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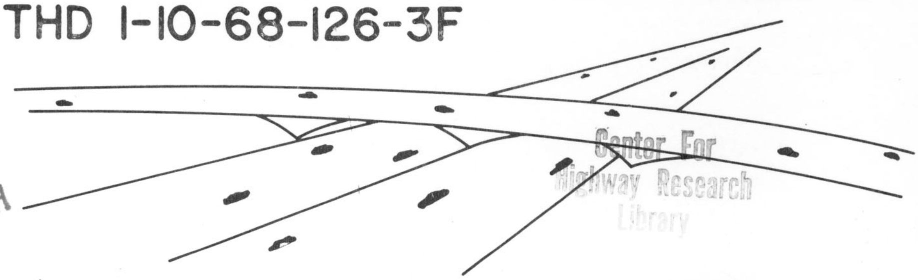

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PAVEMENT SURFACE POLISHING CHARACTERISTICS: A CIRCULAR TRACK TEST

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16. Abstract

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Pavement Surface Polishing Characteristics:

A Circular Track Test

by

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Jon P. Underwood
Orville Darnaby
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Research Report 126-3F

A Laboratory and Field Evaluation of the Polishing Characteristics of Texas Aggregates

Research Study 1-10-68-126

Conducted by

Planning and Research Division, Research Section

Texas Highway Department

In Cooperation With the

U. S. Department of Transportation

Federal Highway Administration

June 1974

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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Acknowledgement is given to the late Mr. Thomas K. Wood, Mr. Travis A. Long and Mr. James F. Todd with District 14 (Austin) for the interest and particularly the help in providing test facilities for this project.

Even though Mr. Orville Darnaby and Dr. W. B. Ledbetter are listed as authors, acknowledgement is given to these researchers and to Dr. Alvin Meyer with Texas Transportation Institute. These TTI personnel designed the experiment, analyzed the data and wrote a report concerning the studies of Portland Cement concrete in this study. With permission of the authors, the material prepared by the TTI personnel is included as a portion of this report.

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Abstract

Pavement Surface Polishing Characteristics: A Circular Track Test

Project Number	:	HPR-1 (13), 1-8-68-126
Investigators	:	Hankins, Underwood, Darnaby, Ledbetter
Research Agency	:	Texas Highway Department
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Date	:	June, 1974
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Key Words	:	Aggregate Polish Characteristics British Wheel Insoluble Residue Test Circular Track Polish Value - British Wheel Polish Value - Circular Track Aggregate Rate of Polish British Portable Tester Aggregate Blends for Skid Resistance

This is the final report for this project. The report briefly describes two interim reports of (1) Field Performance Tests using a skid test trailer and (2) Adaption of the British Wheel for use in Texas. The second report includes the experimental work with the British Wheel and tests using an Insoluble Residue procedure. The primary purpose of this report is to indicate studies accomplished with a Circular Track. The circular track was designed to study the pavement matrix. The results of the study were inconclusive but experiments with asphaltic concrete indicated a linear relationship between the friction properties of aggregate blends including the fine aggregate portion. Studies of Portland Cement Concrete revealed a linear relationship between texture

values before and after polishing. No trends were found in the batch variables of cement factor, fine aggregate type, or curing environment. Based on the inconclusive results of the study, recommendations were made that no further testing be conducted with the circular track.

Implementation

Implementation of the first phase of this project or that portion relating to the British Wheel is in progress. The British BSS:812 test procedure has been modified to meet Texas conditions and, after changes by the Materials and Tests Division, has been adopted. In Texas, specifications prepared, modified, and initiated by the Highway Design Division now require coarse aggregate of durable skid resistance for flexible pavements.

Laboratory tests of the polishing characteristics of aggregate indicate aggregates may be blended to provide skid resistant surfaces at minimum cost. However, it is doubtful if laboratory polish actually simulates field polish, therefore, it is recommended that implementation proceed with caution using selected experimental sections in the field on a trial basis.

By combining the present asphaltic concrete mix design procedure with Schonfeld's Stereo-Photo analysis, an "Asphaltic Concrete Mix Design Technique for Checking Skid Resistance" has been developed. Again because of the difference between laboratory and field polish expected, it is recommended that research be continued on this technique. Surfaces under traffic should be examined to modify or verify the technique and particular emphasis should be placed on verifying the L. A. Wear test as a basis for aggregate attrition. It is also believed that present research into asphalt hardening will be helpful in the study of matrix attrition. Such items as vanadium content in asphalt, asphalt viscosity, and climatological effects influence asphalt weathering which is most frequently noted on the surface. Matrix attrition influences the surface texture and, therefore, the skid resistance. Measurable items of asphalt weathering may be included in the technique as design modifications of aggregate macro texture height and contact area.

Summary

The research conducted in this study may be divided into two phases. The first phase concerned the adaption of the British Wheel for use in Texas. Included in the experimental work was the modifications to the British test method and comparison tests using an Insoluble Residue procedure.

The second phase of the project relates to studies of aggregate blends using a Circular Track. The results of the study were inconclusive but experiments with asphaltic concrete indicated a linear relationship between the friction properties of aggregate blends including the fine aggregate portion. Studies of Portland Cement Concrete revealed a linear relationship between macro-texture values before and after polishing. This relationship indicates a "percentage loss" of macro-texture may be expected for non-studded tire traffic. It was found that the Circular Track designed for this project was not acceptable as test equipment and recommendations were made that no further testing be conducted with the Circular Track.

1. Introduction

1.1 Background and Purpose

Before this project was conceived, considerable testing with a skid trailer had been performed with the testing specifically directed toward the study of pavement surface materials. The studies with the skid trailer revealed:

a. Pavement surfaces polish or become less skid resistant as traffic cumulates.

b. To study the polish characteristics, the surfaces should be separated into flexible and rigid pavement groups.

c. The skid resistance of flexible pavements was basically derived from the coarse aggregate, however, depending on the mix design, the intermediate or fine aggragate could be important.

d. To determine the polish characteristics of coarse aggregate, the pit or source should be studied rather than the general aggregate type.

e. In Texas, the skid resistance of rigid pavements depends on the surface finish and the fine aggregate of the concrete mixture. Studded tires are rare in Texas and generally the coarse aggregate in P. C. Concrete is not exposed during the structural life of the pavement. When exposed, the coarse aggregate represents only a small portion of the surface area.

f. The durability of the surface finish on rigid pavements is a direct function of the strength of the concrete at or near the surface.

It was decided that the capability of providing skid resistant pavement surfaces must be developed as quickly as possible. Also the only practical method which would be fair to contractors, material suppliers, state and federal personnel would be using specifications based on test procedures.

1.2 Objective

The object of the research reported herein was to study the polishing characteristics of Texas materials with the specific purpose of developing specifications and test procedures which would result in skid resistant pavement surfaces.

2. Interim Reports

2.1 Research Report 126-1 "Field Friction Performance of Several Experimental Test Sections"

The first interim report concerned the results of tests with a skid trailer obtained on several experimental test sections. Periodic skid tests were performed on each section in order to develop a performance history. The performance history indicates the rate of polish and various items such as seasonal deviations. The sections were placed in groups and the groups of sections were placed at different times. Generally, the coarse aggregate was considered as the study variable and the group was composed of several sections in which a specific coarse aggregate source was used in a section with several sources in the group. Sections within a group were placed end to end along the same highway to minimize variations in traffic, weather, etc. A few groups were placed in which the intermediate or fine aggregate source was changed in each section. In each case the sections were composed of flexible pavement surfacing material. The results of this study have been outlined in the introduction above. However, when the sections were initiated, little was known about the skid resistance or polishing characteristics of synthetic lightweight aggregate. The testing performed assisted in developing the use of this aggregate type as a skid resistant material which is widely used in the state at the present time.

2.2 Research Report 126-2 "Aggregate Polishing Characteristics: The British Wheel Test and the Insoluble Residue Test"

This project was initialized because it was realized that specifications and test procedures were needed to insure long life skid resistant pavements in the design stage. Also, the specifications and test procedures were needed quickly. A literature search revealed that only one test method to insure skid resistance was commonly used. This was the British Wheel Test which was developed in England. Because of the urgent need of a test method, a British Wheel was purchased. This report describes the adaption and adoption of the British Wheel Test for use in Texas. About the time the British Wheel apparatus was received, the Insoluble Residue Test began recieving attention in many areas of the United States. Therefore, the Insoluble Residue Test was performed on several aggregate sources and compared with the British Wheel results.

Both the British Wheel and the Insoluble Residue Tests were considered satisfactory methods by which to specify long life skid resistant aggregate. However, since Texas uses much silicious river gravel in flexible pavement surfaces and the Insoluble Residue Test tended to specialize in limestone materials, a decision was made to recommend the British Wheel Test for use in Texas.

Basically, the Texas test method was similar to the British method as reported in BSS:812 with the exception that in Texas a single size (150 grit) abrasive was used. A polish duration of nine hours was selected. Also, a commercially produced silicone carbide grit was used as an abrasive. The British Portable Tester used in the testing was calibrated by ASTM E-303 procedures. American slider rubber was used rather than rubber meeting British standards.

The content of the interim report consisted of several experiments which duplicated British work on abrasive grit size and hardness. Variation of Polish Values between sources of a given aggregate type was studied; and variation in Polish Values in different parts of the pit or source was also studied. After establishing an experimental test procedure, some 90 Texas sources were tested.

The interim report recommended the British Wheel Test be used in Texas as a standard procedure to predict the skid resistance life of the coarse aggregate used in flexible pavement surfaces. A Polish Value of 29 was first recommended for use in specifications. Later revisions recommended the Polish Value for specifications be increased to 35.

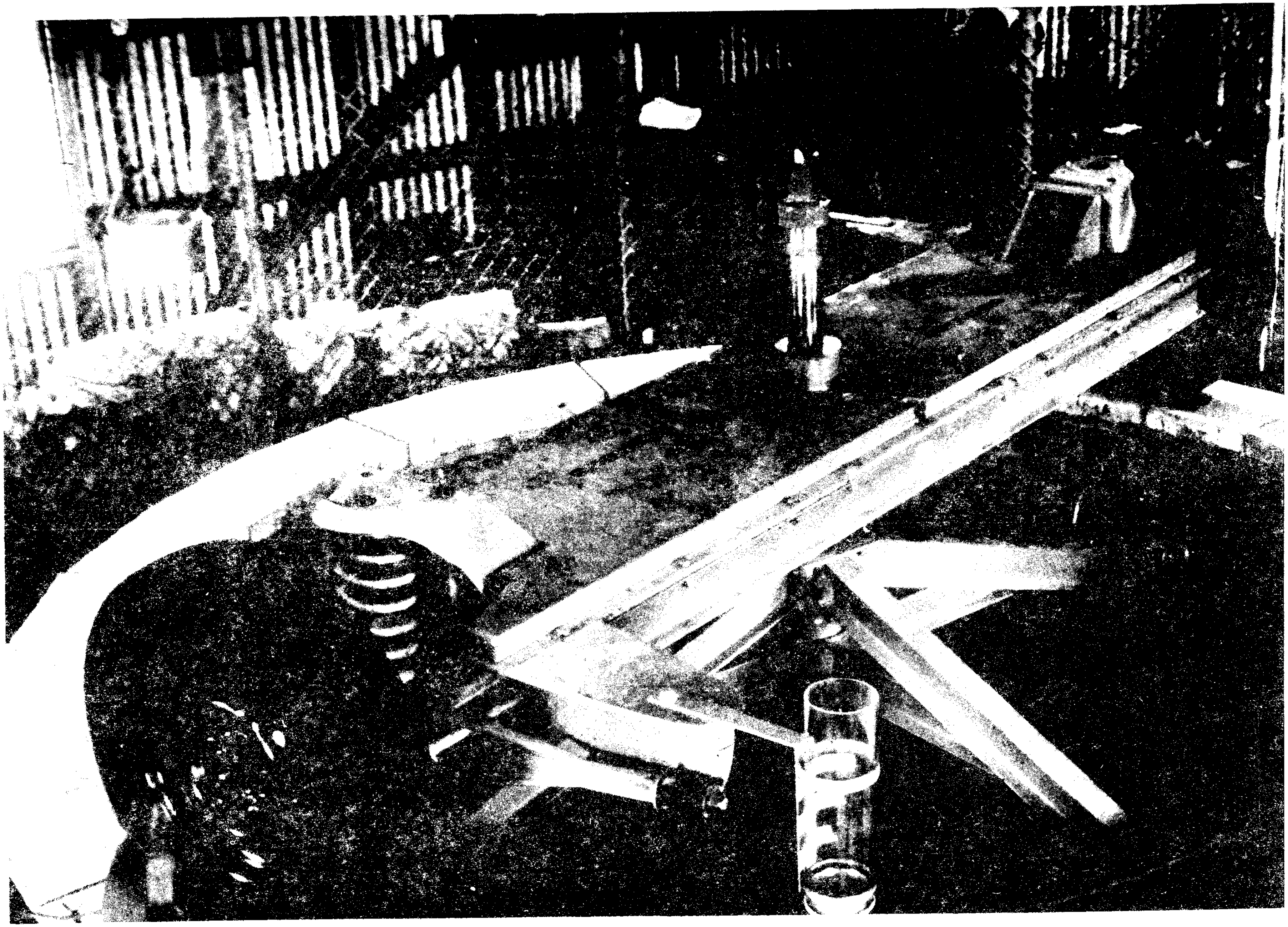
3. Description of Equipment

3.1 Circular Track

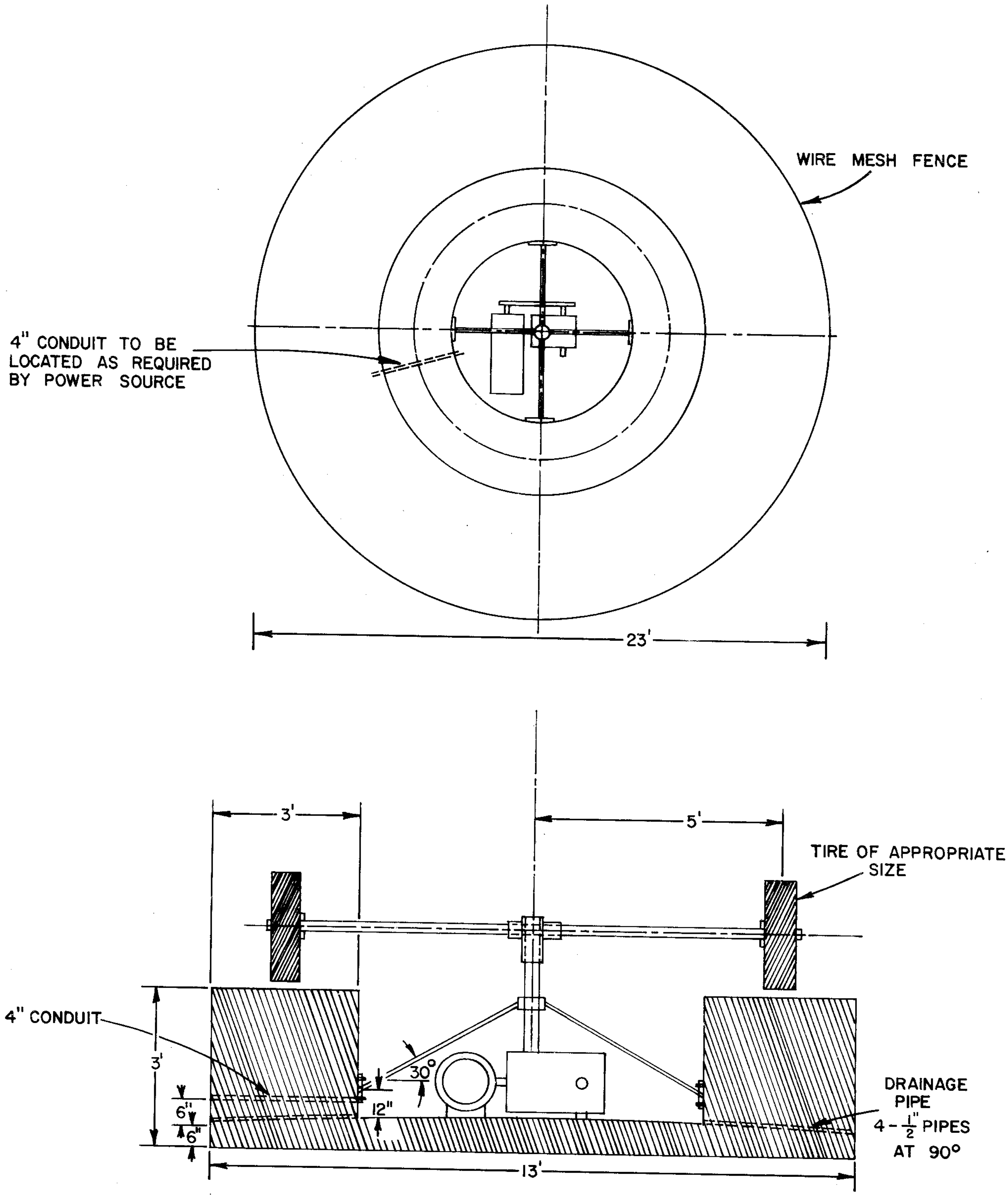
With the completion of the first phase of the project, or the work with the British Wheel, efforts were directed toward the study of asphaltic concrete surfaces. It was believed that the British Wheel offered excellent information of the polish characteristics of the coarse aggregate, however, additional information was needed about the total pavement surface. Specifically, it was desired to study coarse aggregate blends. Aggregate blends would allow the use of a local material of relatively low cost to be combined with a highly skid resistant material. The first investigation was to blend the two aggregates in the correct proportions, but to provide sufficient skid resistance throughout the structural life of the surface.

A literature search was made of the test equipment designed to study the polishing characteristics of the pavement surface. It was decided that the equipment should be able to test as large a portion of the pavement surface as possible, but still be capable of receiving laboratory prepared specimens. Few items of test equipment have been conceived which meet the requirements above, however, a circular test track was selected as the best of the test equipment. Information requests revealed several agencies had developed circular tracks and about six agencies were studying or had studied aggregate polish with tracks.

A picture of circular track fabricated for the project may be found in Figure 1. A schematic is shown in Figure 2. The track was designed to have a five-ft. radius, however, the radius could be changed slightly to develop two wheel paths, one with a radius of 4' - 9½" and the second with a radius of 5' - 2½". It should be noted that the equipment was not designed as a variable radius unit as several other agencies have fabricated. Once in a testing mode the radius was at a set length.



Photograph of the Circular Track - Figure 1



SCHEMATIC OF THE CIRCULAR TRACK

FIGURE 2

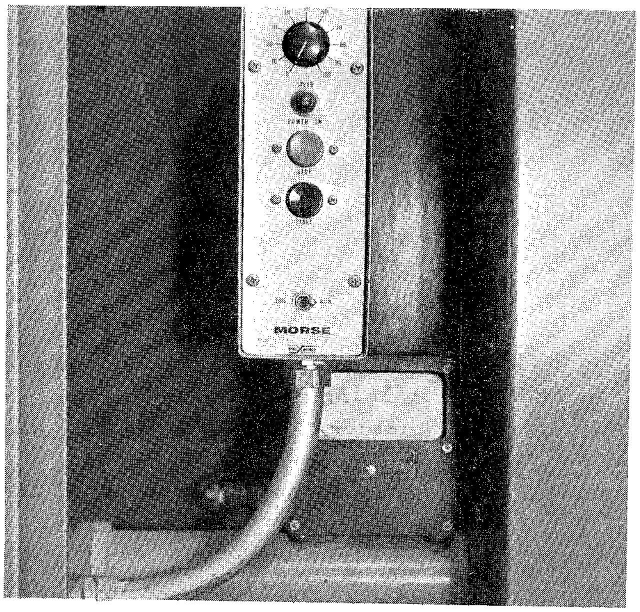
The track was powered by a 25 h.p. D.C. electric motor. Controls were included so that the speed of the motor could be varied. The motor was coupled to a right angle drive and a vertical shaft was attached to the output of the drive unit. The vertical shaft contained a key way which allowed the axle portion to float freely in a vertical direction, but the key forced rotational movement of the axle. The axle unit was fabricated from "I" beams and plate steel. Near each end of the axle unit, axles designed for a Ford pickup (Twin I Beam) were installed complete with shocks and springs. Summarizing the axle unit, the fabricated "I" beam plate steel portion was free to move vertically, but powered through the keyed vertical shaft and the wheels were free to move independent of the fabricated axle unit as influenced by the shocks and springs. The dead load or weight on the axle could be changed by varying the weight placed on the fabricated axle unit. Generally, the dead load consisted of plate steel which was stacked on the axle unit.

ASTM, E-17, 14" skid test tires were used in polishing the track specimens. In all tests, the tire had been ground smooth, leaving a zero tread depth. The cant of the tire-wheel assembly could be adjusted by raising or lowering the interior end of the "Twin I Beam" axle. The tow of the tire-wheel assembly was adjustable using a mechanism included with the "Twin I Beam" axle which forced the wheel out of a plane perpendicular with the radius.

The track was composed of a ring of reinforced concrete. Particular attention was given to the surface finish to produce a smooth flat surface conforming to a horizontal plane.

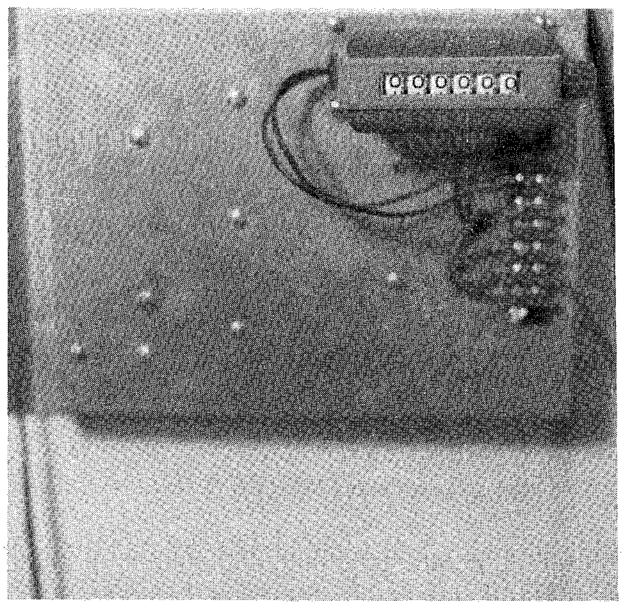
An obsolete radar unit was revised to produce pulses of electrical energy proportional to wheel passes. Counters and dials were installed to indicate axle speed and number of applications (see Figures 3 & 4).

Experiments to determine the setting of the tow and cant of the polish wheels may be found in Appendix A.



Dial Indicating Rotational Velocity

Figure 3



Revolution Counter

Figure 4

4. Studies of Asphaltic Concrete

4.1 Experimental Design

As stated previously, the studies of asphaltic concrete were directed toward experiments with blends of coarse aggregate material. In the final portion of the study with the British Wheel, a small amount of work involved blending two different aggregates in polish specimens. The aggregates from two sources were blended in known percentages, polished and compared with the calculated Polish Values. The calculated Polish Values were obtained by multiplying the known material percentages by the Polish Values of the 100% material for each source and adding the products. The comparison of actual Polish Value with calculated Polish Value indicated excellent correlation.

Therefore, the idea was conceived to develop similar information using aggregate blends in asphaltic concrete on the Circular Track. The basis for comparison in the investigation reported herein was the calculated British Wheel Polish Values (BWPV). In other words, the polish values measured on the Circular Track (CTPV) were compared with the BWPV. The British Portable Tester (BPT) with a modified slider (1¼" slider and 3" contact swing) was used to measure the friction in both the British Wheel and Circular Track. The only difference in BPT testing was that the British Wheel specimens were slightly convex (rounded) whereas the Circular Track specimens were flat.

In order to study the two coarse aggregates in blends, the intermediate aggregate, fine aggregate, and asphalt were held constant as far as possible in each mix design. The intermediate aggregate was limestone screenings whose size was composed of the percentages (retained) shown opposite the sieve sizes below:

Sieve Size	Percentage
4- 10	8.2
10- 40	54.3
40- 80	17.1
80-200	12.1
Pass 200	8.3

The fine aggregate was a silicious field sand whose size follows:

Sieve Size	Percentage
10- 40	1.2
40- 80	33.1
80-200	60.8
Pass 200	4.9

The asphalt was an AC-10 obtained from Gulf States Asphalt Company.

It was necessary at times to vary the amount of asphalt, the intermediate aggregate, and the fine aggregate to obtain a workable and stable mix. However, the procedure established in Construction Bulletin, C-14 published by the Texas Highway Department Construction Division formed the basis for the mix design method. A description of specimen preparation and studies leading to the development of a compaction procedure may be found in Appendices B & C respectively.

The coarse aggregates from nine sources were selected for study. The basis for selection were range in British Wheel Polish Values and range in aggregate type. The aggregates selected were as follows:

Aggregate Nomenclature	Aggregate Type	British Wheel Polish Value
A	Basaltic Trap Rock	35
B	Sandstone	44
C	River Gravel	23
D	Iron Blast Furnace Slag	46
E	River Gravel	27
F	Calcareous Limestone	31
G	Synthetic Lightweight	41
H	Dolomitic Limestone	24
I	Calcareous Limestone	34

Three blend percentages of the coarse aggregate portion of the mix were selected for study. The percentages selected were 25-75, 50-50 and 75-25.

For a clearer explanation of the percentages, assume two aggregate sources are to be blended which are Source X and Source Y. The percentages selected were 25% of X with 75% of Y; 50% of X with 50% of Y; and 75% of X with 25% of Y. Three specimens were prepared in which all the coarse aggregate was obtained from a single source. Replicate specimens were also prepared and tested to determine variation in mixing and in specimen position on the track.

Figure 5 shows the experimental design of the study of aggregate blends in asphaltic concrete. The letters shown at the top and on the left side are the same used for aggregate nomenclature revealed previously. The values in the blocks are blend percentages of the Coarse Aggregate Materials also described above. Note that the percentages are based on only the coarse aggregate portion of the asphaltic concrete mix. For the purposes of this report the coarse aggregate portion is defined as that aggregate material retained on the #10 mesh sieve.

4.2 Asphaltic Concrete Mix Design

The mix design for aggregate blends was accomplished in the following order:

1. Nine mix designs were developed, each including only one of the coarse aggregate materials as listed in "4.1 Experimental Design" above. The intermediate aggregate, fine aggregate, and asphalt used was also described in "4.1" above. Construction Bulletin, C-14 was used in design.

2. After the design was completed for each source the aggregate percentages for that source were set and maintained during blending procedures.

3. The total weight needed for one circular track specimen was found for each source where all the +10 mesh material was from that source.

4. The percent asphalt was determined for each source studied and for each blend combination of materials using specific gravities of the materials as the predictors.

5. The mixes were blended as shown in the example on Figure 6. Note the figures under the "100%" column for source C were multiplied by 0.25 and the "100%" column figures for source D were multiplied by 0.75. Also note the total asphalt percentage for the specimen in question was 6.4 percent. The actual percentage aggregate in the mix was 93.6, therefore the figures under the "25%" and the "75%" columns were multiplied by 0.936 and noted under the column headings "Mix %".

VALUES SHOWN ARE BLEND PERCENTAGES OF COARSE AGGREGATE MATERIAL COMBINATIONS

	A	B	C	D	E	F	G	H	I
A									
B		100%							
C	25C-75A 25C-75A	25C-75B 75C-25B 75C-25B							
D	75D-25A		50D-50C						
E	75A-25E 50A-50E		25E-75C		100%				
F		25F-75B 25F-75B 50F-50B	75F-25C	50F-50D 50F-50D 75F-50D	75F-25E	100%			
G	50G-50A 50G-50A	50G-50B 50G-50B 75G-25B	50G-50C	25G-75D 25G-75D 50G-50D	75G-25E	75G-25F 50G-50F 50G-50F 25G-75F			
H	50H-50A 50H-50A 75H-25A	25H-75B 50H-50B 50H 50B	75H-25C	75H-25D 25H-75D	50H-50E		25H-75G 50H-50G		
I	25I-75A	25I-75B 50I-50B	50I-50C	50I-50D	25I-75E 50I-50E	25I-75F 50I-50F 75I-25F	75I-25G 75I-25G 75I-25G		

EXPERIMENTAL DESIGN IN THE STUDY OF ASPHALTIC CONCRETE

FIGURE 5

ASPHALTIC CONCRETE MIX DESIGN
Date Run 9-28-70
SOURCE C - River Gravel
SOURCE D - Iron Blast Furnace Slag
MIX PROPORTIONS - SOURCE C - 25.0 Percent
SOURCE D - 75.0 Percent

	SOURCE C			*	SOURCE D		
SIZE	100%	25%	MIX%		100%	75%	MIX%
5/8-1/2	0.0	0.0	0.0		0.0	0.0	0.0
1/2-3/8	6.5	1.6	1.52		6.7	5.0	4.70
3/8- 4	34.5	8.6	8.07		35.5	26.6	24.92
4 - 10	27.0	6.8	6.32		27.8	20.8	19.52
LS SCRE	17.0	4.3	3.98		16.0	12.0	11.23
SAND	15.0	3.8	3.51		14.0	10.5	9.83
TOTAL	100.0	25.0			100.0	75.0	
ASPH	6.4	1.6	1.60		6.4	4.8	4.80
TOTAL			25.00				75.00

MIX WEIGHTS (GRAMS)

	SOURCE C	ACCUM	SOURCE D	ACCUM	
5/8-1/2	0.	0.	0.	0.	
1/2-3/8	93.	93.	273.	273.	
3/8- 4	492.	585.	1445.	1718.	
4 - 10	385.	970.	1132.	2850.	
LS SCRE	243.	1213.	651.	3501.	894.
SAND	214.	1427.	570.	4071.	784.
ASPH	98.		278.		376.
TOTAL	1525.		4349.		

EXAMPLE OF ASPHALTIC CONCRETE MIX DESIGN
USING AGGREGATE BLENDS
FIGURE 6

6. Again refering to Figure 6, 25 percent of the total specimen weight needed for source C was found to be 1525 grams. Also 75 percent of the total specimen weight needed for source D was found to be 4349 grams. The figures under the "Mix %" column for source C were multiplied by 1525 to determine the weight of the material needed for the various sieve sizes for source C. The same information was developed for source D using 4349 grams as a total. The three figures in the lower right portion of the page are the sums of the limestone screenings, field sand, and the asphalt.

In checking the calculations listed on Figure 6, it may be found that a computer program was used and "round-off" of trailing digits was observed.

4.3 <u>Experiments to Determine a Circular Track Test Method for Asphaltic Concrete</u>

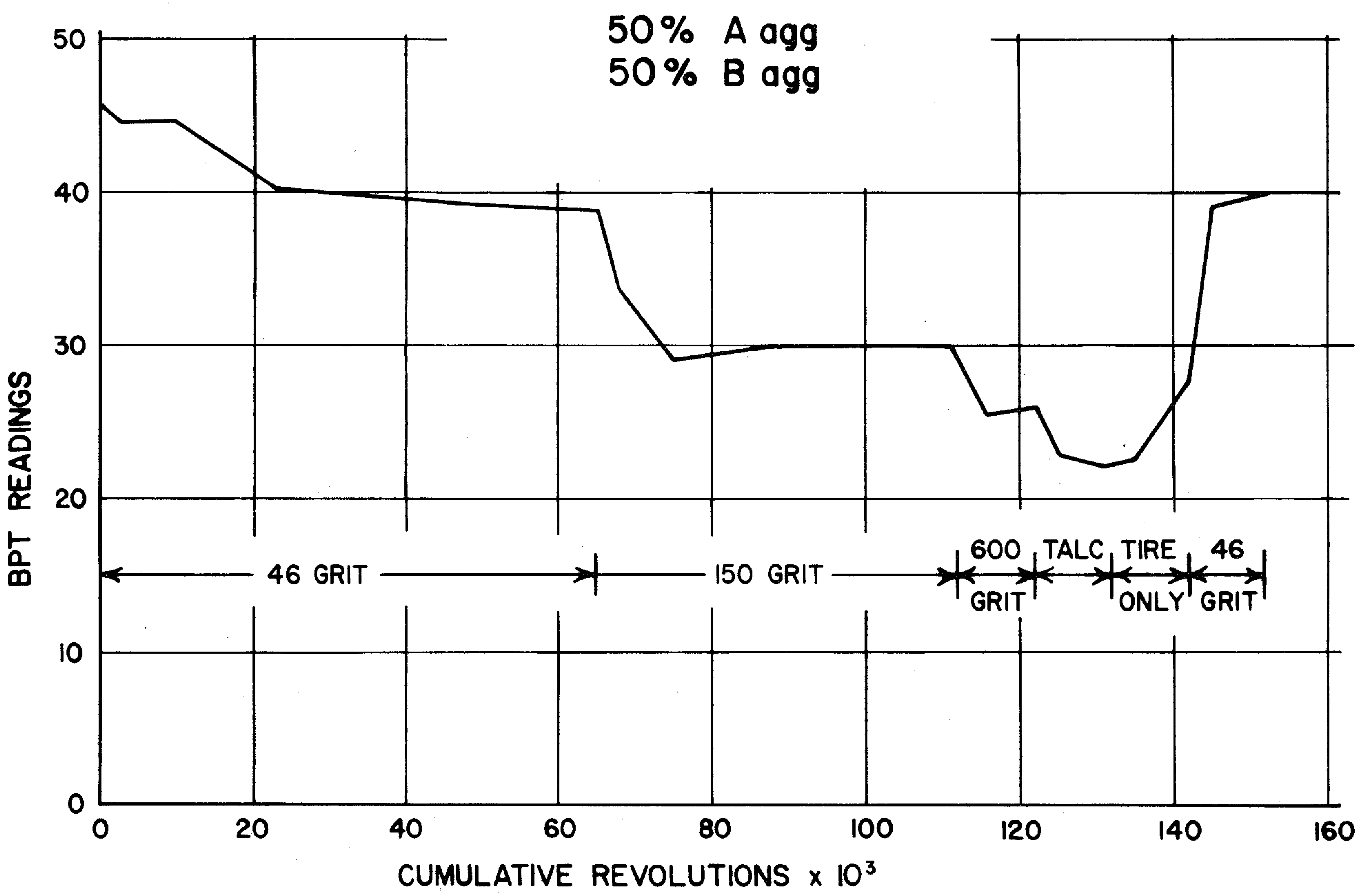
In order to develop a test method, thirty specimens were prepared and placed on the track. Smooth ASTM E-17 tires were used with 1085 pounds weight on each tire. The angular rotation was set to produce a linear velocity of 10 mph at the wheel center. An apparatus was fabricated which would produce a continual spray of water just preceding tire passage on each wheel. Also a grit distributor (See Figure 1) was attached to spread a 46 size silicone carbide grit preceding each wheel. The tire was set perpendicular to the axis of the axle. The specimens were placed in the receptacles and butted tightly end to end (see Preparation of Asphaltic Concrete Test Specimens - Appendix B).

When testing was initialized, the specimens began moving within the receptacles. Generally the specimens were shoved to the inside and toward the direction of rotation. With this finding, various tow and cant settings were attempted for short durations and, before each setting, the specimen was moved back to its correct location in the receptacle. The findings of the short duration test periods with various tow and cant settings revealed the specimens moved or shoved at each wheel setting. A decision was then made to bond the specimens to the receptacle. An epoxy was used and immediate improvement in specimen movement was noted. In addition to using epoxy to bond the specimens, the load was lightened to 880 pounds per wheel. Also, when a new series of specimens were made and placed on the track, a heavy layer of grit was placed on the specimens and the rotational speed was reduced to produce a lineal speed of one mph. The one mph speed was maintained for 500 wheel applications and then the speed was increased to 5 mph for the remainder of the testing. The heavy grit and one mph speed mentioned above was used to allow the tire to slip freely over the surface and to allow possible further consolidation or "setting" of the specimen. Also note that the testing speed was reduced.

During the above mentioned experiments with wheel setting load and speed, the asphaltic concrete specimens had shown extreme signs of disintegration and several specimens had been replaced at varying periods. When testing was resumed on the second set of thirty specimens, disintegration was again evident. The disintegration was basically that of aggregate raveling, however, it was noted the 46 grit silicone carbide used as an accelerated polishing agent actually ground the macro-texture from each surface leaving each surface relatively smooth. Aggregate raveling was particularly noted on one specimen composed of lightweight synthetic aggregate. Closer inspection revealed the asphalt binder of the lightweight aggregate specimen to be light brown in color. In fact, it appeared as if the aggregate particles were bound with a light brown clay. The material in this specimen had completely raveled to the base plate, a depth of 1¼-inch. This was recognized as asphalt stripping, probably due to water movement under high pressure. Because of these facts, the continual application of water spray was removed from the specimens.

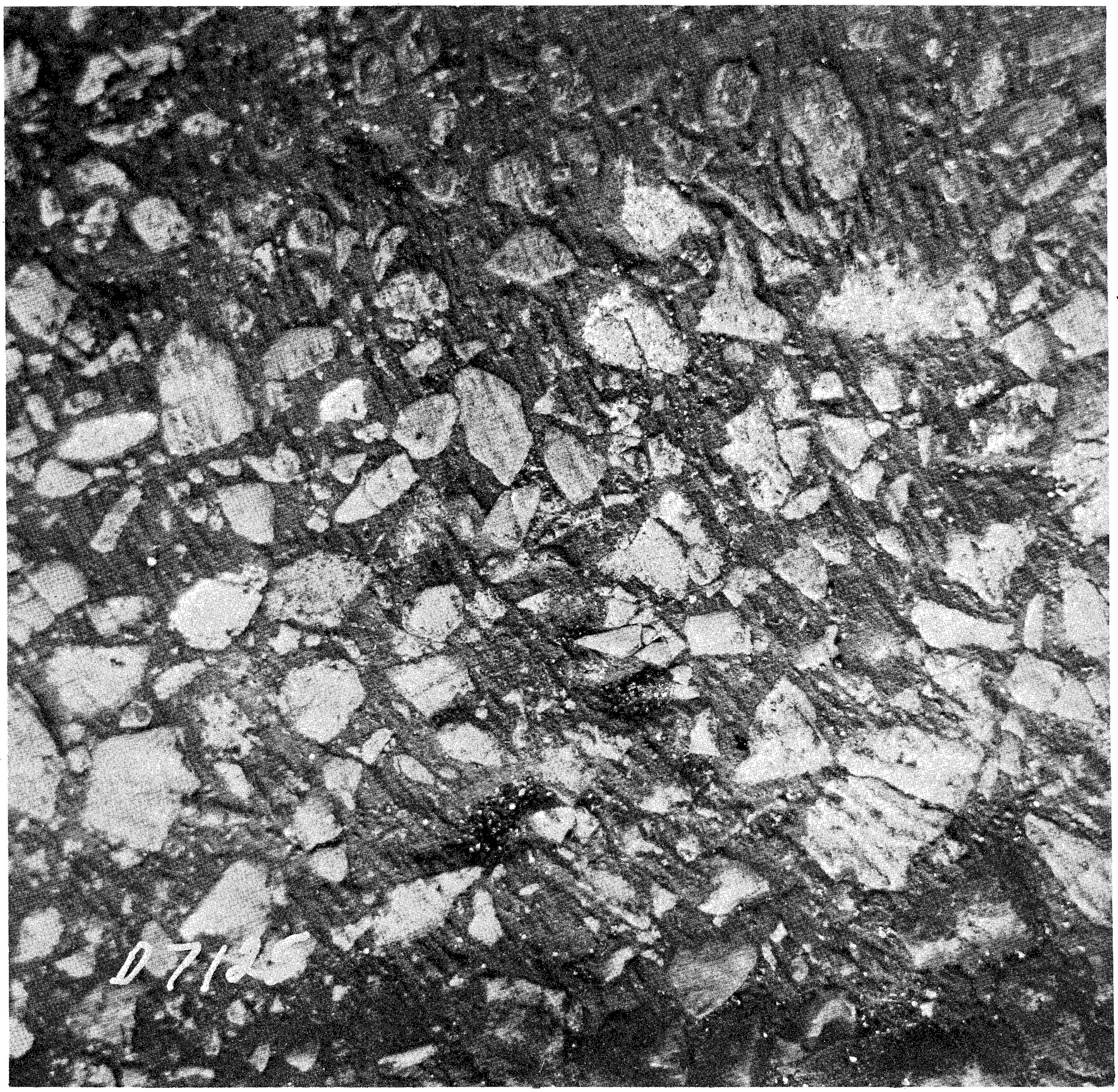
A third set of specimens was made and placed on the track. In the third test, a study was made of the grits used for accelerated polish. The test consisted of using various grit sizes for selected polish periods and observing the friction values as produced by the British Portable Tester (BPT). It should be noted that the British Portable Tester slider was modified to a smaller slider width and contact length. The slider width was $1\frac{1}{4}$-inches and the contact length with the surface was three inches. The reason for using this modification was to conform to that used in the tests with the British Wheel developed in an earlier phase of the project. An example plot of BPT values versus wheel passes, which shows the effect of grit sizes, may be found in Figure 7. Note the BPT values are generally lower when smaller grit sizes are used; when a larger grit size is then applied the BPT values become greater. In fact, when the 46 grit size was applied the second time, the values become constant at about the same BPT level as that found when the 46 grit was first applied. All specimens revealed the same trends as that shown in Figure 7.

The experiments with various grit sizes showed one other unusual event. At about 10,000 wheel applications using the 46 grit, small grooves began to form in the specimen surface. With additional wheel applications, the grooves became deeper and a pattern similar to an enlarged fingerprint was established. When observing patterns between specimens, the patterns seemed similar but not in exact dimension in each case. The grooves were continuous, leading from matrix, through aggregate and again through the matrix, etc. The groove width and depth were of the approximate size of the 46 grit abrasive. Apparently the grit would lay in a certain pattern on the specimen and as the tire rolled over the specimen the grit would abrade along that pattern, forming the grooves. Figure 8 is a photograph showing the grooves when using 46 grit. Attempts were made to study the grooving phenomenon, when smaller silicone carbide grits were used, and in each case grooves were formed. The grooves were smaller in size, when 150 grit size was used, and almost discernable with the 600 grit. It was believed that the micro-texture formed by the grooves influenced the BPT values. Based on the above facts, a final change in test procedure was made. A commercial talc powder was used as the accelerated polishing abrasive and the surface was brushed periodically to prevent a pattern



EXAMPLE PERFORMANCE PLOT SHOWING THE EFFECT OF POLISHING WITH VARIOUS GRIT SIZES

FIGURE 7



Grooves Developed by Use of 46 Silicone Carbide Grit

Figure 8

build up. Talc powder was used because the talc has a hardness less than most available grits and has a very small size. It was believed that:

1. The talc would allow the tire to slip over the surface without excessive overturning moment on the aggregate resulting in less specimen disintegration.

2. The talc would not abrade the macro-texture into a "flat" condition.

3. The talc would not form groove patterns or form a micro-texture as noted with the larger, harder grit.

Therefore, the Circular Track test method used for asphaltic concrete was as follows:

1. Specimen preparation as reported in "Preparation of Asphaltic Concrete Test Specimens" - Appendix B.

2. The specimens were epoxied to a specimen receptacle, the receptacles were shimmed to produce a level surface where necessary, and the specimens were bolted to the track end to end as close together as possible.

3. A load was placed on the axle resulting in an 880 pound weight on each wheel.

4. A smooth ASTM, E-17, 14 inch tire was used with 24 psi. The tire-wheel was set in a plane perpendicular to the axis of the axle.

5. A heavy layer of 46 silicone carbide grit was used and the linear speed of the wheel was set at one mph for the first 500 wheel applications. After 500 applications the grit was removed from the track and the tires were brushed. A talc powder was applied to the surface and the testing began at a lineal wheel speed of 5 mph.

6. Data collected consisted of the following:

    a. BPT tests at two preselected spots on each specimen. The spots were noted and tests were obtained at the same location at each test period.

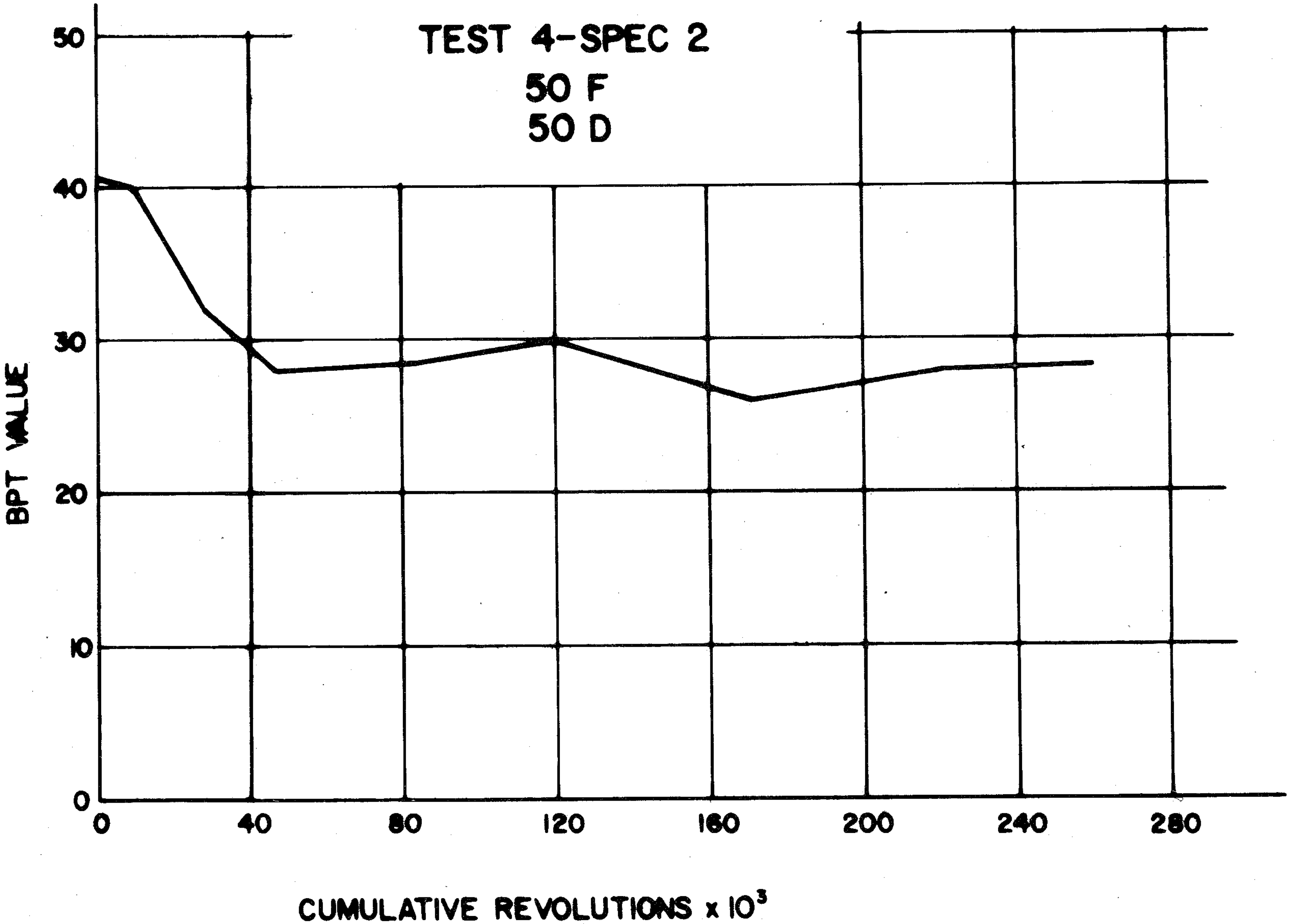
    b. Stereo Photo pairs, Surfindicator texture values, Putty Impression texture values, and photographs were taken on Specimens 4, 21, 23, 25, 28, and 30 at each stop. (See Appendix G)

    c. The above data was collected at periodic intervals to show the BPT performance as wheel applications cumulated. The measurements were obtained at the following periods (stops).

Beginning or Zero	Wheel Applications
3,360	Wheel Applications
10,080	" "
23,520	" "
47,040	" "
77,280	" "
120,960	" "
171,360	" "
221,680	" "
265,500	" "

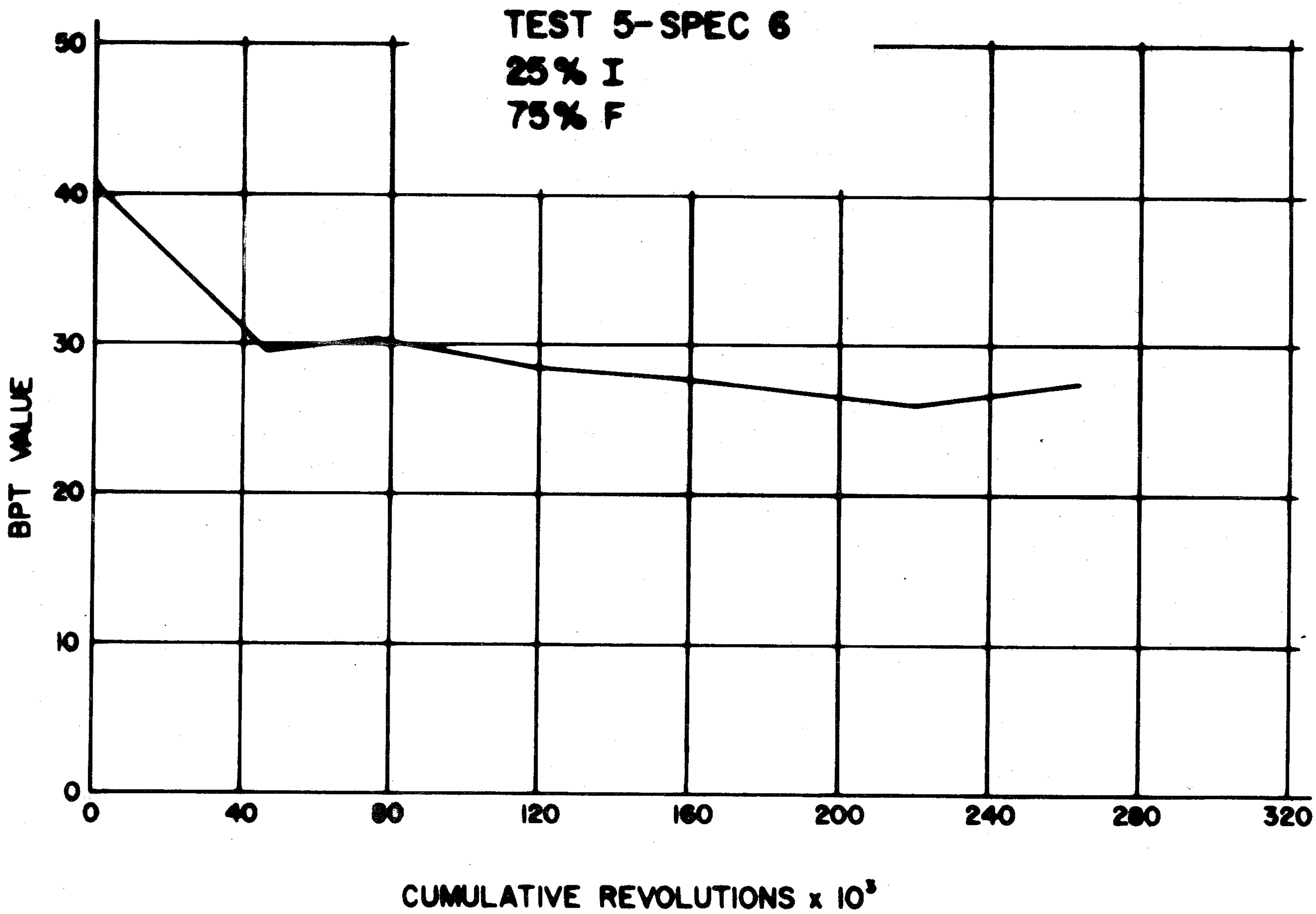
4.4 Analysis - Asphaltic Concrete

Two sets of 30 specimens were used in the analysis. The first set was termed Test 4 and the second Test 5. Example plots of the polish are shown in Figures 9 and 10. Test 4 was stopped at 270,000 revolutions or 540,000 wheel applications; Test 5 was stopped at 265,000 revolutions. The results of the tests are found in Tables I and II. Note the specimen number is listed in the first column, the percent blends of the coarse aggregate are shown in the second column, the calculated British Wheel Polish Value in the third column, the initial BPT value for the circular track specimens in the fourth column, the final BPT value called the Circular Track Polish Value (CTPV) in the fifth column, and a CTPV corrected for volumetric percentage (WPV) is listed in the sixth column. The sixth column will be explained later.



EXAMPLE OF POLISH DURATION-TEST 4

FIGURE 9



EXAMPLE OF POLISH DURATION-TEST 5

FIGURE 10

TABLE I
Test Data and Summary of Results
Test 4

Spec. No.	Percent Material		BWPV	Initial BPT Value	CTPV Final BPT Value	WPV Corrected BPT Value
1	50% - H	50% - A	30	49	31	29
2	75 - I	25 - G	36	52	29	33
3	100 - B		44	48	32	38
4	75 - I	25 - G	36	42	29	33
5	50 - C	50 - D	35	35	25	32
6	25 - I	75 - F	29	41	27	30
7	75 - H	25 - A	27	42	28	32
8	25 - F	75 - B	41	43	28	36
9	50 - I	50 - E	31	40	27	30
10	25 - C	75 - B	39	39	28	35
11	25 - H	75 - B	39	41	26	36
12	75 - F	25 - D	35	38	25	32
13	75 - A	25 - E	33	37	26	31
14	50 - G	50 - B	43	38	30	37
15	50 - F	50 - G	36	37	28	34
16	75 - I	25 - G	36	35	28	33
17	75 - H	25 - C	24	35	25	30
18	50 - I	50 - D	40	37	28	36
19	25 - F	75 - B	41	41	30	36
20	75 - G	25 - E	37	39	29	35
21	50 - I	50 - F	33	40	24	31
22	50 - F	50 - G	36	38	26	34
23	50 - F	50 - B	38	36	26	34
24	50 - I	50 - B	39	37	27	35
25	75 - C	25 - E	24	35	22	26
26	50 - H	50 - A	30	43	26	29
27	100 - F		31	35	25	30
28	25 - H	75 - G	37	39	28	34
29	25 - A	75 - D	43	40	33	38
30	50 - G	50 - B	43	39	33	37

TABLE II
Test Data and Summary of Results
Test 5

Spec. No.	Percent Material		BWPV	Initial BPT Value	CTPV	WPV
1	50% - B	50% - H	34	39	30	32
2	50 - F	50 - D	39	41	28	35
3	75 - H	25 - D	30	41	26	29
4	50 - F	50 - D	39	41	29	34
5	50 - A	50 - E	31	44	25	30
6	75 - I	25 - F	34	42	24	31
7	75 - C	25 - B	28	39	25	28
8	100 - E		27	43	24	27
9	75 - F	25 - E	30	41	27	29
10	75 - A	25 - C	32	40	29	31
11	25 - I	75 - E	29	43	29	29
12	75 - F	25 - C	29	41	27	29
13	50 - A	50 - G	39	41	30	35
14	50 - I	50 - C	29	42	27	28
15	25 - G	75 - D	45	44	31	38
16	25 - I	75 - A	35	49	30	32
17	25 - F	75 - G	39	50	31	35
18	25 - H	75 - D	41	50	28	36
19	75 - A	25 - C	32	47	26	31
20	50 - H	50 - B	34	52	28	32
21	25 - G	75 - D	45	43	32	38
22	75 - G	25 - B	42	49	31	37
23	50 - A	50 - G	39	45	28	35
24	75 - C	25 - B	28	40	26	28
25	50 - H	50 - E	26	40	26	27
26	50 - G	50 - D	44	40	32	38
27	25 - F	75 - G	39	42	30	35
28	50 - G	50 - C	33	42	28	31
29	50 - H	50 - G	33	42	28	32
30	25 - I	75 - B	42	43	33	36

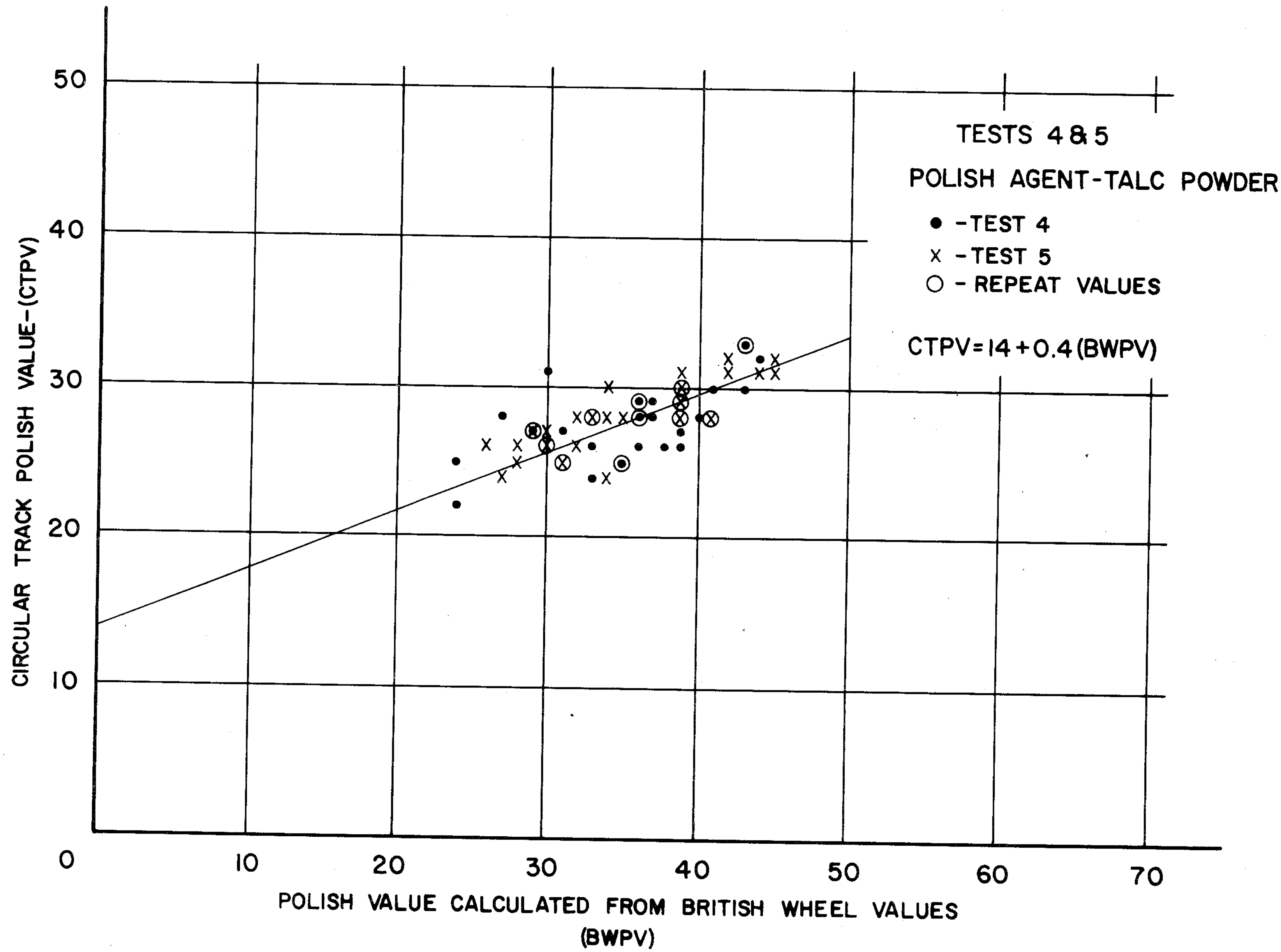
Pictures showing a specimen at various test stops may be found in Appendix D. In observing the specimens as they polish, it was noted that initially the specimen surface was entirely composed of a fine aggregate-asphalt mortar and the BPT value was generally relatively large. Very soon the fine aggregate-asphalt mortar wears away from the top of the coarse and intermediate size aggregate. At this stage, the BPT values are lower for aggregate with low micro-texture (such as river gravel) and on many occasions jump to higher values when the coarse aggregate contains good micro-texture (such as lightweight, sandstone, and slag). Then a slow process of fine aggregate removal from the coarse aggregate occurs. The coarse aggregate becomes increasingly exposed. The matrix consolidates; films with debris; and glazes to a smoother harder surface, probably with consolidation of smaller debris and grit (talc powder). The BPT values slowly become smaller in value and stabilize. This stable value has been termed the Circular Track Polish Value (CTPV). At times, aggregates of various sizes were stripped or dislodged from the surface causing slight variations in BPT values when considering periodic tests.

A plot showing the relationship of the Circular Track Polish Value and calculated British Wheel Values was shown in Figure 11. A trend in the relationship between the two variables was indicated, however, a large variance in data was also noted. The range in CTPV's was much smaller than the range in BWPV's. This small range in CTPV's made assessment difficult.

Observations of the results of work with aggregate blends to this point, both with the British Wheel and with the Circular Track, had indicated a linear relationship between the polish values of two aggregates. It was postulated that:

1. For a given tire, the friction at the tire-pavement interface must result from that with which the tire contacts, the pavement surface.

2. The friction properties of the pavement surface could be explained by the composition of the material exposed on the pavement surface.



RELATIONSHIP OF BRITISH WHEEL & CIRCULAR TRACK POLISH VALUES

FIGURE 11

3. The composition of the material exposed on the pavement surface could be explained by the contact area of each material in the pavement surface. (Statement 3 includes only the adhesion friction component of friction and not the hysterisis component as explained by Kummer and Meyer[2].)

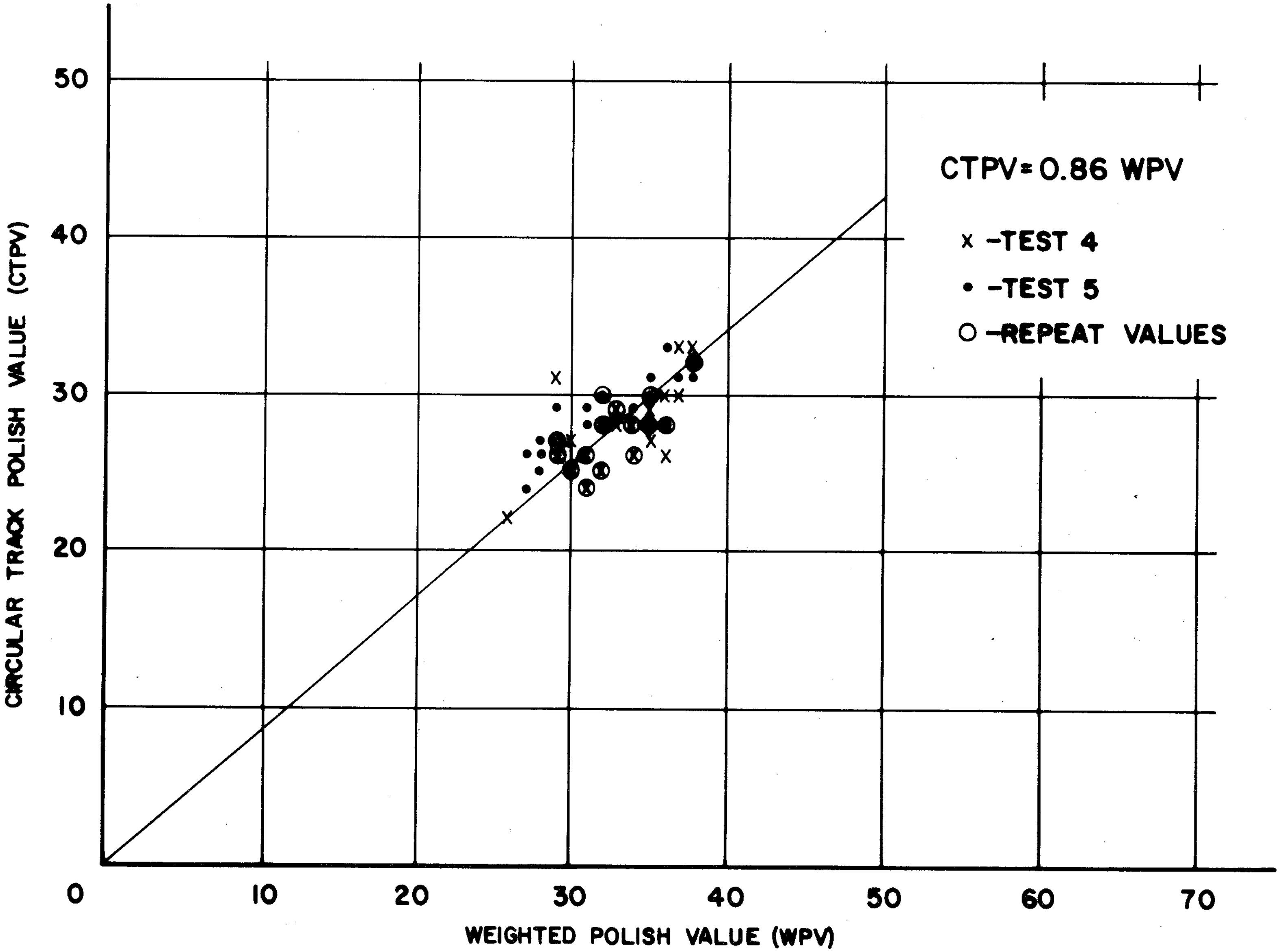
4. The contact area of each material in the pavement surface could be denoted as the percent of the total area.

5. The area percentage of the various materials would be a direct function of the mix volumetric percentages of the same materials. That is, if 35% (by volume) of the total mix consisted of +10 mesh lightweight aggregate, then 35% of the surface area would consist of +10 mesh lightweight aggregate particles.

With the above postulation in mind, the volumetric percentages of each component of each mix was determined. The volumetric percentage of each component was multiplied by a Polish Value to develop a Weighted Polish Value (WPV), thus forming a new basis by which to compare the CTPV's.

In the case of the coarse aggregate, the British Wheel Polish Values were known, however, estimates of the Polish Value for fine aggregates were derived from the Circular Track results. In order to obtain an estimate of the contribution of the fine aggregate, the actual percentage of fine aggregate (-10 mesh portion) was multiplied by the CTPV. This estimate was obtained for each specimen and the results averaged. The average contribution of the fine aggregate was found to be a constant of 8.4 or an equivalent Polish Value of 28.

The Weighted Polish Value was then calculated and is shown in column 6 of Tables I and II. This Weighted Polish Value is the summation of the Polish Values of all materials in a particular mix in which the Polish Values were "weighted" by multiplying the Polish Value of a particular material by the percent by volume of that material in the mix. A Polish Value of 28 was used for the fine aggregate and the percent of asphalt was not considered in the percentage. Figure 12 is a plot of the CTPV and the WPV. Note the linear curve was forced through a zero "origin intercept" point. Even though there is considerable scatter in the plot



EFFECTS OF BRITISH WHEEL-CIRCULAR TRACK P.V. RELATIONSHIP
AFTER VOLUMETRIC % CORRECTIONS
FIGURE 12

points, it is believed that the curve indicates a trend which substantiates the theory proposed above.

Table III indicates a comparison of replicate specimens which were tested. Note column 10 shows the range in circular track Polish Values expected between specimens in which the asphaltic concrete mix was the same. The average range of 2, or even the maximum range of 5, does not fully explain the scatter of data points found in Figures 11 and 12. It is believed that the scatter in data points shown in Figures 11 and 12 may be due to the following:

1. BPT operator error or ability to test with the BPT over exactly the same area in periodic tests.

2. Variation in macro-texture between specimens.

3. Lack of uniformity of material blends on the surface of the specimen.

TABLE III
Comparison of Replicate Specimens

Specimen			Replicate			Replicate			Range in CTPV
Test No.	Spec. No.	CTPV	Test No.	Spec. No.	CTPV	Test No.	Spec. No.	CTPV	
5	10	29	5	19	26				3
5	7	25	5	24	26				1
4	16	28	4	4	29	4	2	29	1
5	2	28	5	4	29				1
4	8	28	4	19	30				2
4	1	31	4	26	26				5
5	1	30	5	20	28				2
5	15	31	5	21	32				1
5	23	28	5	13	30				2
								Average	2

4.5 Results and Discussion

The basic results of the study are shown in Figure 12. The results do not produce conclusive facts. However, the following theory is believed to be better substantiated:

1. The portion of the tire-pavement friction contributed by the pavement surface must be developed by the surface materials which the tire contacts.

2. The friction produced by the surface materials can be explained in part by the Polish Values of the individual components of the mix when these components are weighted by the volumetric percentages of those components. Since the asphalt is generally worn from the surface, the asphalt should not be considered in the volumetric percentage.

In theory, aggregates may be blended to produce design friction levels; however, the fine aggregate must also be considered in the blend. Actually, this theory corresponds closely and is influenced by the stereo-photo analysis proposed by Schonfeld(5). Based on the above theory and the stereo-photo analysis procedures reported by Schonfeld, an "Asphaltic Concrete Mix Design Technique for Checking Skid Resistance" has been prepared and may be found in the Appendix E. This procedure combines the design method found in the C-14 Bulletin with the stereo-photo analysis procedure. Schonfeld has correlated the Skid Number of an ASTM-type skid test unit with the pavement texture using six texture variables. The design proposed uses a mutation of the same six variables as follows:

Variable Name		Description		Design Condition
A	-	Macro-Texture Height	-	Obtained from weighted sieve analysis results of C.A.
B	-	Macro-Texture Width	-	Obtained from weighted sieve analysis results of C.A.
E + C	-	C.A. Shape & Micro-Texture	-	A weighted British Wheel Polish Value for Aggregate Blends.
D	-	Macro-Texture Density	-	% (+10) Mesh - from sieve analysis.
F	-	Micro-Texture of Background (Matrix)	-	The -10 Mesh Weighted by Insoluble Residue Value.

The "Asphaltic Concrete Mix Design Technique For Checking Skid Resistance" is based on theory and is in no way proven. Much of the content, such as estimates of aggregate attrition loss, is judgement. However, there is an excellent probability that further research could provide information resulting in a useful procedure.

In considering the above theory noted previously in "4.5", one must also speculate on the conditions which are unknown. The major unknown condition is the performance of the asphaltic concrete mixes under actual traffic. Most aggregates shown to have durable skid resistant surfaces in Texas are those which retain their friction due to attrition loss on the surface. Attrition is the dislodging of small particles from the aggregate. Sandstones and synthetic lightweight aggregates are believed to retain their skid resistant properties due to attrition which renews a sandpaper-like surface on the aggregate. The item which must be considered in aggregate blends is the fact that aggregates with high attrition may abrade to the extent that the tire no longer is in sufficient contact with the skid resistant aggregate. The aggregate subject to less attrition would carry the brunt of the tire contact.

Another unknown condition is the effect of aggregate weathering. Most researchers which have studied this effect report a relatively long term or seasonal condition which reveals lower skid resistance in the summer and early fall and higher skid resistance in winter and spring. Unreported tests obtained during the compilation of data for Interim Report 126-1 verify a seasonal effect which shows a skid resistance differential of as much as 15 Skid Numbers on certain surfaces. However, it could be postulated that those aggregates which have high attrition due to traffic also would suffer most in weathering.

An unknown which may not be associated with aggregate polishing characteristics, but which must be considered, is the macro-texture formed on the pavement surface. It is believed that the macro-texture should be considered at least in part with construction practices. It has been found that the same asphaltic concrete mix placed by the same contractor with the same placing and finishing equipment can result in Skid Numbers (SN40) which vary as much as 30. Visual observations indicated the higher Skid Numbers occurred on that portion of the surface with greater macro-texture; lower Skid Numbers where associated with portions of the surface having smaller macro-texture. It is unusual that a trend to vary the finishing of P.C. concrete to produce greater texture has spread rapidly throughout the nation, yet very little work has been accomplished to study the effect of construction practices on skid resistance of asphaltic concrete.

The Circular Track with combined friction testing equipment has not been beneficial in collecting the data needed for this study. Basically, the BPT values from the Circular Track have not had adequate range for sufficient analysis. It is believed that the BPT does not test a sufficient area for the study of asphaltic concrete surfaces. Also, the tire applications of the circular track used in this study in no way approximate the manner in which tire applications may be expected under actual traffic. It was found that asphaltic concrete specimens would disintegrate unless some form of abrasive was used between the tire and the specimens. When a large hard grit was used as an abrasive, the specimen surface was ground to flat condition. When a small soft grit was used, the matrix of the surface was contaminated and eventually a flat relatively smooth surface resulted. Because of these facts, it was impossible to develop an accurate study of the effects of aggregate attrition. It was decided to delete further studies of asphaltic concrete and develop a study of Portland Cement Concrete. In order to develop a greater range in BPT values, a larger rubber striker and a longer swing were used. Using the larger striker and longer swing increased the BPT values by a factor of about 1.7. By increasing the BPT values by the 1.7 factor, the range of BPT values was also increased.

5. Studies of Portland Cement Concrete

5.1 Experimental Program

The studies of Portland Cement Concrete were designed to determine the interrelationship between concrete finish type, excess surface water, curing method, curing environment, cement factor, and aggregate type and fineness modulus as measured by changes in BPT Values and texture depth under polishing with the Circular Track.

5.1.1 Coarse Aggregates

The concrete test specimens used in performing these tests were made utilizing one coarse aggregate type; a crushed limestone (S) obtained from San Antonio, Texas.

The physical properties of the coarse aggregate are shown in the Appendix in Table F-1 and the gradation is given in Table F-3.

5.1.2 Fine Aggregates

The concrete test specimens used in performing these tests were made utilizing four fine aggregate types: a siliceous gravel (G), obtained from Bryan, Texas; a crushed limestone (S), obtained from San Antonio, Texas; a combination or mixture (M) of the above siliceous gravel and crushed limestone; and a lightweight fine aggregate (LF), obtained from a burned clay processed by a rotary kiln in Texas.

Three of the fine aggregates (G, S, and M) were sized in two gradations: a fineness modulus of 2.8 (termed optimum), and a fineness modulus of 3.2 (termed high).

The physical properties of these fine aggregates are shown in the Appendix in Table F-1 and their gradations are given in Table F-3.

5.1.3 Cement Factor

Each batch was designed with a cement factor of either 4 1/2, 5, or 6 sacks of Type 1, Portland Cement per cubic yard of concrete.

5.1.4 Surface Finishes

After molding the test specimens, one of four surface finishes was applied to the wearing surface. The surface finishes are shown in Figure 13 and described in the Appendix in Table F-4.

5.1.5 Excess Surface Water

Excess surface water was applied to some of the test specimens after they had received their appropriate surface finish. The excess surface water was applied to the test specimens for 30 minutes with a spray nozzle which simulated a 1/2"/hr. rainfall rate.

5.1.6 Curing Method

After the appropriate surface finish was applied, either the test specimen was allowed to cure naturally with no evaporation retardant applied, or a white pigmented curing compound was sprayed on the test specimen as soon as the water sheen had disappeared from the surface.

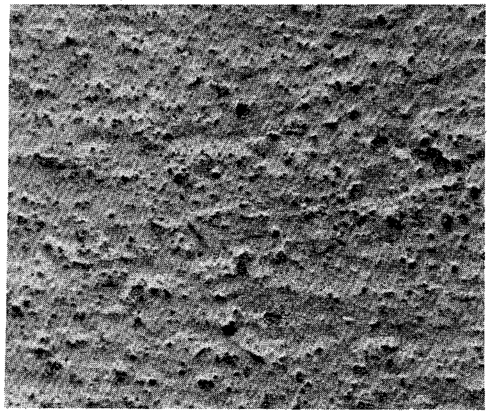
5.1.7 Curing Environment

As soon as the appropriate surface finish and curing method were applied to the test specimens, they were placed in the appropriate curing environment for the 28 day curing period. The constant environments required for the testing were accurately maintained and monitored during the testing periods. The environmental designations and variations are shown in the Appendix in Table F-2.

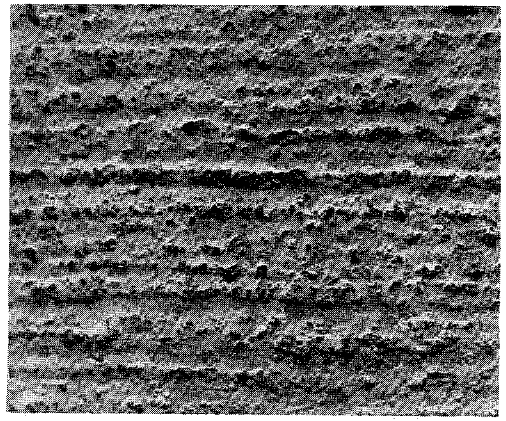
5.2 Specimen Preparation

The concrete for all batches was mixed in a six ft. portable rotary-drum mixer. Materials were stored inside the concrete laboratory so as to maintain a relatively constant batch temperature of 75^{o}F.

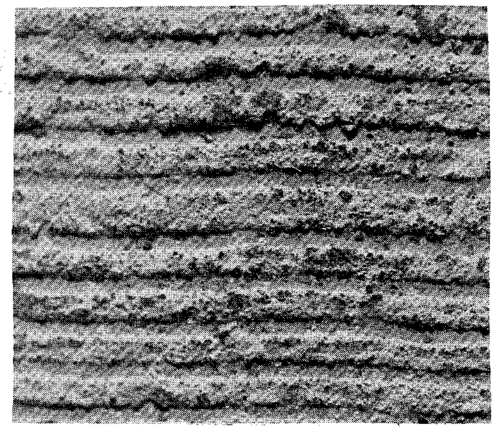
The mixes were designed using the absolute volume method, a water-cement ratio



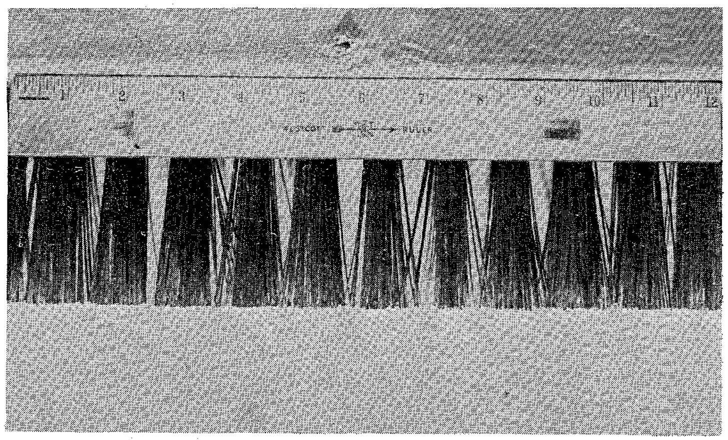
Burlap Finish



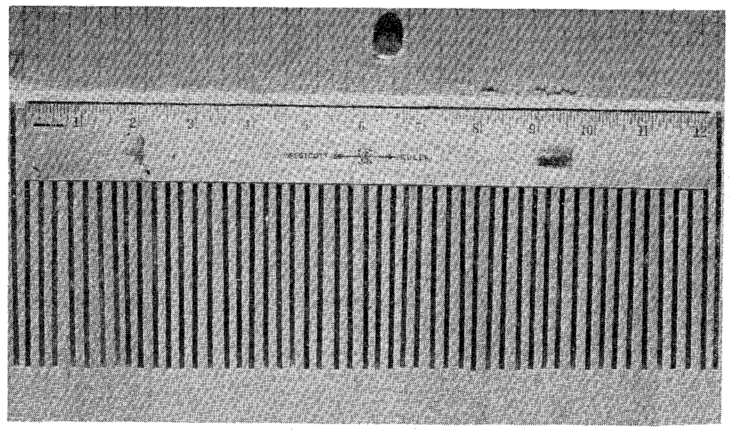
Broom Finish



Tines Finish
(Longitudinal & Transverse)



Plastic-Bristle Broom



Tines

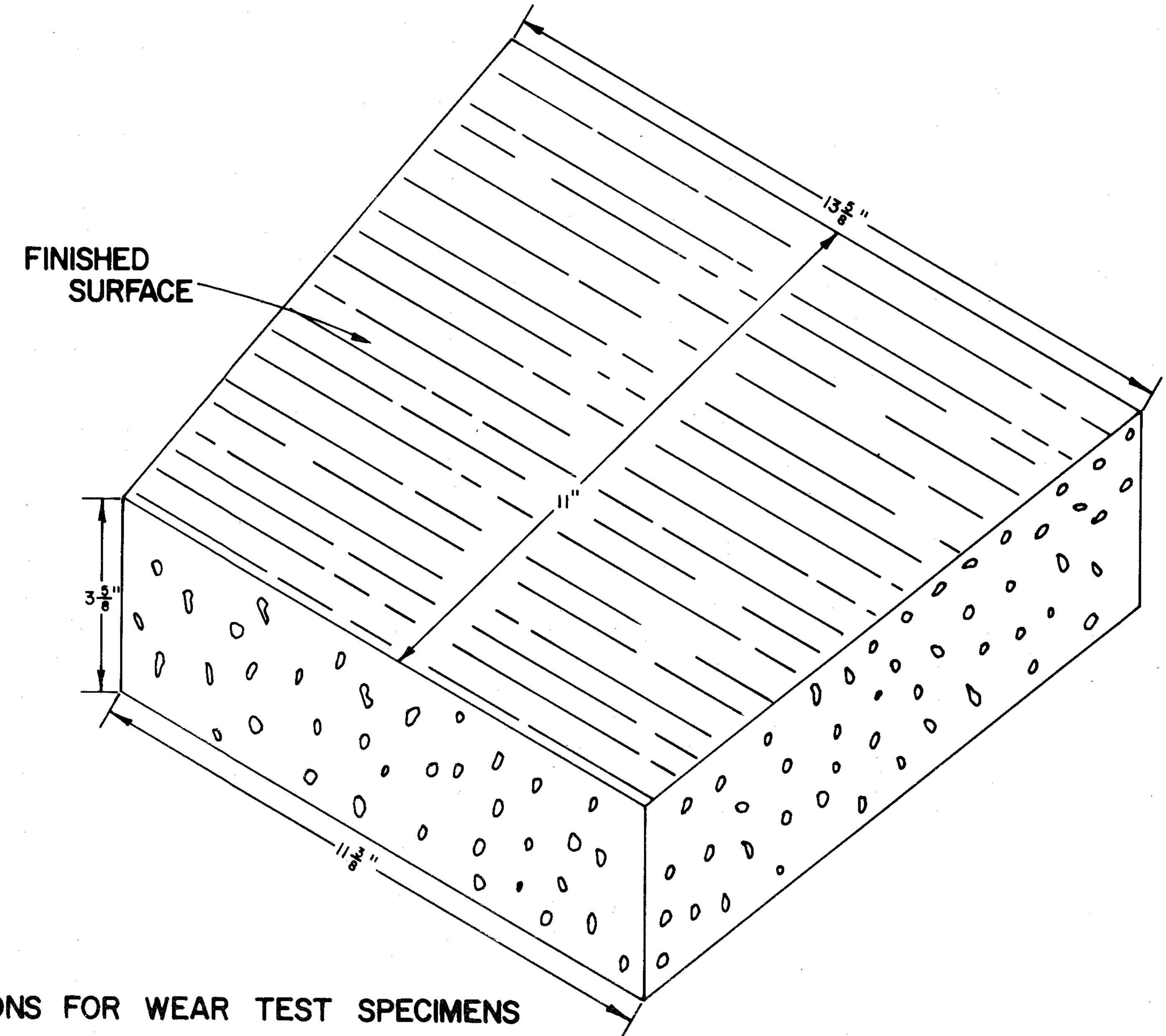
FIGURE 13 Surface Finishes and Finishing Equipment

(W/C) of 0.5, and an air content of 3 percent. A slump of 1 in. ± 1/2 in. was maintained throughout the batching of the test specimens. Due to the presence of free moisture in the aggregate used, the mixing water had to be altered slightly in some cases to maintain the desired slump. It became necessary, when the lightweight fine aggregate was used, to add a water and cement slurry to obtain the desired slump and not significantly alter the specified W/C ratio. The time lapse between the introduction of cement to the mix and the start of the final surface finishing operation was held as constant as practicable for all test specimens.

Prior to batching, a small "butter batch", consisting of identical materials as the batch, was placed in the mixer. This compensated for the materials which would normally stick in the mixer. After discarding the "butter batch", the coarse aggregate and part of the mixing water containing the air entrainment admixture was introduced. After approximately one minute of mixing, the cement and fine aggregate were added. The remaining mixing water was then added until the desired slump was obtained. The mixing continued for approximately five minutes after the cement was added.

After the mixing was completed, the slump test (ASTM C143-66), unit weight (ASTM C139-63), and air content (ASTM C231-68) were determined. The concrete mix data are given in the Appendix in Table F-5.

At the completion of these control tests, the concrete was then taken to the appropriate environmental room and placed in the forms. The concrete for each test specimen was placed in the forms in two lifts with internal vibration applied to each lift. The size and shape of the test specimen forms are shown in Figure 14. An electric powered 1 3/8 in. square-head spud-type concrete vibrator was used at a constant speed of 8000 vpm (in air), regulated by an amplitude control unit. Approximately twenty seconds of internal vibration was applied to each lift. The test specimens were then struck-off flush with a vibratory screed in order to facil-



DIMENSIONS FOR WEAR TEST SPECIMENS
FIGURE 14

itate the finishing operation which followed; the designated curing method was then performed on each specimen. After 22 to 26 hours, the forms were removed and the specimens were labeled and left in their designated environment for the 28 day curing period.

Following the curing period, it was necessary to place some of the specimens in the freezing room (-8°F) until they were wear-tested. The freezing was accomplished to suspend continued hydration. Impact Hammer readings taken at 28 days and again prior to wear-testing indicated no appreciable change in the strength of the specimens while in the frozen state.

5.3 Data Collection

5.3.1 Putty Impression Test

The Silicone Putty Impression Test was performed on the wearing surface of each test specimen at the end of the 28 day curing period and at the completion of wear testing. Initial and final average texture depth values for each test specimen are shown in Table IV.

5.3.2 British Portable Skid Resistance Test

British Portable Tester (BPT) values were determined for the wearing surface of each test specimen according to ASTM E303-66T at the end of the 28 day curing period prior to wear testing and at 1250, 2500, 3500, 5000, 7500, 10,000, 15,000, 20,000, 30,000, 40,000, 60,000, 75,000, and 85,000 revolutions of the test tires. The initial BPT values and the CTPV are shown in Table V.

5.3.3 Compressive Strength Test

Compressive strength tests were performed on three 6 in. x 12 in. concrete cylinders which were made from each batch of concrete. The compressive strength testing was performed at the end of the 28 day curing period according to ASTM C39, and the results of these tests are shown in the Appendix in Table F-5.

TABLE IV Average Texture Depth (in^3/in^2 or in)

Test Set	Batch Code[a]	Burlap Finish				Broom Finish				Long. Tines Finish				Transverse Tines Finish			
		CN[b]		CW[c]		CN[b]		CW[c]		CN[b]		CW[c]		CN[b]		CW[c]	
		Init.	Final	Init.	Final	Init.	Final	Init.	Final	Init.	Final	Init.	Final	Init.	Final	Init.	Final
1	G	.036	.019	.047	.039	.045	.033	.055	.029	.069	.061	.050	.038	–	–	–	–
1	H	.036	.019	.032	.023	.049	.033	.052	.034	.053	.032	.060	.046	–	–	–	–
1	I	.041	.017	.026	.024	.036	.023	.056	.032	.052	.044	.042	.032	–	–	–	–
1	D	.046	.035	–	–	.046	.044	–	–	.058	.041	–	–	.031	.022	–	–
1	P	.029	.019	–	–	.033	.024	–	–	.032	.022	–	–	.035	.026	–	–
2	A	.026	.018	–	–	.052	.033	–	–	.067	.054	–	–	.063	.052	–	–
2	C	.029	.021	–	–	.049	.032	–	–	.047	.039	–	–	.045	.045	–	–
2	B	.022	.015	–	–	.043	.034	–	–	.042	.033	–	–	–	–	–	–
2	J	.015	.007	.020	.016	.038	.024	.036	.014	.054	.033	.042	.033	–	–	–	–
2	K	.031	.018	.030	.010	.044	.028	.046	.030	.040	.032	.044	.035	–	–	–	–
3	L	.022	.019	.018	.013	.041	.033	.047	.038	.052	.044	.052	.044	–	–	–	–
3	M	.028	.020	–	–	.084	.067	–	–	.055	.045	.045	.038	–	–	–	–
3	N	.025	.020	–	–	.070	.058	–	–	–	–	–	–	.090	.073	.056	.044
3	E	.035	.026	.036	.026	.056	.045	–	–	.014	.053	–	–	–	–	–	–
3	F	.017	.009	.018	.013	.060	.049	–	–	–	–	–	–	.039	.032	.063	.046

[a]See Table F-5 for explanation

[b]No excess surface water

[c]Excess surface water

TABLE V CTPV - For Portland Cement Concrete

Test Set	Batch Code[a]	Burlap Finish				Broom Finish				Long. Tines Finish				Transverse Tines Finish			
		CN[b]		CW[c]		CN[b]		CW[c]		CN[b]		CW[c]		CN[b]		CW[c]	
		Init.	CTPV	Init.	CTPV	Init.	CTPV	Init.	CTPV	Init.	CTPV	Init.	CTPV	Init.	CTPV	Init.	CTPV
1	G	72	54	72	56	79	59	71	58	76	59	80	60	-	-	-	-
1	H	75	59	75	56	68	59	77	60	77	58	64	60	-	-	-	-
1	I	65	51	76	55	77	60	74	58	83	62	74	57	-	-	-	-
1	D	72	56	-	-	85	62	-	-	66	54	-	-	76	62	-	-
1	P	76	55	-	-	84	58	-	-	73	56	-	-	79	58	-	-
2	A	76	42	-	-	86	50	-	-	70	53	-	-	84	55	-	-
2	C	74	57	-	-	76	56	-	-	64	46	-	-	78	55	-	-
2	B	71	50	-	-	81	63	-	-	64	49	-	-	-	-	-	-
2	J	73	48	73	51	85	63	86	63	76	53	79	56	-	-	-	-
2	K	76	59	76	59	76	60	81	61	73	58	78	63	-	-	-	-
3	L	76	53	75	55	78	57	80	61	73	54	78	59	-	-	-	-
3	M	75	51	-	-	81	65	-	-	71	56	74	55	-	-	-	-
3	N	71	50	-	-	81	65	-	-	-	-	-	-	86	71	87	68
3	E	75	52	76	52	80	64	-	-	76	58	-	-	-	-	-	-
3	F	70	52	75	53	82	66	-	-	-	-	-	-	78	65	85	65

[a]See Table F-5 for explanation

[b]No excess surface water applied

[c]Excess surface water applied

5.3.4 Photographs

Once the test specimens were placed on the track, initial BPT readings were taken in two areas on all specimens and selected specimens were photographed. After 100, 500, 1000, 1250, 1680, 2500, 3360, 5000, 6720, 7500, 10,000, 10,080, 15,000, 20,000, 30,000, 40,000, 60,000, 75,000, and 85,000 revolutions, BPT readings and pictures were taken. The test specimens were then removed from the track, inspected, and final Impact Hammer readings and putty impressions were taken.

5.4 Test Site

The test specimens were wear-tested in three sets. Each set consisted of five batches or thirty test specimens. Ninety test specimens were tested in all.

Each batch was designed with a unique set of batch variables to determine the effects of excess surface water, fineness modulus, curing environment, curing method, fine aggregate type, surface finish, and cement factor on the surface characteristics of the test specimens after accelerated wear.

The test specimens were wear-tested with a slick tire (no abrasive or water) and only the outside portion of the test specimens were wear-tested. The variable involved in the design of these batches is shown in the Appendix in Table F-6.

5.5 Results

The results of the accelerated wear testing were measured in terms of the final average texture depth (ATD) in inches, the change in texture depth (ΔATD) in inches, and the CTPV. These values were graphed to compare the effects of the finish types and the effects of the test variables on the surface characteristics of the test specimens.

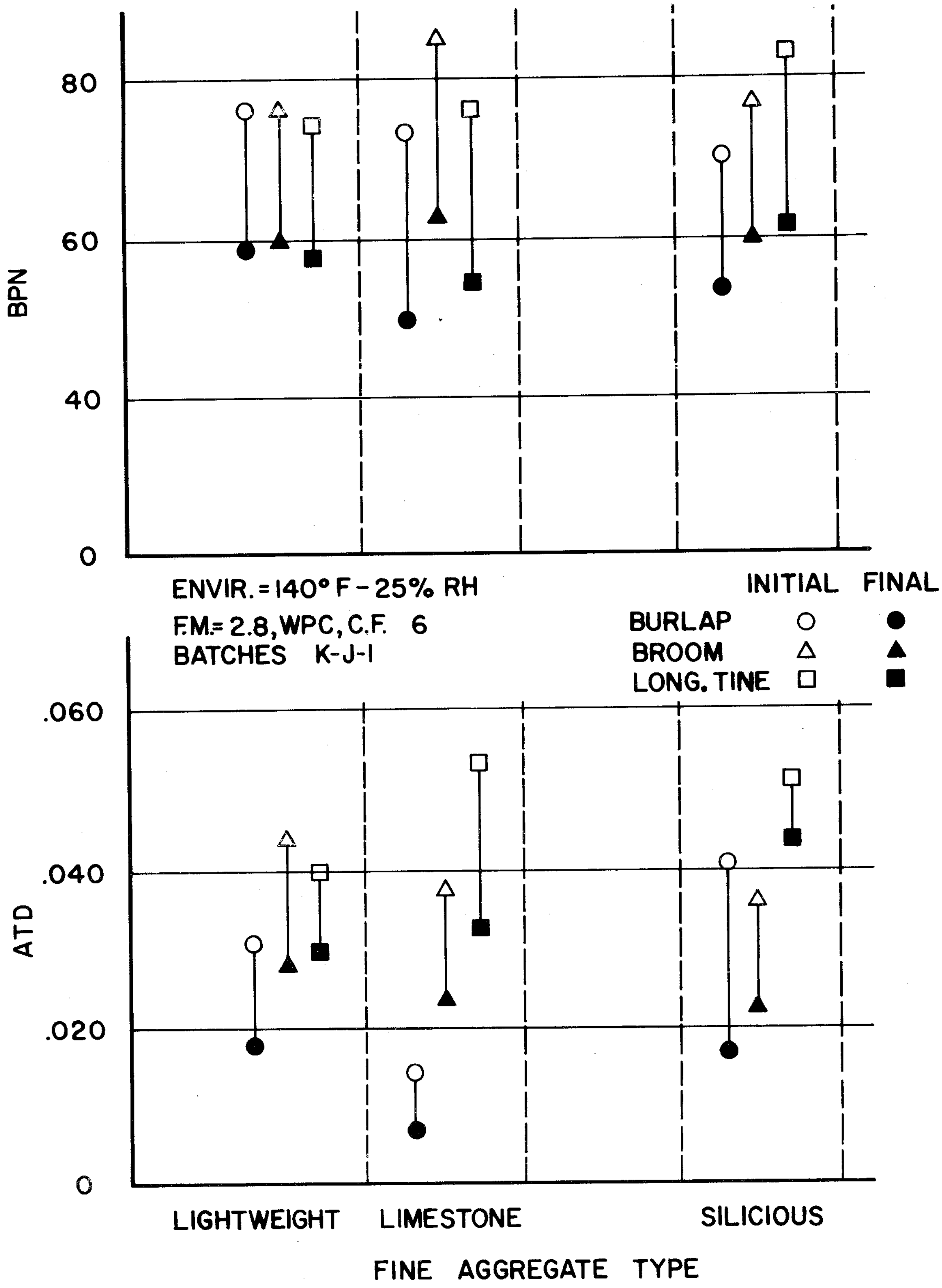
The graphs, Figures 15 to 20, show that generally the higher the initial texture depth of the specimen, the higher the final texture depth of the specimen; i.e., no one texture wore more than any other. A plot of Initial and Final Texture may be found in Figure 21. The effects of the batch variables (cement factor, aggregate type, and curing environment) on surface wear characteristics seemed to be negligible. There were no trends established.

5.6 Discussion

These results were, in one sense, disappointing as no distinct relationships were found between surface wear and any of the variables investigated. These results could be interpreted in three ways. First, the methods used to measure surface wear characteristics (British Portable Tester and Putty Impression) did not truly reflect the change in the surface texture and skid resistance of a concrete surface when subjected to wear. There is justification for this interpretation in that BPT values do not relate to actual skid numbers at 40 mph and that the Putty Impression test is conducted over a relatively small area. However, both tests have been used successfully and it is our opinion that this interpretation may not be valid.

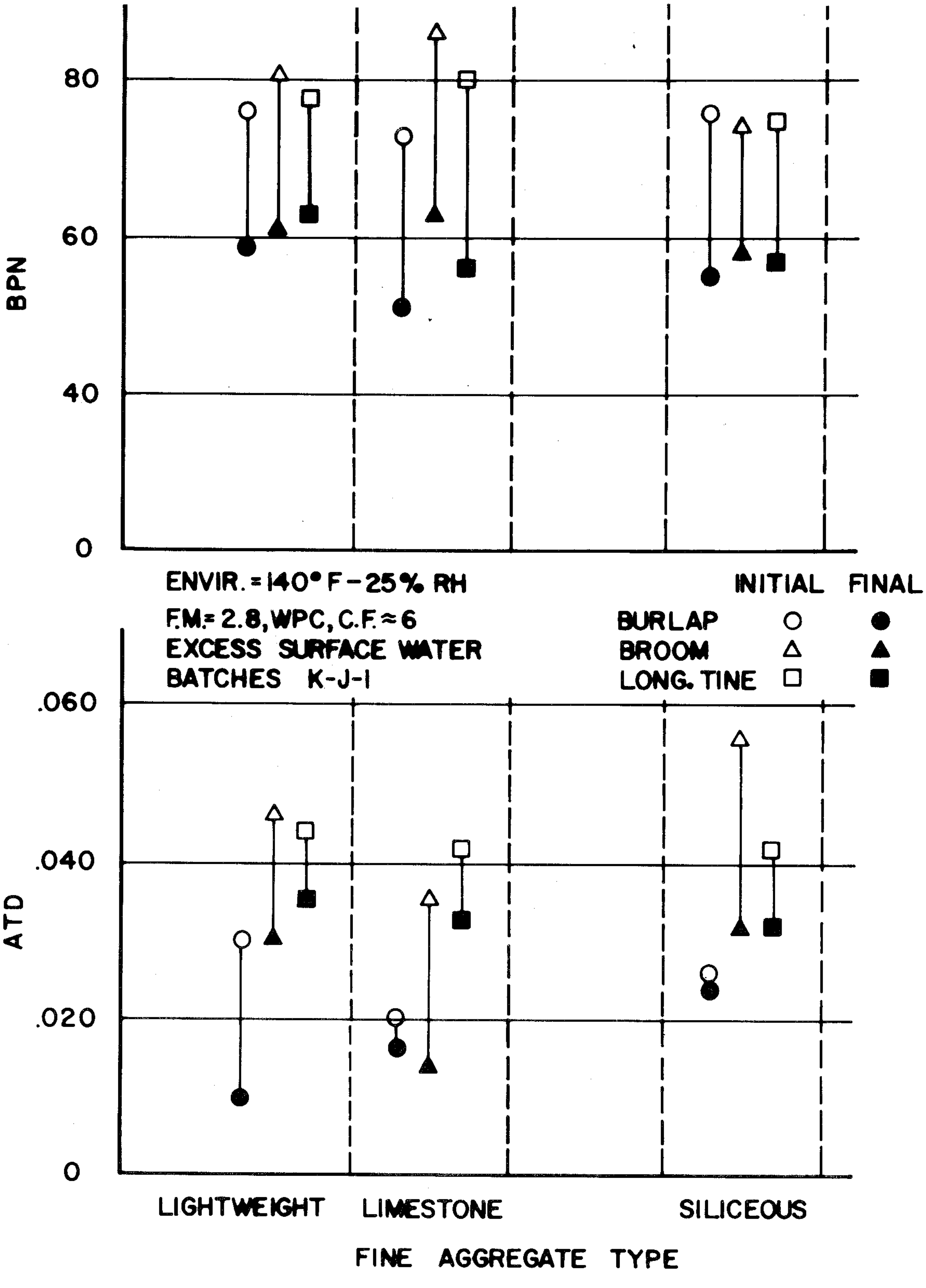
The second interpretation is that the Circular Test Track did not realistically simulate actual wear of a pavement in service for a number of years. Examination of the specimen surfaces reveals that the wear does not look at all like the wear exhibited on real pavements; this interpretation may indeed by partially, or wholly, correct. If so, the results cannot be translated into actual practice.

The third interpretation is that the variables involved had little or no effect on the wearability and skid resistance of the concrete surfaces. If this were the case, then deeper textures would certainly be called for as they would result in better skid resistances for just as long a period of time as the burlap drag. Furthermore, there would be little or no need to insure that high insoluble residue fine aggregates were used or to insure that the pavement was protected against excess surface water added during construction. However, this interpretation is doubtful because of the questionable validity of the wear procedure and the measurements used. Furthermore, in the final analysis, such an interpretation does not appear logical in the face of existing evidence concerning the performance of concrete pavements in service. (8, 9, 10)



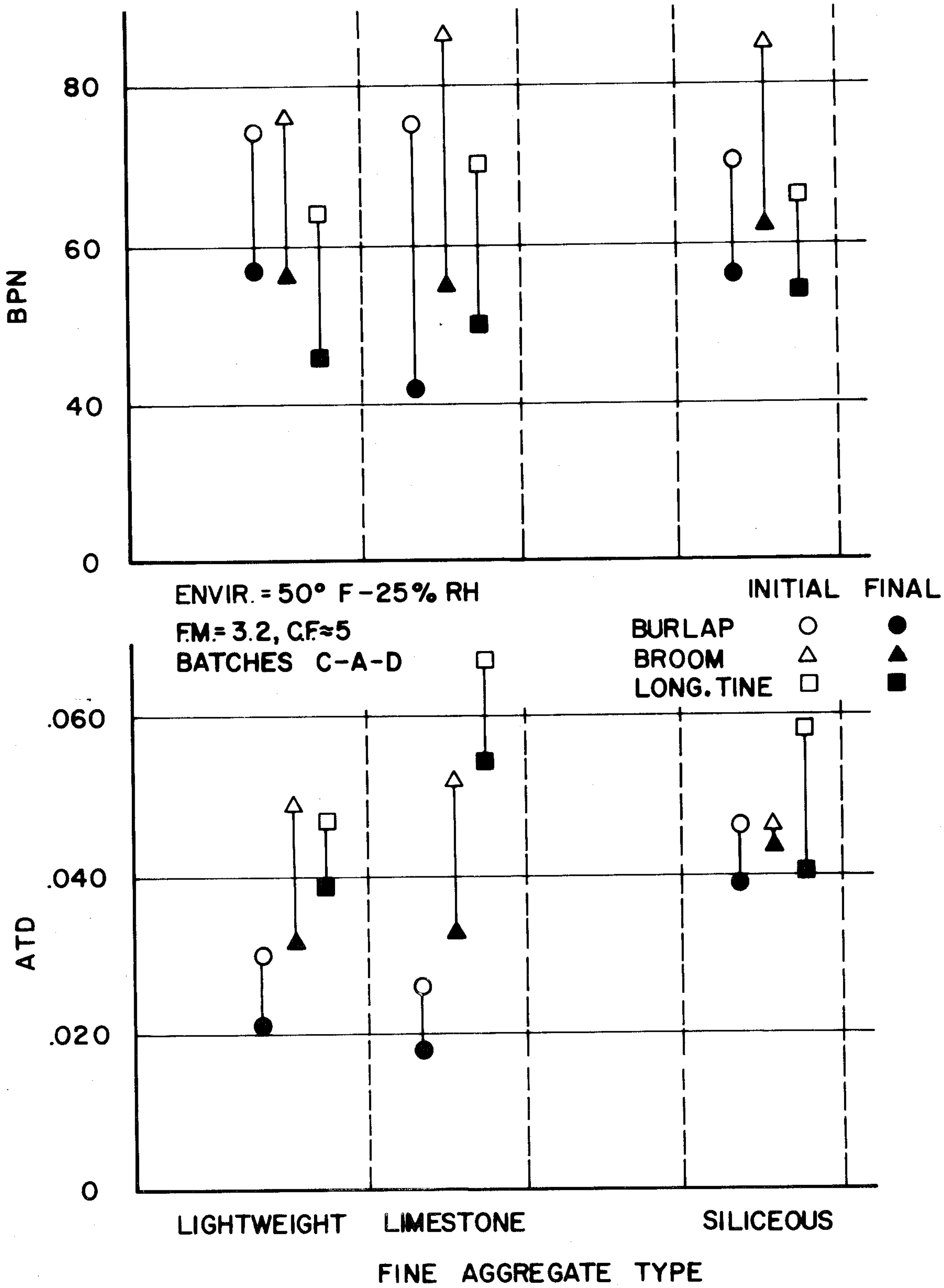
TEST RESULTS FOR BATCHES K-J-1
NO EXCESS SURFACE WATER

FIGURE 15



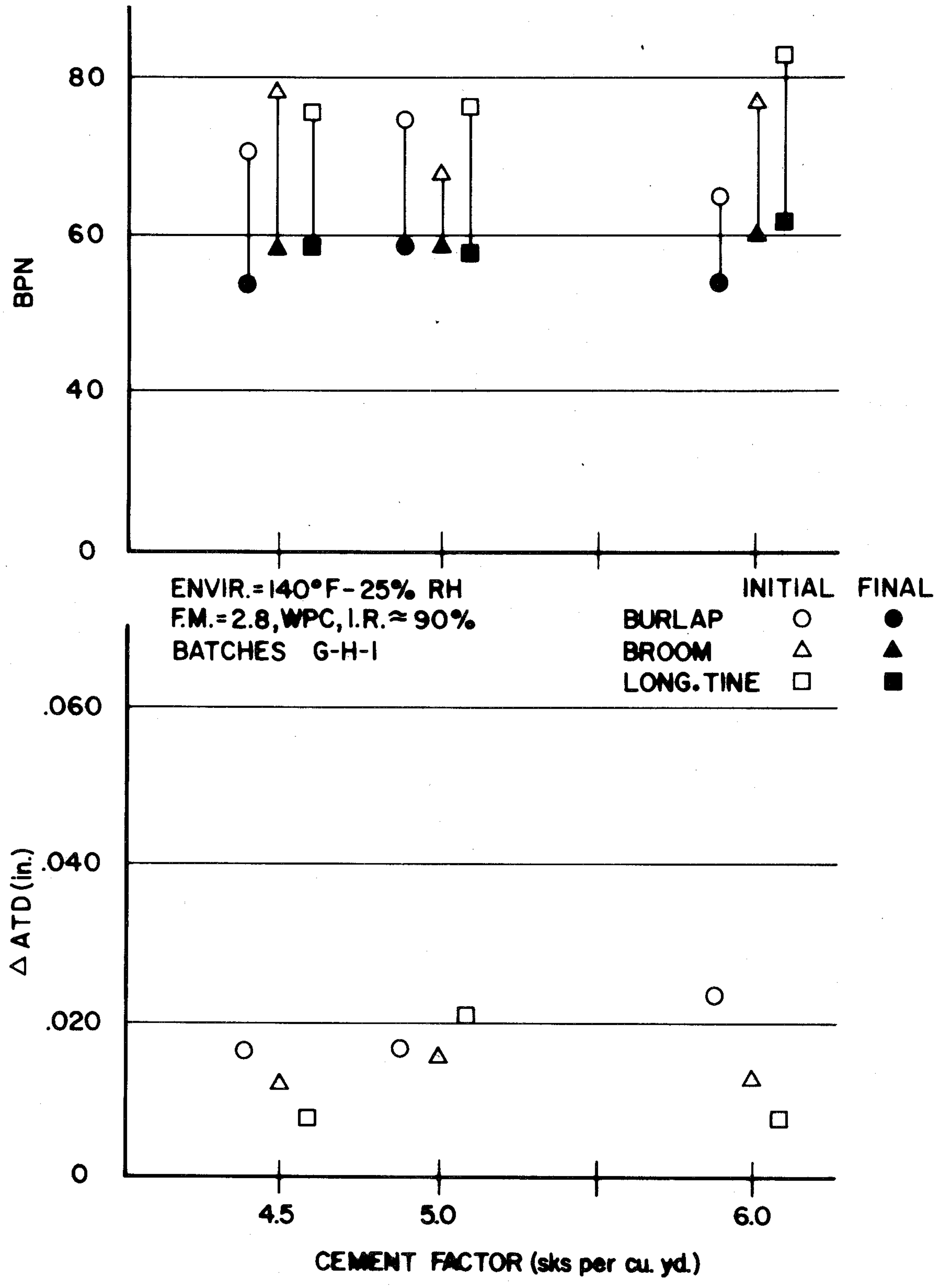
TEST RESULTS FOR BATCHES K-J-1
EXCESS SURFACE WATER

FIGURE 16



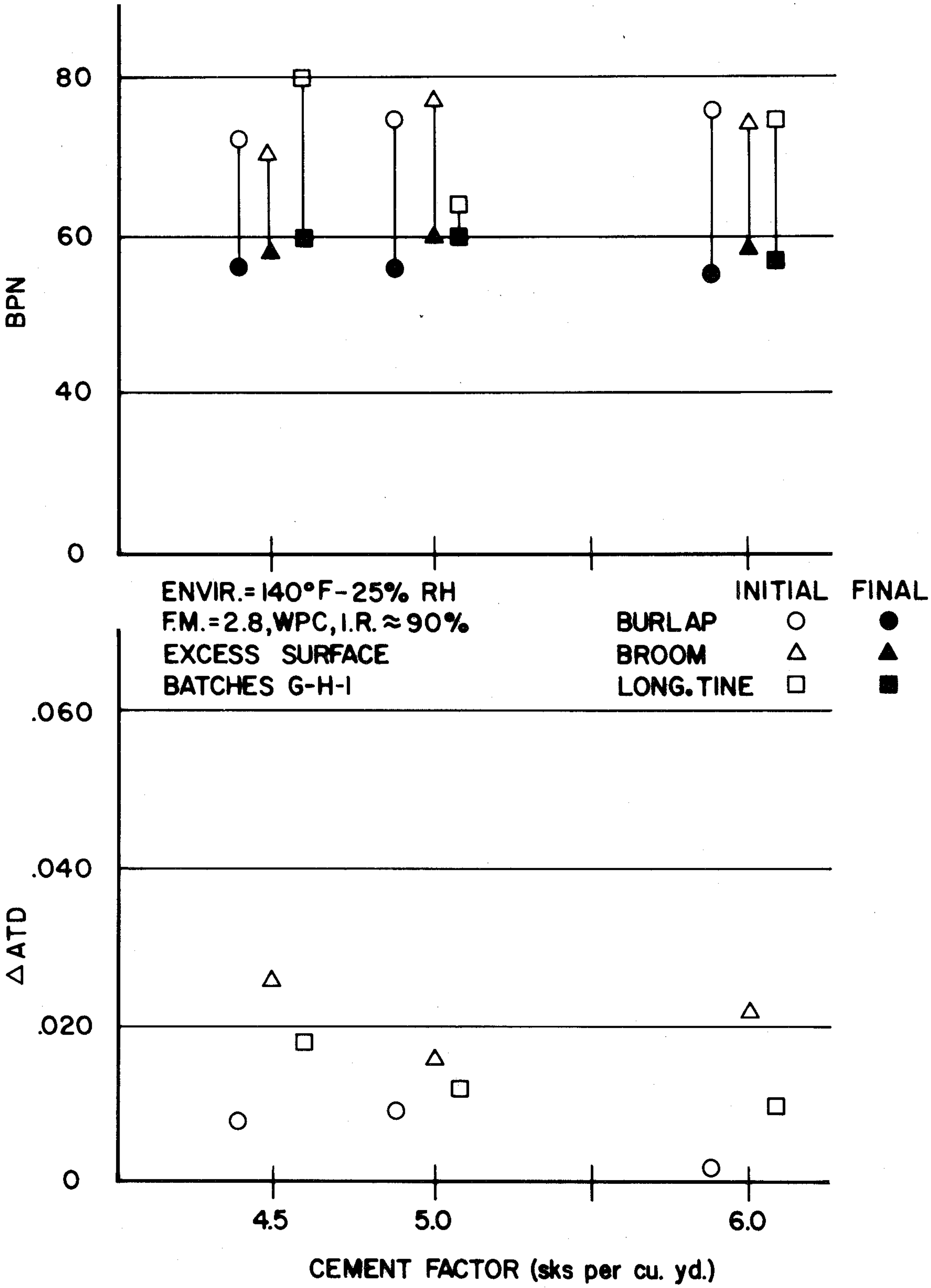
TEST RESULTS FOR BATCHES C-A-D

FIGURE 17



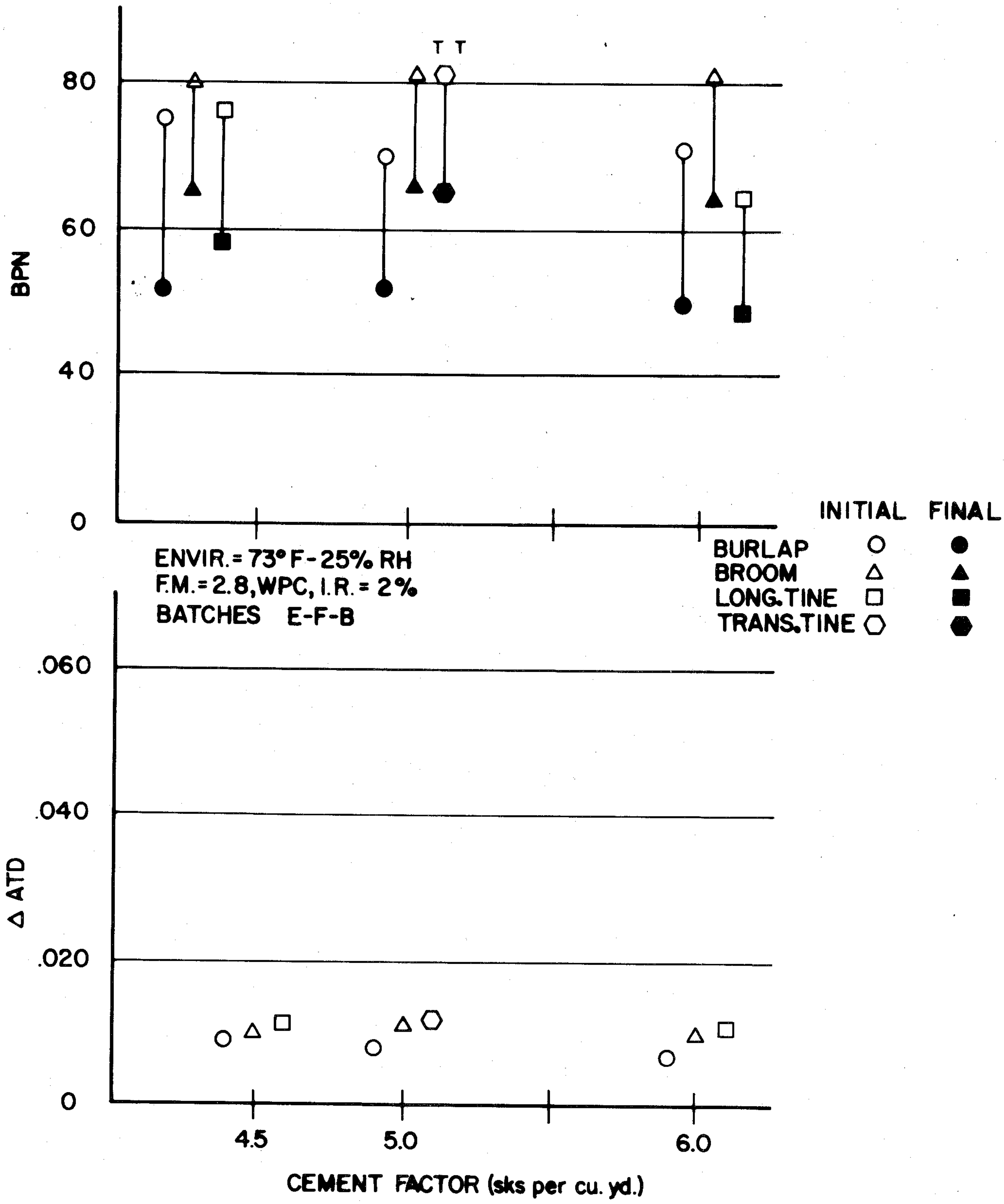
TEST RESULTS FOR BATCHES G-H-I
NO EXCESS SURFACE WATER

FIGURE 18



TEST RESULTS FOR BATCHES G-H-I
EXCESS SURFACE WATER

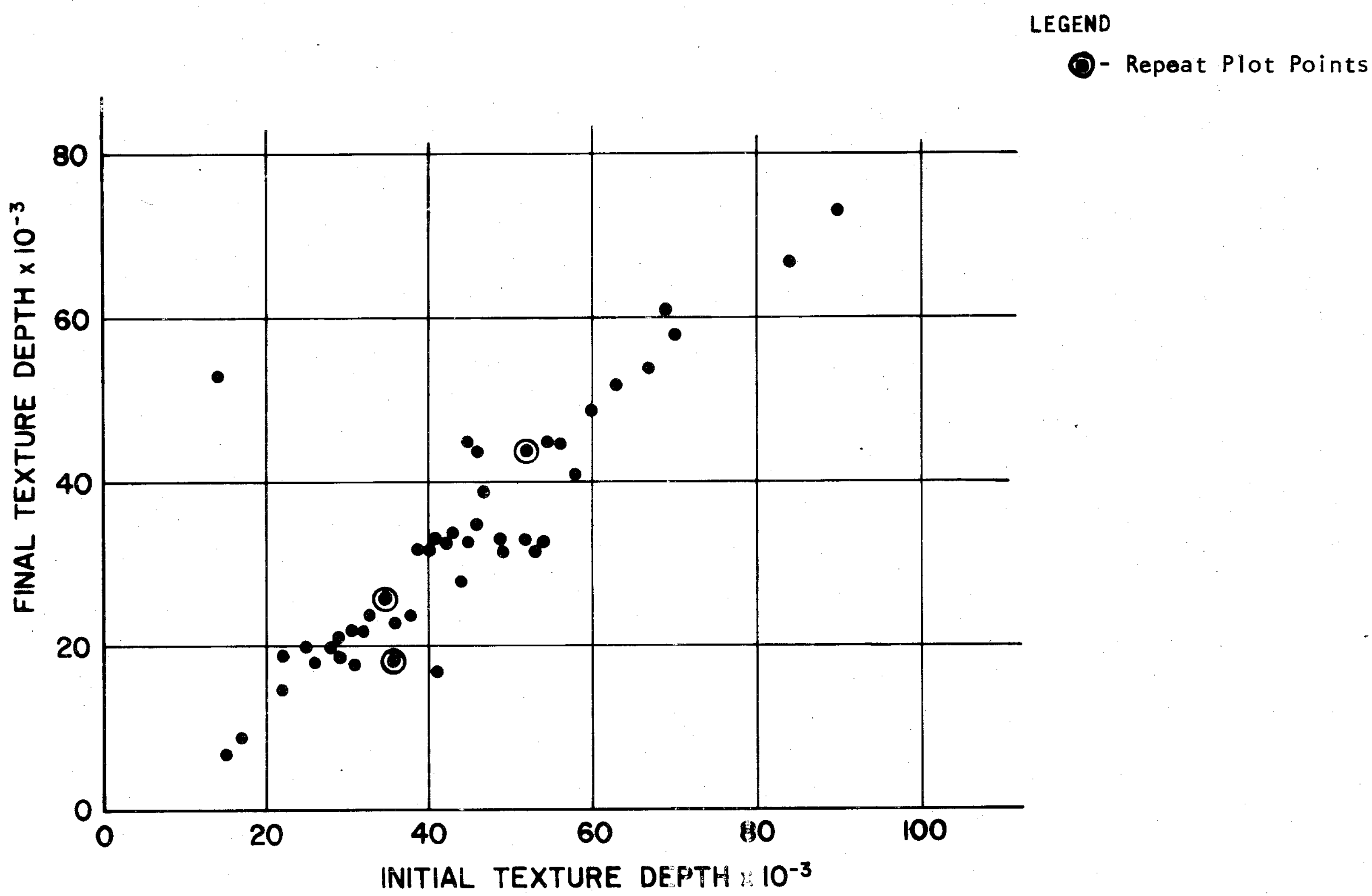
FIGURE 19



TEST RESULTS FOR BATCHES E-F-B

FIGURE 20

PORTLAND CEMENT CONCRETE



COMPARISON OF INITIAL AND FINAL TEXTURE

FIGURE 21

6. Conclusions and Recommendations

6.1 Conclusions

As a result of this study, the following has been concluded:

a. Aggregate material used in the pavement surface, when subjected to laboratory tests, does in fact have definite polishing characteristics.

b. The coarse aggregate used in bituminous pavement surfaces can be ordered or ranked as to skid resistance properties with the use of the British Wheel Test.

c. Laboratory tests indicate a linear (percentage) relationship between the friction properties of aggregates when they are blended in volumetric percentages including the fine aggregate. Caution should be used in planning blended asphaltic concrete mixes for field use based on the results of this study since field polish is believed to be much different than that produced by the circular track.

d. The circular track and related test equipment used in this study did not realistically simulate actual polish of a pavement in service nor produce a range in test results sufficient to analyze the polish characteristics of asphaltic concrete or Portland Cement Concrete surfaces.

6.2 Recommendations

The following recommendations are offered:

1. No further polish tests should be performed using the circular track.

2. Further studies of polish characteristics of asphaltic concretes and Portland Cement Concretes should be accomplished utilizing field test sections rather than laboratory apparatus, particularly since the time differential between the two methods in obtaining results is not great when using present laboratory test equipment.

3. Use of the British Wheel Test as a method to specify skid resistant coarse aggregate for bituminous pavement surfaces should be continued.

4. Continued research effort should be given to developing the "Asphaltic Concrete Mix Design Technique For Checking Skid Resistance." Particular emphasis should be given toward verifying or revising the technique using field tests with a skid test unit.

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Appendix A

Experiments of Tire Position Relative to the Axle Axis

In order to determine the correct position of the tow and cant of the tire-wheel assembly, studies were performed using sandpaper. The surface of the track had received a smooth finish. A powder was sprinkled on the surface to provide a relatively frictionless contact area and an 8½" x 11" sheet of sandpaper was placed on the powdered area with the sanded side up. The tire attached to the completed axle assembly was then rolled across the sandpaper at a slow velocity. The sandpaper movement was observed closely and measurements of the movement were made in the radial and circumferential directions. Various positions of tow and cant were studied. Observations of the cant revealed:

1. If the top of the tire was moved further from the center point than the bottom of the tire, the sandpaper moved toward the center point.

2. Opposite movement of the sandpaper was detected if the top of the tire was closer to the center point than the bottom of the tire.

3. Radial movement due to cant was slight and, because of a twisting motion of the sandpaper, difficult to measure.

In considering the tow of the tire, the following observations were made:

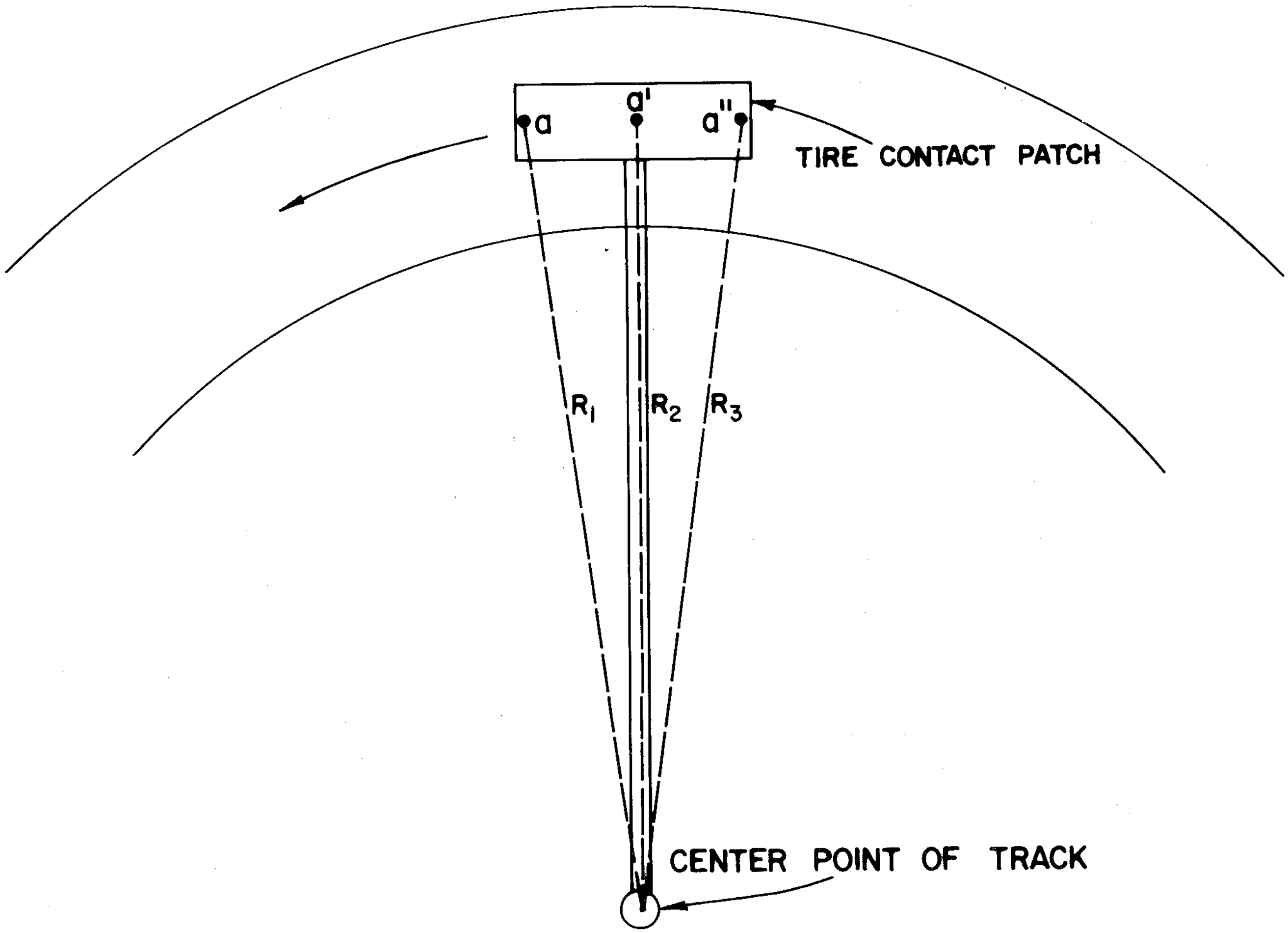
1. When the tow was adjusted such that the leading edge of the tire was at a greater radius than the trailing edge (towed out), the sandpaper moved toward the centerpoint.

2. When the leading edge of the tire was towed in, the sandpaper moved from the center point.

3. In every case after tire passage, the sandpaper was moved from its original position and, during tire passage, a twisting motion of the sandpaper was observed which was believed to be due to tire squirm.

4. As the leading edge of the tire made contact with the sandpaper, little movement was noted, but as the trailing edge of the tire moved from the sandpaper the sandpaper moved rapidly from the tire.

Basically, Figure A-1 shows the theory developed from the experiment. In Figure A-1, assume the tire is set in a plane perpendicular to the axis of the axle. As the



STUDIES OF TIRE TOW AND CANT SETTING

FIGURE A-1

tire rolls counter clockwise around the track, the leading edge of the tire makes contact with a point on a specimen at point "a". The radius at point "a" is R_1. As the tire continues to roll around the track, the tire moves to position "a'". The radius at point "a'" is R_2 which is shorter in length than R_1. This means the tire has scrubbed across the surface from point "a" to point "a'", a distance equal to $R_1 - R_2$. Then as the tire continues to roll around the track, the tire is again forced form point "a'" to point "a''". The radius is forced from R_2 to R_3, with R_3 being greater in length than R_2. Again the tire has scrubbed back a distance equal to $R_3 - R_2$. If the tire has been positioned perpendicular to the axle axis, R_1 is equal to R_3.

If the tire is towed out, R_1 will be greater than R_2 and R_2 will be greater than R_3. However, when compared with the tire positioned perpendicular to the axis, the total scrubbing movement would be approximately the same. That is, the towed out tire would move from "a" to "a''" with the movement being toward the center point of the track. With the tire positioned perpendicular to the axis, the scrubbing movement would be from point "a", inward to point "a'", then out again to point "a''". With the tire towed in, the total movement would again be the same, but the scrubbing movement would be from the center point of the track. Because of the above analysis, a decision was made to position the tire in a plane perpendicular to the axis of the axle for testing with the circular track. However, it should be noted at this point that the above experiment shows the greatest fallacy of the Circular Track - a Circular Track can in no way duplicate the general tire polish expected on a pavement surface.

Appendix B

Preparation of Asphaltic Concrete Test Specimens

Initially, it was desired to test both laboratory prepared specimens and specimens obtained from existing pavement surfaces. However, specimens obtained from existing pavements were not included in any phase of the subject project.

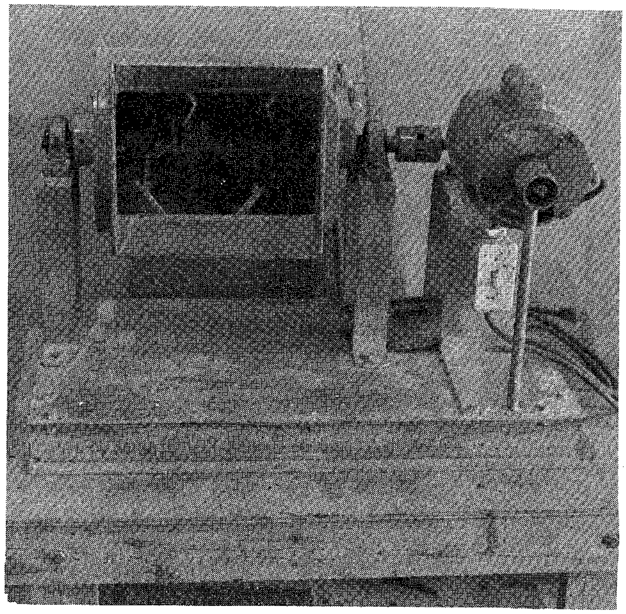
After designing an asphaltic concrete mix, the correct proportions of the materials were weighed and heated. The asphalt was added to the aggregate and the material was mixed in a small pugmill shown in Figure B-1. The pugmill was fabricated for the subject project and the size was such that the pugmill would accept a charge sufficient to prepare one specimen for the Circular Track. After mixing, the material was again reheated and placed in a preheated mold similar to that shown in Figure B-2. The specimen was immediately compacted, allowed to cool, and removed from the mold. The individually prepared specimens were placed in specimen receptacles and the receptacles were placed on the track. The specimen receptacles were bolted to the track after being shimmed to the proper height when necessary.

The specimen shape was trapezoidal with the following dimensions:

Height = 11.00 inches
Long Base = 13.71 inches
Short Base = 11.40 inches

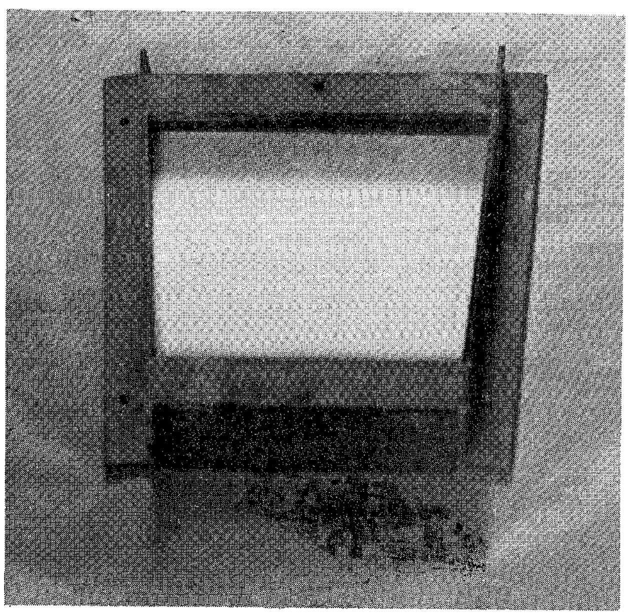
The base length at the center of the height was 12.55 inches. When placed end to end, a continuous ring was formed which included 30 specimens.

Both the compaction mold and the specimen receptacles conformed to the specimen dimensions. Also, both the mold and receptacle were fabricated from ¼ inch steel plate to which two lengths of 1¼-inch angle iron had been attached. The lengths of angle iron had dimensions equivalent to the Long and Short Base dimensions given above. However, the molds also contained two additional lengths of 1¼-inch angle



Pugmill Used in Mixing Asphaltic Concrete Specimens

Figure B-1



Specimen Compaction Mold

Figure B-2

iron butted against each end of the base pieces forming an enclosed container. The mold was, therefore, a trapezoidal container 1¼-inches in depth with a ¼ inch steel plate as a base and open at the top. The specimen receptacle was similar to the mold with the exception of the end angle members. The receptacles were fabricated such that the asphaltic concrete specimens butted together with no steel member between. This allowed the tire to contact only the specimen (S).

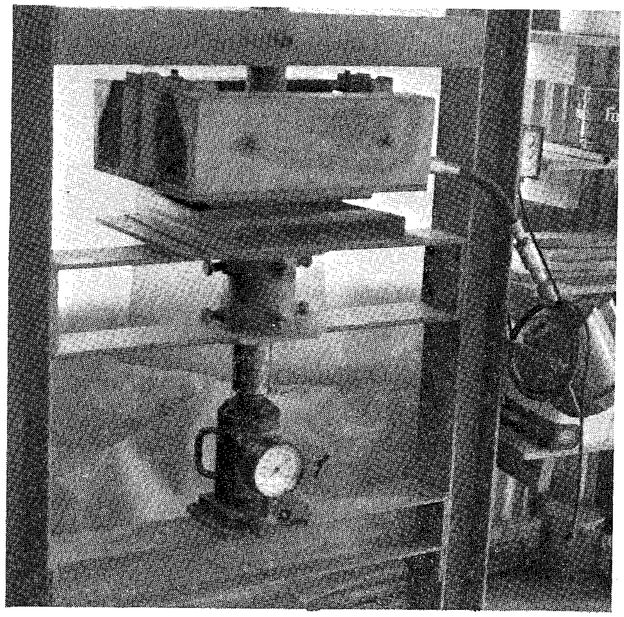
The compaction equipment is shown in Figures B-3 and B-4. Note the mold may be placed on a horizonal plate and a vertical force may be applied by a hydraulic jack which lifts the specimen to a platen above the mold. The platen conforms to the shape and dimensions of the specimen with the exception that the dimensions are undersized by 1/16-inch on each side. A vibratory apparatus was attached to the platen which allowed a circular movement in the horizontal direction and an oscillating vertical movement. An electrical heating element was fabricated which was placed between the upper and lower platen to preheat the platen faces. The compaction procedure adopted was as follows:

1. The reheated asphaltic concrete material was placed in a preheated mold in such a manner as to minimize voids around the edges and to assure mix uniformity within the mold.

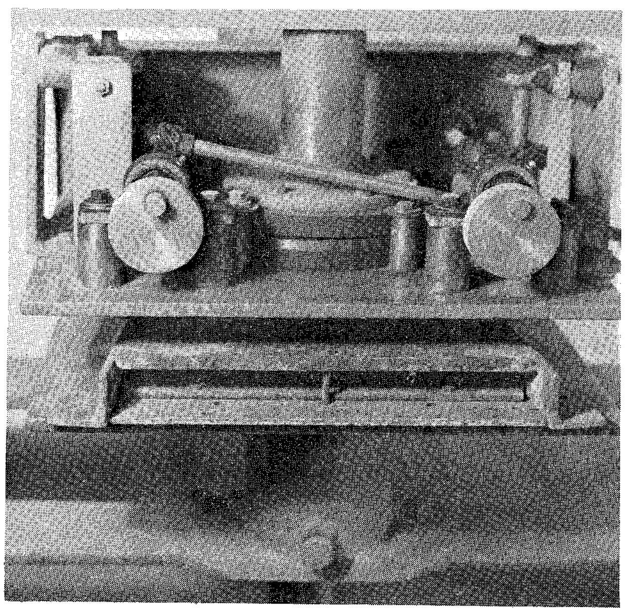
2. The mold was placed on the lower platen and moved vertically until the mix was in contact with the upper platen.

3. A vertical force of 3000 lb (22 psi) was applied to the specimen and the vibration was initiated. The vibration duration was 30 seconds.

4. A load of 30,000 lbs (217 psi) was then applied to the specimen with no vibration.



Speciman Compaction Unit
Figure B-3



Vertical and Horizontal Gyratory Feature
Figure B-4

Appendix C

Studies of Density Resulting From the Compaction Unit

Experiments were performed to determine the effectiveness and in part the design of the specimen compaction apparatus. After consulting with the Department's Materials and Test Division personnel, a decision was made to duplicate the Hveem compaction unit as closely as possible. That is, a gyratory motion was to be used combined with a small vertical gyratory load and finally a large vertical leveling load. It should be noted that the gyration mentioned as follows is not the gyration expected in preparing Hveem specimens. However, the object is similar - that of rolling or moving the aggregate as the compactive force is applied in an effort to allow the aggregate to seek void spaces not previously occupied. The specimen compaction unit for asphaltic concrete used in this project is described in Appendix B - Preparation of Asphaltic Concrete Test Specimens. The experimentation was divided into two parts as follows:

1. Studies to determine the effectiveness of various loads, gyratory conditions, and gyratory time periods.
2. Studies to determine the effectiveness of obtaining density in different areas of the specimen.

Studies of the effectiveness of loads, gyratory conditions, and gyratory time periods can be shown in factorial form in Figure C-1. The leveling loads used were 20,000 pounds and 30,000 pounds. Where gyration was used, the small initial load applied immediately prior to and during gyration was ten percent of the leveling load or 2000 pounds for the 20,000 pound leveling load and 3000 pounds for the larger load. The load types were:

1. A direct leveling load with no gyration.
2. A gyratory load with only vertical oscillation. The eccentric cams producing vertical oscillation were employed but the horizontal cams producing a horizonal circular movement were disengaged. The leveling load was applied after gyration.

3. A gyratory load with both vertical and horizontal eccentrics used. Again the leveling load was applied after gyration.

The gyratory time periods were 15 and 30 seconds when gyration was used. Two specimens were prepared for each combination as indicated by the A and B in Figure C-1. A series of Hveem (2 inch height - 4 inch diameter) specimens were prepared from each mix which formed the basis of comparison. The average density of the Hveem specimens was termed "laboratory" density. The density of each combination studied was divided by the laboratory density and reported as "percent laboratory density." The asphaltic concrete was composed of a river gravel, limestone screenings, field sand, and an AC-10 asphalt. The mix design and mixing weights were held constant for all specimens in the above study. The density, as noted above, may be defined as the unit weight of the specimen with voids divided by the theoretical unit weight of the specimen without voids.

As an additional phase of the experiment, specimens were prepared using lightweight coarse aggregate, limestone screenings, field sand, and AC-10 asphalt. The procedures described previously were used in specimen preparation. The results of the tests are shown in Figure C-2. One method of analysis is shown in Figure C-3. Increased density is apparently obtained with increased leveling loads; however, gyration also increases the density. Because loss in temperature was expected during the gyration process, a maximum gyration time of 30 seconds was selected. The larger leveling loads and longer gyration times appeared to produce higher and more consistent density. The average "% Laboratory Density" was expected to be about 96 for natural aggregates and about 95 for synthetic aggregates.

The second part of the experiment was to determine the consistency of density throughout the specimens. For this study, the river gravel specimens mentioned above were sawed into four equal parts (that is quarters) and the density was obtained for each of the four parts. The results are shown in Figure C-4 in bargraph

Specimens Composed of River Gravel, Limestone Screenings Field Sand and AC-10 Asphalt.
Values are % Compacted Density except numbers in parenthesis are % Laboratory Density.

		Leveling Load	
		20,000	30,000
Direct			87.2 - A (91.9) 88.3 - B (93.0) 87.8 - Avg.
Direct + Vertical	15	88.0 - A (92.7) 85.8 - B (90.4) 86.9 - Avg.	85.9 - A (90.5) 86.3 - B (90.9) 86.1 - Avg.
	30	84.2 - A (88.7) 85.8 - B (90.4) 85.0 - Avg.	89.4 - A (94.2) 93.1 - B (98.1) 91.3 - Avg.
Direct + Vertical + Horizontal	15	90.9 - A (95.8) 79.0 - B (83.2) 85.0 - Avg.	87.7 - A (92.4) 87.0 - B (91.7) 87.4 - Avg.
	30	92.0 - A (96.9) 89.6 - B (94.4) 90.8 - Avg.	89.9 - A (94.7) 92.8 - B (97.8) 91.4 - Avg.

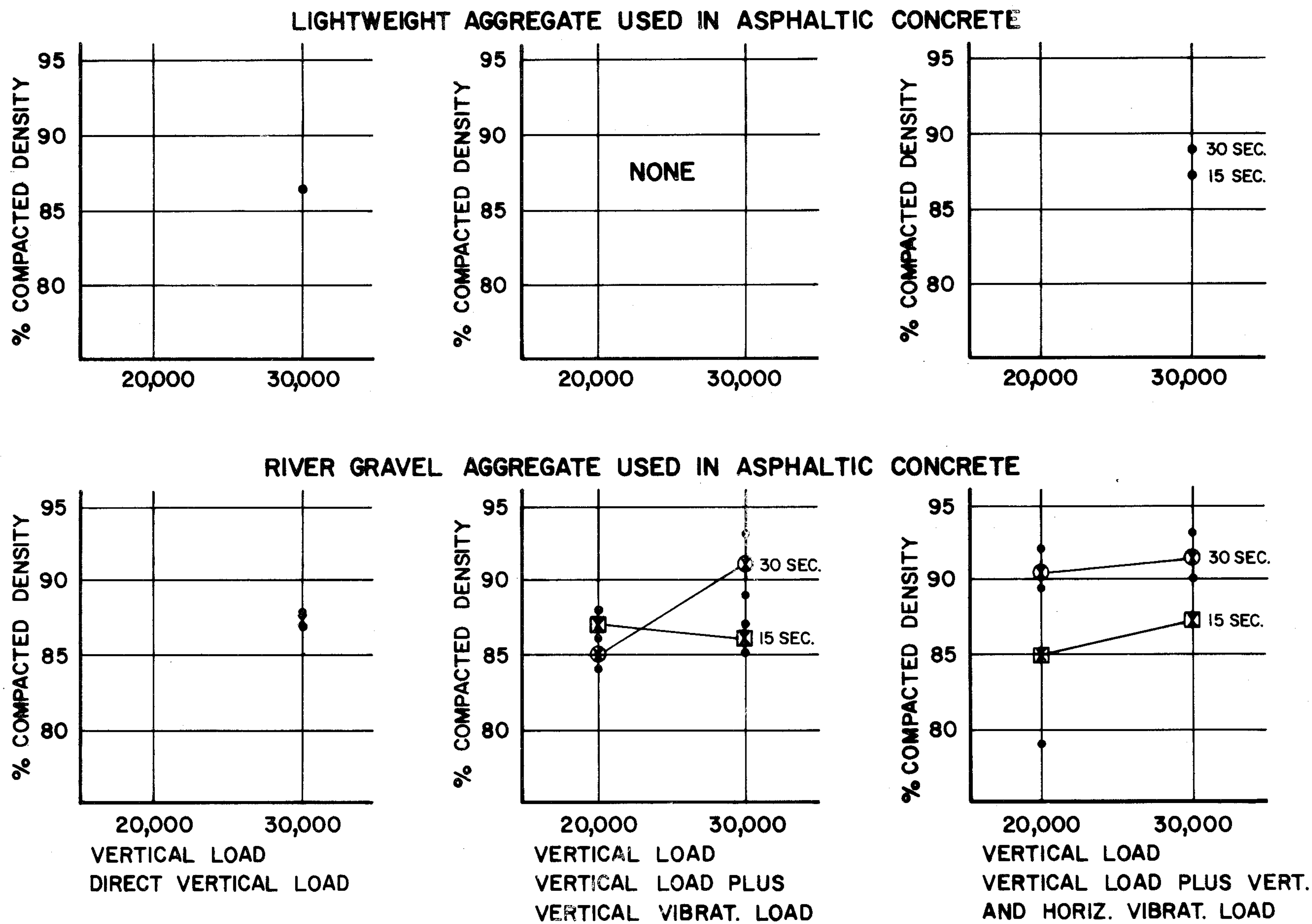
STUDY OF DENSITY PRODUCED BY COMPACTION APPARATUS

Figure C-1

Study of Density Produced
By Circular Track Compaction
Apparatus
Specimens Composed of Lightweight Aggregate, Limestone Screenings
Field Sand and AC-10 Asphalt

	% Comp. Density	% Lab. Density (% of HVEEM SPECIMENS)
30,000 Direct	86.6	92.1
30,000 + 15 Sec. Vib.	87.1	92.7
30,000 + 30 Sec. Vib.	89.1	94.8

Figure C-2

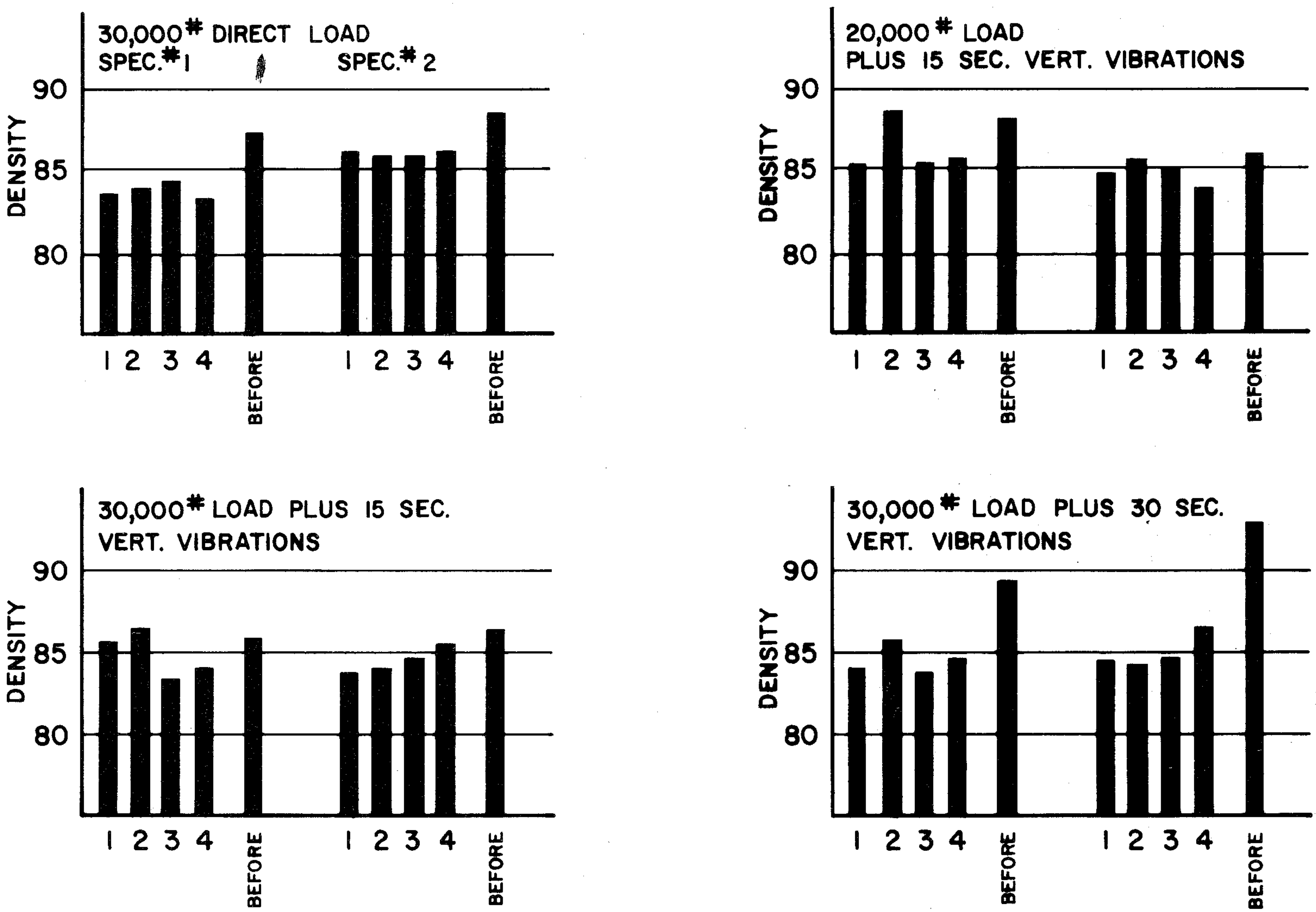


ANALYSIS OF DENSITY PRODUCED BY COMPACTION APPARATUS

FIGURE C-3

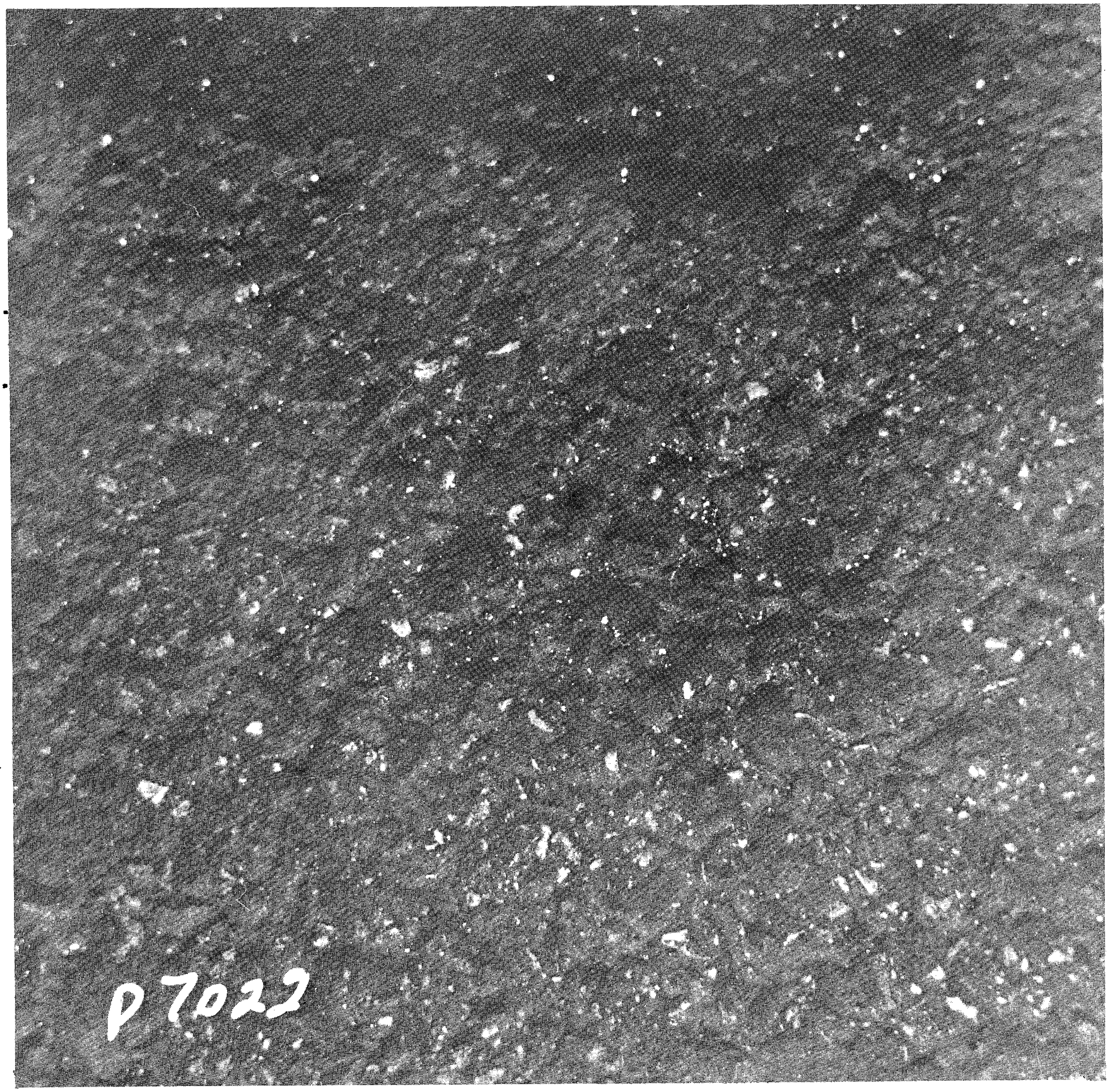
form. Statistical tests indicated no significant variation at the 95 percent level among parts or between replicate specimens for the densities of the 30,000 pound leveling load, 30 second horizontal and vertical gyration specimens. A large difference was noted in the densities before and after cutting, but it was believed this was due to aggregate movement in sawing the (new and tender) specimens.

A decision was made to adopt the compaction procedure using 30 second horizontal and vertical gyrations with a 3000 pound gyratory load. After gyration, a 30,000 pound leveling load was used.



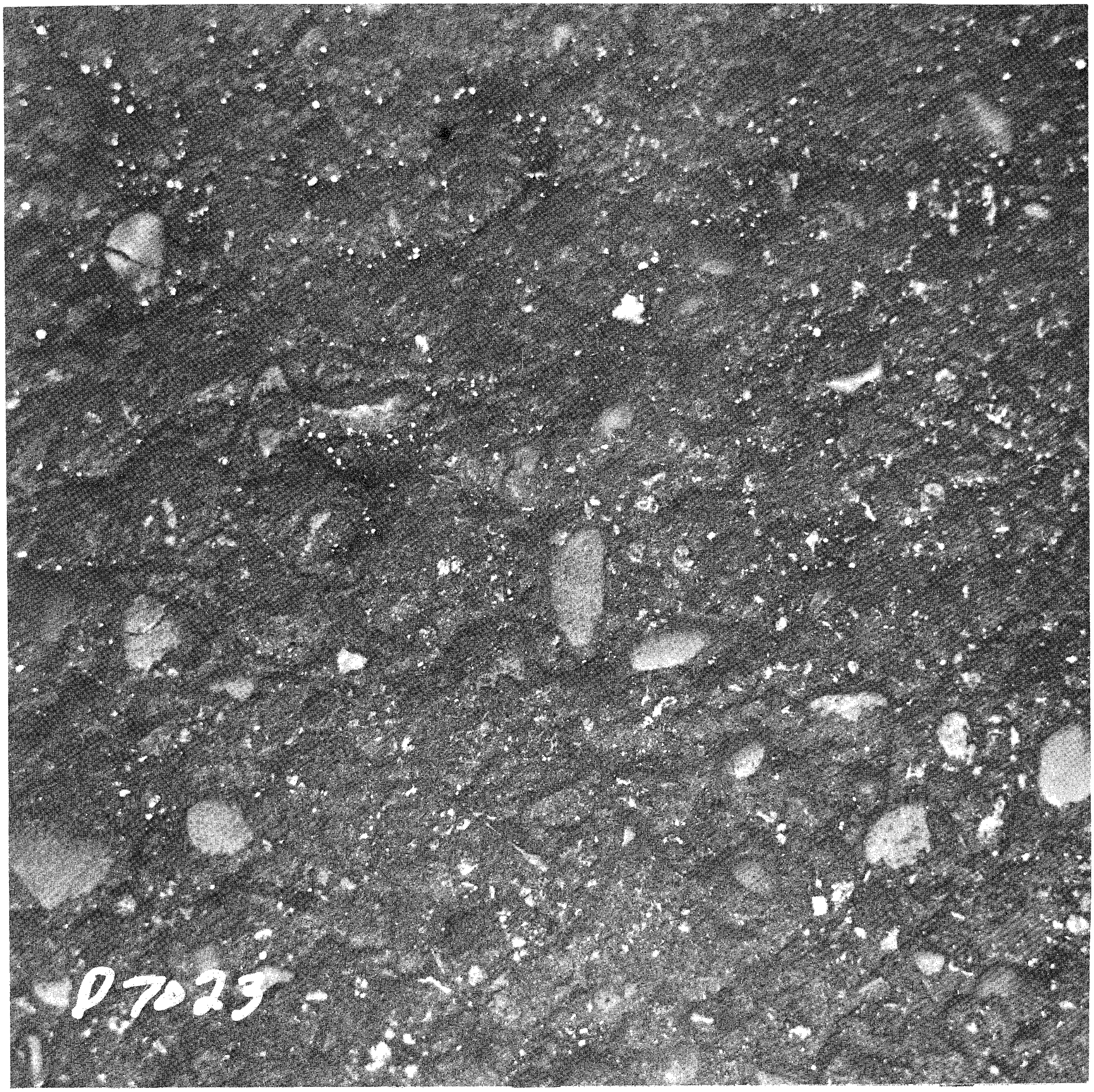
STUDY OF DESITY VARIATION WITHIN SPECIMENS

FIGURE C-4



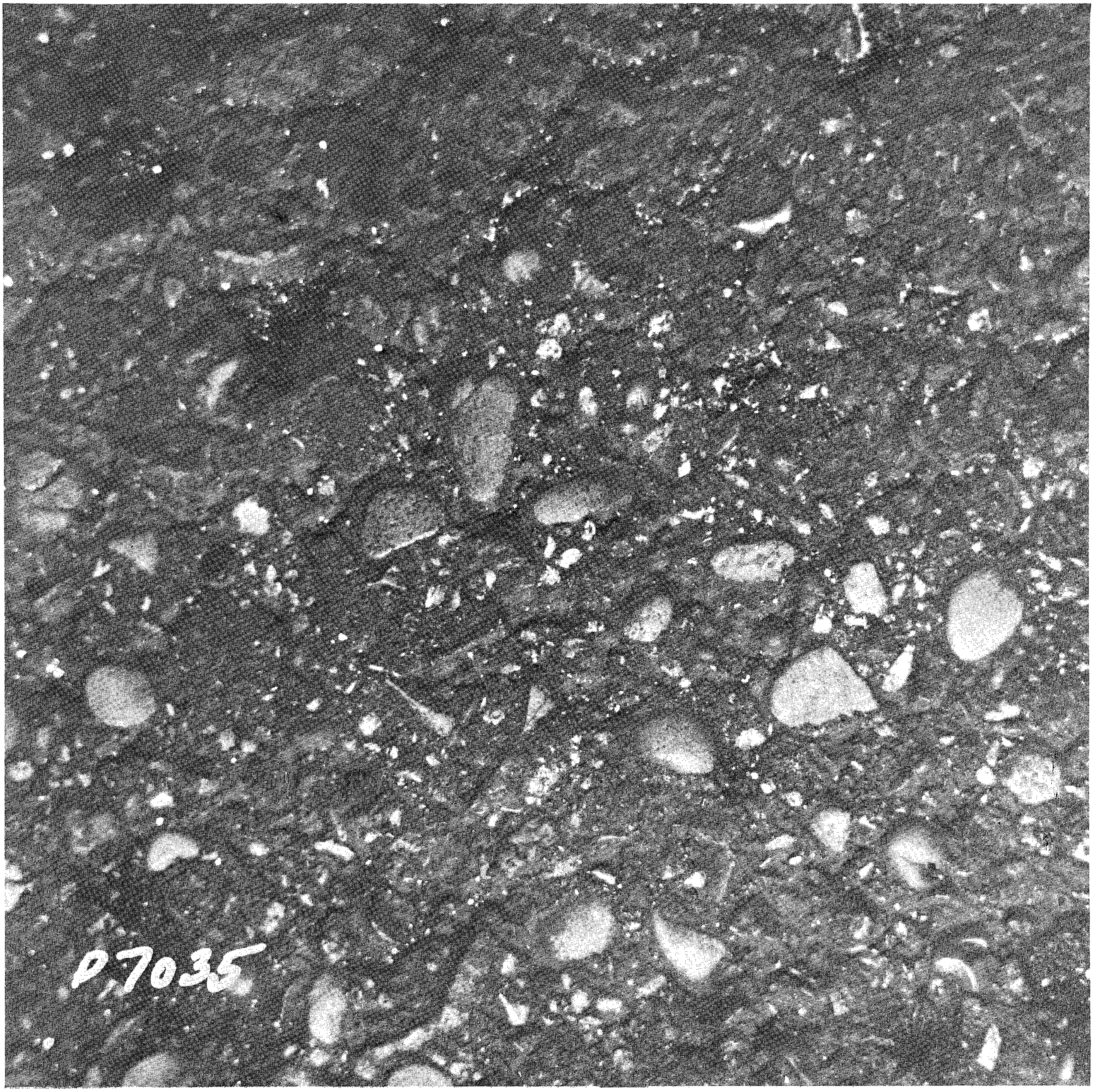
50% A and 50% C

0 Revolutions



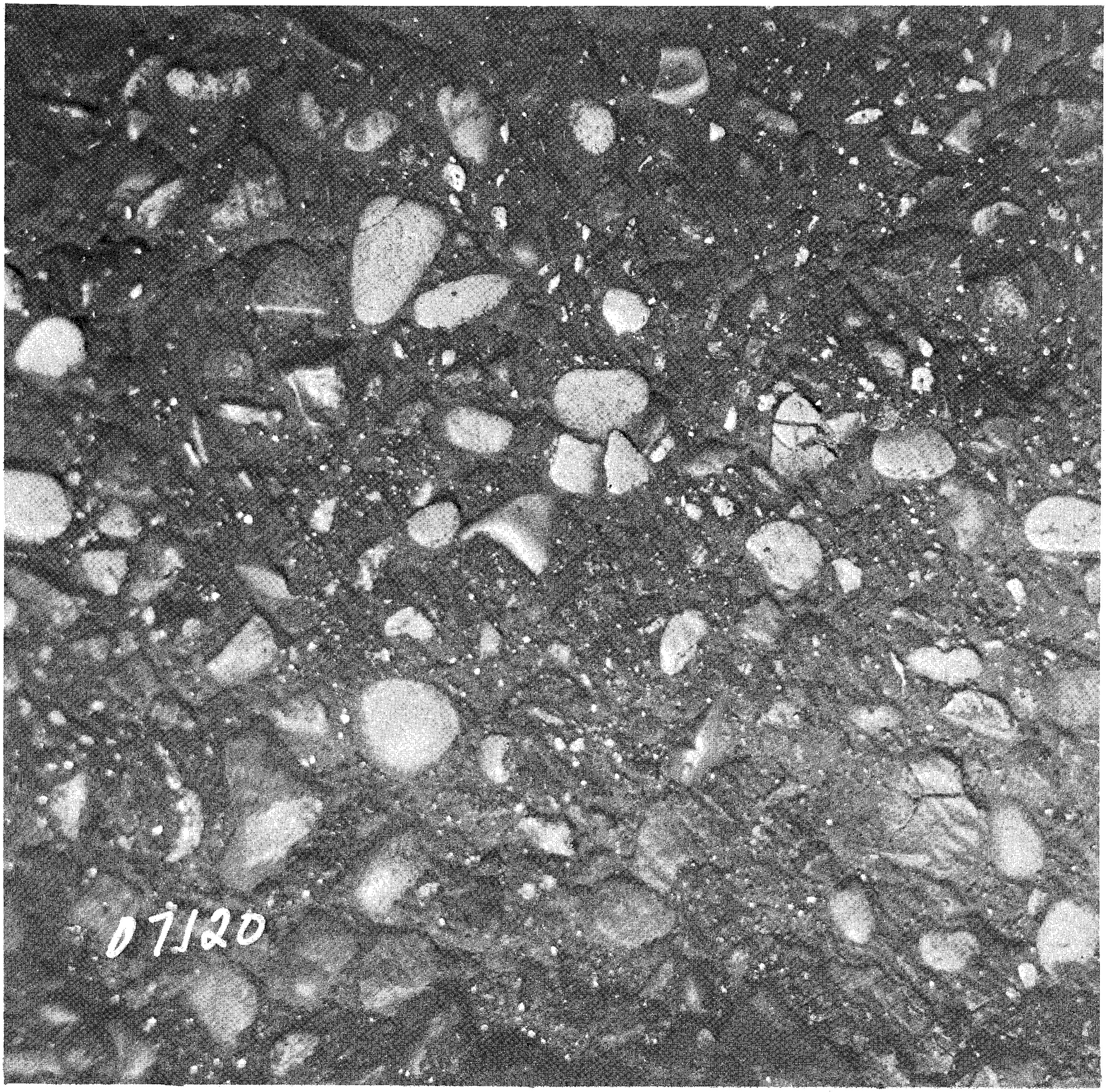
50% A and 50% C

1700 Revolutions



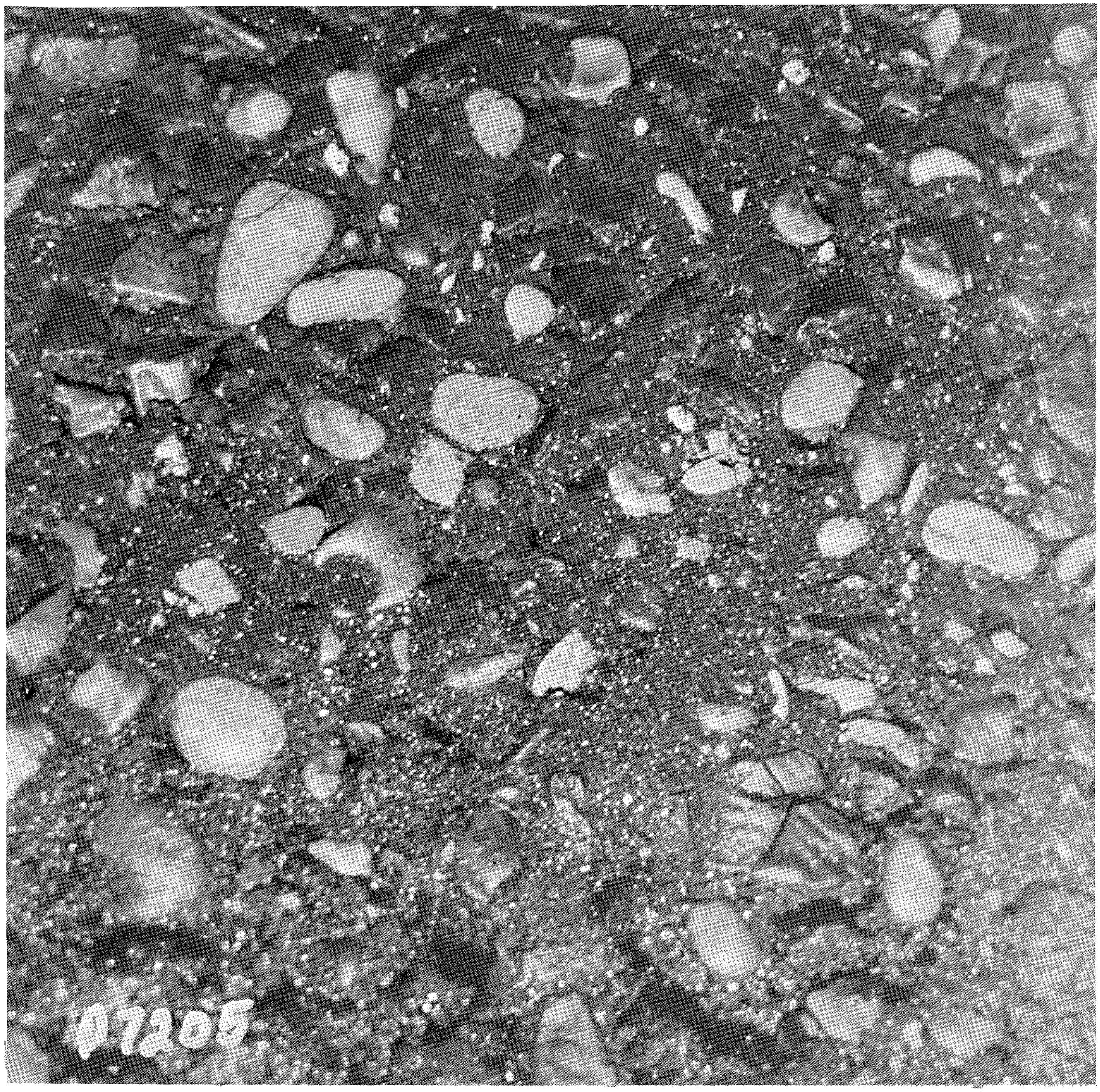
50% A and 50% C

3360 Revolutions



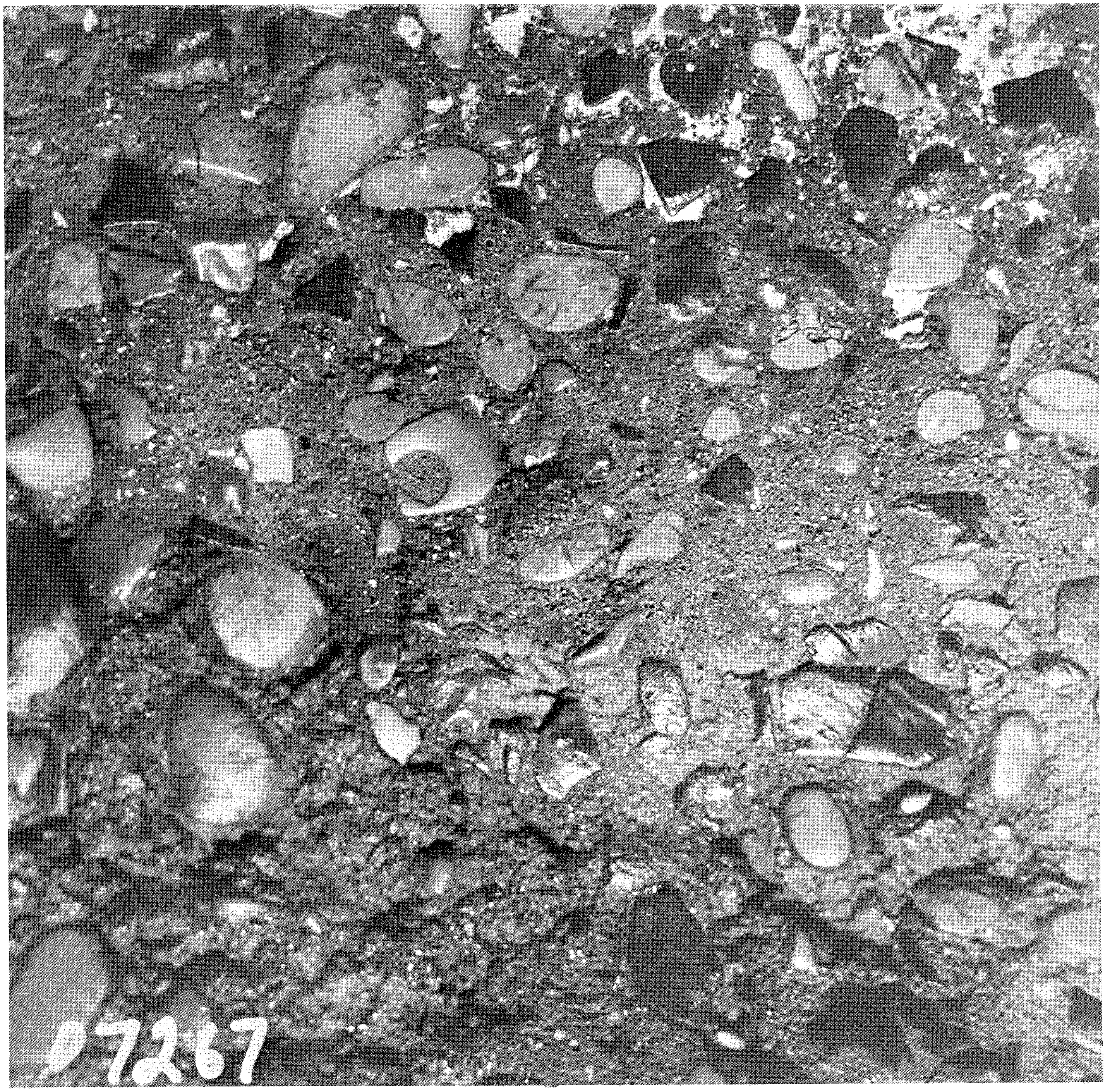
50% A and 50% C

47,040 Revolutions



50% A and 50% C

75,080 Revolutions



50% A and 50% C

122,120 Revolutions

Appendix E

ASPHALTIC CONCRETE MIX DESIGN TECHNIQUE FOR CHECKING SKID RESISTANCE

1. Obtain Mix Combination and Gradation Information from "Asphaltic Analysis Work Sheet" Form No. 544. Copy this information on Form 1.

2. Complete Form 2 by listing the "Percent by Weight of the Total Mix" for each bin and the asphalt. List the specific gravity of each material. Divide the Percent by Weight (Column a) by the Specific Gravity (Column b) for each material and list in Column C. Sum Column c. Divide each entry in Column c by the Total found for Column c to determine the Percent by Volume of the total mix for each material and list in Column d.

3. Complete the percent by volume columns of Form 1 to determine the percent by volume of each sieve size by multiplying the "% by Weight" with the volume percentage of the bin in question. Sum the "% by Volume" values for each sieve size and record under the "Combined Analysis % by Volume" column in the usual manner. The cumulative sum of the "+10" (+2.00mm) portion is equal to the value "D". Obtain D from Table 5 using D%. Record on Form 5.

4. The Values of "A", "B" and "F" may be calculated using a weighted average method found on Form 3. First copy the "Combined Analysis % by Volume" of the "+10" portion from Form 1 onto Form 3. Multiply the "Average Sieve Size in mm" (Column a) by the Combined Analysis (Column b) and record in Column c. Sum Column c and Column b. Divide the sum of Column c by the sum of Column b to determine the Weighted Average Size. The average height of the coarse aggregate protruding from the asphaltic concrete surface is estimated to be 25 percent of the Weighted Average Size and may be calculated as A_u on Form 3. To calculate A_u, multiply 0.25 by c/a.

   Since decay or attrition of the coarse aggregate occurs, the attrition is assumed to be a function of the mechanical abrasion as measured by the L.A. Wear Test. It is further assumed that the attrition caused by tire wear would be more severe if the aggregate is exposed to weather for longer periods before tire passage. Or, considering a surface has polished to its lowest skid resistance level, those surfaces with less traffic per day would have more chance of weather than surfaces with higher Average Daily Traffic. Estimates of the combined effect of weather and traffic are found in Table II. To obtain "A_c", multiply "A_u" by the appropriate "Coarse Aggregate Height Adjustment Factor" found in Table II. Determine the "A" values from Table III using "A_c" and record on Form 5.

   The value "B_c" may be calculated by multiplying the Weighted Average Size by 0.75 where the width of the coarse aggregate exposed is assumed to be 75 percent of the size of the aggregate. Determine the "B" value from Table IV using "B_c" and record on Form 5.

   The calculation of the "Weighted Average Size" of the fine aggregate is similar to that explained for the coarse aggregate. Equation 1 is an adjustment of the fine aggregate height based on the Insoluble Residue Test. The Value "F_c" may be calculated by multiplying the Weighted Average Size of the fine aggregate (-10) portion of the mix by the "Fine Aggregate Reduction Factor". Determine the "F" value from Table VII using "F_c" and record on Form 5.

5. Values of "E+C" may be calculated by obtaining a Weighted Polish Value on Form 4. In Column a, record the % by Volume +10 mesh material found in Bin 1 on the first line. On the second line, record the Polish Value of Bin 1 if applicable. (If the coarse aggregate material is not of sufficient size to obtain a test or if the +10 mesh portion of the mix is less than 10%, the Polish Value should be left blank and not considered.) Next, multiply the "% by Volume of the +10 mesh" value by the Polish Value and record on the third line (Total). Repeat the above operation for the other Bins. Sum the "Total" values found on the third line and record in Column e. Sum the "% by Volume of +10 mesh" value for each bin found on the first line and record in Column f.

   Divide the value found in Column e by the value found in Column f to determine the Weighted Polish Value. Using Table I, determine the "E+C" value corresponding to the Polish Value (Weighted) and record as "E+C". Also, record the "E+C" value on Form 5.

6. The Texture Parameters "A", "B", "D", "E+C", and "F" have previously been recorded on Form 5. Using Chart 1 and considering a 30 mph "Test Speed", select the appropriate curve which depends on the "E" (or actually the "E+C") value calculated. Find on the absissa or horizontal scale the "D" value which was calculated. Move vertically from the "D" value until the intersection with the appropriate curve is found. Move horizontally and to the left until intersection is made with the ordinate or vertical "Friction Weight" scale. Determine the "Friction Weight" and record on Form 5. Determine the Friction Weight for "E" for 60 mph in the same manner.

   Repeat the above operation to determine the friction Weights for "F" and for "B" using Charts 2, 3, or 4. Record each on Form 5. Note that the chart selected depends on the "D" parameter. Use the Random Texture Curves since the Transverse Texture Curves are to be used for striated P.C. Concrete finishes. Finally, sum the Friction Weights of "E", "F", and "B" for each speed and record in the "Total Friction Weight" spaces.

   A computer program is available to calculate the "Total Friction Weight" if desired; however, at the present time it will be necessary to submit Form 5 To D-10 Research Section with "A", "B", "D", "E+C" and "F" values recorded.

   Two examples are attached. Note that both are Type D mixes with a siliceous gravel coarse aggregate used in one, whereas a sandstone is used in the other.

TABLES & EQUATIONS

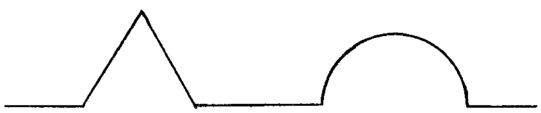
TABLE I

PREDICTION OF THE "E + C" TEXTURE VALUES FROM THE POLISH VALUE

E+C TEXTURE VALUE	POLISH VALUE
E 5	60
E 4	50
E 3	40
E 2	30
E 1	20

1

Polished (No Texture Visible)

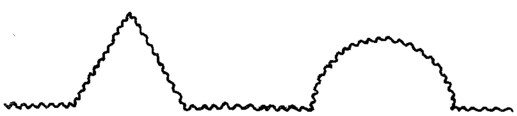


2

Smooth (Texture Visible But Micro — Projections Too Small For Visual Estimate Of Height

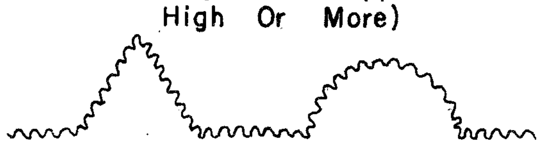
3

Fine Grained (Micro-Projections Appr. 1/4 mm High)



4

Coarse Grained — Subangular (Micro — Projections Appr. 1/2 mm High Or More)



5

Coarse Grained — Angular (Micro — Projections Appr. 1/2 mm High Or More)

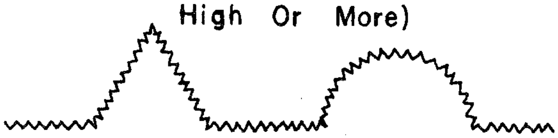


TABLE II

COARSE AGGREGATE HEIGHT ADJUSTMENT FACTOR FOR ATTRITION LOSS

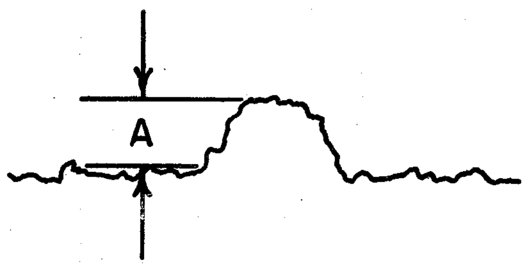
ESTIMATED ADT	L.A. ABRASION VALUE	ADJUSTMENT FACTOR
LESS THAN 2,000	LESS THAN 20	0.95
	20 – 29	0.90
	30 – 39	0.80
	GREATER THAN 39	0.65
2,000 TO 10,000	LESS THAN 20	0.98
	20 – 29	0.95
	30 – 39	0.89
	GREATER THAN 39	0.80
GREATER THAN 10,000	LESS THAN 20	1.00
	20 – 29	0.98
	30 – 39	0.94
	GREATER THAN 39	0.88

NOTE: The L.A. Abrasion Value Should Be That Of The Material Which Dominates The Coarse Aggregate Portion Of The Mix.

TABLE III

HEIGHT PARAMETER A

MEASURED IN MILLIMETERS FROM THE TOP OF THE BACKGROUND TO THE TOP OF THE PROJECTION

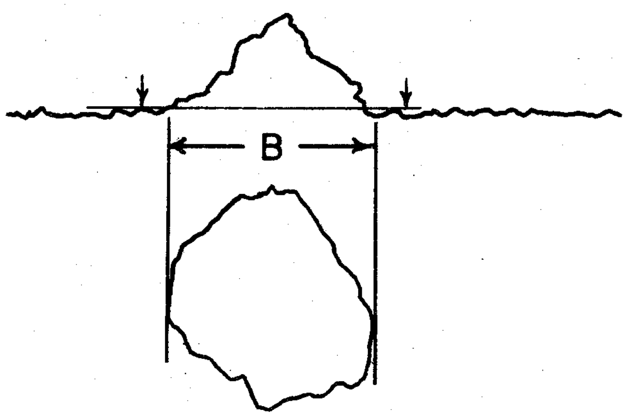


HEIGHT VALUE	HEIGHT IN mm
A 0	0 mm
A 1	1/4 mm
A 2	1/2 mm
A 3	1 mm
A 4	2 mm
A 5	4 mm
A 6	8 mm

TABLE IV

WIDTH PARAMETER B

MEASURED IN MILLIMETERS AND IS THE HORIZONTAL DIMENSION OF THE PROJECTION — MEASURED AT THE LEVEL OF THE TOP OF THE BACKGROUND



WIDTH VALUE	WIDTH IN mm
B 0	16 mm
B 1	8 mm
B 2	4 mm
B 3	2 mm

NOTE: Particles Less Than 2 mm Wide Are Regarded As Background.

TABLE V

DENSITY PARAMETER D

DENSITY VALUE	PERCENT OF TOTAL AREA COVERED BY ASPERITIES
D 0	0 %
D 1	25 %
D 2	50 %
D 3	75 %
D 4	100 %

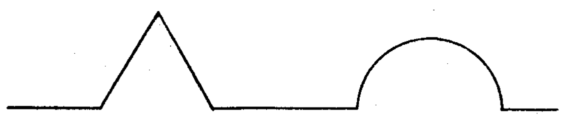
TABLE VI

FINE TEXTURE OF BACKGROUND PARAMETER F

DENOTES SIZE, SHARPNESS OR ROUNDNESS OF THE MICRO—PROJECTIONS IN THE BACKGROUND

1

Polished (No Texture Visible)

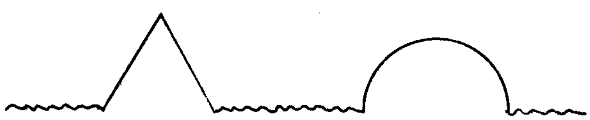


2

Smooth (Texture Visible But Micro — Projections Too Small For Visual Estimate Of Height)

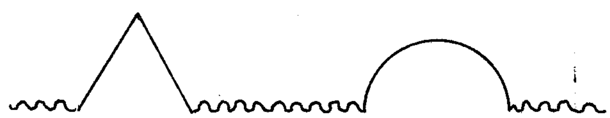
3

Fine Grained (Micro—Projections Appr. 1/4 mm High)



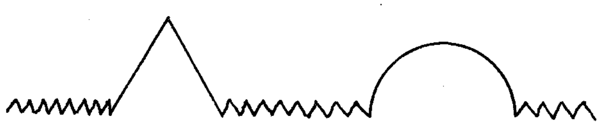
4

Coarse Grained—Subangular (Micro —Projections Appr. 1/2 mm High Or More)



5

Coarse Grained — Angular (Micro — Projections Appr. 1/2 mm High Or More)



EQUATION #1

$$FARF = \frac{50 + 0.5\ (IRP)}{100}$$

WHERE

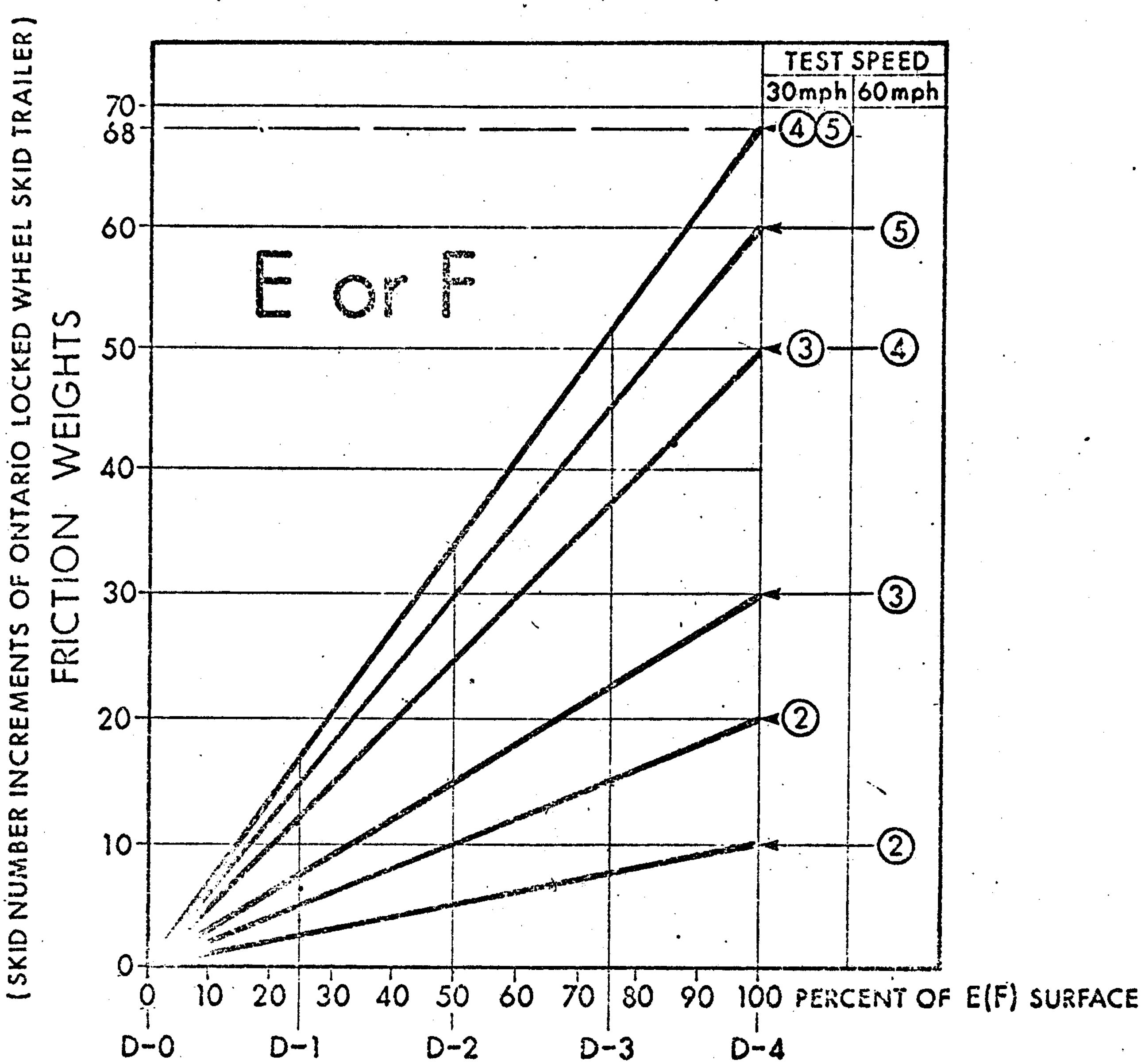
FARF = Fine Aggregate Reduction Factor
IRP = Insoluble Residue Percentage

NOTE: THE INSOLUBLE RESIDUE VALUE SHOULD BE THAT OF THE MATERIAL WHICH DOMINATES THE FINE AGGREGATE PORTION OF THE MIX.

ESTIMATES SHOULD BE MADE OF THE SHAPE OF THE FINE AGGREGATE; HOWEVER, IF THE INSOLUBLE RESIDUE PERCENTAGE IS LESS THAN 50%, IT SHALL BE ASSUMED THAT THE FINE AGGREGATE HAS ROUNDED.

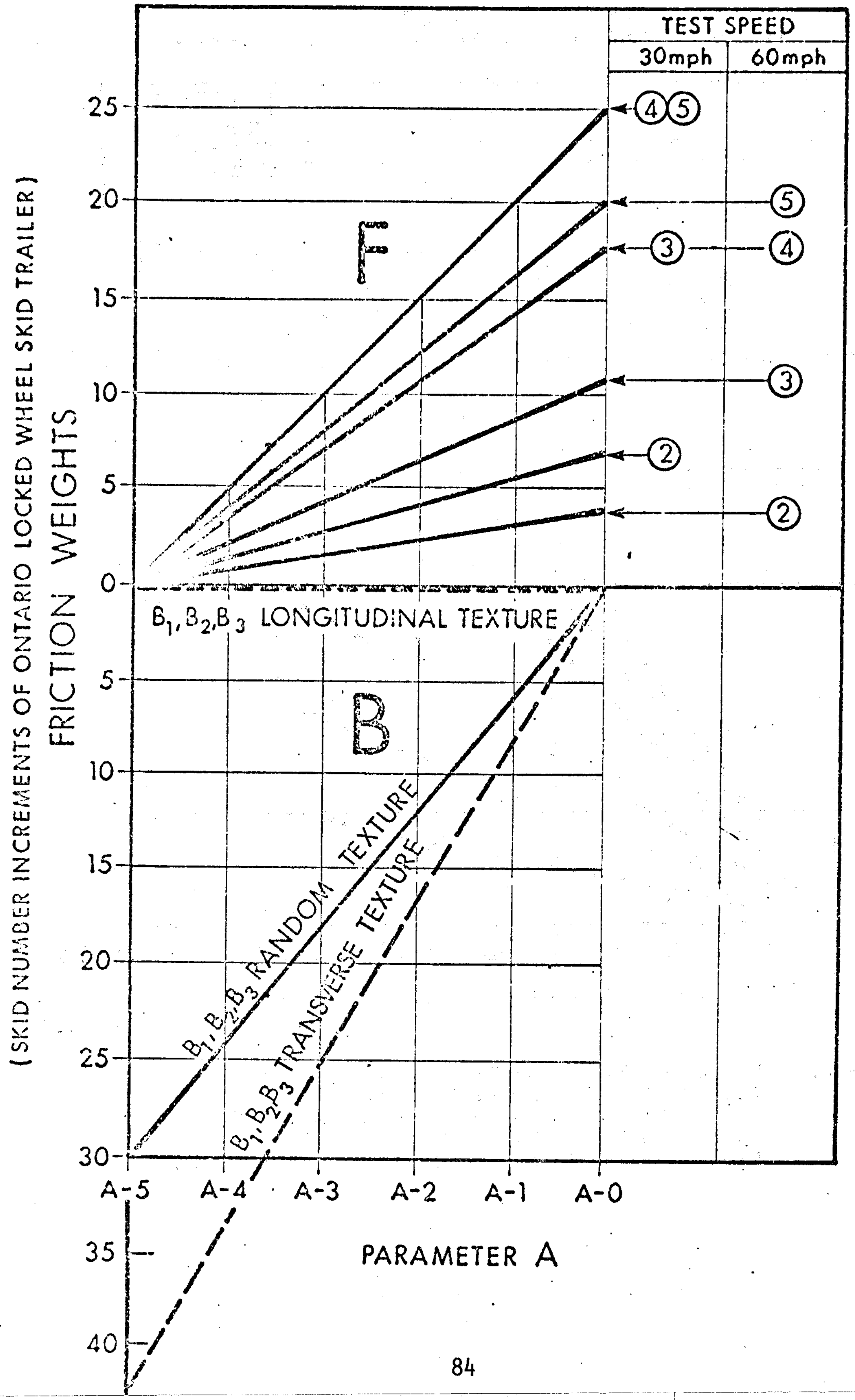
CHART NO. 1

SKID RESISTANCE PHOTO-INTERPRETATION
FRICTION WEIGHTS
OF PAVEMENT TEXTURE PARAMETER E
OR, IF MACRO-PROJECTIONS ARE ABSENT (D ZERO), OF PARAMETER F



NOTE: IF THE DENSITY PARAMETER IS D–1, D–2 OR D–3, ADD TO THE FRICTION WEIGHT FOR PARAMETER E OBTAINED FROM THIS GRAPH THE FRICTION WEIGHTS FOR PARAMETERS A, B AND F OBTAINED FROM CHART NO. 2, CHART NO. 3 OR CHART NO. 4, RESPECTIVELY.

SKID RESISTANCE PHOTO-INTERPRETATION
FRICTION WEIGHTS
OF PAVEMENT TEXTURE PARAMETERS A, B AND F, FOR D 1



SKID RESISTANCE PHOTO-INTERPRETATION
FRICTION WEIGHTS
OF PAVEMENT TEXTURE PARAMETERS A, B AND F, FOR D 2

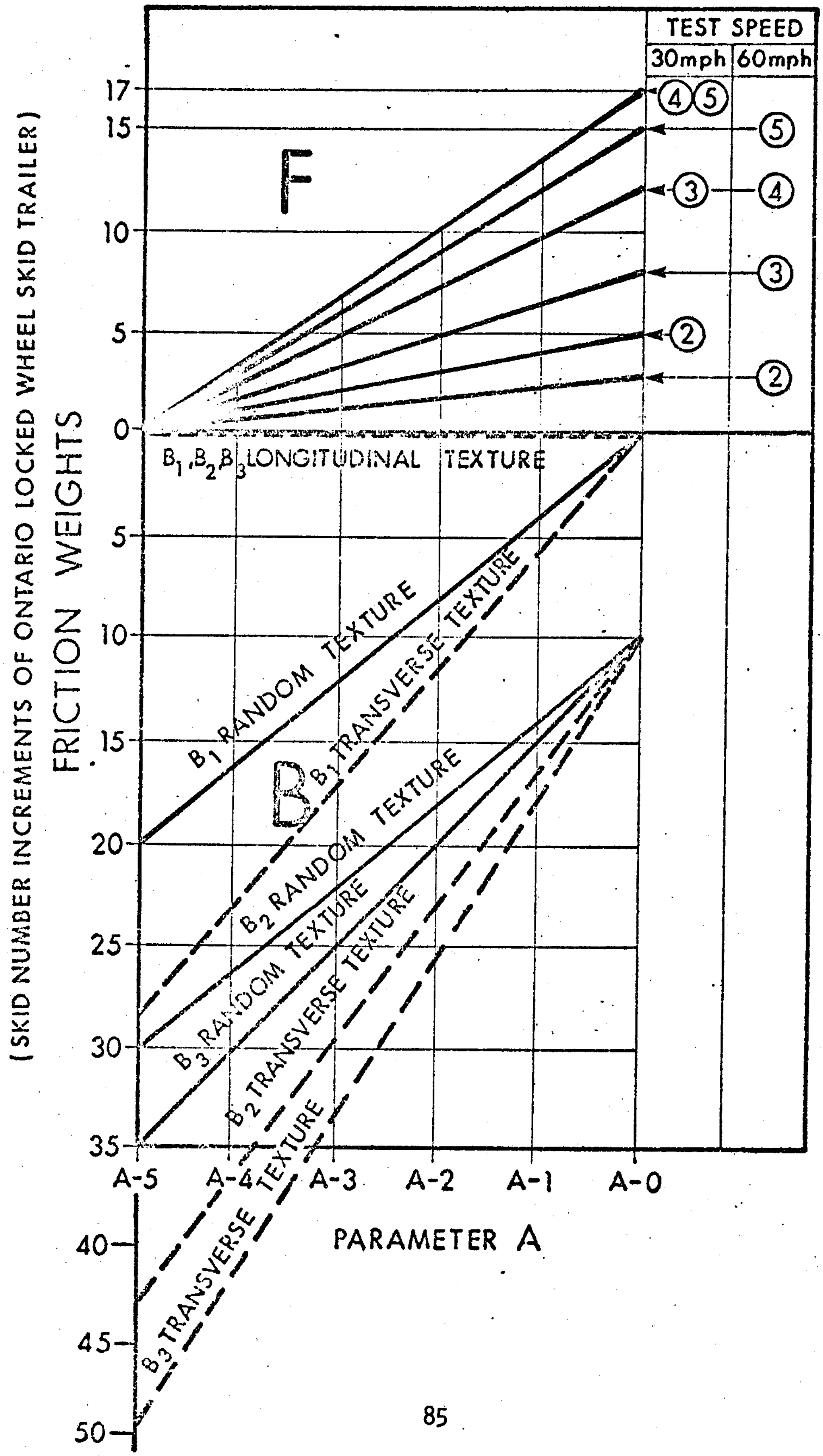
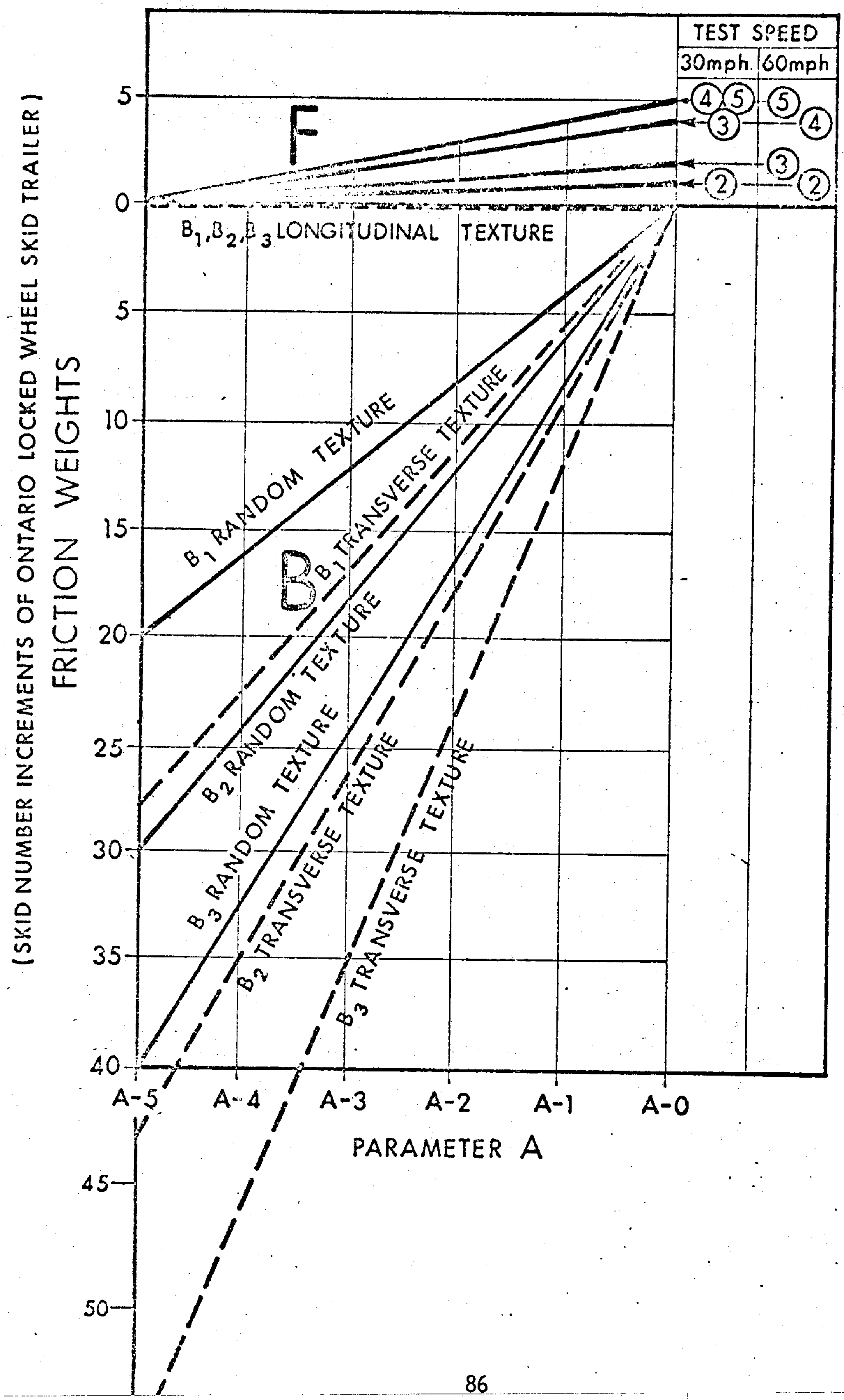


CHART NO. 4

SKID RESISTANCE PHOTO-INTERPRETATION
FRICTION WEIGHTS
OF PAVEMENT TEXTURE PARAMETERS A, B AND F
FOR D 3



TEXAS HIGHWAY DEPARTMENT
ASPHALTIC CONCRETE SIEVE ANALYSIS WORK SHEET

County________ Highway________ Project________ Control________

Date________ Time________ Station________ Sampled By________

Spec. Item________ Type________ Design No.________

Sieve Size	Bin No. 1 (a)			Bin No. 2 (b)			Bin No. 3 (c)			Bin No. 4 (d)			Combined Analysis % (a+b+c+d)
	Weight (grams)	Total % x	%	Weight (grams)	Total % x	%	Weight (grams)	Total % x	%	Weight (grams)	Total % x	%	
1¾" — ⅞"													
⅞" — ⅜"													
⅝" — ⅜"													
½" — ⅜"													
⅜" — 4													
¼" — 10													
4 — 10													
+ 10													
10 — 40													
40 — 80													
80 — 200													
Pass 200													
Total	gm	100.0%	%	gm	100.0%	%	gm	100.0%	%	gm	100.0%	%	%

PER CENT MOISTURE IN AGGREGATES IN HOT BINS						
Bin No.	(a) Tare Wt. (gms.)	(b) Gross Wet Wt. (gms.)	(c) Gross Dry Wt. (gms.)	(d) Wt. Moist (gms.) b-c	(e) Dry Wt. Aggr. (gms.) c-a	% Moist. $\frac{d}{e}$ x100%
1						
2						
3						
4						

Asphaltic Binder =________%

Total = 100.0%

____

Inspector

FORM I

TEXAS HIGHWAY DEPARTMENT

COUNTY__________ HIGHWAY__________ PROJECT__________ CONTROL __________

DATE__________ TIME__________ STATION__________ SAMPLED BY__________

SPEC. ITEM__________ TYPE__________ DESIGN NO.__________

INS. RES.														
POLISH VALUE														
SIEVE SIZE (mm)	SIEVE SIZE (in.)	BIN NO. 1			BIN NO. 2			BIN NO. 3			BIN NO. 4			COMBINED ANALYSIS % BY VOLUME
		% BY WEIGHT	% BY VOL.		% BY WEIGHT	% BY VOL.		% BY WEIGHT	% BY VOL.		% BY WEIGHT	% BY VOL.		
44.4 – 22.2	1 3/4" - 7/8"													
22.2 – 9.52	7/8" - 5/8"													
15.9 – 9.52	5/8" - 3/8"													
12.7 – 9.52	1/2" - 3/8"													
9.52 – 4.76	3/8" - 4													
6.35 – 2.00	1/4" - 10													
4.76 – 2.00	4 – 10													
+ 2.00	+ 10													=D
2.00 – 0.42	10 – 40													
0.42 – 0.177	40 – 80													
0.177 – 0.074	80 – 200													
– 0.074	PASS 200													
	TOTAL	%	%		%	%		%	%		%	%		

ASPHALTIC BINDER =______% BY WEIGHT =______% BY VOLUME

TOTAL______

PREPARED BY____________________

FORM 2

DETERMINATION OF VOLUMETRIC PERCENTAGES

	(a) PERCENT BY WEIGHT OF TOTAL MIX	(b) SPECIFIC GRAVITY OF MATERIAL	(c) $\frac{a}{b}$	(d) PERCENT BY VOLUME OF TOTAL MIX
BIN 1				
BIN 2				
BIN 3				
BIN 4				
ASPHALT				
TOTAL				

FORM 3

COARSE AGGREGATE-CALCULATIONS OF "A" AND "B"

(a) AVERAGE SIEVE SIZE (mm)	SIEVE SIZE	(b) COMBINED ANALYSIS % BY VOLUME	(c) a x b	(d) WEIGHTED AVERAGE SIZE $\frac{c}{b}$
11.11	$\frac{1}{2}-\frac{3}{8}$			
7.14	$\frac{3}{8}-4$			
4.18	$\frac{1}{4}-10$			
3.38	4-10			

$$A_u = 0.25 \times \frac{c}{b}$$

$A_u = 0.25 \times \quad = \quad$ mm

$$A_c = A_u \times \text{ADJUSTMENT FACTOR (TABLE II)}$$

$A_c = \quad \times$ A=

$$B_c = 0.75 \times \frac{c}{b}$$

$B_c = 0.75 \times \quad = \quad$ mm B=

FINE AGGREGATE-CALCULATIONS OF "F

(d) AVERAGE SIEVE SIZE (mm)	SIEVE SIZE	(e) COMBINED ANALYSIS % BY VOLUME	(f) e x d	g WEIGHTED AVERAGE SIZE $\frac{f}{e}$
1.21	10-40			
0.30	40-80			
0.13	80-200			
0.04	-200			

$F_c = \frac{f}{e} \times$ FARF (EQUATION I)

F =

$F_c = \quad \times$

FORM 4

CALCULATIONS OF "E+C"

	(a)	(b)	(c)	(d)	(e)	(f)
	BIN I	BIN 2	BIN 3	BIN 4		
% BY VOLUME OF +10 MESH						
POLISH VALUE						
TOTAL						

WEIGHTED POLISH VALUE = $\frac{e}{f}$ ________________

WEIGHTED POLISH VALUE = ____________ =

E+C = ______________ (From TABLE I)

FORM 5

DETERMINATION OF SKID QUALITIES OF ASPHALTIC CONCRETE MIX

TEXTURE PARAMETERS DETERMINED FOR MIX

A= ______
B= ______
D= ______
E+C= ______
F= ______

CHART LOCATION	TEXTILE PARAMETER CONSIDERED	FRICTION WEIGHT	
		30 mph	60 mph
CHART I	E (or E+C)		
CHART 2,3 or 4 (Depending on D)	F		
CHART 2,3 or 4 (Depending on D)	B		
TOTAL FRICTION WEIGHT			

EXAMPLE I

L.A. Wear (abrasion) - BIN 3	= 20
Polish Value - BIN 3	= 24
- BIN 2	= 30
Insoluble Residue Test - BIN 1	= 85%
- BIN 2	= 5%
Expected ADT	= 22,500

Texas Highway Department
Construction Form No. 544 Rev. (2)

TEXAS HIGHWAY DEPARTMENT
ASPHALTIC CONCRETE SIEVE ANALYSIS WORK SHEET

County: Monroe — Highway: SH-2000 — Project: F-1(234) — Control: 5-6

Date: 9-4-67 — Time: — Station: — Sampled By:

Spec. Item: 340 — Type: D — Design No.: Trial #1

Sieve Size	Bin No. 1 (a) Weight (grams)	Total %	x 30.8%	Bin No. 2 (b) Weight (grams)	Total %	x 22.4%	Bin No. 3 (c) Weight (grams)	Total %	x 40.0%	Bin No. 4 (d) Weight (grams)	Total %	x %	Combined Analysis % (a+b+c+d)
1¾"—⅞"													
⅞"—⅜"													
⅝"—⅜"													
½"—⅜"							54	3.6	1.4				1.4
⅜"—4				53	6.7	1.5	1326	89.5	35.8				37.3
¼"—10													
4—10	36	8.3	2.6	688	86.4	19.4	34	2.3	0.9				22.9
+ 10			2.6			20.4			38.1				61.6
10—40	153	35.1	10.8	32	4.0	0.9	24	1.6	0.6				12.3
40—80	143	32.8	10.1	6	0.8	0.2	13	0.9	0.4				10.7
80—200	73	16.7	5.1	9	1.1	0.2	13	0.9	0.4				5.7
Pass 200	31	7.1	2.2	8	1.0	0.2	18	1.2	0.5				2.9
Total	436 gm	100.0%	30.8 %	796 gm	100.0%	22.4 %	1402 gm	100.0%	40.0 %	gm	100.0%	%	93.2 %

Asphaltic Binder = 6.8 %

Total = 100.0%

PER CENT MOISTURE IN AGGREGATES IN HOT BINS						
Bin No.	(a) Tare Wt. (gms.)	(b) Gross Wet Wt. (gms.)	(c) Gross Dry Wt. (gms.)	(d) Wt. Moist (gms.) b-c	(e) Dry Wt. Aggr. (gms.) c-a	% Moist. $\frac{d}{e}$ x100%
1						
2						
3						
4						

J. S.

Inspector

FORM I

TEXAS HIGHWAY DEPARTMENT

COUNTY MONROE HIGHWAY SH-2000 PROJECT F-1 (234) CONTROL 5-6

DATE 9-4-67 TIME ______ STATION ______ SAMPLED BY ______

SPEC. ITEM 340 TYPE D DESIGN NO. TRIAL #1

INS. RES.		85%			5%									
POLISH VALUE					30			24						
SIEVE SIZE (mm)	SIEVE SIZE (in.)	BIN NO. 1			BIN NO. 2			BIN NO. 3			BIN NO. 4			COMBINED ANALYSIS % BY VOLUME
		30.8	33.3		22.4	18.9		40.0	33.3					
		% BY WEIGHT	% BY VOL.		% BY WEIGHT	% BY VOL.		% BY WEIGHT	% BY VOL.		% BY WEIGHT	% BY VOL.		
44.4–22.2	1 3/4"–7/8"													
22.2–9.52	7/8"–5/8"													
15.9–9.52	5/8"–3/8"													
12.7–9.52	1/2"–3/8"							3.6	1.2					1.2
9.52–4.76	3/8"–4				6.7	1.3		89.5	29.8					31.1
6.35–2.00	1/4"–10													
4.76–2.00	4–10	8.3	2.8		86.4	16.2		2.3	0.8					19.8
+2.00	+10		2.8			17.5			31.8					52.1 =D
2.00–0.42	10–40	35.1	11.6		4.0	0.8		1.6	0.5					12.9
0.42–0.177	40–80	32.8	10.9		0.8	0.2		0.9	0.3					11.4
0.177–0.074	80–200	16.7	5.6		1.1	0.2		0.9	0.3					6.1
-0.074	PASS 200	7.1	2.4		1.0	0.2		1.2	0.4					3.0
	TOTAL	100.0 %	33.3 %		100 %	18.9 %		100 %	33.3 %		%	%		

ASPHALTIC BINDER = 6.8 % BY WEIGHT = 14.5 % BY VOLUME

TOTAL ______

PREPARED BY J.S.

FORM 2

DETERMINATION OF VOLUMETRIC PERCENTAGES

	(a) PERCENT BY WEIGHT OF TOTAL MIX	(b) SPECIFIC GRAVITY OF MATERIAL	(c) a/b	(d) PERCENT BY VOLUME OF TOTAL MIX
BIN 1	30.8	2.013	15.30	33.3
BIN 2	22.4	2.568	8.72	18.9
BIN 3	40.0	2.612	15.31	33.3
BIN 4				
ASPHALT	6.8	1.020	6.67	14.5
TOTAL			46.0	100.0

FORM 3

COARSE AGGREGATE-CALCULATIONS OF "A" AND "B"

(a) AVERAGE SIEVE SIZE (mm)	SIEVE SIZE	(b) COMBINED ANALYSIS % BY VOLUME	(c) a x b	(d) WEIGHTED AVERAGE SIZE $\frac{c}{b}$
11.11	$\frac{1}{2}-\frac{3}{8}$	1.2	13.33	
7.14	$\frac{3}{8}-4$	31.1	222.05	
4.18	$\frac{1}{4}-10$			
3.38	4–10	19.8	66.92	
		52.1	302.3	5.80

$A_u = 0.25 \times \frac{c}{b}$

$A_u = 0.25 \times 5.8 = 1.45$ mm

$A_c = A_u \times$ ADJUSTMENT FACTOR (TABLE II)

$A_c = 1.45 \times 0.98 = 1.42$ A= 3

$B_c = 0.75 \times \frac{c}{b}$

$B_c = 0.75 \times 5.80 = 4.35$ mm B= 2

FINE AGGREGATE-CALCULATIONS OF "F

(d) AVERAGE SIEVE SIZE (mm)	SIEVE SIZE	(e) COMBINED ANALYSIS % BY VOLUME	(f) e x d	g WEIGHTED AVERAGE SIZE $\frac{f}{e}$
1.21	10–40	12.9	15.61	
0.30	40–80	11.4	3.42	
0.13	80–200	6.1	0.79	
0.04	-200	3.0	0.12	
		33.4	19.94	

$F_c = \frac{f}{e} \times$ FARF (EQUATION I)

F = 5

$F_c = \frac{0.60 \times 92.5}{100} = .555$

FORM 4

CALCULATIONS OF "E+C"

	(a)	(b)	(c)	(d)	(e)	(f)
	BIN 1	BIN 2	BIN 3	BIN 4		
% BY VOLUME OF +10 MESH	2.8	17.5	31.8			49.3
POLISH VALUE		30	24			
TOTAL	~	525.0	763.2		1288.2	

$$\text{WEIGHTED POLISH VALUE} = \frac{e}{f}$$

$$\text{WEIGHTED POLISH VALUE} = \frac{1288.3}{49.3} = 26.1$$

E+C = E 2 (From TABLE I)

FORM 5

DETERMINATION OF SKID QUALITIES OF ASPHALTIC CONCRETE MIX

TEXTURE PARAMETERS DETERMINED FOR MIX

A = 3
B = 2
D = 2
E+C = 2
F = 5

CHART LOCATION	TEXTILE PARAMETER CONSIDERED	FRICTION WEIGHT	
		30 mph	60 mph
CHART I	E (or E+C)	10	6
CHART 2,3 or 4 (Depending on D)	F	7	6
CHART 2,3 or 4 (Depending on D)	B	22	22
TOTAL FRICTION WEIGHT		39	34

EXAMPLE II

L.A. Wear (Abrasion) - Bin 3	= 30
Polish Value - Bin 3	= 44
- Bin 2	= 30
Insoluble Residue Test - Bin 1	= 85%
- Bin 2	= 5%
Expected ADT	= 22,500

Construction Form No. 544 Rev. (2)

TEXAS HIGHWAY DEPARTMENT
ASPHALTIC CONCRETE SIEVE ANALYSIS WORK SHEET

County: Jacob — Highway: RM-5000 — Project: F-1 (456) — Control: 1-2
Date: 4-25-73 — Time: — Station: — Sampled By:
Spec. Item: 340 — Type: D — Design No.: Trial #2

Sieve Size	Bin No. 1 (a) Weight (grams)	Total %	x 31.0 %	Bin No. 2 (b) Weight (grams)	Total %	x 22.0%	Bin No. 3 (c) Weight (grams)	Total %	x 40.0%	Bin No. 4 (d) Weight (grams)	Total %	x %	Combined Analysis % (a+b+c+d)
1¾" — ⅞"													
⅞" — ⅜"													
⅝" — ⅜"													
½" — ⅜"							59	3.7	1.5				1.5
⅜" — 4				58	7.1	1.6	1431	89.1	35.5				37.1
¼" — 10													
4 — 10	41	8.9	2.8	699	85.3	18.7	37	2.3	0.9				22.4
+ 10													61.0
10 — 40	158	34.5	10.6	34	4.2	0.9	28	1.7	0.7				12.2
40 — 80	147	32.0	9.9	7	0.9	0.2	15	0.9	0.4				10.5
80 — 200	78	17.0	5.3	11	1.3	0.3	15	0.9	0.4				6.0
Pass 200	35	7.6	2.4	10	1.2	0.3	22	1.4	0.6				3.3
Total	459 gm	100.0%	31.0 %	819 gm	100.0%	22.0 %	1607 gm	100.0%	40.0 %	gm	100.0%	%	93.0 %

PER CENT MOISTURE IN AGGREGATES IN HOT BINS						
Bin No.	(a) Tare Wt. (gms.)	(b) Gross Wet Wt. (gms.)	(c) Gross Dry Wt. (gms.)	(d) Wt. Moist (gms.) b-c	(e) Dry Wt. Aggr. (gms.) c-a	% Moist. $\frac{d}{e}$ x100%
1						
2						
3						
4						

Asphaltic Binder = 7.0 %

Total = 100.0%

J. S

Inspector

FORM I

TEXAS HIGHWAY DEPARTMENT

COUNTY JACOB HIGHWAY RM-8000 PROJECT F-1(456) CONTROL 1-2

DATE 4-25-73 TIME ____ STATION ____ SAMPLED BY ____

SPEC. ITEM 340 TYPE D. DESIGN NO. Trial #2

INS. RES.		85%			5%									
POLISH VALUE					30			44						
SIEVE SIZE (mm)	SIEVE SIZE (in.)	BIN NO. 1			BIN NO. 2			BIN NO. 3			BIN NO. 4			COMBINED ANALYSIS % BY VOLUME
		31.0	32.9		22.0	18.3		40.0	34.1					
		% BY WEIGHT	% BY VOL.		% BY WEIGHT	% BY VOL.		% BY WEIGHT	% BY VOL.		% BY WEIGHT	% BY VOL.		
44.4–22.2	1 3/4"–7/8"													
22.2–9.52	7/8"–5/8"													
15.9–9.52	5/8"–3/8"													
12.7–9.52	1/2"–3/8"							3.7	1.3					1.3
9.52–4.76	3/8"–4				7.1	1.3		89.1	30.3					31.6
6.35–2.00	1/4"–10													
4.76–2.00	4–10	8.9	2.9		85.3	15.6		2.3	0.8					19.3
+ 2.00	+10		2.9			16.9			32.4					52.2 =D
2.00–0.42	10–40	34.5	11.4		4.2	0.8		1.7	0.6					12.8
0.42–0.177	40–80	32.0	10.5		0.9	0.2		0.9	0.3					11.0
0.177–0.074	80-200	17.0	5.6		1.3	0.2		0.9	0.3					6.1
-0.074	PASS 200	7.6	2.5		1.2	0.2		1.4	0.5					3.2
	TOTAL	31.0%	32.9%		22.0%	18.3%		40.0%	34.1%		%	%		

ASPHALTIC BINDER = 7.0 % BY WEIGHT = 14.7 % BY VOLUME

TOTAL 100

PREPARED BY J.S.

FORM 2

DETERMINATION OF VOLUMETRIC PERCENTAGES

	(a) PERCENT BY WEIGHT OF TOTAL MIX	(b) SPECIFIC GRAVITY OF MATERIAL	(c) $\frac{a}{b}$	(d) PERCENT BY VOLUME OF TOTAL MIX
BIN 1	31.0	2.013	15.40	32.9
BIN 2	22.0	2.568	8.57	18.3
BIN 3	40.0	2.504	15.97	34.1
BIN 4				
ASPHALT	7.0	1.020	6.87	14.7
TOTAL			46.81	100.0

FORM 3

COARSE AGGREGATE-CALCULATIONS OF "A" AND "B"

(a) AVERAGE SIEVE SIZE (mm)	SIEVE SIZE	(b) COMBINED ANALYSIS % BY VOLUME	(c) a x b	(d) WEIGHTED AVERAGE SIZE $\frac{c}{b}$
11.11	$\frac{1}{2}-\frac{3}{8}$	1.3	14.44	
7.14	$\frac{3}{8}-4$	31.6	225.62	
4.18	$\frac{1}{4}-10$			
3.38	4-10	19.3	65.23	
		52.2	305.29	5.85

$A_u = 0.25 \times \frac{c}{b}$

$A_u = 0.25 \times 5.85 = 1.46$ mm

$A_c = A_u \times$ ADJUSTMENT FACTOR (TABLE II)

$A_c = 1.46 \times 0.94 = 1.37$ A= 3

$B_c = 0.75 \times \frac{c}{b}$

$B_c = 0.75 \times 5.85 = 4.39$ mm B= 2

FINE AGGREGATE-CALCULATIONS OF "F

(d) AVERAGE SIEVE SIZE (mm)	SIEVE SIZE	(e) COMBINED ANALYSIS % BY VOLUME	(f) exd	g WEIGHTED AVERAGE SIZE $\frac{f}{e}$
1.21	10-40	12.8	15.49	
0.30	40-80	11.0	3.30	
0.13	80-200	6.1	0.79	
0.04	-200	3.2	0.13	
		33.1	19.71	0.60

$F_c = \frac{f}{e} \times$ FARF (EQUATION I)

$F_c = 0.60 \times 0.925 = 0.555$

F = 5

FORM 4

CALCULATIONS OF "E+C"

	(a)	(b)	(c)	(d)	(e)	(f)
	BIN I	BIN 2	BIN 3	BIN 4		
% BY VOLUME OF +10 MESH	2.9	16.9	32.4			49.3
POLISH VALUE		30	44			
TOTAL	~	507.0	1425.6		1932.6	

WEIGHTED POLISH VALUE = $\frac{e}{f}$

WEIGHTED POLISH VALUE = $\frac{1932.6}{49.3}$ = 39.2

E+C = E 3 (From TABLE I)

FORM 5

DETERMINATION OF SKID QUALITIES OF ASPHALTIC CONCRETE MIX

TEXTURE PARAMETERS DETERMINED FOR MIX

A= 3

B= 2

D= 2

E+C= 3

F= 5

CHART LOCATION	TEXTILE PARAMETER CONSIDERED	FRICTION WEIGHT	
		30 mph	60 mph
CHART 1	E (or E+C)	25	15
CHART 2,3 or 4 (Depending on D)	F	7	6
CHART 2,3 or 4 (Depending on D)	B	22	22
TOTAL FRICTION WEIGHT		54	43

Appendix F

Tables Related to the Study of Portland Cement Concrete using a Circular Track

Appendix F

TABLE F-1 Aggregate Properties

Aggregate Type	SSD Unit Weight (pcf)	Absorption (Percent Dry Wt.)	Specific Gravity (SSD)
Limestone Coarse (SC)	90	2.88	2.68
Limestone Fine (SF)	85	3.05	2.57
Siliceous Fine (GF)	100	.80	2.76
Mixed (SF and GF)[a]	95	1.42	2.54
Lightweight Fine (LF)	91	.6	2.60

[a]64% Siliceous Fine and 35% Limestone Fine, by wt.

TABLE F-2 Environmental Variations

Temperature Range (^{o}F)	Relative Humidity Range (Percent)	Normal Conditions
138 - 141	23 - 27	140^{o} - 25%
73 - 75	25 - 26	73^{o} - 25%
49 - 50	25 - 26	50^{o} - 25%

Appendix F

TABLE F-3 Aggregate Gradations

Sieve Size	Cumulative Percent Retained		
		Fine Aggregates[a]	
	Coarse Aggregate (S)	(G)[a], (S)[b] FM = 2.8	(M)[c], (LF)[d] FM = 3.2
1 - 1 1/2 in.	0		
3/4 in.	34		
3/8 in.	76		
No. 4	100	0	5
No. 8		5	20
No. 16		25	30
No. 30		55	75
No. 50		80	90
No. 100		95	100
No. 200		98	100

[a](G) Siliceous Gravel

[b](S) Crushed Limestone

[c](M) Mixture of 65% Siliceous and 35% Limestone, by wt.

[d](LF) Lightweight Fine Aggregate

TABLE F-4 Surface Finishes

Designation	Finish Type	Description
1	Burlap	A burlap drag accomplished by passing a wet burlap cloth, with approximately two feet in contact with the surface, over the specimen surface until the desired texture is obtained.
2	Brush	Accomplished by passing a plastic-bristle brush over the specimen surface slightly grooving the concrete. The brush is inclined at an angle of approximately 30 degrees to the surface. Usually two passes were required to obtain the desired uniform texture.
3	Longitudinal Tines	Accomplished by passing a series of thin metal strips (tines), 1/8 in. wide, over the specimen surface, producing grooves of approximately 1/8 in. depth in the concrete. One pass was sufficient to obtain the desired texture. The tines spacing used was 1/4 in. center-to-center. Striations parallel to direction of wheel travel.
4	Transverse Tines	Same as longitudinal tines except striations perpendicular to direction of wheel travel.

TABLE F-5 Concrete Mix Data

Test Set	Batch Code	Aggregate[a] Coarse	Aggregate[a] Fine	Percent Absolute Volume: Cement	Water	F.A.	C.A.	Air	Slump (in.)	Initial Unit Wt. (pcf)	Compressive Strength (psi)
1	G	S	G	8.0	13.0	33.4	42.6	3.0	1	147	4440
1	H	S	G	8.9	13.0	32.5	42.6	3.0	1	147	3960
1	I	S	G	10.6	13.0	30.8	42.6	3.0	1	149	4830
1	D	S	G	8.9	13.5	32.5	41.6	3.5	1 1/4	151	4110
1	P	S	G	10.6	13.5	30.8	42.1	3.0	1	147	5620
2	A	S	S	8.9	13.5	32.5	41.6	3.5	1	144	4270
2	C	S	LF	8.9	13.5	22.0	47.6	5.0	3/4	132	4440
2	B	S	S	10.6	13.0	30.8	42.6	3.0	1 1/2	146	5940
2	J	S	S	10.6	13.0	30.8	42.6	3.0	1 1/4	130	4450
2	K	S	LF	10.6	16.5	22.0	45.9	5.0	3/4	133	5400
3	L	S	M	8.9	13.0	32.5	42.6	3.0	3/4	146	3730
3	M	S	M	8.0	13.0	33.4	42.6	3.0	1	144	4450
3	N	S	M	10.6	13.0	30.8	42.6	3.0	1 1/4	146	5500
3	E	S	S	8.0	13.0	33.4	42.6	3.0	1	144	4840
3	F	S	S	8.9	13.0	32.5	42.6	3.0	3/4	146	5380

[a](S) Limestone (I.R. = 2%), San Antonio, Texas
(G) Siliceous (I.R. = 90%), Bryan, Texas
(LF) Lightweight
(M) Siliceous and Limestone (I.R. = 65%)

TABLE F-6 Batch Variables

Batch No.	No. Specimens	Finish [a]	Excess Surface Water [b]	Curing Method [c]	Curing Environment T (F) - RH(%)	Nominal C.F.	Insol. Res. in F.A.	F.M.
A	1	TT	CN	N	50-25	5	2%	3.2
	2	B	CN	N	50-25	5	2%	3.2
	1	Br	CN	N	50-25	5	2%	3.2
	2	LT	CN	N	50-25	5	2%	3.2
B	1	B	CN	WPC	73-25	6	2%	2.8
	1	B	CW	WPC	73-25	6	2%	2.8
	2	LT	CN	WPC	73-25	6	2%	2.8
	2	Br	CN	WPC	73-25	6	2%	2.8
C	1	TT	CN	N	50-25	5	Lightweight	3.2
	2	B	CN	N	50-25	5	Lightweight	3.2
	1	Br	CN	N	50-25	5	Lightweight	3.2
	2	LT	CN	N	50-25	5	Lightweight	3.2
D	1	TT	CN	N	50-25	5	90%	3.2
	2	B	CN	N	50-25	5	90%	3.2
	1	Br	CN	N	50-25	5	90%	3.2
	2	LT	CN	N	50-25	5	90%	3.2
K	1	B	CN	WPC	140-25	6	Lightweight	2.8
	1	B	CW	WPC	140-25	6	Lightweight	2.8
	1	LT	CN	WPC	140-25	6	Lightweight	2.8
	1	LT	CW	WPC	140-25	6	Lightweight	2.8
	1	Br	CN	WPC	140-25	6	Lightweight	2.8
	1	Br	CW	WPC	140-25	6	Lightweight	2.8

TABLE F-6 (Cont'd.)

Batch No.	No. Specimens	Finish [a]	Excess Surface Water [b]	Curing Method [c]	Curing Environment	Nominal C.F.	Insol. Res. in F.A.	F.M.
P	1	TT	CN	N	50-25	6	90%	2.8
	2	B	CN	N	50-25	6	90%	2.8
	2	LT	CN	N	50-25	6	90%	2.8
	1	B	CN	N	50-25	6	90%	2.8
G	1	B	CN	WPC	140-25	4 1/2	90%	2.8
	1	B	CW	WPC	140-25	4 1/2	90%	2.8
	1	LT	CN	WPC	140-25	4 1/2	90%	2.8
	1	LT	CW	WPC	140-25	4 1/2	90%	2.8
	1	Br	CN	WPC	140-25	4 1/2	90%	2.8
	1	Br	CW	WPC	140-25	4 1/2	90%	2.8
H	1	B	CN	WPC	140-25	5	90%	2.8
	1	B	CW	WPC	140-25	5	90%	2.8
	1	LT	CN	WPC	140-25	5	90%	2.8
	1	LT	CW	WPC	140-25	5	90%	2.8
	1	Br	CN	WPC	140-25	5	90%	2.8
	1	Br	CW	WPC	140-25	5	90%	2.8
I	1	B	CN	WPC	140-25	6	90%	2.8
	1	B	CW	WPC	140-25	6	90%	2.8
	1	LT	CN	WPC	140-25	6	90%	2.8
	1	LT	CW	WPC	140-25	6	90%	2.8
	1	Br	CN	WPC	140-25	6	90%	2.8
	1	Br	CW	WPC	140-25	6	90%	2.8
J	1	B	CN	WPC	140-25	6	2%	2.8
	1	B	CW	WPC	140-25	6	2%	2.8
	1	LT	CN	WPC	140-25	6	2%	2.8
	1	LT	CW	WPC	140-25	6	2%	2.8
	1	Br	CN	WPC	140-25	6	2%	2.8
	1	Br	CW	WPC	140-25	6	2%	2.8

TABLE F-6 (Cont'd.)

Batch No.	No. Specimens	Finish [a]	Excess Surface Water [b]	Curing Method [c]	Curing Environment	Nominal C.F.	Insol. Res. in F.A	F.M.
F	1	B	CN	WPC	73-25	5	2%	2.8
	1	B	CW	WPC	73-25	5	2%	2.8
	1	TT	CN	WPC	73-25	5	2%	2.8
	1	TT	CW	WPC	73-25	5	2%	2.8
	2	Br	CN	WPC	73-25	5	2%	2.8
L	1	B	CN	WPC	140-25	5	65%	2.8
	1	B	CW	WPC	140-25	5	65%	2.8
	1	LT	CN	WPC	140-25	5	65%	2.8
	1	LT	CW	WPC	140-25	5	65%	2.8
	1	Br	CN	WPC	140-25	5	65%	2.8
	1	Br	CW	WPC	140-25	5	65%	2.8
M	2	B	CN	WPC	73-25	4 1/2	65%	2.8
	1	LT	CN	WPC	73-25	4 1/2	65%	2.8
	1	LT	CW	WPC	73-25	4 1/2	65%	2.8
	2	Br	CN	WPC	73-25	4 1/2	65%	2.8
N	2	B	CN	WPC	73-25	6	65%	2.8
	1	TT	CN	WPC	73-25	6	65%	2.8
	1	TT	CW	WPC	73-25	6	65%	2.8
	2	Br	CN	WPC	73-25	6	65%	2.8
E	2	B	CN	WPC	73-25	4 1/2	2%	2.8
	2	LT	CN	WPC	73-25	4 1/2	2%	2.8
	2	Br	CN	WPC	73-25	4 1/2	2%	2.8

a. TT - Trans. Tines, B - Burlap, Br - Broom, LT - Long Tines
b. CN - No excess water, CW - Excess surface water (400 sq. ft./gal.)
c. N - No curing compound, WPC - White pigmented curing compound,

APPENDIX G

TEXTURE VALUES OBTAINED IN THE STUDY OF ASPHALTIC CONCRETE USING A CIRCULAR TRACK

TABLE G-1 (Test 3)

Texture Values Obtained in the Study of Asphaltic Concrete Using a Circular Track

No. Applications	Specimen #4			Specimen #21			Specimen #23		
	Putty Impression (In)	Surf-indicator (Surf. Spec)	Surf-indicator (Surf. Agg)	Putty Impression (In)	Surf-indicator (Surf.Spec)	Surf-indicator (Surf. Agg)	Putty Impression (In)	Surf-indicator (Surf. Spec)	Surf-indicator (Surf. Ag
Beg	.017	180	90	.017	220	60	.012	225	150
3,360	.019	200	75	.024	190	50	.014	190	80
10,060	.016	170	70	.020	175	50	.011	230	90
23,520	.018	125	50	.025	175	50	.031	180	75
47,040	.018	150	80	.018	125	---	.019	180	80
65,000	.018	175	120	.020	150	---	.017	260	125
68,360	.019	175	110	.013	200	80	.010	200	125
75,080	.023	150	75	.037	160	100	.017	200	130
88,520	.019	220	70	.020	170	70	.012	230	90
112,040	.019	220	80	.027	220	50	.015	250	60
115,400	.017	180	70	.028	175	40	.024	275	60
122,120	.025	230	70	.027	175	50	.034	200	50
125,480	---	175	60	---	175	70	.025	200	60
132,200	---	200	70	---	150	60	.013	240	80
135,560	---	190	70	---	175	70	.014	250	60
142,240	---	190	60	---	175	45	.017	225	50
145,640	---	200	80	---	200	50	.027	200	90
152,360	---	225	125	---	150	125	.027	250	125

TABLE G-1 (Test 3) (Con't.)

No. Applications	Specimen #25 Putty Impression (In)	Specimen #25 Surf-indicator (Surf. Spec)	Specimen #25 Surf-indicator (Surf Agg)	Specimen #28 Putty Impression (In)	Specimen #28 Surf-indicator (Surf Spec)	Specimen #28 Surf-indicator (Surf Agg)	Specimen #30 Putty Impression (In)	Specimen #30 Surf-indicator (Surf Spec)	Specimen #30 Surf-indicator (Surf Agg)
Beg	.014	200	120	.015	190	125	.018	200	160
3,360	.019	210	80	.011	200	100	.018	190	180
10,060	.017	200	125	.013	200	90	.018	210	130
23,520	.032	150	90	.029	170	70	.032	200	125
47,040	.018	200	120	.020	220	80	.022	200	110
65,000	.020	250	190	.022	225	150	.019	225	180
68,360	.010	175	175	.013	220	150	.016	270	200
75,080	.015	230	150	.009	240	90	.028	220	150
88,520	.050	200	125	.012	250	140	.015	250	160
112,040	.018	220	170	.017	225	125	.014	250	160
115,400	.019	225	170	.014	225	110	.029	250	160
122,120	.018	250	160	.032	200	100	.031	280	180
125,480	.024	200	125	.020	250	75	.022	250	175
132,200	.050	250	125	.009	200	110	.010	260	160
135,560	.013	220	160	.012	275	90	.017	250	200
142,240	.022	150	140	.025	200	100	.019	225	175
145,640	.028	220	160	.020	200	120	.024	200	200
152,360	---	230	200	.034	200	140	.034	275	175

TABLE G-1 (Con't.) (Test 4)

No. Applications	Specimen #4 Putty Impression (In)	Specimen #4 Surf-indicator (Surf Spec)	Specimen #4 Surf-indicator (Surf Agg)	Specimen #21 Putty Impression (In)	Specimen #21 Surf-indicator (Surf Spec)	Specimen #21 Surf-indicator (Surf Agg)	Specimen #23 Putty Impression (In)	Specimen #23 Surf-indicator (Surf Spec)	Specimen #23 Surf-indicator (Surf Agg
Beg	.025	200	110	.027	240	225	.023	200	210
3,360	.025	210	100	.027	190	220	.035	175	190
10,080	.019	200	100	.031	175	175	.031	200	190
23,520	.028	225	60	.029	250	100	.032	225	150
47,040	.027	220	80	.028	200	90	.031	200	125
77,280	.028	200	75	.027	200	70	.027	200	120
120,960	.031	180	60	.025	175	70	.024	175	110
171,360	.029	150	70	.027	150	70	.027	170	110
221,680	.025	140	70	.027	140	70	.027	160	110
265,500	.025	130	70	.023	130	70	.025	150	100
320,000	---	130	70	---	130	70	---	140	90
	Specimen #25			Specimen #28			Specimen #30		
Beg	.031	260	90	.034	220	180	.038	210	225
3,360	.034	210	70	.032	200	150	.029	140	150
10,080	.035	190	70	.028	180	150	.023	140	140
23,520	.034	200	70	.031	175	150	.032	225	130
47,040	.027	175	100	.029	200	150	.023	200	170
77,280	.029	160	100	.027	180	150	.023	190	160
120,960	.040	130	100	.034	170	150	---	170	130
171,360	.032	120	95	.032	150	150	.035	160	130
221,680	.027	130	95	.025	150	150	.029	150	130
265,500	.023	130	95	.027	140	150	.037	160	130
320,000	---	130	100	---	140	140	---	150	120