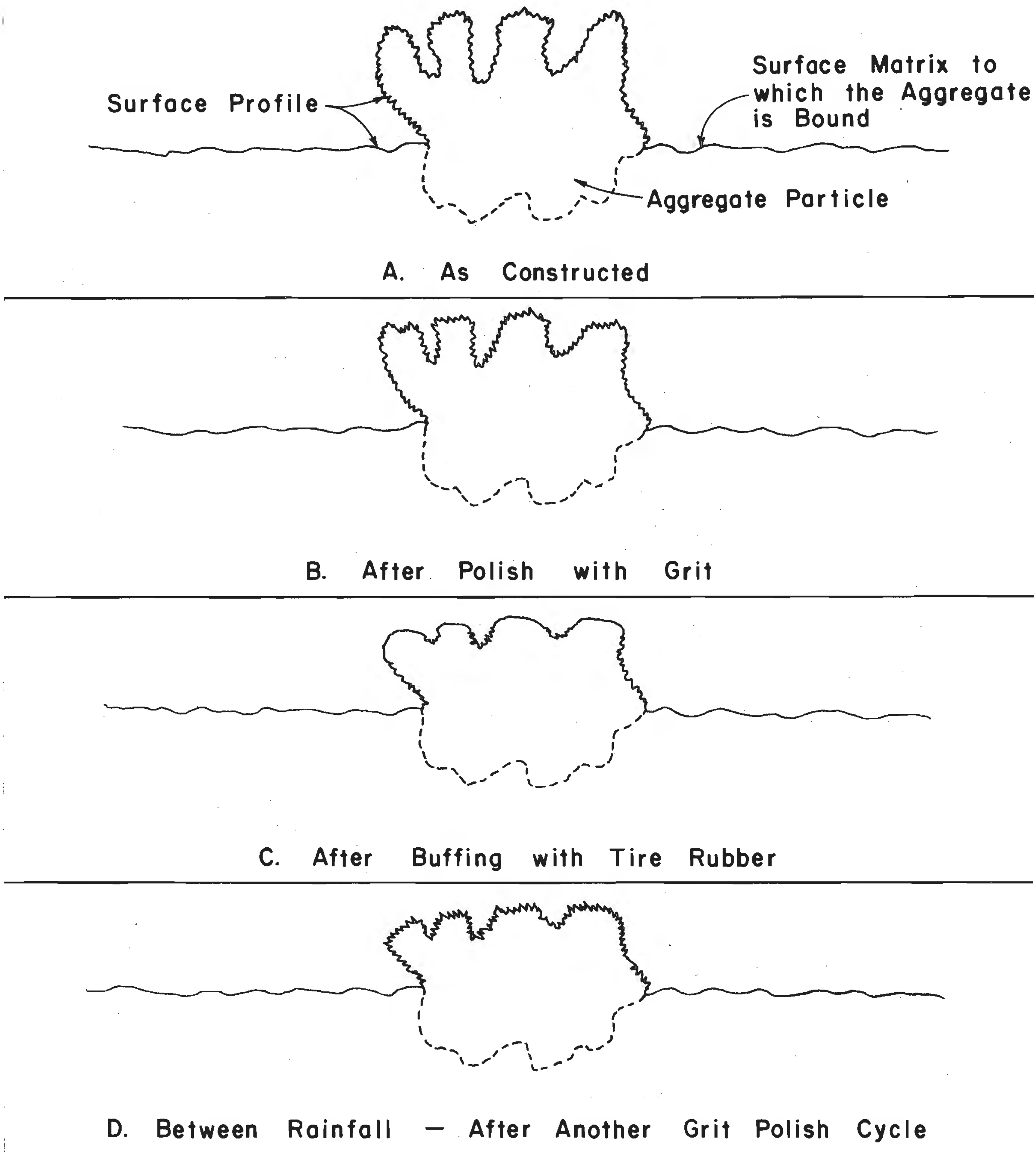
tions. Obviously, there are highways in the state which will not polish to a dangerous level before the highway is resurfaced by the application of a seal or overlay. There are other highways (and highway sections) where good friction must be maintained under heavily traveled conditions (especially on sections where geometrics require a high level of friction for safe operation). Before a design procedure can be developed for highways with varying traffic, knowledge must advance on both laboratory and field rates of polish. In this state, the rate of polish knowledge does not exist simply because periodic friction measurements (performance records) have not been maintained on a sufficient number of materials on a sufficient number of highways. However, it is believed that this research indicates that such a design procedure could be possible. There appears to be a relationship between the laboratory and field rates of polish. There is also a relationship between the laboratory and field friction measurement equipment. By knowing these two relationships, design equations can be developed. These equations will not be shown; however, the specifications could probably be worded to accept a material which has an acceptable BPN_m (or greater) after a specified number of hours of polish. Development of a rate of polish design procedure is not recommended at this time because the procedure would necessarily be developed from information on one test section. However, it is possible that a rate of polish design can be developed in the future as the field polish rates are determined on larger numbers of test sections and the laboratory polish rates are determined for the coarse aggregate materials used in the surfacing of the test sections.

could result. It is believed that the simplest method of gathering knowledge in this area would be to maintain and study records of actual construction jobs which utilize a Polish Value specification and test procedure.

Polishing Theory

A study of the actual polishing action of a vehicle tire was not included in the reported phase of this study; however, a theory has been developed (as patterned after other researchers in this field).(9) To accept the polishing theory one must also accept that for a given tire, water depth, amount of road film, temperature, and vehicle velocity, friction must be equivalent to the texture. That is, the only portion of the pavement surface which contributes to the available friction is texture.

Figure 31 reveals a schematic of the aggregate polish theory. The figure shows an enlarged profile of one aggregate particle in four different stages of polish. In Stage A a profile of the original "as constructed" surface is shown. Assuming a seal or penetration course, the aggregate is embedded to about half of the profile height. Both the micro- and intermediate textures are good. The assumption is made that between Stage A and Stage B the aggregate has been subjected to polish by vehicular traffic. It is theorized that grit is collected on the road and/or is embedded in the tire. When the aggregate is subjected to the micro abrading action of the tire-grit combination some attrition or wearing away of the aggregate is evident. Stage B indicates that some of the intermediate size texture peaks have been worn down; however, there is evidence of micro-texture still in existence. It is postulated that



SCHEMATIC SHOWING AGGREGATE POLISH THEORY

Figure 31

micro-texture is still evident because the grit has abraded or scored the surface. Because the micro-texture is available, the friction might not be reduced (as Gallaway has reported - see Chapter 1).[4] It is theorized by others that the grit is relatively large soon after a rain because the smaller particles are carried to the shoulder by water-runoff-velocity. The remaining grit is slowly crushed to a smaller size between the tire and pavement by traffic action. If the grit is slowly reduced in size, the micro-texture in Stage B is slowly smoothed. Also, if most of the grit is removed or dislodged, it could be possible for only the rubber of the tire to be in contact with the aggregate. It is postulated that Stage C would occur if the aggregate were "buffed" with the fine grit or by the rubber tire. In Stage C the tips of the aggregate asperities have been polished to a rather high degree, and this lowers the adhesion component of friction to some extent depending on the characteristics of the remaining (intermediate size) texture. The micro abrasion is believed to be a small amount (and of small size) during Stage C. Assuming grit is again deposited (by wind, micro abrasion deposits, or by clinging to a wet tire which has been off the road on a soil deposit), a new cycle is started which is shown in Stage D. Micro abrasion occurs; there is more wearing of the aggregate, particularly evident in the intermediate size texture; and some small micro-texture is evident due to the scoring of the aggregate.

In studying the above theory, it must be remembered that there are many types of aggregates. Some aggregates are flaky and there is attrition of large particles (as compared to micro abrasion particle sizes). The above theory may still be used, but the stages must be modified in this event. Some aggregates are hard and dense, and micro abrasion is small. These aggregates require a relatively long length of time to polish under traffic applications. But given sufficient polishing effort these aggregates will polish and will be very slick as compared to the flaky aggregates which retain some form of texture when the flake is removed by the traffic.

There is some evidence that weathering in conjunction with chemical activity alters the micro-texture of the aggregate surface. The theory must be modified for this event.

V. CONCLUSIONS

The following has been concluded from this study and from the material which is contained in this report:

1. The British Wheel Test does denote the friction characteristics of coarse aggregate material.
2. Aggregate types can be ranked and ordered as to their friction characteristics by use of the British Wheel.
3. The British Wheel "Polish Value" of a coarse aggregate material was related to the lowest friction value of the same aggregate material when polished by actual traffic for the aggregate types studied on one test section.
4. The British Wheel "rate of polish" was related to the field "rate of polish" for the coarse aggregate types which were studied on one test section.
5. A Test Method for the British Wheel and resulting specifications can be developed which will insure the use of a coarse aggregate with better friction characteristics (flexible pavement only).
6. The Insoluble Residue Test results (sand size residue) was related to the British Wheel "Polish Value" for those aggregate materials which were predominately limestone (aggregates with a carbonate fraction greater than 50 percent). However, the Insoluble Residue Test results did not appear to be related to British Wheel results in materials which were not predominantly limestone.

7. A relationship exists between the British Portable Tester and the Texas Skid Test Trailer (SN_{40}).

8. In Items 3, 4, 6 and 7 of the Conclusions a "good" correlation did not exist, but considering the necessity of obtaining and maintaining pavement surfaces with good friction characteristics, the correlations are considered adequate for use in design. It should be remembered that obtaining aggregate materials with good friction characteristics is only one step in providing a pavement surface with good friction characteristics. However, this step is important.

VI. RECOMMENDATIONS

Based on the results of this study, the following is recommended:

1. It is recommended that specifications and a test procedure employing the "Polish Value" be developed and/or adapted for use on experimental construction projects. (Actually this recommendation is being implemented at this time.)
2. It is recommended that continued research effort be given to the study of combining aggregate materials with known "Polish Values" in order that optimum economic benefit may be achieved. (This recommendation is also being implemented at this time utilizing a circular track with asphaltic concrete specimens.)
3. It is recommended that continued study be given to the "rate of polish" of aggregate materials in order that the more polish susceptible materials may be utilized on low volume highways. It is believed that a design procedure could be established to be used on all highways whereby local materials could be used (hopefully at less cost) while still being assured of a satisfactory friction level.
4. It is recommended that periodic skid measurements (performance records) be maintained on the surfaces of construction jobs utilizing the results of the British Wheel (whether based on the "Polish Value", combinations of "Polish Values" or "Rate of Polish"). Revised design procedures and related information can be developed from this information.

5. Even though not within the scope of this project, it is recommended that studies be conducted concerning the influence of construction practices on vehicular friction.
6. It is recommended that studies be conducted to determine the relationship of the fine aggregate to vehicular friction, and the polish susceptibility of fine aggregate types should also be studied.
7. Before aggregate polishing under actual traffic applications can be fully understood, a knowledge of the mechanism of the polishing action must be available. One must know whether the rubber, grit, or a combination of both provide the action. The influence of weather and weathering must be known. The influence of chemicals and the chemical action between climatic conditions and the surfacing material must be studied. It is recommended that these studies be conducted.

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A P P E N D I X

1. The Insoluble Residue Test Procedure
2. Specifications For A Polish Value
3. The British Wheel Test Method

INSOLUBLE RESIDUE

TEST PROCEDURE

Part I.

A. Determination of Total Residue Content

1. Grind a small sample of dry coarse aggregate to pass through a No. 50 U. S. Standard mesh sieve. Dry the -No. 50 screenings overnight at 250° F.

2. Remove samples from oven. Cool in a dessicator for one (1) hour. Weigh out two 10-gram test portions. Place each test portion in a 400 ml. beaker.

3. Slowly add the acid* to the beaker until the sample is covered. The acid must be added slowly to avoid possible loss of sample due to boiling and subsequent overflow of the sample.

   * Acid solution = 20° Technical Grade HCl (muriatic acid) diluted 3 to 1 with distilled water.

4. Continue to add acid until reaction completely ceases. As the reaction proceeds decant the excess supernatant formed into another container. Check for completion of reaction by subjecting beaker and contents to low heat over a bunsen burner.

5. After the decanted supernatant has settled decant the resulting clear supernatant and discard.

Note: The Insoluble Residue Test Procedure, Chemistry and Equipment portions of this report were obtained from Report SS 11.7 "An Evaluation of the NCSA Hydrochloric Acid Leaching Procedure"(10) by Edward Garaña.

6. Filter* residue over a Whatman No. 50 filter paper which has been preweighed.

   * We filter using a Buchner porcelein funnel (ID about 11 cm.), and an aspirator.

7. Wash* the residue two or three times by flushing the filtered residue several times with warm water while it is still on the filter paper in the filtering funnel.

   * Let the residue be filtered until a moist mat is left on the filter paper before beginning the washing process.

8. Dry the residue overnight at 250° F. Determine the amount of percent insoluble residue.

$$\text{Percent Insoluble Residue} = \frac{\text{Residue Weight}}{\text{Sample Weight}} \times 100$$

B. Determination of Sample Size for Part II.

9. Determine sample size based on the residue content as determined in Part I and on the amount of residue desired in Part II. Try to get 100-150 grams of residue.

$$\text{Sample Size} = \frac{\text{Amount of Residue Desired}}{\text{Total Residue Content}} \times 100$$

Part II.

10. Screen dry coarse aggregate sample over 1/2 inch and No. 8 U. S. Standard mesh sieves. Retain 1/2 inch - No. 8 screenings for testing. Dry overnight at 250° F.

11. Repeat steps 2 through 8.

Part III.

12. Wash residue over a No. 200 mesh sieve. Dry two (2) hours at 250° F. Determine amount of residue passing the No. 200 mesh sieve. Separate the remaining residue over a No. 8 and a No. 200 mesh sieve.

13. Determine gradation* and report as plus No. 8, No. 8 - No. 200, and minus No. 200.

    * Gradation must be reported on basis of amount residue. Example: Assume a 40 percent insoluble residue divided among plus No. 8, No. 8 - No. 200, and minus No. 200.

    The report should indicate -

    20 percent insoluble residue in +No. 8

    10 percent insoluble residue in No. 8 - No. 200

    10 percent insoluble residue in -No. 200

CHEMISTRY

In the case of the slightly soluble calcium carbonate electrolyte ($CaCO_3$), which is the salt of the weak carbonic acid (H_2CO_3), the calcium carbonate is dissolved by the strong hydrochloric acid (HCl).

The chemical reactions between the calcium carbonate compound and the hydrochloric acid occur in an ionic form. It is for this reason that the hydrochloric acid is used in an aqueous solution in which the molecular hydrochloric acid is completely ionized into the cationic acid H_3O^+ according to the following reaction:

$$HCl + H_2O \rightleftharpoons H_3O^+ + Cl^-$$

This reaction is more generally seen in the following form:

$$HCl \rightleftharpoons H^+ + Cl^-$$

It must be remembered that H^+ is an abbreviated symbol and that actually the hydrogen ion is always hydrated in a water solution.

When the hydrochloric acid is added to the sample of calcium carbonate aggregate, the hydrogen ion from the hydrochloric acid combines with the carbonate ion to form the slightly ionized carbonate ion according to the following reaction:

$$H^+ + CO_3^- \rightleftharpoons HCO^-$$

As additional acid is added to the solution, the solution becomes saturated with hydrogen carbonate ions. At this point the hydrogen ions of the acid being added begin to combine with the hydrogen carbonate ions to form the slightly ionized and unstable carbonic acid.

$$H^+ + HCO^- \rightleftharpoons H_2CO_3$$

With the addition of more acid the solution now becomes saturated with carbonic acid. When the saturation point is reached, the carbonic acid dissolves into carbon dioxide gas and water.

$$H_2CO_3 \rightleftharpoons H_2O + CO_2$$

The final complete form of the reaction of the hydrochloric acid with the calcium carbonate compound is the following:

$$2H^+ + (2Cl^-) + CaCO_3 \rightleftharpoons H_2O + CO_2 + Ca^+ + (2Cl^-)$$

The end products of the leaching of a carbonate being water, carbon dioxide gas, and a soluble salt.

EQUIPMENT

1. Suitable containers for acid leaching
2. Plastic container to store acid
3. Balances
4. Bunsen burner
5. Tripod stand and wire gauze
6. Filter paper - (Whatman No. 50 - 11 cm.)
7. Buchner funnel - (I. D. - 11 cm.)
8. Oven
9. Dessicators
10. Aspirator
11. Evaporating dishes

TEXAS HIGHWAY DEPARTMENT

SPECIAL PROVISION

TO

ITEM 6

CONTROL OF MATERIALS

For this project, Item 6, "Control of Materials", of the Standard Specifications is hereby supplemented with respect to the clauses cited below and no other clauses or requirements of this item are waived or changed hereby.

Article 6.1 Sources of Supply and Quality of Materials is supplemented by the addition of the following requirements:

Coarse aggregate furnished for use in Hot Mix Asphaltic Concrete Pavement shall have a "Polish Value" of not less than 29 when subjected to tests as specified in "Accelerated Polish Test Method for Coarse Aggregate Used in Pavement Surfaces" (attached). This is a quality test for approval of the source and not a job control test.

ACCELERATED POLISH TEST METHOD FOR COARSE AGGREGATE USED IN PAVEMENT SURFACES

Scope:

This test method describes procedures for determining a relative measure of the extent to which different types of aggregate in the wearing surface will polish under traffic.

Definitions:

The "Polish Value" is defined as the state of polish reached by each sample when subjected to accelerated polish by means of a special machine. The test is in two parts:

(1) Samples of stone are subjected to an accelerated polishing action in a special machine.

(2) The state of polish reached by each sample is measured by a British Portable Tester and expressed as the "Polish Value".

Apparatus:

1. Accelerated Polishing Machine: A polishing device as shown in Figure 1. An accelerated polishing machine shall be mounted on a firm level and non-resiliant base of stone or concrete and shall include:

A. A wheel (referred to as the road wheel) having a flat periphery and of such size and shape as to permit 14 specimens described below to be clamped on the periphery so as to form a continuous surface of stone particles, 1-3/4 inches wide and 16 inches in diameter.

B. A means of rotating the road wheel about its own axis at a speed of 315 to 325 revolutions per minute.

C. A means of bringing the surface of a rubber tired wheel of 8 inch diameter and 2 inch width to bear on the stone surface of the road wheel with a total load of 88 $\pm$ one pound. The tire shall be an industrial 8 x 2 pneumatic 4 ply smooth hand truck tire, treated, if necessary, to obtain a true running surface. The tire shall be inflated to a pressure of 45 plus or minus 2 pounds per square inch and shall be free to rotate about its own axis, which shall be parallel to the axis of the road wheel. The plane of rotation of the tire shall be in line with that of the road wheel. Before a new tire is used on a test, it shall be given a preliminary run of 6 hours with a 150 grit silicone carbide using dummy specimens on the road wheel.

D. A means to feed the 150 grit silicone carbide at the rates shown in "Accelerated Polish Test Procedure" and in such a way that the silicone carbide grit is continuously and uniformly spread over the surface of the tire and the specimens where they are in contact. The grit shall be fed directly onto the road wheel near the point of contact with the rubber tired wheel.

E. A means to feed the water at the rate shown in "Accelerated Polish Test Procedure" in such a way that the water is continuously and uniformly spread over the surface of the road wheel near the point of contact with the rubber tired wheel.

2. Metal Molds: A number of accurately machined metal molds for preparing specimens of the dimensions specified in No. 4 - "Preparation of Test Specimen."

3. British Portable Tester: A friction measuring device. The British Portable Tester used shall conform to ASTM Designation E 303-66T with the following modifications:

A. The slider contact path shall be 3" $\pm$ 1/16 inch.

B. The slider width shall be 1-1/4 inches.

C. The rubber which is bonded to the slider shall conform to a 1/4 by 1 by 1-1/4 inch dimension.

D. The rubber shall meet the requirements as specified in ASTM Specification E 249, for Standard Tire for Pavement Tests.

E. The zero adjustment shall be checked before testing the fourteen specimens and after testing the specimens and as often as the operator deems necessary.

F. Calibration procedures of ASTM E 303-66T shall be used, however; after calibration the small slider shall be inserted.

4. A supply of disposable cups and stirring rods for use in molding the specimens.

Materials:

1. Water: A supply of tap water to be spread on the road wheel during testing.

2. Fine Sand: A supply of fine sand for sifting in the aggregate interstices prior to the placement of the polyester bonding agent.

3. Mold Release Agent: A supply of polyester mold release agent used to prevent bond between the mold and polyester.

4. Silicone Carbide Grit: A supply of silicone carbide grit (150 grit size) to be used as the polishing agent.

5. Polyester Bonding Agent: A supply of polyester resin and catalyist.

6. Coarse Aggregate: Approximately a one-half cubic-foot supply of coarse aggregate to be tested. The aggregate shall be normal plant run but laboratory crushed material may be tested.

Test Record Forms: Record test data on an appropriate work sheet (See Figure 1 in the Appendix).

Test Control: Four specially selected specimens shall be used for control and only these four specimens shall be used. The specimens shall be selected from those which have been previously polished for 10 hours conforming to the procedure herein established. The friction value (as determined from the British Portable Tester) of the specimens shall be in the following ranges:

Control Specimen #1 - 10-20
Control Specimen #2 - 20-30
Control Specimen #3 - 30-40
Control Specimen #4 - 40-55

The control specimens shall be tested with the British Portable Tester prior to measuring the "polish value" of the test specimens on any one test. Corrections to the polish value will be made on the basis of change in friction values found with the control specimens.

Preparation of Test Specimens:

1. The aggregate to be tested should pass the 1/2 inch sieve and be retained on the 3/8-inch sieve.

2. Aggregate shall be clean and free of dust.

3. The mold shall be coated with an application(s) of mold release agent.

4. Each specimen shall consist of a single layer of particles and cover an area of 3.5-inches x 1.75-inches.

5. The aggregate particles shall be placed as closely as possible in the molds with a flat surface against the bottom of the mold.

6. The interstices between the stones shall be filled with fine sand to 1/4 to 1/2 of the aggregate depth.

7. Weigh the polyester resin and catalyst into a disposable cup, add the resin to the catalyst and mix thoroughly. A mixture of 0.5 to 0.75 grams of catalyst to 50 to 57 grams of polyester resin yields sufficient material for one specimen and remains workable for 10 minutes.

8. The prepared mold is then filled to overflowing with the polyester bonding agent.

9. The consistency of the polyester should be such as to allow it to flow freely between the particles.

10. The mold is then left until the polyester has stiffened sufficiently to be struck off accurately, level with the curved sides of the mold.

11. The specimen is then left in the mold for 3-4 hours to allow sufficient hardening of the polyester in order that the specimen may be removed from the mold.

12. The excess sand is removed from the face of the specimen.

13. The specimen is then replaced in the mold for a curing period of 4 hours with a weight (conforming to the curved sides) on the mold to insure proper curvature of the specimen upon removal.

Accelerated Polish Test Procedure:

1. Determine the friction value of the control specimens for correction purposes as explained in the "Test Control" paragraph.

2. Determine the original friction number of the prepared test specimens as explained in ASTM Designation E 303-66T and modified by paragraph 3 "Apparatus."

3. Fourteen specimens shall be clamped around the periphery of the road wheel using rubber O-rings near the edges of the specimens.

4. The outer surface of the specimens shall then form a continuous strip of particles upon which the pneumatic-tired wheel shall ride freely without bumping or slipping.

5. The road wheel shall then be brought to a speed of 320 $\pm$ 5 rev/min, and the pneumatic-tired wheel shall be brought to bear on the surface of the specimen with a total load of 88 $\pm$ 1 pound.

6. No. 150 silicone carbide grit shall be continuously fed at a constant rate of approximately 25 grams per minute for the desired testing time. Water shall be fed at the same rate as the silicone carbide grit.

7. The specimens are then removed from the road wheel and washed thoroughly to remove grit.

8. Determine the friction value of the control specimens for correction purposes as explained in the "Test Control" paragraph.

9. After cleaning, the specimens shall be tested on the British Portable Tester to determine the "polish value", as explained in ASTM Designation E 303-66T and modified by paragraph 3 - "Apparatus".

POLISH VALUE TEST

District ____________________ Producer ____________________

Highway ____________________ Pit Location ____________________

Project No. ____________________ Aggregate Type ____________________

Date Sampled ____________________ Lab Sample No. ____________________

Date Tested ____________________ Length of Test Period ____________________

	Before Polish					Average
Specimen 1	______	______	______	______	______	______
Specimen 2	______	______	______	______	______	______
Specimen 3	______	______	______	______	______	______
Specimen 4	______	______	______	______	______	______
				Initial Value		______

	After Polish					Average
Specimen 1	______	______	______	______	______	______
Specimen 2	______	______	______	______	______	______
Specimen 3	______	______	______	______	______	______
Specimen 4	______	______	______	______	______	______
				Polish Value		______

Appendix Figure 1