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DEVELOPMENT OF A PROCEDURE TO
IDENTIFY AGGREGATES FOR BITUMINOUS
SURFACES IN INDIANA

Douglas W. Bruner
Jung Chan Choi
Terry R. West

PURDUE UNIVERSITY

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by

Douglas W. Bruner and Jung Chan Choi
Research Assistants

and

Terry R. West
Research Geologist and Engineer

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16. Abstract Adequate friction resistance is needed to prevent pavement slipperiness and to allow vehicles to stop in a reasonable distance. In stone mastic asphalt surfaces, friction resistance is mainly a function of the interaction between the aggregates exposed at the road surface and the vehicle tires. Performance of the aggregate is reduced over time by wear and polishing as a consequence of vehicular traffic. In this research a method to investigate aggregate performance based on physical, chemical and petrographic factors has been evaluated. The objective was to develop a laboratory method to test Indiana dolomite, limestone, sandstone, and gravel aggregates to predict field performance, and determine causes for the range of values among these aggregates. The assessment of gravel sources was primarily on the basis of individual rock types and those proportions comprising the gravel. Polish and friction values were determined in the laboratory with the British Wheel and Pendulum, and field values with the towed friction trailer. Correlations between parameters were established which provide predictions of friction resistance based on laboratory specimens. Further refinement is required to set performance specifications for in-situ aggregate selection.			
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1. INTRODUCTION

Friction resistance is the force developed when a tire that is prevented from rotating, slides along the pavement surface. Commonly, friction resistance is considered to be a pavement property. It is the opposite of slipperiness (Highway Research Board, 1972).

Bituminous courses are placed over concrete pavements after the concrete has experienced years of wear from highway traffic. The coarse aggregate in the bituminous overlay must supply the primary roughness to yield needed resistance for braking. Although most coarse aggregate types in new bituminous pavements initially provide high friction values, polishing of the coarse aggregate to an equilibrium level eventually occurs. The extent of polishing an aggregate will experience is a function of rock type and gradation, as well as its physical and chemical properties. Difficulties can arise when attempting to isolate the major factors influencing polish and friction properties, and prioritizing those parameters because of their indeterminate and interrelated nature.

The amount of friction provided by a pavement surface is contributed by features of the surface; its macrotexture and microtexture. Macrotexture refers to the large scale roughness of the highway surface which is a function of the geometry of the surface rocks and the relief between them. It is influenced most significantly by aggregate size, and in a portland cement surface by the finishing method. Macrotexture generates resistance to sliding via the hysteresis effects in the tread rubber and facilitates the expulsion of water from the tire-pavement interface. According to Kennedy et al. (1990), macrotexture is a key indicator of a highway's expected performance in terms of friction properties between vehicle speeds of 50 and 130 km/hr. Essentially, the greater the surface relief, the less

reduction in friction properties occurs with an increase in speed. On a friction resistant pavement the contribution of the hysteresis component to the total friction value is usually small. The relatively coarse and open mixes used in Indiana should provide adequate macrotexture, if they are properly mixed and placed. Microtexture, on the other hand, is provided by the surface texture of the aggregate particles themselves and is dependent on the mutual relationship between the grains that comprise a rock

Microtexture is a function of mineral composition, crystal size, structure and other properties of the aggregate. Microtexture, on wet pavements and on specimens, governs prominently the adhesion component because it controls the degree of contact between the rubber tire and the surface. This is accomplished by breaking through the thin water film that remains even after the bulk of the water has been displaced. It is the predominant mechanism affecting friction properties at speeds of up to 50 km/hr. The manner in which microtexture operates is complex because it involves the molecular and electrical interaction between the contacting surfaces (Highway Research Board, 1972). The physical and chemical properties known to affect polish and friction values are texture, composition, durability and soundness.

A review of the literature pertaining to accelerated wear and polishing of aggregates and the measurement of friction resistance reveals that several test methods exist to indicate the extent of wear and polish of aggregates and to measure friction resistance. Wear refers specifically to the loss of material, however gradual. Polishing, on the other hand, involves the loss of material but refers specifically to the smoothing of a surface (Highway Research Board, 1972). The methods which were reviewed are as follows:

- The British Wheel test involves the polishing of aggregate samples (a coupon of aggregates in epoxy) after mounting them on the rim of the road wheel and performing a friction wheel test on them. The polishing action is accelerated by washing grit over the aggregate samples as the friction wheel turns. Aggregate coupons are made by hand placing individual aggregate particles into a mold curved to fit the circumference

of the road wheel and adding epoxy over the particles to hold them in place. Results are obtained on the aggregate specimens before and after polishing by the friction wheel with the use of a free swinging pendulum. The pendulum has a rubber slider which drags across the aggregate surface. The friction between the aggregates and slider slows down the pendulum. The reading obtained from this friction pendulum is reported as the British Pendulum Number (BPN). Details concerning the polishing by the wheel and measuring the BPN are provided in ASTM D-3319 and E-303 (AASHTO T278 and T279). Another method, the NCSU procedure, developed at North Carolina State University, uses larger, flat samples in a larger circular track polishing machine, as specified in ASTM Standard E-660. The NCSU wear and polishing machine employs four pneumatic tires rotating around a central shaft to polish the samples. This polishing procedure more closely simulates the actual field conditions for bituminous pavements. The specimen geometry also allows the use of laboratory fabricated samples or cores. By testing cores, the correlation of field performance becomes more straightforward than with the British Wheel testing. Friction resistance can be measured with a British Pendulum Tester. The Variable Speed Tester is another device similar to the British Pendulum Tester, but gives better results for highly textured surfaces. The Variable Speed Tester is described in ASTM Standard E-707.

- The Michigan Department of Transportation uses a stationary testing device to measure the friction provided by aggregates before and after polishing using a wear track similar to the NCSU circular track wheel polishing device. The stationary friction tester is essentially the same as the towed friction trailer. A full size test tire (ASTM Standard E-501) revolving at 40 miles per hour, is dropped onto the surface of the specimen. An electronic measuring system similar to the one used on the towed friction trailer device, measures the friction level provided. The Aggregate Wear Index (AWI) determined by this method represents the average initial peak force measurement determined on duplicate test slabs after four million wheel passes of wear

track polishing. The MDOT Wear Track test method is described in Michigan Test Method (MTM) 111.

In the study reported here, The British Wheel and Pendulum Test method was used to measure friction resistance. It was selected because it is the most commonly used aggregate polishing test and the equipment to run this test is relatively inexpensive and portable. Details on this test method are provided later in this report.

The challenge of determining the relationship between aggregates and the properties related to friction and polish values is not new. Evaluation techniques have been actively pursued in the United States since the early 1960s. Although approaches may vary from state to state, the goal is essentially the same -- to determine those properties affecting the performance of aggregates in an effort to maintain adequate friction values and safe road conditions.

Some states have been known to evaluate aggregates through mix designs and field testing in an effort to determine an expected level of performance. Other states, such as New Jersey, Kansas and Illinois have taken the process one step further by pursuing studies relating aggregate properties and friction values. The emphasis of these studies was to determine a method, through chemical and physical parameters, which provides a timely prediction of the performance of local aggregate sources.

A detailed petrographic examination is necessary to determine the texture and composition of aggregates. The two direct textural parameters which receive most consideration as factors affecting frictional properties are grain size and shape. Angular grains, at least initially, have a tendency to develop harshly textured surfaces and provide a greater degree of resistance as compared to rocks containing smooth grains. Dierstein and LaCroix (1984) reported that resistance to polishing effects of aggregates is related to grain size, hardness and durability. Larger and harder grains generally provide greater friction values. As an example to illustrate this relationship, Dierstien and LaCroix compared dolomite and limestone sources. Dolomites with generally larger and harder grains, proved superior to limestones. In a study by Shakoor and West (1979), grain size

and particle shape were found to affect polish and thus friction properties; however, they contributed to a lesser degree than did composition.

Groundmass and void content also have an affect on polish and friction values. Overall, it is generally understood that a large percentage of groundmass will increase polishing which, in turn, causes a decrease in friction properties. Fine material has a tendency to fill the void space between grains yielding a smoothing effect. Conversely, a small amount of groundmass may prove beneficial. Large and hard grains within a soft matrix material, such as some sandstones, allow for renewal of rock surfaces to occur as mineral grains break away. The presence of voids provides the gaps in which finer material can collect. As rock surfaces wear, it is possible for newly textured surfaces to develop as inner voids are exposed at the surface. This may be a reason why slag is an effective material to supplement natural aggregates in surface courses.

As mentioned previously, composition has been found to be a principal factor influencing aggregate performance. Review of the study by Russell (1972), provides the reason why magnesium content was selected as the criterion for acceptance of dolomite aggregates in Indiana. A high percentage of MgO corresponds directly with a high dolomite concentration. Russell's study of Illinois aggregates showed that percent MgO had a positive correlation with friction value, that is, greater friction values occurred with increases in MgO content.

In a study performed by Shupe (1958), an increase in magnesium content with Indiana limestone sources showed an increase in friction properties. Shupe noted that it was not the presence of magnesium influencing performance, but the purity of the sample determined with the presence of magnesium. In other words, the less pure limestones having greater magnesium content and thus greater mineral diversity were superior aggregates.

Russell also observed a negative correlation between friction value and quartz content for these dolomite sources. A general decrease in friction value was also observed with an increase in the calcite concentration.

Russell's study of carbonate aggregates, and that by Cummings (1976) focused on acid-insoluble residue content. Russell's study included carbonate aggregates containing less than 12 percent insoluble residue. A positive correlation was found between acid-insoluble residue >74 microns in size and friction values for the dolomite aggregates; however, little correlation was found between these factors for carbonate aggregates in general. Cummings analyzed aggregates containing up to 25 percent acid-insoluble residue. He found a positive correlation with friction value for dolomite aggregates containing insoluble-residue retained on the No. 200 sieve, as well as with the ratio between the No. 30 and No. 200 sieves. In essence, regarding those aggregates having greater than 70 percent of their insoluble material retained on the No. 30 sieve, they yielded poor results in terms of friction values as compared to samples whose majority of insoluble material occurred on the No. 200 sieve.

Dierstein and LaCroix (1984) also mentioned a relationship between acid-insoluble residue and friction values. They concluded that grain size was the primary mechanism affecting variation in friction values for carbonates containing less than 10 percent insoluble content. At greater than 25 percent, the sand size acid-insoluble residue generally accounts for higher friction values.

The common physical parameters deemed to have an impact on aggregate performance are absorption, soundness, abrasion and specific gravity. Senior and Rogers (1991) provide a thorough overview of the first three of these parameters and their significance in evaluating highway aggregates. Los Angeles abrasion is a test commonly used to measure an aggregate's ability to withstand abrasion and impact. The steel balls in the test procedure impart a heavy blow to the oven dried aggregates in a rotating steel drum. This, however, generally does not depict the traffic conditions or the abrasion that occurs on road surfaces from tire contact. Another problem is that the abrasion test on dried aggregates does not truly reflect actual road conditions. In studies referenced by Senior and Rogers, the abrasion loss was increased nine times with an additional moisture content of 5 percent. Aggregate type also influences the test results. Generally, weaker

argillaceous rocks have a tendency to absorb the impact of the steel balls, whereas coarse-grained crystalline materials do not and they experience higher losses.

The sodium sulfate soundness test is a measure of an aggregate's durability and thus, its resistance to weathering. In this test, sodium sulfate crystallization is used to simulate the effects of ice formation during the freezing process. Although this test is currently used by INDOT, it is expected that it will eventually be replaced by the freeze-thaw test owing mostly to the difficulty in obtaining reproducible test results for the sodium sulfate test. Another factor to consider is that the sodium sulfate test likely does not reflect actual weathering conditions.

A relationship between absorption and freeze-thaw resistance is known to exist. Although there are exceptions, aggregates with high absorption generally have lower freeze-thaw resistance. Senior and Rogers (1991) have concluded that the following combinations of tests; Los Angeles abrasion loss, sodium sulfate loss, and absorption; can be used to differentiate between good and poor aggregates. However, these tests are not very accurate in predicting the performance of marginal aggregates. Therefore, as indicated above, these physical tests have shown some shortcomings when predicting field performance.

Specific gravity is related to composition and absorption. Variations in composition within an aggregate source increase with differential polishing. The presence of compositional variation has been shown to retard the effects of polishing by vehicular traffic.

2. PROBLEM STATEMENT

Natural aggregates used in highway construction in Indiana are crushed carbonate rocks and glacial river gravels. This includes both base courses and aggregates for the pavement itself. Historically, dolomites have been specified for use in surface courses for medium volume roads and a combination of dolomite and blast furnace slag used for surface courses of high volume roads. Good friction resistance of the surface course is needed to prevent pavement slipperiness and to allow vehicles to stop in a reasonable distance. Following pavement construction, the frictional resistance of pavements has been monitored after certain time intervals using the ASTM E-274 procedure, "Towed Friction Trailer."

This specification method has ensured that the aggregates and the pavements are evaluated over time but the procedure has had complications. The testing time involved (5 years) has restricted the approval of those aggregate sources for which the Indiana Department of Transportation has no performance data. This includes such aggregates as granite, gneiss, and sandstone. Furthermore, identification of good aggregates for use in surface courses is a subject of increased interest as stone mastic asphalt surfaces (SMA) are now proposed for use in Indiana. Because the performance of SMA surfaces depends on a strong aggregate framework, high quality aggregates are required. The aggregates must provide adequate friction as well as high strength and durability.

Strength and durability can be predicted using physical tests currently used by the Indiana Department of Transportation. However, a laboratory program should be developed in order to adequately predict the field frictional performance of aggregate sources. Although road surfaces would still require monitoring, initiation of a laboratory

program would assist in the segregation between good and poor aggregates before their emplacement in SMA surfaces. This would ultimately lead to less maintenance requirements as a result of aggregates in these surfaces maintaining frictional property expectations. Highway friction levels are important with respect to maintaining safe driving conditions primarily during wet conditions.

3. OBJECTIVES

This report describes the research efforts to determine the wear and polishing properties of aggregates, and how their properties affect friction resistance of pavements containing these aggregates. In addition, for dolomite, the primary natural aggregate material used in surface courses, the study includes a detailed evaluation of standard laboratory tests and petrographic evaluation of the materials. Objectives investigated and reported here are as follows:

- Identify, modify, or develop a method to test aggregates in the laboratory to predict their field frictional performance or at least rank their performance relative to an acceptable reference range.
- Determine causes for the range of values for different aggregates based on the same test. Compare field, laboratory and petrographic data through statistical analyses to determine the relationship among these various tests and parameters in an attempt to predict field performance based on laboratory tests.

There were two companion studies conducted by individual researchers in this extensive evaluation. The first study was concerned with gravel and dolomite samples which involved an analysis of individual rock types that comprise the gravel. This portion of the work focused on the British Pendulum tester and the British Polishing Wheel which were used to test coupons made from the gravel constituents and the carbonate quarry samples. The second portion was a detailed study of dolomite sources used in surface courses for bituminous pavements. This involved laboratory testing and a detailed

petrographic and chemical analysis of these aggregates. Information from the two studies has been combined to provide the information presented here which comprises this overall discussion on aggregates for bituminous surface courses.

4. WORK PLAN

4.1 Overview

Under the current specifications for state highway construction surface courses for medium volume roads in Indiana, dolomite aggregates are required and are evaluated on the basis of the following: magnesium content, Los Angeles abrasion, sodium sulfate soundness, absorption and specific gravity. There are however, other aggregate types that also might be acceptable for use in these bituminous courses, but because of a lack of field performance data or a proper procedure to identify significant characteristics, these aggregates have not typically been used. Methods used to specify alternative aggregate types have been based on proven experience through previous applications and field trials. This of course, makes it difficult to approve materials not previously used.

An objective of the dolomite study was to assist INDOT in developing procedures to allow a systematic evaluation of aggregates for use in bituminous highway overlays. The fundamental approach for this part of the study was to evaluate petrographic and physical characteristics that constitute aggregates with good polish resistance and that can maintain reasonably high friction values. The approach for the research was as follows:

- Sample collection
- Laboratory testing
- Field friction testing
- Inspection and sampling of test sections
- Data analysis

This program was designed to evaluate aggregate materials based on two procedures: (1) laboratory testing and (2) field testing (Figure 4.1). The first involved the collection of crushed aggregate samples from quarries throughout Indiana and from some areas bordering the state, for subsequent laboratory analyses. Since dolomite is the most commonly used aggregate for bituminous overlays, nineteen sources of No. 11 Indiana graded aggregates were collected for purposes of comparison. One source was designated as the reference to which all others would be subsequently compared. Two limestones, two sandstones and six river gravels were also included in this study.

Based on laboratory test data, a continued evaluation of prospective aggregate sources is expected to improve the capability of predicting aggregate performance for specific applications. The laboratory approach in the current study involved an evaluation of aggregate sources using sieve analysis, detailed petrographic examination, physical testing and composition analysis. The petrographic factors evaluated were grain size, grain shape, percentage of groundmass and void content. Physical properties were evaluated by reviewing test data available on the aggregates included in this study. The physical tests evaluated included sodium sulfate soundness, specific gravity, Los Angeles abrasion and absorption. Analyses performed which related directly to mineral composition were the percentage of acid-insoluble residue, elemental magnesium content, polarizing microscope analysis and x-ray diffraction.

These aggregates were also tested for polish and friction properties. Laboratory evaluation of these two properties was accomplished through the use of (1) the British Wheel which polishes the aggregate and (2) the British Pendulum which measures the friction values before and after polishing. The largest aggregate pieces comprising the No. 11, crushed stone graded sample for each source are 3/8 inch in size. These aggregate pieces were selected to construct coupons using a mold and epoxy cement. Coupons were measured for friction value in British Pendulum Numbers (BPNs) based on the British Pendulum tester and reported as the Initial Friction Value (IFV). Subsequently, these coupons were polished to an equilibrium value using the British Wheel and tested again for frictional resistance. The Polished Value (PV) is a measure of the polish

Laboratory Testing

Petrographic Examination

Sieve Analysis
Grain Size
Grain Shape
% Groundmass
Void Content

Composition

Elemental Mg Content
(Dolomite)
X-ray Diffraction
Polarizing Microscope
(Sandstone)
Acid-Insoluble Residue

Physical Properties

Sodium Sulfate Soundness
L.A. Abrasion
Specific Gravity
Absorption

British Pendulum

Quarried Aggregate
(IFV)

British Wheel

Quarried Aggregate
(PV)

Field Testing & Sampling

Towed Friction Trailer

Smooth Tire
(AFN)

Towed Friction Trailer

Ribbed Tire
(AFN)

Macrotexture Depth

(MATXd)

Cored Surfaces

(BPN)

British Pendulum

Extracted Aggregate
(IFV)

British Wheel

Extracted Aggregate
(PV)

Physical Properties

Sodium Sulfate Soundness
L.A. Abrasion
Specific Gravity
Absorption

Figure 4.1. Applied laboratory and field tests.

threshold for a given aggregate source. The difference between the IFV and PV is a direct measure of the polish susceptibility for an aggregate based on the polished level it will experience, and is termed the Wear Index (WI). Results of this study indicate that polish susceptibility and laboratory threshold values may be good indicators of field performance.

The second approach, which involved field friction testing and sampling, made it possible to compare the Average Friction Numbers (AFNs) obtained from highway surfaces to the IFV and PV determined in the laboratory, for those aggregates embodied in the cored pavement. The smooth and ribbed tires of the towed friction trailer were used to measure friction levels associated with texture on the surface of specific pavement sections. After these friction values were obtained, those same road surfaces previously tested by the trailer, were cored to obtain samples. These cores were transported to the laboratory and the upper surfaces measured for friction value using the British Pendulum tester. After obtaining the BPN of the core surfaces, the bitumen was stripped from the cores and the aggregate reclaimed. This retrieved aggregate was then molded into coupons using epoxy cement, measured for IFV, polished by the British Wheel, and tested for PV and WI in the same manner as that accomplished for the quarried aggregate.

Data analysis provided the final step in the evaluation of results from both the laboratory and the field. Data generated through laboratory and physical tests on the extracted aggregates, as well as the BPN values from the core surfaces were correlated with the associated AFNs (Figure 4.2). The AFNs obtained with the smooth and ribbed tire of the towed friction trailer were correlated with their respective laboratory IFV and PV. Also correlated was macrotexture depth ($\text{MATX}_d \times 10^3$) which is calculated using the smooth and ribbed tire friction values determined with the towed friction trailer.

The other part of the study was concerned primarily with gravel samples, and involved an analysis of the individual rock types that comprise the gravel sources included in the study. It included the evaluation of the British wheel testing on quarry aggregates as well. This work involved the preparation of all of the coupons ultimately tested by the British Polishing Wheel and the British Pendulum test. Megascopic evaluation of the aggregate samples, both the carbonates and the gravel samples were determined during

Figure 4.2. Correlation of laboratory and field tests.

this part of the study. However, a detailed microscopic petrographic analysis and associated laboratory analysis were conducted on only the dolomite and related samples.

4.2. Sampling

Because limestone and dolomite are the only bedrock materials used extensively for highway surface courses in Indiana, nineteen crushed dolomite samples were collected from 19 different quarries and one limestone sample was collected from another quarry. This preponderance of dolomite samples occurred because it is the preferred aggregate for bituminous surface wearing courses for moderate traffic roads in Indiana and for high volume roads when blended equally with slag. A sample of 60 kg of Indiana No. 11 size was collected from each quarry. The sampling procedure is described in Indiana Test Method (ITM) 207, "Method of Sampling Stockpiled Aggregates," which supplements AASHTO T2, "Standard Method of Sampling Aggregates," for the purposes of sampling from stockpiles. In addition, two sandstone samples from southern Illinois, six river gravel samples, one dolomite sample, and one limestone sample were obtained through INDOT.

4.3 Sieve Analysis

Aggregate samples obtained from quarries and from INDOT were reduced to 7.5 kg according to the Indiana Standard Specification 904.03 (c), "Minimum Weight of Test Sample," which supplements ASTM Standard C-702 and AASHTO Standard T 248, "Reducing Field Samples of Aggregate to Testing Size." A mechanical splitter was used for this procedure. The size of sieve analysis samples required for coarse aggregates sampling is shown below.

A detailed procedure for sieve analysis is specified in ASTM Standard C-136. The corresponding AASHTO Standard is T 27, "Sieve Analysis of Fine and Coarse Aggregates." Grain size distribution of No. 11, which is used for bituminous surfaces, is also shown below according to Indiana Standard Specification 904.02 (e).

Aggregate Size	Minimum Weight of Test Sample
No. 1	150-200 lbs. (69-90.7 kg)
No. 2	25 lbs. (11.3 kg)
No. 5, 8, 53, and 91	6-8 kg
No. 9 and 11	4-6 kg

Sieve	Coarse Aggregate Sizes (Percent Passing)		
Sizes	No. 5	No. 9	No. 11
1 1/2" (37.5 mm)	100		
1" (25 mm)	85-98		
3/4" (19 mm)	60-85	100	
1/2" (12.5 mm)	30-60	60-85	100
3/8" (9.5 mm)	15-45	30-60	75-95
No. 4 (4.75 mm)	0-15	0-15	10-30
No. 8 (2.36 mm)	1-10	0-10	0-10

The results of grain size distribution showed that almost all the collected samples fell within the range of No. 11 category. All except one uncrushed gravel sample fell within the No. 5 size gradation and one sandstone sample qualified as a No. 9 size gradation. The results are shown in Table 4.1.

The aggregates were sieved to produce samples that would pass the 1/2" size mesh but would be retained on the 3/8" sieve in accordance with ASTM Standard D-3319 and AASHTO Standard T 279, "Accelerated Polishing of Aggregates Using the British Wheel." The aggregate sample was then washed, dried and stored for future test specimen preparation. An approximate total of 700 kg of aggregates was sieved in order to obtain aggregates pieces showing a relatively flat surface and a minimum 3/8" thickness.

4.4 Experimental Procedures

In the second part of the study two approaches were used to provide a thorough examination of the dolomite aggregates used in overlay pavements -- these being laboratory testing and field testing. Laboratory analysis of the rock specimens consisted of the following: sieve analysis, detailed petrographic examination, acid-insoluble residue testing, x-ray diffraction, elemental magnesium analysis and the British Pendulum test. The purpose was to obtain data to correlate quantitative results of these tests with laboratory friction values known as the British Pendulum Number (BPN). The BPN for constructed coupons is recorded as the Initial Friction Value (IFV). After polishing of the coupons the BPN is recorded as the Polished Value (PV). The difference between the two measurements is termed the Wear Index (WI).

Where possible, specific laboratory results have been compared to companion data for purposes of verification. For example, petrographic analysis results produced by one observer were compared to those provided by a second observer. Both the magnesium content and x-ray diffraction were used to determine the relative percentages of minerals present in the aggregate sources. Because a high carbonate content in the sandstone sources was suggested by petrographic studies, the insoluble residue test was then performed to verify the compositional analysis of the sandstones. The acid-insoluble test involved a straightforward procedure involving the analysis of three samples per source.

Field testing consisted of Average Friction Number (AFN) determinations obtained directly from highway surfaces through the use of the towed friction trailer. Coring of the bituminous highway surfaces was accomplished following friction testing. The surface of the cores and exposed aggregates were measured for friction values in the laboratory. This allowed a method to correlate laboratory and field friction values.

4.4.1 Petrographic Analysis of Dolomites

A detailed petrographic examination was necessary to determine the texture and general mineral composition of the carbonate and sandstone sources. This analysis included the determination of average grain size, grain shape, percentage of groundmass

and void content. Aggregate pieces 3/8 inch in size were subdivided with a mechanical splitter so that approximately 200 pieces of rock remained as the representative sample. Individual pieces were separated based on variations in composition, color and texture. A correction factor was determined for each subgroup using weight percent in order to compensate for composition and texture variations. Afterward, a number of thin-section samples were selected to represent the diversity of aggregates within a source. A modal analysis of individual grains for each thin-section was determined using a polarizing microscope, calibrated eyepiece and mechanical stage.

4.4.2 Grain Size

Krynine (1948) defines texture as the interrelationship between the individual particles that comprise a rock and he also indicates size definitions for rock texture. Fine grained rocks are those with an average grain size less than 0.0625 mm, and medium grain size texture lies between 2.0 and 0.0625 mm. These are the boundaries which subdivide particles into the common designations of silt and sand. All of the analyzed samples fell within these two categories.

The size of individual grains was determined based on the point count method by advancing a thin-section a specified distance using the mechanical stage on the polarizing microscope. After a grain was isolated by the cross-hairs of the calibrated eyepiece, the stage was rotated to measure the grain along its greatest dimension. A minimum of 200 grains was measured per thin-section to ensure a confidence level of 95%. The standard deviation of the grain size was determined for each sample, providing a means to check the grain size heterogeneity.

4.4.3 Grain Shape

In a previous study performed by West et al. (1970), grain shape was determined through the use of Krumbein's pebble roundness chart (Krumbein, 1948). This chart also proved helpful in the current study. Based on a scale of 1 to 10, the majority of the grains

were found to be euhedral to subhedral in shape, measuring from 1 to 4 and averaging between 2 and 2.5 (Figure 4.3).

Subsequently in the study, it was determined that the range of grain shapes between samples was apparently too narrow to provide a useful correlation with BPN values. An angularity chart developed by Lees (1964) was found to provide a greater range of grain shapes possibly allowing for a more detailed correlation. Lees' chart consists of 16 categories of angularity (Figure 4.4). For simplicity, the scale was modified to measure values between 1 and 16, with 1 being rounded and 16 very angular. Approximately 30 percent of the samples were analyzed using this method, resulting in a range extending from 6 to 10. The degree of angularity appears to correspond closely with that of Krumbein's chart, with essentially the same range of parameters. Grain shape was measured concurrently with grain size.

4.4.4 Groundmass

Very fine or amorphous material was commonly intercepted by the cross-hairs in the calibrated eyepiece. This material is termed groundmass and was subdivided into two categories -- cement and matrix. Cement is defined as the fine to coarse material between grains; and matrix as the fine material commonly surrounding floating grains. In many instances, it was difficult to distinguish between these two materials. Ultimately, the best procedure, as concluded in this study, is not to attempt to distinguish between cement and matrix, but to include them collectively as groundmass.

4.4.5 Void Ratio

Void ratio measurements were based on the observation of voids viewed under the cross-hairs of the calibrated eyepiece, while moving the thin section a specified distance on the mechanical stage of the polarizing microscope. The percentage of voids was determined as the ratio of the voids counted to the total point counts for the sample. Voids as small as 0.003 mm were recorded.

Figure 4.3. Krumbein's Pebble Roundness Chart (1948).

4.4.6 Composition

4.4.6.1 Magnesium Content

A dolomite that qualifies for aggregate use in bituminous surface courses for the moderate traffic category is defined, according to INDOT, as a carbonate rock containing from 10.3 to 13.2% elemental magnesium. INDOT currently uses the elemental magnesium content analysis as the acceptance criteria for dolomite sources, with a minimum level set at 10.3%. Seventeen of the sources were analyzed using an EDTA titration method in accordance with ASTM procedure C 602, Specification for Agricultural Liming Materials. This information was provided by INDOT. Data on the percentage of elemental magnesium were correlated with the polish resistance and BPN values to evaluate its significance as an acceptance criterion. The relative percentage of dolomite was calculated directly from percent elemental magnesium.

$$\text{Mg Fraction in Dolomite} = \frac{\text{Molecular Weight of Mg}}{\text{Molecular Weight of MgCa}(\text{CO}_3)_2} = \frac{24.31\text{g}}{184.41\text{g}} = 0.1318$$

$$\% \text{Dolomite} = \frac{\% \text{Elemental Mg}}{0.1318}$$

Therefore, 10.3% elemental magnesium corresponds with 78.1% dolomite whereas 13.2% corresponds with 100% dolomite in the aggregate.

4.4.6.2 X-Ray Diffraction

The minerals comprising the greatest abundance in the carbonate rocks sampled in this study are dolomite and calcite, with quartz and other silicates as secondary constituents. Dolomite and calcite show quite similar appearances under polarized light. Difficulties occurred during the attempt to distinguish between these two minerals using traditional petrographic techniques. This is a common petrographic challenge.

Determination of the composition of cement and matrix materials also involved a degree of uncertainty. In an effort to avoid a subjective approach and to maintain

reasonable consistency, x-ray diffraction was selected as the preferred method to quantify the relative proportions of the two carbonate minerals. This was selected rather than the carbonate staining methods which also yield some inaccuracies.

X-ray diffraction is a method that utilizes the intensity of x-rays diffracted from crystal surfaces to determine the relative proportions of those minerals present. For calibration purposes, relatively pure samples of dolomite and calcite were obtained from Ward's Earth Science Inc. These standards were prepared for use in the diffractometer similar to that procedure recommended by Hutchinson (1974). The standard samples were crushed using a mortar and pestle until most of the 10 gram samples passed through a 230 mesh sieve. The standard samples were then oven dried at about 110°C and placed in a dessicator. Relative proportions of these two standards were mixed by weight percent in intervals of 10 percent, to provide known concentrations or ratios of calcite to dolomite for use as standards.

The primary intensity peak for dolomite occurs at 31.0° and for calcite at 29.40°, 2θ. Three samples were prepared at each of the 10 percent interval concentrations and placed, in turn, in the diffractometer. The areas under the major calcite and dolomite peaks were calculated and a ratio of the two determined. A best fit calibration curve was obtained, yielding a correlation coefficient of 0.91 based on these points using a program titled Table Curves by Jandel Scientific. The calibration curve is similar to that utilized by Tennant and Berger, 1957 (Figure 4.5).

Previous to this work, aggregate pieces 3/8" in size had been divided into groups on the basis of major composition, texture and color variation for a given source. Approximately 100 grams of aggregate were obtained for each source to ensure a representative percentages for these properties. The aggregate sample was passed first through a jaw crusher and then twice through a pulverizer. Subsequently, each source was quartered and one fourth of the sample was crushed further using a mortar and pestle. Crushing continued until approximately 17 grams passing the 230 mesh sieve were obtained for each source. The samples were oven dried and placed in a dessicator. The

Figure 4.5. X-ray diffraction calibration curve.

calcite to dolomite ratio was determined based on x-ray diffraction in the same manner as performed on the standards. Three samples from each source were analyzed.

Other lower intensity peaks were commonly observed. Included were those for quartz and for clay minerals such as illite, gibbsite and kaolinite. Because of the presence of these other minerals, it was not possible to determine directly the exact proportion of dolomite from the calibration curve. The total soluble fraction (S), obtained from the acid-insoluble residue test, was multiplied by the dolomite fraction (D) determined from the peak ratios and calibration curve. In the event that a ratio could not be calculated owing to the small amount of calcite present, it was assumed that calcite was absent. For cases when calcite was obviously present, its percentage was determined by subtracting the percent insoluble material (I) and the percent dolomite (D) from 100. An average of the differences between the value of dolomite obtained in the magnesium analysis from that obtained in the x-ray diffraction analysis was 3.6 percent.

Calculations:

$$\% \text{Dolomite} = (D \times S)100$$

$$\% \text{Calcite} = 100 - \%D - \%I$$

4.4.7 Polarizing Microscope

It was anticipated that the analysis of mineral composition for the sandstone sources would be difficult because of the diversity of minerals generally present in these rocks. In order to account for the relative concentration of minerals present, traditional petrographic methods were expected to provide the best results. A polarizing microscope and the point count method were utilized in this analysis.

The mineral composition of the sandstone sources turned out to be rather simple. Carbonate and siliceous materials were found to be the predominant constituents based on polarized light microscopy. Quartz was generally observed as anhedral crystals, and as a

result of the somewhat thick nature of the thin-sections, it was found to be slightly yellow in color. Euhedral rhombs and groundmass were assumed to consist of carbonate minerals. Later, because of this observed high concentration of carbonate minerals in the sandstone, it was decided to perform an acid-insoluble test. The acid-insoluble test results corroborated the results of the petrographic analysis. Results of the two tests, petrographic and acid-insoluble, only differed by a range from 3 to 12 percent.

4.4.8 Acid-Insoluble Residue Test

The acid-insoluble test was performed by dissolving approximately 500 grams of the aggregate graded finer than a 3/8 inch sieve in 6N HCl. Three tests were performed on each source and the average determined as the percent insoluble. Initially, it was assumed that the larger grain sizes obtained would be the predominant and important insoluble material by weight, and the material finer than the No. 200 sieve could be ignored. However, after reviewing of the data and evaluating the technique, it was determined that, in most cases, the silt and clay size material was the predominant insoluble fraction and must be considered. The insoluble analysis was completed on all of the carbonate samples using ASTM procedure D 3042, Standard Test Method for Insoluble Residue in Carbon-ate Aggregates. Although not currently within the scope of this study, identification and quantification of the fine material through x-ray diffraction analysis may yield interesting results with respect to polish and BPN values.

4.4.9 Physical Properties Based on Laboratory Testing

Existing data for the representative sources were obtained from the Indiana Department of Transportation. The sodium sulfate test is currently used to determine aggregate soundness. Because there has been some difficulties in obtaining reproducible results for this test, an unconfined freeze-thaw test is expected to eventually replace it. Three other tests related to aggregate quality and soundness were considered, these were specific gravity, absorption and Los Angeles abrasion.

4.4.10 British Wheel Procedure

The British Wheel test procedure involves the use of two separate pieces of equipment. The first of these is known as the British Wheel machine. The second is the British Pendulum. In the late 1950s, the Road Research Laboratory (RRL), of London, England, developed a laboratory test for investigating the extent to which aggregates used in pavement surfaces will wear and polish when subjected to heavy traffic conditions. This test was adopted as a British Standard (BS 812) for use in preevaluation of aggregate performance. Later, this procedure was included in ASTM Standard as ASTM D 3319 and ASTM E 303.

4.4.10.1 British Wheel Machine

The British Wheel machine is depicted in Figure 4.6. The apparatus was designed to obtain a rapid rate of wear and polish by passing each specimen of aggregate under a pneumatic tire driven at a speed of 320 ± 5 revolutions per minute (15 miles/hr). The major components of the British Wheel are as follows:

- Road Wheel -- Aggregate specimens were prepared and mounted on the 16-in. diameter steel wheel having a flat periphery 2-1/2 in. wide (Figure 4.7).
- Rubber Tired Wheel -- Originally, an industrial 8 X 2 pneumatic smooth-tread hand-truck tire (Dunlop RLI 8 X 2) was used for this test, but Dunlop discontinued manufacturing this tire in February 1979. Therefore, an alternative tire was used for this study and modification of the steel wheel was necessary to mount the alternative tire, as per ASTM Standard D-3319. The aggregate surface was in contact with a cross-hatch pattern tread tire equivalent to a Goodyear Industrial All Weather Hand Truck Tire, size 8-in. diameter (Goodyear Product Code 202-008-002) with an inner tube (Goodyear Product Code 199-010-700). The pneumatic tire was inflated to a pressure of 35 ± 2 psi. The tire rests on the road wheel test specimens with a force of 88 ± 1 pound. This force is developed by a weighted lever system in which the axle of the rubber tired wheel is fixed.

Figure 4.6. The British Wheel machine.

Figure 4.7. The Road Wheel.

Figure 4.8. Some prepared specimens.

- Grit Feed System -- Accelerated wearing and polishing is induced by the continuous, uniform application of an abrasive between the rubber tire and the road wheel. 150-grit size silicon carbide grit is vibrated from a small hopper to a chute at a rate of 6 ± 2 g/min. Water is supplied at a rate of 50 to 75 ml/min and washes the grit onto the road wheel near the point of contact of the wheel and rubber tire.
- Aggregate Specimen -- The aggregates were sieved to produce samples that would pass the 1/2-in. square mesh size but would be retained on the 3/8-in. sieve. They were then washed, dried, and stored for future specimen preparation. Only aggregate particles which had relatively flat surfaces and a minimum 3/8-in. thickness were used for making the specimens. Each specimen was prepared by closely placing each aggregate in an inverted mold. Wax was placed on the mold sides and the top plate to act as a release agent. Ottawa sand was used to fill the space between each aggregate particle so that the tops of the aggregates were exposed. A polyester resin material was mixed with methyl ethyl ketone peroxide (MEKP) and placed in each mold to anchor the aggregate and complete the specimen. Each molded specimen was then allowed to cure for at least 3 hours before removal from the mold. The mold and the top plate were then taken apart and the molded specimen removed. The sand, placed in the bottom of the inverted mold, prevented the polyester resin from penetrating to the bottom of the mold or to the wearing surface of the specimen. Specimen preparation was a very tedious and time consuming process, and there were problems on the change of pot life whenever a new supply of polyester resin was delivered from the manufacturing company. Some prepared specimens are shown in Figure 4.8.

The British Wheel simulates the polishing action of vehicular traffic on the aggregate. Fourteen curved coupons, two samples consisting of ten molds and four control specimens, are inserted along the circumference of the steel wheel. The small pneumatic tire is placed in contact with the molds on the steel wheel. As the tire and wheel turn grit and water are evenly applied to initiate a polishing action. The aggregates are polished for a period of approximately ten hours -- the period of time at which polish

equilibrium generally occurs for most rock types. These results provide the polish susceptibility for a given source of aggregate. This process was accomplished using ASTM procedure D 3319, Accelerated Polishing of Aggregates Using the British Wheel.

4.4.10.2 British Pendulum Tester

Friction values on the aggregate coupons were measured before and after polishing using a device known as the British Pendulum. The British Pendulum Tester is a dynamic pendulum impact tester which measures the energy loss when a rubber slider edge is propelled by gravity over the aggregate test specimen (Figure 4.9). After removal from the polishing wheel, each test specimen is cleaned of all grit, then locked into the specimen base. The pendulum tester is leveled and zeroed, and the height of the pendulum is adjusted so that the slider impacts the same area of the test specimen at each test, and a thin film of water is applied to the specimen. Then, the pendulum is released. A pendulum arm of fixed radius (20 in.) and weight (5 lbs) falls freely under gravity. The rubber slider affixed to the end of the arm makes contact with the surface under a preset normal load and for a specific contact length. The angle between the pendulum arm and the horizontal after the slider passes over the surface is a measure of the energy absorbed by that surface. A large angle indicates a high energy loss, whereas a small angle indicates little energy loss. When the pendulum arm is released from a fixed initial horizontal position, it carries a pointer along a circular scale calibrated to read frictional measurements known as British Pendulum Numbers (BPN). The numbers range from 0 to 150.

The values obtained from the first three swings are not recorded, so as to allow the slider to self-adjust to the surface of the specimen. Five swings are then made, and their values recorded along with the numbers of hours of polishing. Water is added between each recorded measurement. Prior to polishing an aggregate sample the friction value of the aggregate is determined with the British Pendulum and termed the Initial Friction Value (IFV). The BPN obtained as a consequence of polishing with the British Wheel and measured with the British Pendulum is called the Polished Value (PV). The

Figure 4.9. The British Pendulum tester.

difference between the IFV and PV is termed the Wear Index (WI), which indicates a reduction in frictional resistance depicted for a given aggregate source.

Two sizes of rubber slider are available for use with the apparatus and the one to be selected depends on the shape of the test surface. A 1/4 by 1 by 3-in. rubber slider is used for testing flat surfaces and a 1/4 by 1 by 1 and 1/4-in. rubber slider is used for testing curved polishing wheel specimens. Details of the procedure are provided in ASTM procedure E 303, Standard Method for Using the British Pendulum Tester.

4.4.11 Towed Friction Trailer

The second approach to determine friction characteristics of a given aggregate is accomplished using field testing. In this method the level of friction is measured on traveled sections of selected highways using an instrument called the towed friction trailer. ASTM procedure E 274, Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire, is the procedure used for this method. Older road surfaces in reasonably good condition, requiring little resurfacing maintenance, were chosen for analysis in this part of the study.

The trailer is towed behind a truck at speeds of approximately 40 to 50 mph, with all readings being normalized to 40 mph using well-established, highly accurate correlation equations. Water is sprayed on the roadway and then, when activated, the smooth and ribbed test tires on the trailer are alternately locked for individual periods of 1.2 seconds. At this point the frictional resistance between the locked tire and wetted highway surface is measured. The first 0.2 seconds of each measurement cycle is disregarded, with 100 measurements obtained and averaged during the remaining 1.0 second.

The recorded friction values for a given road surface are termed Average Friction Numbers (AFNs). The AFNs from the smooth and ribbed tires are reported as Friction Number Smooth (FNS) and Friction Number Ribbed (FNR). An AFN of 20 for the FNS and of 30 for the FNR are flagging values used to indicate the need for follow-up evaluations to determine if corrective action on the pavement may be required. The AFN corresponds to the coefficient of wet sliding friction.

Macrotexture Depth ($\text{MATX}_d \times 10^3$) is a measure of the small scale roughness supplied by the highway surface. A desirable $\text{MATX}_d \times 10^3$ level for new road surfaces is 60. The $\text{MATX}_d \times 10^3$ flagging value at which friction values are expected to decrease rapidly is ≤ 20 . The equation to calculate $\text{MATX}_d \times 10^3$ friction numbers based on the smooth and the ribbed tire AFN values from the towed friction trailer and is shown below:

$$\text{MATX}_d \times 10^3 = 8.66 + 47.89 \left(\frac{\text{FNS}}{\text{FNR}} \right)^5$$

An attempt was made to measure AFNs in the Fall, 1993. Owing to the onset of winter only some pavements were measured. Measurement of the remaining surfaces was delayed until Spring, 1994. Because of the effects of seasonal variations, caution is advised when comparing some of these AFNs.

4.4.12 Cored Samples

After friction testing was completed, the pavements were cored where the testing had been accomplished. Subsequently, the surface of the 8 inch diameter cores was wetted and measured for friction level in the laboratory using the British Pendulum tester. Three passes of the Pendulum were initiated over the top surface and the average calculated as the BPN. This approach allowed for a direct comparison between BPN and AFN values.

Aggregates were then extracted from the cores. Fresh pieces of 3/8 inch aggregates were used to construct coupons which were tested in the same manner as discussed above, using the British Wheel and Pendulum. That is, the coupons were tested using the British Pendulum before and after polishing by the British Wheel test. This extraction of the aggregates from cored samples and treatment in the same manner as for the quarried aggregates, allowed for a direct correlation between the friction values obtained in the laboratory and in the field.

5. ANALYSIS OF DATA

5.1 Petrographic Examination for Gravel Samples

The objective of petrographic examination for the gravel samples was to describe and classify the constituents of the sample and determine the relative amounts of the constituents. This method is based on ASTM Standard C-294 and C-295 with supplementary information from Michigan Test Methods (MTM) 104 and 112.

5.1.1 Nature of Indiana Gravel Deposits

The major gravel resources in Indiana are found in the landforms deposited directly from glaciers or by glacial meltwater streams during continental glaciation. At first glance, the composition of the Indiana gravels seems to be a bewildering array of rock and mineral types, and in many samples 10 to 20 varieties of rocks can be found (Carr and Webb, 1970). Included are carbonates, sandstone, siltstone, chert, shale, iron clay, gneiss, schist, quartzite, granite, granodiorite, diorite, gabbro, andesite, basalt, gabbro, syenite, dacite, rhyolite, amphibolite, and quartz (Shakoor and West, 1979, McGregor, 1960). But, gravels of Indiana contain as much as 96 percent sedimentary rocks from the shale, limestone, and dolomite formations which comprise the Indiana bedrock. It has been concluded that the quartz- and feldspar-rich igneous and metamorphic rocks have been transported from northeastern Canada (McGregor, 1960). Figure 5.1 shows the dominant lithologies of the bedrock in Indiana.

Figure 5.1. Map of Indiana showing dominant lithologies of bedrock.
(from McGregor, 1960).

5.1.2. Selection of Samples for Examination

Approximately 2.5 kg of a gravel sample was prepared for sieve analysis by reducing the sample material to the required quantity according to ASTM Standard C 702. Then, 300 representative particles were evaluated from each of the following sieve fractions:

- 1 inch to 3/4 inch
- 3/4 inch to 1/2 inch
- 1/2 to 3/8 inch
- 3/8 inch to No. 4

The maximum size (3/8 inch to No. 4) was chosen after the No. 5 and No. 11 size samples were examined. Fractions smaller than No. 4 were not included in the study because it is generally accepted that the coarse aggregate portion largely determines the skid resistance for bituminous pavements, and the finer portion represents only ten to thirty percent of the total No. 11 size sample used for bituminous surface aggregate. All particles in the size fraction were examined if fewer than 300 particles were present. When the sample contained less than 30 particles in a size fraction, that material was combined with the next smaller fraction before selecting particles for examination.

The percentage of crushed particles was determined according to the definition of a fractured face in the Indiana Standard Method (ISM) 204 which reads as follows: Fractured Face -- A broken surface constituting an area of at least 25 % of the largest cross sectional area of the particle. A fractured particle is defined as one being fractured either by mechanical means or by nature. Natural fractures must be similar to those fractures produced by a crusher.

This examination procedure was performed three times for each gravel sample in order to obtain reliable results. Values for the uncrushed gravel content of each sample are provided in the appendix.

5.1.3. Examination of Gravels

Rock particles were identified in a surface wet condition which enhances the color and structure of the particles. Hand lens and binocular microscope were used to identify individual rock constituents. A knife was used to differentiate the common, harder minerals (quartz and feldspars) from common, soft minerals (calcite and dolomite). Then, 0.1 N HCl was applied on soft rocks to differentiate the carbonates. Limestones produced a brisk effervescence while dolomite showed slow effervescence or produced effervescence only when scratched. Fifteen rock types were chosen according to their frequency in the sample. If particles of indeterminate type were encountered in the samples, they were included with the known types with similar texture and hardness. Fifteen rock categories were used including: limestone, dolomite, sandstone, siltstone, shale, chert, iron clay, granite, diorite, felsite, basalt, gabbro, gneiss, quartzite and quartz, and schist.

Rock classes and the common rock types are listed in Table 5.1. Gravels in each sieve size were examined for lithologic identification. Next, they were placed in trays labeled according to their lithologic types. When the examination of each sample was completed, the different lithologic types in each sieve size were counted, weighted and the percentages calculated.

5.1.4 Results of Gravel Study

Information from the data sheet permits the computation of weight percentages to show:

- Percentage of gravel retained on each sieve size in the original gravel samples (Table 5.2).
- Weight and count of selected particles on each sieve (Table 5.3).
- Composition of fractions of the petrographic analysis on the basis of 100 percent retained on the No. 4 sieve (Table 5.4).
- Count and weight of each lithologic type retained on each sieve size, and percentages based on count and weight.

- Percentage of carbonate, and other sedimentary rocks, igneous, and metamorphic rocks in the analyzed gravel samples based on count and weight (Table 5.5).
- Weight percentage of carbonate, and other sedimentary rocks, igneous, and metamorphic rock in the total sample recalculated on the basis of 100 percent retained on the No. 4 sieve (Table 5.6).
- Percentage of uncrushed gravel retained on each sieve (Table 5.7).
- Weight percentage of uncrushed gravel in the total sample recalculated on the basis of 100 percent retained on the No. 4 sieve (Table 5.8).

Results show that gravel samples examined consist mainly of carbonate rocks ranging from 47.8 percent to 84.7 percent. Igneous rock is the second most abundant constituent of the gravel, ranging from 8.3 percent to 33.3 percent, followed next by metamorphic rocks ranging from 5.3 percent to 16.1 percent. Other sedimentary rocks such as chert, sandstone, siltstone, shale, clay ironstone, which are believed to be as deleterious materials, consist of a portion ranging between 1.5 percent and 7.6 percent of gravel samples. Figure 5.2 shows the composition of the gravel samples examined.

5.2 Results of Dolomite Study

Results from experimental procedures for the dolomite study were correlated against the Initial Friction Values (IFVs) and Polished Values (PVs) for the respective aggregates. For ease of comparison, the polish susceptibility of aggregate sources was also correlated against the various laboratory tests. Polish susceptibility was determined by finding the difference between the IFV and PV, and reported as the Wear Index (WI). Results of these parameters are observed in Table 5.9. Significance levels are generally reported from $P=0.0\%$ to $P=5.0\%$. Significance levels at $P=0.0\%$ are considered highly significant. Comparisons between the friction values and other laboratory parameters had to be significant at the $P=5.0\%$ probability level to be considered as relevant correlations.

Figure 5.2. Rock type distribution of examined gravel samples.

In the event that the WI did not correlate but the PV did, the PV was used to illustrate the correlation. As a result of not being able to correlate laboratory PVs with field AFNs, it was not possible to set performance limits on the various laboratory test parameters.

Interrelationships also exist between physical and chemical parameters that may indirectly affect friction values. Therefore, caution must be advised against eliminating any information based on the correlation with friction values alone. In this section, only the direct relationships to friction values are considered in detail. Interpretive codes for the dolomite correlations are provided in Table 5.10 and relate to Table 5.11. Table 5.11 is a matrix arrangement that allows observations of direct and indirect statistical correlations which include correlation coefficient, probability and sample size. All relationships, direct and indirect, were considered in the regression analyses of Section 6, Integration of Data. Comparisons between the limestone and sandstone sources were limited to the most prevalent factors.

5.2.1 Sieve Analysis

As mentioned previously, gradation is maintained within a fairly close range for the various aggregate sources. Crushing operations are also fairly similar among these various quarries. As a result, consistency between particle gradation and shape of Indiana No. 11 aggregates is expected to be fairly similar among road surfaces. Because of the observed consistency between aggregate sources, and an expected consistency with macrotexture, a statistical analysis was not performed on the sieve analysis. Gradation results of the sampled aggregates, provided in Figure 5.3 and tabulated in Table 5.12, indicate a reasonable uniformity.

Figure 5.3. Gradation of dolomite aggregates.

5.2.2 Petrographic Analysis

5.2.2.1 Grain Size

The determination of grain size was accomplished by two petrographers. One measured the entire suite of nineteen dolomite samples, and the other analyzed five samples to provide a comparison of the first. None of the results from either of the petrographic analyses provided values for average grain size, median grain size, grain standard deviation or percentage of grains that were significant at the $P=5.0\%$ significance level when correlated with the WI. However, when compared to the IFV and PV, results from the first observer showed that median grain size was a factor at the $P=1.0\%$ probability level indicating a significant correlation (Figure 5.4).

Overall, friction values decreased with an increase in median grain size. However, on closer examination of Figure 5.4, friction values may improve with increasing grain size up to approximately 0.06 mm. The general trend for median grain sizes of greater than 0.06 mm is a reduction in friction values. This observation is theoretically possible as a result of the larger grains remaining fixed while subjected to the polishing action of the British Wheel or vehicular traffic. Laboratory data relating to the petrographic analysis are tabulated in Table 5.13.

5.2.2.2 Grain Shape

Two independent techniques, one by each petrographer, were used to determine grain shape. The first petrographic measured nineteen samples using Krumbein's pebble roundness chart, and the second measured five dolomite samples using Lees' angularity chart. Correlations with the IFV, PV or WI were not observed at the $P=5.0\%$ probability level using either method. In future studies, methods such as the scanning electron microscope or Quantimet 570, an image process and analysis system, should be considered in an effort to reduce subjective determinations based on the use of comparative charts.

Figure 5.4. Correlation of Polished Value and median grain size.

5.2.2.3 Groundmass and Void Content

Cement, matrix, or cement and matrix grouped together as groundmass, did not show a correlation at the $P=5.0\%$ level by either petrographer. The same conclusion holds true for void content. A reason for the lack of correlation may be a consequence of the washing operation that occurs as the coupons are being polished by the British Wheel. The fine material that normally breaks loose and fills void spaces under actual highway conditions is washed away during this laboratory procedure.

5.2.3 Composition

5.2.3.1 Magnesium Content

Data acquired from the magnesium analysis, based on seventeen samples, were analyzed from several different perspectives: (1) as the elemental magnesium concentration; (2) dolomite concentration calculated from percent magnesium; and (3) percent calcite determined by the remaining material after subtraction of the dolomite and insoluble material. The elemental magnesium and dolomite concentrations correlated with the WI yielding probabilities at the $P=1.0\%$ level. The magnesium and thus the dolomite concentration also correlated with the PV.

Unlike the observations of previous researchers, polish susceptibility increased with an increase in magnesium concentration (Figure 5.5). The dolomites analyzed in this study were shown to perform better with an increase in impurities. An example of this observation may be seen with sample D-013. Initially, it was expected to be one of the poorest performers as a result of a lower magnesium content, high calcite and high clay content. Results of this analysis proved D-013 to be a superior aggregate (Figure 5.6). This observation brings forth the issues associated with the complexity of predicting aggregate performance on a broad scale. Data on the results from the compositional analysis are tabulated in Table 5.14.

The concentration of calcite correlated with the PV and WI at $P=2.35\%$ and $P=0.01\%$, respectively. As the concentration of the softer calcite mineral increases in dolomite rock, polish susceptibility decreases (Figure 5.7). The presence of small amounts

Figure 5.5. Correlation of polish susceptibility and elemental magnesium.

Figure 5.6. Performance of an impure dolomite, D-013, compared to the reference dolomite standard, D-001.

Figure 5.7. Correlation of polish susceptibility and calcite concentration using results from the elemental magnesium test.

of the softer calcite mineral in the dolomite sources allows for a more heterogeneous mixture. This heterogeneity permits uneven wear which reduces the polish effect on exposure to polishing conditions. A critical concentration of calcite will eventually be reached at which point the calcite will enhance polishing conditions, as observed with the limestone samples in this study.

5.2.3.2 X-Ray Diffraction

The concentrations of the major minerals, dolomite and calcite, were quantified using x-ray diffraction. Based on twenty samples, both minerals correlated with the PV and WI. The twentieth sample was from a source that had been sampled and retested on two separate occasions as a consequence of having failed the initial elemental magnesium test.

Results from x-ray diffraction yielded probability values of $P=0.04\%$ for the two minerals when correlated with WI. As previously mentioned, for the elemental magnesium test, polish susceptibility increased with an increase in dolomite concentration and decreased with an increase in calcite (Figure 5.8 and 5.9). As a result of very low concentrations of calcite in the dolomite samples, and no observable calcite peak, calcite was considered to be absent in the majority of the samples. Data from the mineral concentrations did not correlate with the IFV at the $P=5.0\%$ significance level.

5.2.3.3 Acid-Insoluble Residue Test

The data evaluated based on the acid-insoluble residue test were also divided into three categories. These consisted of the percent material ≥ 74 microns, percent material < 74 microns and the ratio of the amounts of these two. Individual gradations for > 74 microns were not considered as a result of generally low amounts of insoluble material (Table 5.15).

The only category registering at a significant level was the fine material at < 74 microns. This parameter was based on nineteen observations that correlated with both the IFV and PV. The significance level correlating with the PV was at $P=1.0\%$. The

Figure 5.8 Correlation of polish susceptibility and dolomite concentration using results from x-ray diffraction.

Figure 5.9. Correlation of polish susceptibility and calcite concentration using results from x-ray diffraction.

insoluble residue factors did not correlate with the WI. The influence of silt and clay-size minerals on the PV is illustrated Figure 5.10. A decrease in polishing results from the presence of the finer material. The insoluble residue concentration of the tested dolomites all fell well below 10 percent, the point at which grain size is likely to be the predominant mechanism affecting friction values. Probability levels between the two parameters, median grain size and percent insoluble of silt and clay size material, were $P=0.81\%$ and $P=1.0\%$ for the PV. This indicates that median grain size is slightly more significant than the insoluble material. The correlation of fine material with PV agrees with the concept that a small amount of soft and fine material is beneficial in terms of friction value. Polishing is reduced because larger and harder grains are able to break away from the finer material.

5.2.4 Physical Tests

Three of the four physical tests, specific gravity, absorption and sodium sulfate soundness, correlated with the PV and WI. Specific gravity and absorption also correlated with the IFV. The significance levels associated with the WI were $P=4.64\%$, $P=1.79\%$, and $P=1.44\%$, respectively. The fourth physical test, Los Angeles abrasion, did not correlate with friction or polish values at a significant probability level. The laboratory data for the physical tests are summarized in Table 5.16.

5.2.4.1 Specific Gravity

Specific gravity can be considered as a measure of mineral purity of a sample. As a consequence of large amounts of impurities, the specific gravity will be reduced from that of a more pure sample. As mentioned in a previous section, the more impure samples provide greater polish resistance. The specific gravity for pure dolomites generally ranges from 2.86 to 3.10. Dolomites in this study ranged from 2.39 to 2.73, with most being approximately 2.6. As can be observed in Figure 5.11, polish susceptibility is reduced for the samples with a lower specific gravity, thus indicating greater polish resistance with increasing impurity.

Figure 5.10. Correlation of Polished Value and acid-insoluble fraction less than 74 microns.

Figure 5.11. Correlation of polish susceptibility and specific gravity.

5.2.4.2 Absorption

Materials with a high absorptive capacity are generally weaker aggregates. As absorptive capacity increases, the polishing effect decreases (Figure 5.12). Again, the presence of some weaker material aids in the reduction of the polishing effect. As with other laboratory parameters, there may be a point where equilibrium is reached and the weaker materials will cause an increase in polishing.

5.2.4.3 Sodium Sulfate Soundness

This test is a measure of aggregate durability and is related to absorption. As sulfate soundness loss increases, aggregate susceptibility to polishing decreases (Figure 5.13).

5.2.5 Limestone versus Sandstone

In the comparison of limestone and sandstone sources with the standard, a contrasting observation regarding performance is observed between these aggregates (Figure 5.14). Limestones are generally poor performers when compared to sandstone sources. However, limestone aggregates may out perform some of the dolomites in terms of polish and friction resistance. Therefore they should not be ruled out as quality aggregates. A thorough evaluation of limestones should be conducted, in a fashion comparable to that done for dolomites in this study.

Petrographic factors indicate that the median grain size may have little influence on aggregate performance for the sandstone aggregates. The median grain sizes between the two sources, S-001 and S-002 were 0.049 and 0.026 mm, respectively, but both performed equally well equilibrating at approximately 36 PV. Although inconclusive, the predominant factors affecting the sandstones may result from hard mineral grains in a soft calcite matrix. Median grain size ranged from 0.022 to 0.027 mm for the limestone sources, and both equilibrated at 27 PV. This range is too small to draw any conclusions on the effects of grain size. However, the finer of the two sandstones, 0.026 mm, out performed the limestones of a similar size by 9 PV, which is a significant margin.

Figure 5.12. Correlation of polish susceptibility and absorption.

Figure 5.13. Correlation of polish susceptibility and sodium sulfate soundness.

Figure 5.14. Polish threshold of the limestone and sandstone sources with the reference dolomite and other dolomite sources.

There was a significant difference in the concentration of chert between the two limestone sources, seven vs. two percent for LS-001 and LS-002, respectively. As can be observed with Figure 5.14, for these two samples the amount of chert was found to have little influence on initial or final friction values.

Because the limestone sources consisted predominantly of groundmass, determination of the influence of grain shape on the performance was not possible. However, the presence of large portions of groundmass resulted in poorer performance when compared to the sandstones. This observation indicates that a large fraction of groundmass is generally not desirable. Results on the void content for the various aggregate types proved too random to reach any meaningful conclusions on its influence regarding performance (Table 5.13).

The predominant mechanism affecting the performance of these aggregate types is composition. A rough estimate of approximately half and half, soft insoluble material and the harder silica minerals may enhance performance, as observed with the sandstone sources. This contrast results in a differential polishing effect. The predominant constituent of the limestone sources consists of the soft mineral, calcite, with a range of composition between 59 and 96%. Sufficient data were not available to make a meaningful comparison that showed the influence various physical tests have on polish resistance for limestones and sandstones polish resistance (Table 5.16).

6. INTEGRATION OF DATA

6.1. Analysis of Data from Gravel Study

Two frictional values were ultimately obtained on each aggregate specimen using the British Wheel apparatus. The first value is obtained for the specimen before it is tested on the British Wheel and is known as the Initial Friction Value (IFV). The second value, so called Polished Value (PV), is recorded after the aggregate specimen has been polished for ten hours, unless the polish value is achieved in a short time according to ASTM Standard D-3319. The ASTM specified 10 hours of polishing is equivalent to about 200,000 revolutions. The difference between the Initial Friction Value and the Polished Value is termed the Wear Index (WI) and is a relative measure of the amount of aggregate polishing that occurs.

For the 14 specimens, two sets of five specimens of a different aggregate source were tested with four specimens of the same reference aggregate (control specimen). The reference aggregate (standard aggregate) was used to determine the precision of the British Wheel test. The reference stone is from an aggregate source of reef dolomite. For this study, a sufficient quantity of reference stone was obtained on one quarry visit to complete the research.

A British Pendulum Number was determined initially and then after 1, 3, 6, and 10 hours to obtain a plot of BPN versus time. This shows the shape of a non-linear exponential decay function (Fager and Smith). Some selected aggregate sources were tested for an additional time, 14, 18, and 20 hours to evaluate the polishing effect and variation of BPN.

According to historical perspectives, the tentative acceptance criteria for the minimum polish value permitted for surface course mixes is as follows. These limits are only a starting point for future refinement (Dringer, 1990).

Minimum Polish Value	Quality
24 or less	Poor
25 to 30	Marginal
31 or more	Good

6.1.1 Reliability of Data

Figure 6.1 shows a relationship of BPN vs. time for selected aggregate samples which have been polished for 20 hours. All have declined from IFV and show declining values or a leveling off at 10 hours. Note that polishing for 10 hours seems to be sufficient and practical to establish a consistent polished value (PV).

First, nine specimens of the reference sample (D-001) were polished and tested. The BPN values of the reference sample were compared with those of four control specimens (D-001) whenever new sets of aggregate sources were tested. There were 27 sets of BPN data completed on the control specimen (also referred to as the standard aggregate). The BPN vs. time data are shown in Table 6.1. Correlation between a standard aggregate and a reference aggregate indicates that an average range of standard deviation for the standard aggregates is 1.8 BPN units, and the mean value of the standard aggregate and the value of the reference aggregate show that there is not much difference between those values.

For the recorded data of five swings for each specimen at each time interval, only the last four data sets were used for statistical analysis. The standard deviation for each specimen was less than 1.0 BPN unit. According to ASTM Standard E-303, the standard deviation is a maximum of 1.0 BPN unit for the British rubber slider. Sandstone sources were tested twice to check the reproducibility of polishing for these aggregate sources. Results are shown in Figures 6.2 and 6.3. Each two sets of graphs show that polishing

Figure 6.1. Results of the British Wheel test for selected sources (20 hours).

Figure 6.2. Correlation of results for S-001 tested twice.

Figure 6.3. Correlation of results for S-002 tested twice.

data are consistent when good specimens are prepared, and accurate calibration of the testing equipment is accomplished.

6.1.2. Dolomite sources

Figure 6.4 shows all of the dolomite sources tested, and Figure 6.5 shows the error bars for BPN vs. time of dolomite aggregates. Based on the study of the characteristics of crushed dolomite samples in comparison to the research results, several interesting relationships were observed. The twenty dolomite aggregate samples are listed in Table 6.2. Except for D-004, D-013 and D-014 from two different quarries (D-013 and D-014 are from the same quarry) which are ranked first, second, third for PV, the seventeen aggregate sources are divided into three groups for comparison purposes according to the quarry location. Numbers D-002, D-003, D-005, D-006, D-007, D-008, D-018, D-019, D-020 were grouped as District A. Numbers D-009 through D-012 were grouped as District B, and numbers D-001, D-015, D-016, and D-017 were grouped as District C. The group denoted "District C" shows the highest BPN value. The group designated "District B" shows a middle BPN value, and the group quoted "District A" shows the lowest BPN value. It seems that three groups subdivided according to geographic location of quarries represent a similar lithologic nature within each group.

PV of individual dolomite aggregates shows that D-004 ranked first and its specific gravity was the lowest while the absorption is highest for all the samples. D-013 and D-014 ranked second and third respectively, and D-014 showed a specific gravity that was second lowest while absorption is second highest for all samples. Data for specific gravity and absorption of D-013 were not available, but both D-013 and D-014 were from the same quarry. The individual aggregates of District A ranked 8th through 16th, those of District B ranked 4th through 7th, and those of District C ranked 18th to 20th.

The relationship between BPN and physical property of aggregates is discussed later in this report. It seems that the three groups subdivided according to geographic location of quarries represent a similar lithologic nature within individual groups.

Figure 6.4. British Wheel test results of dolomite aggregates.

Figure 6.5. Error bars for dolomite aggregates

6.1.3 Limestone

Two cherty limestone sources were tested. These two sources initially had a higher IFV and polished to a higher PV in comparison with the group denoted "District C" among dolomite sources. However, pure limestone in the gravel sources showed both lower IFV and PV in comparison with dolomite in the gravel (See Section 6.1.4.2). The results are as follows:

I.D.	IFV	STDV	PV	STDV	WI	STDV	Remark
LS-001	41.7	0.5	27.2	1.5	14.5		
LS-002	41.6	1.5	26.6	1.5	15.0		

LS-001 ranked between 13th and 14th for IFV and ranked between 7th and 8th for PV in comparison with the dolomite aggregates. LS-002 ranked 16th for IFV and ranked between 15th and 16th for PV.

6.1.4 Gravel Aggregates

The gravel sources tested using the polishing test were subdivided according to rock types, in order to evaluate the characteristics of these individual rock types. Some rock types such as quartzite, sandstone, and chert were not tested because those pieces were either elongated and/or did not constitute enough pieces to make a proper coupon specimen. Some problems occurred in the testing of coupons made from uncrushed gravel specimens. Occasionally aggregate particles popped out from specimens. If enough particles were lost, the specimen would break apart and fall from the wheel. Broken specimen were replaced by previously used standard specimens and the testing process continued.

6.1.4.1 Dolomite portion, gravel sources

Dolomite in the gravel shows a considerable variation in BPN depending on the source (See Figures 6.6 and 6.7). It seems that dolomite characteristics are related to the

Figure 6.6. British Wheel test results of dolomite in gravel sources.

Figure 6.7. Error bars for dolomite in gravel sources.

local bedrock or where a gravel pit is located geographically. 100 % crushed dolomite shows the highest values, 50% crushed dolomite shows intermediate values, and uncrushed dolomite show the lowest values. Observations made with the PV indicate that 100 % crushed dolomite still showed the highest values, but there was no relationship between 50% crushed and uncrushed dolomites. However, uncrushed dolomite show the lowest values for WI. In other word, uncrushed dolomites show the highest resistance to polishing. The results are listed below.

I.D.	IFV	<i>STDV</i>	PV	<i>STDV</i>	WI	<i>STDV</i>	Remark
G-001-DO	48.5	0.9	30.7	2.6	17.8		100% crushed
G-002-DO	47.4	0.4	31.0	2.0	16.4		100% crushed
G-003-DO	40.6	2.6	27.8	2.7	12.8		uncrushed
G-004-DO	44.4	1.7	28.1	1.5	16.3		50% crushed
G-005-DO	43.1	0.9	25.5	1.6	17.6		50% crushed
G-006-DO	42.0	1.6	29.4	2.2	12.6		uncrushed
Average	44.3	3.1	28.8	2.1	15.6	2.3	

6.1.4.2 Limestone in Gravel Sources

Limestone in the gravel sources also shows that BPN varied considerably depending on the source (Figures 6.8 and 6.9). 100% crushed dolomite shows higher values than that of uncrushed limestone. In the case of PV value, 100 % crushed limestone still shows higher values than that of uncrushed limestone. But, regarding WI, 100 % crushed limestone shows higher values than that of uncrushed limestone. Limestone in the gravel sample had a lower initial average IFV and was polished to an even lower average PV as compared to dolomites in the gravel. The results are observed on the following page.

Figure 6.8. British Wheel test results of limestone in gravel sources.

Figure 6.9. Error bars for limestone in gravel sources.

I.D.	IFV	STDV	PV	STDV	WI	STDV	Remark
G-001-LS	42.5	1.4	29.5	2.0	12.0		100% crushed
G-002-LS	35.6	3.7	26.1	3.3	9.5		uncrushed
G-003-LS	35.4	3.3	25.8	3.1	9.6		uncrushed
G-004-LS	34.0	4.0	23.9	2.7	10.1		uncrushed
G-005-LS	31.9	1.8	23.2	0.5	8.7		uncrushed
G-006-LS	38.7	1.7	26.4	1.5	12.3		100% crushed
Average	36.4	3.7	25.8	2.2	10.5	1.7	

6.1.4.3 Igneous/Metamorphic Rock

Basalt, gabbro, granite, diorite, and gneiss were selected to perform friction resistance testing. Individual specimens of one rock type were prepared from a single gravel source. These rocks show similar values for both IFV and PV (see Figures 6.10 and 6.11). In the Michigan Department of Transportation specification on aggregate (MTM 111), igneous and metamorphic rocks are regarded as one rock type.

Average Initial Friction Values (IFV) for igneous/metamorphic rocks are lower than those for dolomites in gravel, but the average of Polish Value (PV) for igneous and metamorphic rock is higher than the dolomite in gravel. Therefore, igneous/metamorphic rocks in the gravel sources are expected to improve frictional resistance for these gravel aggregates, which in Indiana are composed mainly of carbonate rocks.

I.D.	IFV	STDV	PV	STDV	WI	STDV	Remark
Basalt	39.8	2.3	29.2	1.8	10.6		
Diorite	42.7	2.9	30.3	5.5	12.4		
Gabbro	41.6	3.0	30.6	1.7	11.0		
Gneiss	41.9	2.0	29.3	2.6	12.6		
Granite	42.5	1.6	27.6	2.6	14.9		
Average	41.7	1.2	29.4	1.2	12.3	1.7

Figure 6.10. British Wheel test results of igneous/metamorphic rocks in gravel sources.

Figure 6.11. Error bars for igneous/ metamorphic rocks in gravel sources.

An estimate of the IFV and PV for crushed gravel samples can be obtained by using information from the previous discussion. It is summarized below:

I.D.	IFV	PV	Remarks
Dolomite	44.3	28.8	100% crushed
Limestone	36.4	25.8	100% crushed
Igneous/Metamorphic	41.7	29.4	100% crushed

First a megascopic petrographic exam is performed. In this procedure the percent of rock constituent is obtained for a crushed gravel as follows: dolomite, limestone, igneous/metamorphic and other sedimentary rocks. A weighted average is used to estimate the IFV and PV for the gravel samples. The following is an example: Given dolomite=37%, limestone=31%, igneous/metamorphic=28%, and other=4%. The percentage of the three major rock types are normalized to 100% by multiplying by 100/94 yielding dolomite=38.5%, limestone=32.3% and igneous/metamorphic=29.2%.

$$\text{IFV} = 44.3(0.385) + 36.4(0.323) + 41.7(0.292) = 41.0$$

$$\text{PV} = 28.8(0.385) + 25.8(0.323) + 29.4(0.292) = 28.0$$

6.1.5 Sandstone

Two sandstone sources from Illinois were tested in this study. The sample designated "S-001" was a greenish-gray, fine sandstone with small amounts of greenish-gray shale. The sample designated "S-002" was a dark brown fine sandstone with small amounts of dark brown shale. Physical properties of the sandstone are listed in the petrographic discussion of this report. These two sandstone sources provided excellent friction characteristics. The IFV of S-001 ranked between 3rd and 4th, and IFV of S-002 ranked between 4th and 5th in comparison with the dolomite sources. However, both

sources gave the highest PV values of any aggregate sources tested. The results are as follows:

I.D.	IFV	<i>STDV</i>	PV	<i>STDV</i>	WI	<i>STDV</i>	Remark
S-001	46.5	2.1	37.3	1.4	9.2		
S-002	46.0	1.3	37.6	0.7	8.4		

6.1.6 Slag

An air-cooled blast furnace slag denoted as “SL-001” from the Levy Company, Inc., Indiana, was tested to evaluate polish characteristics. The IFV of SL-001 ranked between 7th and 8th, and PV of this source ranked 8th in the comparison with those of dolomite sources. However, slag can be quite variable. This variability can be affected by the grade of iron ore, the cooling process, and use of additives, which tend to control porosity (Dierstein and Lacroix, 1984).

I.D.	IFV	<i>STDV</i>	PV	<i>STDV</i>	WI	<i>STDV</i>	Remark
SL-001	44.1	1.3	28.8	1.2	15.3		

6.1.7 Blended Sample

An experimental attempt was made to test blended samples. These samples involve a percentage mixture of two different aggregates with different physical characteristics from different locations (Texas Department of Highway and Public Transportation, 1991). SL-001 and D-001 were used in this study because INDOT has commonly used this mixed aggregate in highway construction. The aggregate particles were selected on a percentage basis. The following blended samples were tested:

- 100 percent slag (5 specimens)
- 70-30 blend slag and dolomite (5 specimens)
- 50-50 blend slag and dolomite (5 specimens)

- 30-70 blend slag and dolomite (5 specimens)

In addition, 100 percent D-001 was used as a standard. Ten specimens of blended samples and four standard aggregate samples were tested each time. The mean value of the standard sample was used as the value for 100 percent dolomite. Linear relationships exist between the percentage of each portion vs. IFV and PV in spite of the BPN deviation between the reference and the standard specimens. The correlation coefficient of the linear regression for IFV vs. the percentage is 0.991 and that for PV vs. percentage is 0.975 (Figures 6.12 and 6.13).

I.D.	IFV(BPN)	<i>STDV</i>	PV(BPN)	<i>STDV</i>	WI(BPN)
SL:DO (1.0:0.0)	47.7	1.7	32.7	1.7	15.0
SL:DO (0.7:0.3)	46.6	2.7	30.9	2.1	15.7
SL:DO (0.5:0.5)	44.7	0.3	30.6	1.6	14.1
SL:DO (0.3:0.7)	43.2	0.4	28.5	0.5	14.7
SL:DO (0.0:1.0)	41.5	1.5	27.9	2.6	13.6

6.1.8. Core Samples

Several sites were selected to obtain cores from different pavements. After friction testing was performed by a towed friction trailer on the road, 8-in. cores were obtained and brought to the INDOT laboratory. INDOT personnel measured friction values using the British Pendulum Tester with the long rubber slide. Then, the aggregate was extracted from the core in the INDOT laboratory. However, the No. 11 aggregate contains only five to twenty-five percent of material retained on the 3/8-inch sieve. Therefore, preparation of a specimen for the British Wheel test was difficult to accomplish because good aggregate pieces having a flat surface with proper dimensions were not abundant.

Shortly after this project began, an attempt was made to correlate BPNs with field-measured Average Friction Numbers (AFNs). However, correlation between the two friction values was difficult as a consequence of the following factors:

Figure 6.12. British Wheel test results of blended samples.

Figure 6.13. Regressions of blended samples.

- The aggregates tested were composed of a diversity of rock types such as dolomite, gravel, slag, and blended aggregate (slag and dolomite mixture).
- As was observed earlier with the gravel sources, coupons fabricated with aggregates extracted from cores with acetone performed poorly during the British Wheel test.
- Also inhibiting correlation was the amount of extracted particles. It was difficult to find good particles from several of the core samples.

Thus, a meaningful comparison between field data and laboratory data based on the British Wheel test was not possible. The results that were obtained are provided as follows:

I.D.	IFV	<i>STDV</i>	PV	<i>STDV</i>	WI	Remark
R-10577	43.6	<i>1.2</i>	31.4	<i>0.9</i>	12.2	Gravel
R-11046	38.8	<i>1.7</i>	25.5	<i>3.0</i>	13.3	Dolomite
R-11776	36.2	<i>1.1</i>	26.4	<i>0.9</i>	9.8	Dolomite
R-12812	39.4	<i>2.2</i>	29.6	<i>0.6</i>	9.8	Dolomite
R-13019	40.2	<i>2.3</i>	31.1	<i>2.0</i>	9.1	Gravel
R-14456	42.1	<i>2.0</i>	27.1	<i>0.6</i>	15.0	Dolomite
R-15310	41.8	<i>3.1</i>	27.1	<i>4.2</i>	14.7	Dolomite
R-18045	47.3	<i>3.6</i>	30.2	<i>0.5</i>	17.1	Slag
RS-14940	41.8	<i>1.8</i>	30.8	<i>1.3</i>	11.0	Dolomite
RS-16084	40.7	<i>3.4</i>	25.9	<i>2.9</i>	14.8	Slag and Dolomite
RS-17254	42.2	<i>2.6</i>	28.6	<i>0.4</i>	13.6	Dolomite

6.2 Analysis of Dolomite Petrography Study

In this research, a large quantity of data was generated from the laboratory analysis, field analysis and review of INDOT records. The goal of the statistical analysis was to determine the aggregate properties that predict performance of aggregates under in service conditions. Performance estimates were determined through the subsequent

correlation of aggregate properties with BPN and AFN data sets. Relevance of data was determined through, correlation coefficients, stepwise regression and multiple linear regression. The statistical analysis was performed using the Purdue University Statistical Analysis System (SAS REG). From this point on, data collected from INDOT literature will be considered as part of the laboratory data set.

6.2.1 Regression Analysis of Laboratory Data

Correlation of laboratory data and friction values through stepwise regression was the first step in determining interdependent relationships. The IFV and PV were separately set as dependent variables, and the laboratory data as independent variables. Implementation of stepwise regression was initially applied on all laboratory parameters. Owing to a limited number of observations with the elemental magnesium test, the initial parameters were limited to fifteen observations. After running stepwise regression and determining that the elemental magnesium test was not a significant factor, that parameter was removed and stepwise was run again using all remaining parameters. The new regression model used a parameter, sodium sulfate soundness, that was determined to be significant. However, sodium sulfate soundness limited the regression model to eighteen observations in each parameter. That particular parameter was then removed in order to determine the effects of the complete data set of nineteen observations per parameter on the regression model.

The above regression analysis was accomplished using two different perspectives. Method I employed the use of all the interactions between parameters and the squaring of those parameters. Method II was similar to Method I, with the exception that the only parameters used were those resulting from tests currently performed or which could easily be performed by INDOT. The equations developed through stepwise regression to predict laboratory friction values are shown in Table 6.3. The correlation coefficients between all terms were checked to ensure that the correlations complemented one another and were not simply a repetition of information. Stepwise regression details are shown in Table 6.4. A thorough listing of the codes for the derived equations of Table 6.3 and

Table 6.4 is found in Table 5.10. Although significant levels should be maintained at a limit of $P=5.0\%$, future researchers may use their discretion to limit the terms in the equations at a satisfactory regression step (Table 6.4).

As an example for limiting an analysis, stepwise regression was terminated at step 6 for Equation 6.1 based on a relatively high R^2 value, all of the terms being within the $P=0.0\%$ to $P=5.0\%$ significance range, and relatively few terms within the equation. By comparison, step 9 also seemed like a reasonable choice; however, adding three more terms to the equation only increased the R^2 value by 0.09. A certain amount of freedom is lost in the equation by adding more terms, resulting in a greater R^2 value necessary to maintain the $P=5.0\%$ significance level.

The parameters in Method I rely heavily on petrographic factors such as average grain size, percent grains, groundmass, and void space. Of all the tests performed, these were the most subjective because they are based primarily on observations using the point count, petrographic technique. Although the results of these factors were positive in this study, instruments such as the Quantimet 570 -- an image process analysis system, or the scanning electron microscope, may give more consistent results between observers. It may be more appropriate to apply and continue to update the data base of Method II with current INDOT analyses and experiment with less subjective techniques, allowing for refinement of Method I.

The equations for Method II rely heavily on the acid-insoluble residue test and physical tests such as specific gravity and absorption. Composition, excluded, because of a limited number of elemental magnesium observations, may also eventually be found to play a significant role in affecting friction values. The equations for Method II are still significant and are useful for estimating friction values. However, as a consequence of weaker correlation coefficients and the limiting of aggregate parameters, greater variability in the predicted values occurs (Table 6.5).

In order for any of the equations to be of value in future applications, all data within the parameters must fall within the minimum and maximum values shown in Table 5.10 and Table 6.3. The limits observed in Table 6.3 were determined by calculating the

product of related observations in each parameter within each of the nineteen samples. The products of these observations yielded a data set from which maximum and minimum values could be determined.

As can be observed in the equations of Table 6.3, a large fraction of the test parameters dove-tailed significantly with the friction parameters whether or not they correlated directly with friction values. These equations may change significantly as the data base is updated with new information as additional laboratory data are added. Some of these test parameters may eventually be found to be less significant, and others more significant as this data base is updated and statistically analyzed. As discussed earlier, the above equations are currently useful as long as the data provided are within the minimum and maximum values of Table 5.10 and Table 6.3. In order for either method to be useful for field applications, correlation between the laboratory and field friction values must be determined.

6.2.2 Regression Analysis of Field Data

The primary step in the regression analysis of the field parameters was to determine the significance of the results from the physical tests on the field friction values. It was hoped that the physical tests could assist in the prediction of AFN values. As a result of a limited number of observations in the parameters, only sixteen of the possible twenty-three observations could be used (Table 6.6). As can be observed in Table 6.7, stepwise regression failed to indicate correlations at the $P=5.0\%$ level with absorption, Los Angeles abrasion or sodium sulfate soundness with the Friction Number Smooth (FNS), Friction Number Ribbed (FNR) or Macrotexture Depth ($\text{MATX}_d \times 10^3$). Bulk specific gravity weakly correlated with the FNS. However, the emphasis of this study has been on aggregate microtexture. FNS is a measure of macrotexture, which is a function of the interaction between rocks.

The degree of influence of the physical parameters most likely varies between aggregate types. Because of a limited number of similar aggregates present, the lack of correlation between the physical parameters and field friction values may have resulted

from grouping all aggregate types into the same regression model. In future applications it may be more appropriate to limit correlations to specific groups of aggregates.

6.2.3 Correlation of Laboratory to Field Data

Ideally, a correlation that could assist in the prediction of the polishing threshold of aggregates in the field would be between the friction values of the laboratory PVs and field AFNs, including $\text{MATX}_d \times 10^3$. AFNs, through linear regression, did correlate with the IFVs, but the PVs from aggregates extracted from the cores did not (Figures 6.14, 6.15, and 6.16). The IFV-FNR, IFV-FNS and IFV-MATX_d results correlated at $P=0.04\%$, $P=0.12\%$ and $P=1.76\%$. The PV-FNR, PV-FNS and PV-MATX_d $\times 10^3$ results, also based on eleven observations, correlated at $P=66.1\%$, $P=16.52\%$ and $P=92.62\%$, respectively. Owing to this lack of correlation with the PV, an attempt was pursued to use the IFV as the correlating mechanism to the AFN. In order to use this relationship the researchers felt that it was important to determine a correlation between the IFV and PV. Correlating at a probability level of greater than $P=5.0\%$, the IFV-PV relationship was not determined (Figure 6.17). Although requiring further investigation consideration should be given to using the IFV to predict field values.

Correlation of BPN values from the core surfaces to the respective AFNs or $\text{MATX}_d \times 10^3$ was not significant at the $P=5.0\%$ probability level (Figures 6.18, 6.19 and 6.20). These results also limit the ability to correlate laboratory and field parameters.

Bulk specific gravity weakly correlated at $P=4.44\%$ with the BPNs measured from the core surfaces (Figure 6.21). This is a direct laboratory -- field friction correlation and deserves further investigation. As Figure 6.22 indicates, bulk specific gravity also correlated with the FNS value at $P=4.8\%$. Again, FNS is a measure of macrotexture and not highly significant as the emphasis of this study is primarily based on microtexture. Bulk specific gravity did not correlate with the FNR at $P=5.47\%$ or the MATX_d at $P=52.44\%$. These correlations were determined owing to the ability to correlate using twenty-three observations as opposed to the sixteen observations of Section 6.2.2.

Figure 6.14. Correlation of the Average Friction Number from the ribbed trailer tire to the Initial Friction Value and Polished Value determined from coupons composed of extracted core aggregates.

Figure 6.15. Correlation of the Average Friction Number from the smooth trailer tire to the Initial Friction Value and Polished Value determined from coupons composed of extracted core aggregates.

Figure 6.16. Correlation of Macrotexture Depth to the Initial Friction Value and Polished Value determined from coupons composed of extracted core aggregates.

Figure 6.17. Correlation relationship between the Initial Friction Value and Polished Value to determine a possible British Pendulum Number relationship to the Average Friction Number.

Figure 6.18. Correlation of the Average Friction Number from the ribbed trailer tire to the core surface British Pendulum Number.

Figure 6.19. Correlation of the Average Friction Number from the smooth trailer tire to the core surface British Pendulum Number.

Figure 6.20. Correlation of Macrottexture Depth to the core surface British Pendulum Number.

Figure 6.21. Correlation of core surface British Pendulum Number and bulk specific gravity.

Figure 6.22. Correlation of the Average Friction Number from the smooth trailer tire and bulk specific gravity.

On further investigation, the PVs of the quarried dolomites were found to strongly correlate with bulk specific gravity. Thus, prediction of the laboratory PV using bulk specific gravity is highly probable. If found significant with further testing of more dolomites and other aggregate, replacement of the British Wheel and Pendulum test may be possible. It is recommended that this method be thoroughly evaluated. This conclusion was based on nineteen samples which resulted in a probability of $P=0.03\%$ (Figure 6.23). More field data are necessary to pursue the correlation of laboratory and field friction values between like aggregates.

Figure 6.23. Correlation of the laboratory dolomite Polished Value to the associated bulk specific gravity levels.

7. CONCLUSIONS

The research results for this portion of Project HPR-2082, “Development of a Procedure to Identify Aggregates for Bituminous Surfaces in Indiana”, proved to be quite successful. The ability to apply an accelerated laboratory test method to identify the polish resistance of various aggregates was demonstrated in this report. This development alone permits the ranking of potential surface course aggregates on the basis of their resistance to polishing.

7.1 Conclusions from Gravel and British Wheel Testing

- The gravels of this study were composed primarily of carbonate aggregates that showed considerable variability in polishing thresholds. Igneous and metamorphic constituents polished to a lesser degree and are expected to improve overall aggregate performance. Limestones in general polished more than did dolomites.
- Estimates of the Initial Friction Value and Polished Value for crushed gravel samples can be made based on the percentage of rock types present in the sample. A weighted average is used to make this calculation.

7.2 Conclusions from the Dolomite Petrographic Study

- The higher elemental magnesium values correspond with the purer dolomite aggregates. Results of this study indicate that the higher purity dolomites are poorer performers. It appears that the presence of clay mixed with the dolomite increases the frictional resistance of these aggregates.
- The two limestones of this study performed better than some dolomites currently approved for highway use. They contained chert and fine insoluble material. The more impure limestones are generally expected to be somewhat better performers than the purest sources, but this needs further evaluation.
- Multiple linear regression proved satisfactory in determining interactions between laboratory tests performed on the dolomites and friction values. Empirical equations were developed allowing reasonable probability of estimating the laboratory friction values.

7.3 Conclusion from the Laboratory -Field Correlation

The regression analysis to predict field friction value was found to be inconclusive, apparently because the test data base included a diversity of aggregate types such as dolomite, limestone, sandstone, gravel and slag. Attempts to correlate laboratory to field values also proved to be limited because of the broad aggregate base and small number of complete data samples (only 11). There were three observed relationships that may assist with program implementation.

- 1) The highest correlation was found between Average Friction Number for the towed friction trailer versus laboratory Initial Friction Value as determined from aggregates removed from asphalt cores. However, the primary interest involves the Polished Value; INDOT may want to use the Initial Friction Value to select limits for acceptable friction levels.
- 2) The limited data (Table 6.6) indicates (at least generally) that a value of 30 for PV corresponds to an FNR value greater than 30 and an FNS value greater than 20. The 30 value for PV appears to be a more stringent requirement than are 30 and 20 respectively for FNR and FNS. A 30 value for FNR corresponds more nearly to 15 to 25 for PV; and a 20 value for FNS more nearly to 15 to 20 for PV.
- 3) A weak laboratory-field correlation was observed between bulk specific gravity and the core surface British Pendulum Number.

8. RECOMMENDATIONS

The physical tests provide an evaluation for aggregate durability and soundness relative to frictional resistance. This indicates that INDOT should continue to measure physical parameters of aggregates, such as sodium sulfate soundness loss, Los Angeles abrasion, absorption and specific gravity. Testing the dolomites for elemental magnesium content should also continue as this parameter is a good indicator of carbonate rock purity. Another test that should be considered for addition is acid-insoluble residue content, at least in special cases. The presence of fine, insoluble material was found to improve aggregate performance. Although the British Wheel and Pendulum tests are currently a necessary step in expanding the data base, eventually they likely can be omitted when sufficient data become available to predict friction values based on standard laboratory data.

Using the above laboratory parameters and stepwise regression, equations were developed to predict laboratory friction values to within two to three British Pendulum Numbers. As more information becomes available a new regression model can be developed yielding even better results. Prediction of laboratory friction values can then be determined from the newly developed empirical equations thus eliminating the need for the British Wheel and Pendulum test. However, to adequately predict the performance of these sources the data must fall within the limits of the equations.

Laboratory friction values can be determined to an even greater degree of accuracy if a detailed petrographic analysis is implemented to include grain size, grain shape, percent voids and percent groundmass material. Less subjective techniques for the petrographic work, such as the Quantimet 570 -- an image process and analysis system or the scanning electron microscope, are recommended.

As a consequence of potentially wide range of aggregate parameters, it is suggested that the conclusions developed for aggregate performance in this study be considered for

sources only within and bordering Indiana. INDOT may wish to consider the development of equations for individual geologic formations. The applications developed here would probably have shown greater validity if individual, distinct equations would have been limited to sources within an individual geologic formation. However, more data values are needed before this can be accomplished.

Individual aggregate types have different physical parameters that affect their performance level. Poor correlation of laboratory results with the field parameters may have been a consequence of grouping results of all aggregate types from the field analysis. However, this was a statistical necessity because of the small data base. An effort should be made to test more highway sections where one aggregate type is embodied in the bitumen. Because the primary focus of this study was on dolomite aggregates, it is recommended that, at least initially, highway sections containing dolomite alone be included in this expanded study.

This study emphasizes the performance of dolomite aggregates. The physical and chemical parameters studied may not be valid for other aggregate types. It is therefore necessary to expand this study to include other aggregates by using similar analyses and developing parameters for these aggregate types. Limestone is a common aggregate source in Indiana which was not ruled out as a quality aggregate based on this study. The two limestone sources tested, contained the impurities chert and fine insoluble material, which likely improved their frictional resistance. It is therefore suggested that analysis of the limestones be the next step in this detailed analysis. Prior to the recommended study of Indiana limestones, a detailed review of earlier work by Shupe (1958) is strongly recommended to provide insight into the interrelationships of carbonate minerals and impurities.

9. IMPLEMENTATION SUGGESTIONS

Significant correlations between the friction numbers of the towed friction trailer and the Polished Value determined with the British Wheel and Pendulum test would have been ideal for predicting field performance. However, strong correlations were observed only with the Initial Friction Value.

For the British Wheel and Pendulum testing portion of this study, the Initial Friction Value and Polished Value were determined for gravel samples and dolomites, plus two limestones, two sandstones and one air-cooled blast furnace slag. The samples were ranked in descending order. If a minimum acceptable value is designated for either the Initial Friction Value or Polished Value, an acceptance criteria could be established. A Polished Value of 30 would exclude more than 50% of the dolomite sources and some of the tested slag samples. Blended samples of dolomite and slag typically had a Polished Value greater than 30. Crushed gravels generally showed Polished Values of approximately 28. Limestones showed values below 30 with an average of 26.

Estimates of Initial Friction Values and Polished Value for crushed gravel samples can be made based on the percentage of rock types present in the sample, and the average values obtained in the coupon samples using the British Wheel test method. A weighted average is used to perform this calculation. An example calculation is provided under section 6.1.4.3. Based on the limited data of Table 6.6, a 30 value for PV corresponds to an FNR value greater than 30 and an FNS value greater than 20. A 30 value for FNR corresponds more nearly to 15 to 25 for PV and a 20 value for FNS more nearly to 15 to 20 for PV.

A weak correlation was also observed between bulk specific gravity and the core surface British Pendulum Number. Although requiring further analysis, this correlation may eventually assist in predicting field performance of aggregates. Of course, this would require use of the British Pendulum as a field instrument.

Additional studies are needed to implement the current work even though it has accomplished much in working out this complicated relationship. Two tasks are indicated:

1. A study of limestone sources involving British Wheel and Pendulum testing using aggregate coupons. A significant number of sources should be included (20 dolomite sources were included in the current study). A range in composition of the limestones including various amounts of chert, clay and dolomite contents should be included. This would provide a meaningful comparison of limestone versus dolomite quality in regard to frictional resistance.
2. A study of pavement cores for overlays containing single types of aggregate such as dolomite, limestone and slag. Skid trailer friction values, FNR and FNS, would be determined on the pavement prior to coring. IFV and PV values would be determined on coupons made from aggregates removed from these asphalt cores. A comparison between these four friction values (FNR, FNS, IFV and PV) can then be made on these cores containing a single rock type. The standard laboratory data would be analyzed for comparisons, including the acid insoluble test. This work can best be done by the author of the current study, working closely with the INDOT Materials and Tests Laboratory.

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TABLES

Table 4.1. Results of the sieve analysis.

Sample I.D.	Sieve Size (Percent Passing)								Rock Types	Remarks
	1" 25mm	3/4" 19mm	1/2" 12.5mm	3/8" 9.5mm	No. 4 4.75mm	No. 8 2.36mm	No. 30 0.6mm	No. 200 0.075mm		
No. 11	100	100	100	75.0-95.0	10.0-30.0	0.0-10.0	0	0	Dolomite	No. 11
D-001	100.0	100.0	100.0	78.7-83.5	16.2-22.9	1.4-2.8	0.1-0.2	0.0	"	"
D-002	100.0	99.6-100.0	98.7-99.6	38.5-52.0	2.9-7.7	0.2-0.5	0.1	0.0	"	"
D-003	100.0	100.0	99.8-100.0	72.5-77.8	13.8-20.0	1.0-1.7	0.2	0.0	"	"
D-004	100.0	100.0	100.0	82.6-85.1	6.4-9.9	0.1-0.3	0.1-0.2	0.0-0.2	"	"
D-005	100.0	100.0	99.8-100.0	74.3-77.4	15.3-18.3	1.3-1.7	0.2	0.0	"	"
D-006	100.0	100.0	99.8-100.0	90.0-93.0	29.3-37.6	1.6-2.9	0.2	0.0-0.1	"	"
D-007	100.0	100.0	99.7-100.0	85.6-90.8	6.9-17.3	0.4-4.1	0.3-1.6	0.2-0.8	"	"
D-008	100.0	100.0	100.0	86.3-89.5	16.6-25.7	0.4-1.5	0.1-0.2	0.0	"	"
D-009	100.0	100.0	100.0	69.6-78.8	9.1-15.4	0.5-1.4	0.2-0.4	0.1	"	"
D-010	100.0	100.0	100.0	89.8-90.5	22.6-26.5	2.4-2.5	0.5	0.1	"	"
D-011	100.0	100.0	99.9-100.0	82.4-87.5	17.8-26.5	2.5-4.3	0.1	0.0	"	"
D-012	100.0	100.0	100.0	86.6-89.9	29.5-37.3	7.9-9.4	1.3-1.7	0.3-0.5	"	"
D-013	100.0	100.0	100.0	92.5-94.0	25.9-28.7	0.5-1.2	0.1	0.0	"	"
D-014	100.0	100.0	99.7-100.0	82.2-85.2	19.5-24.4	1.1-1.6	0.0	0.0	"	"
D-015	100.0	100.0	100.0	88.2-89.6	34.4-36.2	8.8-10.3	0.1-0.2	0.0	"	"
D-016	100.0	100.0	100.0	81.5-82.3	9.9-16.3	2.2-7.0	1.8-5.1	1.3-3.0	"	"
D-017	100.0	100.0	99.6-99.8	85.1-87.9	15.8-22.6	0.3-0.8	0.1-0.2	0.0	"	"
D-018	100.0	100.0	100.0	77.5-84.6	6.5-14.4	0.5-1.5	0.2-0.3	0.0	"	"
D-019	100.0	100.0	100.0	84.1-89.9	23.9-31.4	2.6-5.0	0.2-0.3	0.0	"	"
D-020	100.0	100.0	100.0	81.2-82.9	7.1-14.5	0.5-2.6	0.3-0.4	0.0-0.2	"	"
G-001	100.0	100.0	100.0	80.3-83.0	10.1-13.8	0.4-2.1	0.2-0.6	0.1-0.4	Gravel	No. 11
G-002	100.0	100.0	100.0	85.6-87.5	13.1-19.8	0.3-1.5	0.1-0.4	0.1-0.3	"	"
G-003	100.0	83.8-86.4	35.0-47.0	10.7-24.9	0.2-3.7	0.0-0.1	0.0-0.1	0.0-0.1	"	No. 5
G-004	100.0	100.0	100.0	83.3-88.5	15.8-24.0	0.8-7.2	0.3-2.9	0.2-0.3	"	No. 11
G-005	100.0	100.0	100.0	63.0-66.8	1.9-2.3	0.1	0.1	0.1	"	"
G-006	100.0	100.0	100.0	99.8-100.0	36.0-43.2	0.9-2.2	0.1-0.4	0.1-0.3	"	"
LS-001	100.0	100.0	99.4-99.9	80.5-82.9	17.4-19.2	1.9-2.0	0.5-0.6	0.4-0.5	Limestone	No. 11
LS-002	100.0	100.0	100.0	98.2-98.4	22.3-24.6	0.8-2.3	0.2-0.4	0.2-0.3	"	"
S-001	100.0	100.0	100.0	96.5-97.2	23.3-26.8	1.9-3.7	0.9	0.7	Sandstone	No. 11
S-002	100.0	100.0	83.9-90.1	59.9-63.8	16.9-21.1	1.7-4.2	0.2-0.7	0.2-0.3	"	No. 9

Table 5.1. Rock classes and the common rock type
(from Federal Highway Administration, 1991).

Class	Rock Type	Comments
Igneous		Formed from molten rock.
Subclass Extrusive	felsite basalt obsidian pumice	Fine grained. General name which includes the rocks: rhyolite; trachyte; latite; andesite. Dark color. Glassy. Frothy; lightweight.
Subclass Intrusive	granite syenite granodiorite monzonite diorite gabbro diabase pyroxenite peridotite	Medium to coarse-grained. Gabbro and diabase have the same composition; gabbro is coarse grained, diabase is medium grained
Sedimentary	limestone dolomite sandstone shale chert conglomerate	Formed by particle deposition or chemical precipitation.
Metamorphic	slate schist gneiss quartzite marble dolomitic marble serpentine	Formed by high heat and/or pressure acting on existing rock.

Table 5.2. Percentage of gravel retained on each sieve size in the original gravel samples.

Sample I.D.	Trials	Sieve Size (Weight Retained, g)								Total (g)	Remarks
		1" 25mm	3/4" 19mm	1/2" 12.5mm	3/8" 9.5mm	No. 4 4.75mm	No. 8 2.36mm	No. 30 0.6mm	< No. 30 < 0.6 mm		
G-001	1st	0.0	0.0	0.0	428.8	1802.3	282.6	6.1	4.8	2524.6	No. 11
	2nd	0.0	0.0	0.0	497.8	1772.5	243.7	5.6	6.1	2525.7	"
	3rd	0.0	0.0	0.0	497.1	1687.0	297.1	38.2	15.7	2535.1	"
	Average(%)	0.00	0.00	0.00	18.77	69.37	10.86	0.66	0.35	100.00	
G-002	1st	0.0	0.0	0.0	365.2	1845.4	325.4	4.4	2.8	2543.2	No. 11
	2nd	0.0	0.0	0.0	317.5	1805.1	400.7	7.4	3.8	2534.5	"
	3rd	0.0	0.0	0.0	339.8	1694.4	465.1	28.0	9.9	2537.2	"
	Average(%)	0.00	0.00	0.00	13.43	70.19	15.64	0.52	0.22	100.00	
G-003	1st	0.0	407.8	1231.9	612.9	264.0	3.6	0.2	1.5	2521.9	No. 5
	2nd	0.0	369.8	1010.1	696.3	439.8	13.4	0.0	1.1	2530.5	"
	3rd	0.0	340.7	986.5	552.1	531.2	89.2	0.4	2.9	2503.0	"
	Average(%)	0.00	14.80	42.73	24.64	16.35	1.41	0.01	0.07	100.00	
G-004	1st	0.0	0.0	0.0	409.4	1717.7	379.5	12.4	7.9	2526.9	No. 11
	2nd	0.0	0.0	0.0	290.6	1645.9	559.9	25.7	8.2	2530.3	"
	3rd	0.0	0.0	0.0	422.1	1498.3	423.0	108.2	74.2	2525.8	"
	Average(%)	0.00	0.00	0.00	14.80	64.12	17.97	1.93	1.19	100.00	
G-005	1st	0.0	0.0	0.0	833.4	1621.2	50.1	0.3	1.8	2506.8	No. 11
	2nd	0.0	0.0	0.0	835.8	1607.1	55.9	0.1	1.7	2500.6	"
	3rd	0.0	0.0	0.0	927.4	1531.5	44.9	0.1	1.8	2505.7	"
	Average(%)	0.00	0.00	0.00	34.56	63.35	2.01	0.01	0.07	100.00	
G-006	1st	0.0	447.0	1146.6	483.0	433.3	3.5	0.1	2.0	2515.5	No. 8
	2nd	0.0	346.0	1128.2	520.3	497.4	9.9	0.5	1.2	2503.5	"
	3rd	0.0	321.0	1162.9	576.1	448.1	3.6	0.1	0.9	2512.7	"
	Average(%)	0.00	14.79	45.64	20.97	18.31	0.23	0.01	0.05	100.00	

Table 5.3. Weight and count of selected particles on each sieve size.

Gravel I.D.	Trials	1" to 3/4"		3/4 to 1/2"		1/2" to 3/8"		3/8" to No. 4		Total Wt. (g)
		Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)	
G-001	1st Trial					265	428.20	300	136.01	564.21
	2nd Trial					300	497.32	300	198.07	695.39
	3rd Trial					300	497.01	300	164.28	661.29
G-002	1st Trial					246	365.19	300	167.74	532.93
	2nd Trial					206	317.92	300	169.74	487.66
	3rd Trial					226	340.14	300	186.81	526.95
G-003	1st Trial	31*	407.80*	197	1231.90	263	612.90	300	263.95	2108.75
	2nd Trial	28*	369.84*	179	1008.25	300	664.29	300	271.50	1944.04
	3rd Trial	24*	340.67*	159	986.48	250	552.09	300	212.60	1751.17
G-004	1st Trial					231	409.59	300	180.61	590.20
	2nd Trial					155	290.52	300	151.50	442.02
	3rd Trial					240	422.13	300	157.67	579.80
G-005	1st Trial					300	534.00	300	235.50	769.50
	2nd Trial					300	538.40	300	232.00	770.40
	3rd Trial					300	535.00	300	241.50	776.50
G-006	1st Trial	34*	447.00*	221	1146.60	246	483.00	300	231.20	1860.80
	2nd Trial	26*	346.00*	225	1128.20	276	520.20	300	217.90	1866.30
	3rd Trial	27*	321.00*	207	1162.90	288	576.00	300	237.00	1975.90

* : This portion was combined with the fraction of -3/4" to + 1/2 ", because particles were less than 30.

Table 5.4. Composition of fractions of the petrographic analysis on the basis of 100 percent retained on the No. 4 sieve.

Sample I.D.	Fraction	Sieve Size (Weight Retained, g)								Total (g) (%)
		1" 25mm	3/4" 19mm	1/2" 12.5mm	3/8" 9.5mm	No. 4 4.75mm	No. 8 2.36mm	No. 30 0.6mm	< No. 30 < 0.6 mm	
G-001	A*	0.0	0.0	0.0	18.8	69.4	10.9	0.7	0.4	100.0
	B*	0.0	0.0	0.0	18.8	69.4				88.1
	C*	0.0	0.0	0.0	21.3	78.7				100.0
G-002	A*	0.0	0.0	0.0	13.4	70.2	15.6	0.5	0.2	100.0
	B*	0.0	0.0	0.0	13.4	70.2				83.6
	C*	0.0	0.0	0.0	16.1	83.9				100.0
G-003	A*	0.0	14.8	42.7	24.6	16.4	1.4	0.0	0.1	100.0
	B*	0.0	14.8	42.7	24.6	16.4				98.5
	C*	0.0	15.0	43.4	25.0	16.6				100.0
G-004	A*	0.0	0.0	0.0	14.8	64.1	18.0	1.9	1.2	100.0
	B*	0.0	0.0	0.0	14.8	64.1				78.9
	C*	0.0	0.0	0.0	18.8	81.2				100.0
G-005	A*	0.0	0.0	0.0	34.6	63.4	2.0	0.0	0.1	100.0
	B*	0.0	0.0	0.0	34.6	63.4				97.9
	C*	0.0	0.0	0.0	35.3	64.7				100.0
G-006	A*	0.0	14.8	45.6	21.0	18.3	0.2	0.0	0.1	100.0
	B*	0.0	14.8	45.6	21.0	18.3				99.7
	C*	0.0	14.8	45.8	21.0	18.4				100.0

A* : Composition of fractions retained on each sieve.

B* : Composition of fractions retained on each sieve coarser than No.4.

C* : Composition of fractions of the petrographic analysis on the basis of 100 percent retained on the No. 4 sieve.

Table 5.5. Percentage of carbonate, other sedimentary, igneous, metamorphic rock in the gravel sample based on count and weight.

I.D	Rock Type	Sieve Fraction Analyzed					
		1" to 1/2" (%)*		1/2" to 3/8" (%)		3/8" to No.4 (%)	
		Count	Wt.	Count	Wt.	Count	Wt.
G-001	Carbonate			51.2	52.2	50.7	51.2
	Other Seidmentary			8.4	7.1	7.9	7.7
	Igneous			25.3	25.3	27.4	27.1
	Metamorphic			15.0	15.4	14.0	14.1
	Total			99.9	100.0	100.0	100.1
G-002	Carbonate			87.7	87.6	83.3	84.2
	Other Seidmentary			0.9	0.7	2.4	1.7
	Igneous			8.1	8.8	7.1	8.2
	Metamorphic			3.3	2.9	7.1	5.8
	Total			100.0	100.0	99.9	99.9
G-003	Carbonate	70.5	69.3	69.3	69.4	69.9	70.7
	Other Seidmentary	5.1	4.1	6.4	5.9	7.1	6.5
	Igneous	13.4	15.1	17.3	17.6	15.7	15.7
	Metamorphic	10.9	11.5	6.9	7.1	7.3	7.1
	Total	99.9	100.0	99.9	100.0	100.0	100.0
G-004	Carbonate			58.9	58.7	63.2	63.2
	Other Seidmentary			4.2	3.5	4.0	3.0
	Igneous			25.5	26.6	23.0	23.7
	Metamorphic			11.4	11.1	9.8	10.1
	Total			100.0	99.9	100.0	100.0
G-005	Carbonate			63.1	64	56.4	56.8
	Other Seidmentary			7.1	6.4	8.2	7.3
	Igneous			18.9	18.9	20.2	19.8
	Metamorphic			10.9	10.6	15.1	16.2
	Total			100	99.9	99.9	100.1
G-006	Carbonate	49.9	50.2	42.2	42.9	43.2	45.7
	Other Seidmentary	2.2	2.0	4.3	3.9	3.7	4.0
	Igneous	31.3	31.3	35.6	36.2	37.4	36.6
	Metamorphic	16.7	16.5	17.9	16.9	15.7	13.7
	Total	100.1	100.0	100.0	99.9	100.0	100.0

* : The sizes of 1 to 3/4 inch and 3/4 to 1/2 inch were combined

Table 5.6. Percentage of carbonate, other sedimentary, igneous, metamorphic rock in the gravel sample recalculated on the basis of 100 percent retained on the No. 4 sieve.

I.D	Rock Type	Sieve Fraction Analyzed									Total (%)
		1" to 1/2" (%) [*]			1/2" to 3/8" (%)			3/8" to No.4 (%)			
		A ¹	B ²	A X B	A ¹	B ²	A X B	A ¹	B ²	A X B	
G-001	Carbonate				52.2	11.1		51.2	40.3		51.4
	Other Seidmentary				7.1	1.5		7.7	6.1		7.6
	Igneous				25.3	5.4		27.1	21.3		26.7
	Metamorphic				15.4	3.3		14.1	11.1		14.4
	Total				21.3	100.0	21.3	78.7	100.1	78.8	100.1
G-002	Carbonate				87.6	14.1		84.2	70.6		84.7
	Other Seidmentary				0.7	0.1		1.7	1.4		1.5
	Igneous				8.8	1.4		8.2	6.9		8.3
	Metamorphic				2.9	0.5		5.8	4.9		5.3
	Total				16.1	100.0	16.1	83.9	99.9	83.8	99.9
G-003	Carbonate		69.3	40.5		69.4	17.4		70.7	11.7	69.6
	Other Seidmentary		4.1	2.4		5.9	1.5		6.5	1.1	4.9
	Igneous		15.1	8.8		17.6	4.4		15.7	2.6	15.8
	Metamorphic		11.5	6.7		7.1	1.8		7.1	1.2	9.7
	Total	58.4	100.0	58.4	25.0	100.0	25.0	16.6	100.0	16.6	100.0
G-004	Carbonate				58.7	11.0		63.2	51.3		62.4
	Other Seidmentary				3.5	0.7		3.0	2.4		3.1
	Igneous				26.6	5.0		23.7	19.3		24.3
	Metamorphic				11.1	2.1		10.1	8.2		10.3
	Total				18.8	99.9	18.8	81.2	100.0	81.2	100.0
G-005	Carbonate				64	22.6		56.8	36.7		59.3
	Other Seidmentary				6.4	2.3		7.3	4.7		7.0
	Igneous				18.9	6.7		19.8	12.8		19.5
	Metamorphic				10.6	3.7		16.2	10.5		14.2
	Total				35.3	99.9	35.3	64.7	100.1	64.8	100.0
G-006	Carbonate		50.2	30.4		42.9	9.0		45.7	8.4	47.8
	Other Seidmentary		2.0	1.2		3.9	0.8		4.0	0.7	2.8
	Igneous		31.3	19.0		36.2	7.6		36.6	6.7	33.3
	Metamorphic		16.5	10.0		16.9	3.5		13.7	2.5	16.1
	Total	60.6	100.0	60.6	21	99.9	21.0	18.4	100.0	18.4	100.0

* : The sizes of 1 to 3/4 inch and 3/4 to 1/2 inch were combined

1: Weight percentage from Table 4.4.

2: Weight percentage from Table 4.5.

Table 5.7. Percentage of uncrushed gravel retained on each sieve.

I.D.	Trials	1 inch to 1/2 inch*				1/2 inch to 3/8 inch				3/8 inch to No. 4			
		Count	Wt. (g)	Total	Wt. (%)	Count	Wt. (g)	Total	Wt. (%)	Count	Wt. (g)	Total	Wt. (%)
G-001	1st					23	44.31	428.20	10.35	26	12.74	136.01	9.37
	2nd					15	26.53	497.32	5.33	20	18.05	198.07	9.11
	3rd					21	40.18	497.01	8.08	23	9.61	164.28	5.85
	Average								7.92				8.11
G-002	1st					1	1.59	365.19	0.44	7	1.53	167.74	0.91
	2nd					0	0.00	317.92	0.00	4	0.86	169.74	0.51
	3rd					1	1.39	340.14	0.41	2	2.37	186.81	1.27
	Average								0.28				0.90
G-003	1st	113	832.37	1639.70	50.76	158	382.01	612.90	62.33	163	156.01	263.95	53.11
	2nd	99	699.19	1378.09	50.74	170	373.13	664.29	56.17	148	149.31	271.50	54.99
	3rd	64	471.72	1327.15	35.54	127	289.14	552.09	52.37	171	133.72	212.60	62.90
	Average				45.68				56.96				59.00
G-004	1st					52	99.18	409.59	24.21	58	45.11	180.61	24.98
	2nd					44	91.79	290.52	31.60	68	37.65	151.50	24.85
	3rd					68	99.86	422.13	23.66	61	38.06	157.67	24.14
	Average								26.49				24.66
G-005	1st					17	34.10	534.00	6.39	7	7.50	235.50	3.18
	2nd					10	20.30	538.40	3.77	10	6.70	232.00	2.89
	3rd					10	22.30	535.00	4.17	13	14.20	241.50	5.88
	Average								4.77				3.98
G-006	1st	1	5.70	1593.60	0.36	1	2.20	483.00	0.46	1	1.40	231.20	0.61
	2nd	2	11.50	1474.20	0.78	4	6.60	520.20	1.27	2	0.50	217.90	0.23
	3rd	4	20.30	1483.90	1.37	8	19.20	576.00	3.33	3	2.80	237.00	1.18
	Average				0.84				1.69				0.67

* : The sizes of 1 to 3/4 inch and 3/4 inch to 1/2 inch were combined.

Table 5.8. Weight percentage of uncrushed gravel in the total sample recalculated on the basis of 100 percent retained on the No. 4 sieve.

I.D	Rock Type	Sieve Fraction Analyzed									Total (%)
		1" to 1 1/2" (%)*			1/2" to 3/8" (%)			3/8" to No.4(%)			
		A ¹	B ²	A X B	A ¹	B ²	A X B	A ¹	B ²	A X B	A X B
G-001	Carbonate Other Seidmentary Igneous Metamorphic Total				7.92	1.69		8.11	6.38	8.07	
				21.3			78.70				
G-002	Carbonate Other Seidmentary Igneous Metamorphic Total				0.28	0.05		0.90	0.76	0.80	
				16.1			83.90				
G-003	Carbonate Other Seidmentary Igneous Metamorphic Total	45.86	26.78		56.96	14.24		59.00	9.79	50.82	
		58.4		25.0			16.60				
G-004	Carbonate Other Seidmentary Igneous Metamorphic Total				26.49	4.98		24.66	20.02	25.00	
				18.8			81.20				
G-005	Carbonate Other Seidmentary Igneous Metamorphic Total				4.77	1.68		3.98	2.58	4.26	
				35.3			64.70				
G-006	Carbonate Other Seidmentary Igneous Metamorphic Total	0.84	0.51		1.69	0.35		0.67	0.12	0.99	
		60.6		21			18.40				

*: The sizes of 1 to 3/4 inch and 3/4 to 1/2 inch were combined

1: Weight percentage from Table 4.4.

2: Weight percentage from Table 4.7.

Table 5.9. British Pendulum results.

Sample I.D.	IFV	PV	WI	% Loss	IFV/PV
D-001	40.0	24.9	15.1	37.8	1.61
D-002	43.3	25.0	18.3	42.3	1.73
D-003	41.8	27.3	14.5	34.7	1.53
D-004	46.9	35.3	11.6	24.7	1.33
D-005	44.0	27.7	16.3	37.0	1.59
D-006	42.7	26.9	15.8	37.0	1.59
D-007	44.0	28.8	15.2	34.5	1.53
D-008	44.6	28.7	15.9	35.7	1.55
D-009	44.8	31.0	13.8	30.8	1.45
D-010	45.9	31.3	14.6	31.8	1.47
D-011	46.2	30.0	16.2	35.1	1.54
D-012	47.6	31.3	16.3	34.2	1.52
D-013	43.5	32.7	10.8	24.8	1.33
D-014	46.7	32.0	14.7	31.5	1.46
D-015	40.5	24.1	16.4	40.5	1.68
D-016	40.1	23.6	16.5	41.1	1.70
D-017	41.3	24.9	16.4	39.7	1.66
D-018	43.6	28.4	15.2	34.9	1.54
D-019	41.6	28.0	13.6	32.7	1.49
D-020	41.9	28.1	13.8	32.9	1.49
S-001	46.5	37.3	9.2	19.8	1.25
S-002	46.0	37.6	8.4	18.3	1.22
LS-001	41.7	27.2	14.5	34.8	1.53
LS-002	41.6	26.6	15.0	36.1	1.56

Table 5.10. Table of equation codes and statistical parameters.

I.D.	Data Set	Observations	Minimum	Maximum
B	Initial Friction Value (IFV)	19	40	47.6
C	Polish Value (PV)	19	23.6	35.3
D	Wear Index (WI)	19	11.6	18.3
E	IFV/PV	19	1.33	1.73
F	% Magnesium	16	10.7	13.1
G	% Dolomite from Mg	16	81.2	99.4
H	% Calcite from Mg	16	0.2	12.2
I	Calcite/Dolomite from Mg	16	0.002	0.142
J	% Dolomite from X-ray	19	82.72	99.92
K	% Calcite from X-ray	19	0	15.17
L	Calcite/Dolomite from X-ray	19	0	0.183
M	% Insoluble >200 Sieve	19	0.02	4.45
N	% Insoluble < 200 sieve	19	0.06	6.28
O	% total Insoluble </>	19	0.08	9.82
P	Insoluble Ratio	19	0.39	34.5
Q	Average Grain Size (mm)	19	0.057	0.194
R	Median Grain Size (mm)	19	0.039	0.114
S	Grain Size Standard Deviation	19	0.027	0.139
T	% Cement	19	7	27.8
U	% Matrix	19	2.8	47.5
V	% Groundmass	19	12.6	64.8
W	% Voids	19	3.5	13.4
X	Grain Shape	19	1.6	2.5
Y	% Grains	19	31.2	77.6
Z	Specific Gravity	19	2.39	2.732
AA	% Absorption	19	0.79	6.25
AB	LA Abrasion	19	22.47	36.98
AC	Sodium Sulfate Soundness	18	0.31	13.18
Second Petrographic Observation				
AD	Grain Shape	5	6.1	8.9
AE	Average Grain Size (mm)	5	0.035	0.094
AF	Median Grain Size (mm)	5	0.032	0.09
AG	% Cement	5	0	10.7
AH	% Matrix	5	15.4	55.7
AI	% Groundmass	5	15.4	56
AJ	% Voids	5	8.3	13
AK	% Grains	5	31	75.6
AL	Grain Standard Deviation	5	0.02	0.05

Table 5.11. Matrix arrangement of correlation coefficients, significance level in percent and observations for laboratory parameters.

I.O. Code	Correlation/Percent Probability/Observations																			
	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	
B	1	0.03948	-0.17348	-0.50278	-0.3454	-0.3446	0.13304	0.13925	-0.43701	0.30158	0.28054	0.15757	0.54152	0.14328	0.14328	-0.00751	-0.58608	-0.03282	0.35072	
	0	0.01	48.45	0.06	17.45	17.53	80.83	89.87	5.4	10.83	21.58	50.7	1.37	6.95	64.68	72.16	0.64	86.45	14.1	
	20	20	20	20	20	17	17	17	17	20	20	20	20	20	20	20	19	19	19	
C	0.03946	1	-0.0648	-0.01005	-0.05202	-0.05201	0.54542	0.55242	-0.77055	0.0234	0.02519	0.20274	0.58124	0.44940	0.00184	0.07770	-0.50786	0.18087	0.15008	
	0.01	0	0.06	0.01	0.45	0.45	2.35	2.15	0.03	0.03	0.32	30.13	1	4.68	89.38	75.16	0.81	45.87	63.61	
	20	20	20	20	20	17	17	17	17	20	20	20	20	20	20	20	19	19	19	
D	-0.17340	-0.0648	1	0.00314	0.75560	0.75840	-0.83723	-0.84453	0.71301	-0.71032	-0.73954	-0.15402	-0.28051	-0.25718	0.1872	-0.30380	0.27247	-0.42935	0.25540	
	48.45	0.06	0	0.01	0.05	0.04	0.01	0.01	0.04	0.04	0.02	51.46	21.73	27.37	42.04	20.59	25.91	0.68	20.11	
	20	20	20	20	17	17	17	17	17	20	20	20	20	20	20	20	19	19	19	
E	-0.50278	-0.01005	0.00314	1	0.75743	0.75778	-0.71414	-0.72345	0.75237	-0.06776	-0.08036	-0.20164	-0.40317	-0.43817	0.18001	-0.00005	0.53011	-0.22328	0.03109	
	0.06	0.01	0.01	0	0.04	0.04	0.13	0.1	0.01	0.13	0.1	20.51	2.71	5.33	47.41	68.46	1.99	35.82	89.86	
	20	20	20	20	17	17	17	17	17	20	20	20	20	20	20	20	19	19	19	
F	-0.3454	-0.05282	0.75560	0.75743	1	-0.88847	-0.80437	0.88685	-0.73237	-0.73345	-0.45373	-0.05587	-0.83132	0.1592	0.07515	0.52515	-0.08027	-0.02329		
	17.45	0.45	0.05	0.04	0	0.01	0.01	0.01	0.01	0.01	0.06	6.6	0.43	0.68	54.04	78.21	3.07	74.23	93.16	
	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	18	18	18	18	
G	-0.3446	-0.05281	0.75840	0.75778	1	1	-0.88894	-0.80482	0.88848	-0.72351	-0.73373	-0.45489	-0.65516	-0.83048	0.15608	0.07357	0.62527	-0.08052	-0.02324	
	17.53	0.45	0.04	0.04	0.01	0	0.01	0.01	0.01	0.01	0.09	6.68	0.43	0.87	54.07	78.68	3.07	73.86	93.19	
	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	18	18	18	18	
H	0.13394	0.54542	-0.83723	-0.71414	-0.80847	-0.88804	1	0.00763	-0.80036	0.83365	0.84186	0.07077	0.26867	0.22877	0.02220	0.23568	-0.24302	0.37917	-0.18875	
	80.83	2.35	0.01	0.13	0.01	0.01	0	0.01	0.01	0.01	0.01	0.01	70.09	24.72	30.14	83.23	37.08	30.44	14.75	
	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	18	18	18	
I	0.13825	0.55242	-0.84453	-0.72345	-0.80437	-0.80462	0.98783	1	-0.81512	0.84225	0.8533	0.08806	0.18268	0.24333	0.01509	0.21251	-0.25711	0.35051	-0.18140	
	50.87	2.15	0.01	0.1	0.01	0.01	0	0	0.01	0.01	0.01	0.01	74.26	21.31	34.68	95.42	42.04	33.04	17.53	
	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	18	18	18	
J	-0.43701	-0.72055	0.71361	0.75237	0.88685	0.88846	-0.80036	-0.81512	1	-0.86542	-0.8858	-0.31236	-0.06187	-0.58769	-0.15382	-0.08808	0.53024	-0.22314	-0.10251	
	5.4	0.33	0.04	0.01	0.01	0.01	0.01	0.01	0	0.01	0.01	0.01	16	0.15	0.9	51.79	78.58	1.79	35.85	
	20	20	20	20	17	17	17	17	17	20	20	20	20	20	20	20	19	19	19	
K	0.30158	0.0234	-0.71032	-0.86778	-0.72327	-0.72351	0.83305	0.84225	-0.88542	1	0.90788	-0.08988	0.30749	0.14204	0.3085	0.40484	-0.24738	0.53198	-0.05947	
	18.83	0.33	0.04	0.13	0.1	0.1	0.01	0.01	0.01	0	0	0.01	70.8	18.72	55.03	8.16	6.57	30.73	1.91	
	20	20	20	20	17	17	17	17	17	20	20	20	20	20	20	20	19	19	19	
L	0.28054	0.02519	-0.73954	-0.86038	-0.73345	-0.73373	0.84186	0.8533	-0.8958	0.90786	1	-0.0948	0.31827	0.14872	0.3871	0.42239	-0.24431	0.54008	-0.07097	
	99.76	0.32	0.02	0.01	0.06	0.06	0.01	0.01	0.01	0.01	0	69.18	17.14	63.85	11.13	7.10	31.34	1.47	77.28	
	20	20	20	20	17	17	17	17	17	20	20	20	20	20	20	20	19	19	19	
M	0.15757	0.20274	-0.15482	-0.26164	-0.45573	-0.45489	0.07077	0.00096	-0.31235	-0.00098	-0.0940	1	0.55796	0.06003	-0.40940	-0.48102	-0.47075	-0.30721	0.10327	
	60.7	38.13	61.46	20.61	6.6	6.66	6.06	74.26	18	70.6	66.16	0	1.06	0.01	2.49	4.7	4.19	10.15	66.0	
	20	20	20	20	17	17	17	17	17	20	20	20	20	20	20	20	19	19	19	

Table 5.11. (Continued).

I.D. Code	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
N	0.54152 1.37	0.50124 1	-0.26051 21.73	-0.40317 2.71	-0.05597 0.43	-0.05510 0.43	0.20687 24.72	0.31020 21.31	-0.09167 0.15	0.30740 16.72	0.31027 17.14	0.55766 1.06	0	0.00782 0	-0.22101 37.73	-0.37141 20	-0.26084 11.74	-0.30719 0.41	0.63009 26.88
O	0.41405 6.95	0.40496 4.68	-0.25716 27.37	-0.43817 5.33	-0.03132 0.86	-0.03040 0.87	0.22877 36.14	0.24333 34.06	-0.50780 0.9	0.14204 35.03	0.14022 53.85	0.06083 0.01	0.00282 0	1	-0.39518 6.48	-0.45609 4.92	-0.81124 0.54	-0.35758 13.29	0.38768 26.76
P	0.14328 54.00	0.00164 99.38	0.4294 42.94	0.16091 47.41	0.1592 54.94	0.15808 54.97	0.02220 93.23	0.01509 95.42	-0.15382 51.79	0.3965 20	0.3071 11.13	0.40940 2.49	-0.22181 34.73	0.39518 6.49	0	0.33545 10.03	0.09471 89.07	0.26055 24.47	0.33084 15.48
Q	-0.09751 72.16	0.07770 75.10	-0.30088 20.59	-0.09085 66.48	0.07515 78.21	0.07357 76.66	0.23506 37.06	0.21251 42.94	-0.0886 78.56	0.40484 8.57	0.42239 7.16	-0.40102 19	-0.37141 4.7	-0.45609 11.74	0.33545 10.03	1	0.48468 0.45	0.05781 4.5	0.30470 5.08
R	-0.58000 0.84	-0.56766 0.81	0.27247 25.91	0.53011 1.96	0.52515 3.87	0.52527 3.07	-0.24302 36.44	-0.25711 33.64	0.53924 1.79	-0.24736 30.73	-0.24431 31.34	-0.47075 4.19	-0.02884 0.41	-0.81124 0.54	0.06471 0.54	0.46468 4.5	1	0.37278 11.9	-0.43976 5.98
S	-0.03202 66.45	0.16087 45.07	-0.42935 6.00	-0.23226 35.82	-0.08027 74.23	-0.09052 73.88	0.37917 14.75	0.35851 17.53	-0.22314 35.95	0.53109 1.91	0.54986 1.47	-0.38721 10.15	-0.26719 26.68	-0.35758 13.20	0.28055 24.47	0.05781 0.01	0.37278 11.8	1	-0.3581 13.22
T	0.35072 14.1	0.15088 53.81	0.25549 26.11	0.03109 69.80	-0.02720 93.10	-0.02324 93.19	-0.18675 46.86	-0.18140 50.12	-0.10251 67.82	-0.05847 81.21	-0.07097 77.26	0.10527 89.8	-0.38721 10.15	-0.35758 13.20	0.28055 24.47	0.05781 0.01	0.37278 11.8	1	-0.3581 13.22
U	-0.03011 80.20	0.06253 70.93	-0.17880 46.35	-0.10237 87.07	-0.45725 7.5	-0.45761 7.47	0.52637 3.81	0.51205 4.28	-0.11884 02.86	0.16894 48.93	0.17823 47.05	-0.20889 38.13	-0.13792 57.34	-0.07260 91.05	-0.17278 47.03	0.06772 78.3	-0.02073 83.20	0.16031 43.76	-0.31653 16.36
V	0.14750 54.00	0.1408 56.53	-0.0530 82.25	-0.08015 72.58	-0.52634 3.86	-0.52588 3.85	0.48006 5.51	0.47807 6.16	-0.1503 53.91	0.13754 57.44	0.14089 50.50	-0.19481 42.47	0.26916 21.34	0.07404 76.32	-0.02415 92.18	-0.04919 84.16	-0.16865 43.86	0.04040 86.93	0.11644 85.5
W	-0.16035 40.81	-0.0373 87.95	-0.19720 43.03	-0.07760 75.19	0.29746 27.17	0.29729 27.2	-0.12035 65.71	-0.11523 67.09	0.03953 87.23	0.09083 90.39	0.09501 93.86	-0.02742 91.13	-0.33161 10.55	-0.20886 38.32	0.21217 38.32	0.10454 44.95	0.01407 85.44	0.1113 85.01	-0.0035 76.92
X	-0.01568 84.92	0.00650 72.45	-0.20562 30.64	-0.1724 61.79	-0.43570 3.24	-0.43854 3.21	0.54466 2.91	0.55231 2.85	-0.38119 12.87	0.38726 12.16	0.38454 12.46	0.15225 53.38	0.07927 74.7	0.12555 60.80	0.11576 83.80	-0.06888 66.71	-0.2083 27.05	-0.0018 73.67	0.0089 77.93
Y	-0.12045 59.74	-0.12045 53.25	0.10776 60.08	0.1176 63.18	0.52405 3.72	0.52445 3.7	-0.52738 3.7	-0.51697 4.06	0.18308 50.47	-0.18116 45.6	-0.18438 44.69	0.23005 34.34	-0.2898 27.51	-0.03481 66.75	-0.02327 92.47	0.01209 86.08	0.21348 36.02	-0.07324 76.57	-0.11844 82.91
Z	-0.67007 0.17	-0.74505 0.03	0.47022 4.84	0.03207 0.36	0.20564 26.03	0.20668 26.45	-0.33267 20.76	-0.33725 20.85	0.47132 4.16	-0.55454 1.37	-0.56715 1.22	0.19434 42.53	-0.28904 26.84	-0.05844 81.85	-0.20581 21.88	-0.20748 38.4	0.40071 3.20	-0.24628 30.34	-0.38161 12.62

Table 5.11. (Continued).

I.D. Code	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
AA	0.85025 0.26 18	0.78468 0.01 18	-0.35038 1.76 18	-0.68208 0.13 18	-0.31927 22.81 18	-0.32030 22.84 18	0.40084 12.41 18	0.39038 12.65 18	-0.4573 4.8 18	0.50699 1.08 18	0.58033 0.82 18	-0.21236 38.27 18	0.20438 40.13 18	0.0092 97.02 18	0.32375 17.63 18	0.31403 18.04 18	-0.41583 7.86 18	0.35127 14.03 18	0.31182 18.37 18
AB	0.13232 56.92 19	0.108 66.00 19	-0.0059 66.00 19	-0.05668 61.71 18	0.41468 11.01 18	0.41374 11.11 18	-0.35858 17.13 18	-0.36368 16.82 18	0.18122 43.29 18	-0.03758 80.11 18	-0.09827 60.8 18	-0.28173 24.35 18	-0.09973 68.46 18	-0.2048 40.08 18	0.03115 88.83 18	-0.00887 87.16 18	-0.05487 82.34 18	-0.06895 78.54 18	0.16189 50.84 18
AC	0.44441 6.46 18	0.60273 0.81 18	-0.56587 1.44 18	-0.85848 0.29 18	-0.78433 0.09 18	-0.78478 0.09 18	0.71126 0.28 18	0.71368 0.28 18	-0.70448 0.11 18	0.81744 0.83 18	0.81102 0.77 18	0.22345 37.26 18	0.51016 3.05 18	0.41808 6.43 18	0.21461 30.25 18	-0.13626 50.86 18	-0.06998 0.72 18	0.02608 91.54 18	0.24395 32.95 18
AD	-0.50047 36.06 5	-0.93993 7.78 5	0.85444 23.08 5	0.86291 4.14 5	0.8372 1.87 5	0.83747 1.86 5	-0.74312 14.06 5	-0.76982 13.54 5	0.59244 28.25 5	-0.15331 80.58 5	-0.16458 75.38 5	-0.88745 5.88 5	-0.84007 23.89 5	-0.78739 10.81 5	0.58463 32.12 5	0.74109 15.11 5	0.63477 24.68 5	0.58695 20.81 5	0.05297 89.78 5
AE	-0.32064 56.88 5	-0.48734 42.74 5	0.29678 82.53 5	0.4545 44.19 5	0.86586 20.11 5	0.86672 20.03 5	-0.86703 20 5	-0.70233 18.6 5	0.52391 36.46 5	-0.41471 46.75 5	-0.42719 47.23 5	-0.43141 48.63 5	-0.28138 67.1 5	-0.36008 54.48 5	0.02126 87.26 5	0.87248 0.52 5	0.78333 11.71 5	0.7842 4.83 5	-0.38887 54.15 5
AF	-0.37136 53.83 5	-0.43154 46.01 5	0.15216 60.7 5	0.37282 53.95 5	0.52628 35.9 5	0.53105 35.71 5	-0.50038 38.4 5	-0.51159 37.63 5	0.25978 70.14 5	-0.08135 82.19 5	-0.06655 81.53 5	-0.1827 60.41 5	-0.28868 83.74 5	-0.3186 60.13 5	0.04707 83.88 5	0.9463 1.48 5	0.98341 0.84 5	0.91074 3.16 5	-0.37328 31.23 5
AG	0.18658 74.68 5	0.57898 30.65 5	-0.88832 18.15 5	-0.7207 16.95 5	-0.68387 5.92 5	-0.68241 5 5	0.78733 11.30 5	0.81275 8.45 5	-0.81628 6.10 5	0.83838 24.84 5	0.87858 20.69 5	0.74603 14.78 5	0.35125 56.21 5	0.57873 30.58 5	-0.36169 54.07 5	-0.40057 41.28 5	-0.08166 88.59 5	-0.27708 85.11 5	-0.4 50.46 5
AH	-0.43738 46.14 5	-0.07813 89.04 5	-0.57025 30.68 5	-0.34272 57.23 5	-0.15402 80.38 5	-0.15588 80.26 5	0.18803 74.04 5	0.18808 74.04 5	0.55341 33.32 5	-0.76883 12.87 5	-0.73964 15.31 5	0.13508 82.73 5	-0.11023 85.98 5	0.01515 96.07 5	-0.78335 10.92 5	0.54418 34.31 5	0.29511 82.98 5	0.87091 21.82 5	-0.88189 22.38 5
AI	-0.38009 52.8 5	0.08328 86.14 5	-0.78618 11.25 5	-0.5884 32.88 5	-0.41402 46.83 5	-0.41472 46.75 5	0.43632 48.26 5	0.41788 48.08 5	0.31707 60.82 5	-0.58118 30.41 5	-0.53658 34.8 5	0.35803 39.3 5	-0.00941 89.16 5	0.18788 76.22 5	-0.80408 3.52 5	0.00048 50.41 5	0.38047 50.11 5	0.39511 30 5	-0.78215 11.8 5
AJ	-0.32165 8.8 5	-0.68318 20.38 5	-0.14301 81.65 5	0.3058 61.7 5	0.38984 52.03 5	0.38708 52.07 5	-0.17224 78.18 5	-0.38703 78.18 5	0.88404 20.28 5	-0.45478 44.18 5	-0.45887 44.08 5	-0.45908 43.81 5	-0.85487 23.04 5	-0.58324 30.2 5	-0.1894 74.78 5	0.80355 5.93 5	0.75335 14.15 5	0.1318 3.03 5	-0.83488 25 5
AK	0.44838 44.77 5	-0.00506 98.36 5	0.74714 14.07 5	0.48124 41.16 5	0.33708 57.81 5	0.33778 57.83 5	-0.38703 51.06 5	-0.38703 51.06 5	0.58176 64.09 5	0.58176 64.09 5	0.5534 33.32 5	-0.77141 88.34 5	-0.88381 88.34 5	-0.10445 88.73 5	0.80013 0.15 5	-0.47318 42.08 5	-0.3388 57.89 5	-0.64893 23.51 5	0.76011 10.48 5
AL	-0.46428 43.08 5	-0.5504 33.04 5	0.21857 72.27 5	0.45843 43.76 5	0.05947 22.88 5	0.05712 22.82 5	-0.58129 20.37 5	-0.58129 20.37 5	0.57708 30.74 5	-0.41038 46.33 5	-0.43013 46.07 5	-0.47313 42.07 5	-0.30307 52.35 5	-0.4514 44.54 5	-0.00507 89.26 5	0.89134 0.1 5	0.82317 0.80 5	0.02603 45.2 5	-0.45881 2.38 5

Table 5.11. (Continued).

I.D. Code	Correlation/Percent Probability/Observations																			
	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL		
B	-0.03011	0.14750	-0.16835	-0.01560	-0.12045	-0.67037	0.65025	0.13232	0.44441	-0.50047	-0.32004	0.10858	-0.43738	-0.36009	-0.82705	0.44938	-0.46428			
	90.20	54.60	48.81	97.82	58.74	0.17	0.56	58.92	6.48	39.05	59.69	53.83	74.89	48.14	52.8	8.0	44.77	43.08		
	19	10	10	19	10	10	10	10	10	10	5	5	5	5	5	5	5	5		
C	0.00253	0.1408	-0.0373	0.08058	-0.15271	-0.74505	0.76489	0.100	0.80273	-0.81593	-0.4734	0.43154	0.57888	-0.07913	0.09328	-0.89310	-0.00508	-0.55609		
	76.93	56.53	43.03	38.84	53.25	0.03	0.01	88.58	0.81	7.78	48.74	48.81	30.65	88.94	88.14	20.38	98.30	33.04		
	19	10	10	10	10	10	10	10	10	5	5	5	5	5	5	5	5	5		
D	-0.17080	-0.0530	-0.10229	-0.20562	0.10770	0.48202	-0.53836	-0.0059	-0.56587	0.85444	0.20878	0.15218	-0.80832	-0.57875	-0.78918	-0.14301	0.74714	0.91857		
	48.35	82.75	43.03	38.84	68.06	4.64	1.79	98.09	1.44	23.08	82.53	80.7	19.15	30.68	11.25	81.85	14.07	72.27		
	19	10	10	10	10	10	10	10	10	5	5	5	5	5	5	5	5	5		
E	-0.10237	-0.08815	-0.07789	-0.1224	0.1178	0.83287	-0.68209	-0.05868	-0.65949	0.89291	0.4545	0.37282	-0.72077	-0.34272	-0.55944	0.3058	0.40124	0.45843		
	87.87	72.56	75.19	61.70	83.16	0.30	0.13	81.81	0.20	4.14	44.10	53.65	16.95	57.23	32.68	81.7	41.10	43.76		
	19	10	10	10	10	10	10	10	10	10	5	5	5	5	5	5	5	5		
F	-0.45725	-0.52538	0.26240	-0.53579	0.52405	0.26564	-0.31927	0.41488	-0.78433	0.0372	0.88586	0.57929	-0.86387	-0.15482	-0.41402	0.38894	0.33700	0.85847		
	7.5	3.68	27.17	3.24	3.72	26.83	22.81	11.01	0.09	1.87	20.11	35.0	5.92	60.39	48.83	52.03	57.81	22.86		
	10	10	10	10	10	10	10	10	10	15	5	5	5	5	5	5	5	5		
G	-0.45781	-0.52568	0.26229	-0.53854	0.52445	0.29888	-0.32039	0.41374	-0.78479	0.0374	0.88672	0.53105	-0.88241	-0.15589	-0.41472	0.38629	0.33778	0.85712		
	7.47	3.85	27.2	3.21	3.7	26.45	22.84	11.11	0.09	1.88	20.03	35.71	6	60.28	48.75	52.07	57.83	22.82		
	10	10	10	10	10	10	10	10	10	15	5	5	5	5	5	5	5	5		
H	0.52857	0.48809	-0.12035	0.54488	-0.52738	-0.33287	0.40064	-0.35958	0.71128	-0.74372	-0.88703	-0.50639	0.78733	0.18883	0.43632	-0.14001	-0.38703	-0.59129		
	3.81	5.51	65.71	2.91	3.58	20.8	12.41	17.03	0.29	14.98	20	39.4	11.39	74.84	48.28	82.23	51.98	20.37		
	10	10	10	10	10	10	10	10	10	15	5	5	5	5	5	5	5	5		
I	0.51705	0.47897	-0.11523	0.55231	-0.51687	-0.33235	0.39930	-0.38380	0.71980	-0.78602	-0.70233	-0.51159	0.81275	0.16800	0.41280	-0.17224	-0.38152	-0.61081		
	4.20	6.18	87.08	2.85	4.00	20.85	12.85	16.62	0.28	13.54	10.8	37.83	9.45	70.7	48.80	76.16	54.00	27.37		
	10	10	10	10	10	10	10	10	10	15	5	5	5	5	5	5	5	5		
J	-0.11884	-0.1503	0.03953	-0.38119	0.48308	0.47132	-0.4573	0.19122	-0.70448	0.89244	0.52391	0.23878	-0.81828	0.55541	0.31207	0.88404	-0.37007	0.57708		
	82.08	53.91	87.23	12.87	50.47	4.10	4.0	43.26	0.11	29.25	38.40	70.14	9.10	33.32	60.92	20.20	53.00	30.74		
	10	10	10	10	10	10	10	10	10	10	5	5	5	5	5	5	5	5		
K	0.18894	0.13754	0.00693	0.38728	-0.18118	-0.55454	0.50989	-0.09758	0.81744	-0.15331	-0.41471	-0.08135	0.83838	-0.76883	-0.58116	-0.45470	0.59178	-0.41838		
	46.93	57.44	88.39	12.19	45.8	1.37	1.08	88.11	0.83	80.58	48.75	92.16	24.64	12.87	30.41	44.10	20.32	48.33		
	10	10	10	10	10	10	10	10	10	10	5	5	5	5	5	5	5	5		
L	0.17823	0.14089	0.06501	0.38454	-0.18438	-0.58215	0.58033	-0.08827	0.81892	-0.19458	-0.4270	-0.08855	0.87958	-0.73984	-0.53858	-0.45587	0.5534	-0.43013		
	47.05	58.58	88.88	12.49	44.89	1.22	0.82	88.9	0.7	75.38	47.23	91.55	20.69	15.31	34.8	44.06	33.32	48.07		
	10	10	10	10	10	10	10	10	10	10	5	5	5	5	5	5	5	5		
M	-0.20886	-0.19401	-0.02742	0.15225	0.23005	0.19434	-0.21238	0.22245	-0.88745	-0.43141	-0.31827	0.74903	0.13580	0.35893	-0.45880	-0.27741	-0.4733			
	30.13	42.47	91.13	83.36	34.34	42.53	38.27	24.35	37.28	5.88	48.83	60.41	14.70	82.75	58.3	43.81	85.14	42.07		
	10	10	10	10	10	10	10	10	10	10	5	5	5	5	5	5	5	5		

Table 5.11. (Continued).

I.D. Code	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL
N	0.13792 57.34 10	0.20018 21.34 10	-0.3181 -16.55 10	0.07927 74.7 10	-0.2638 27.51 10	-0.2604 28.54 10	0.20439 40.13 10	-0.00973 66.46 10	0.51016 3.15 10	-0.16607 23.80 10	-0.26139 87.1 10	-0.26899 63.74 10	-0.26899 56.21 10	0.31525 65.99 10	-0.1023 89.16 10	-0.00041 23.04 10	-0.65487 60.34 10	-0.38397 52.35 10
O	-0.02768 91.05 10	0.07404 76.32 10	-0.20688 38.06 10	0.12555 80.86 10	-0.03461 88.75 10	-0.05844 81.65 10	0.0092 97.02 10	-0.2046 40.08 10	0.41808 8.43 10	-0.79736 10.61 10	-0.38608 54.48 10	-0.3186 60.13 10	0.57673 30.56 10	0.01515 98.07 10	0.18766 76.22 10	-0.58324 30.2 10	-0.10445 60.73 10	-0.4514 44.54 10
P	-0.17278 47.03 10	-0.02415 92.18 10	0.21217 38.32 10	0.11576 83.68 10	-0.03327 92.47 10	-0.20581 21.86 10	0.33375 17.63 10	0.03115 88.03 10	0.21461 30.25 10	0.59463 32.12 10	0.02126 97.26 10	0.04767 93.08 10	-0.38169 54.97 10	-0.70335 10.92 10	-0.80406 5.5 10	-0.1084 74.78 10	0.68013 6.15 10	-0.00507 99.28 10
Q	0.08772 78.3 10	-0.04916 84.16 10	0.18454 44.95 10	-0.08898 88.71 10	0.01208 98.08 10	-0.20746 30.4 10	0.31403 16.04 10	-0.00887 97.16 10	-0.13628 58.06 10	0.71499 15.01 10	0.87348 0.52 10	0.9463 1.48 10	-0.48057 41.26 10	0.54418 34.31 10	0.00048 54.41 10	0.88355 5.83 10	-0.47316 42.08 10	0.89134 0.01 10
R	-0.02073 83.26 10	-0.18885 43.68 10	0.01407 95.44 10	-0.20693 27.05 10	0.21346 36.02 10	0.06071 3.26 10	-0.41583 7.66 10	-0.05467 62.34 10	0.83477 0.72 10	0.76333 24.99 10	0.80341 11.71 10	-0.05168 0.64 10	0.20847 89.59 10	0.29511 88.11 10	0.20847 5.5 10	0.75335 14.15 10	-0.3389 57.89 10	0.62317 6.80 10
S	0.18931 43.76 10	0.04049 86.63 10	0.1113 65.01 10	-0.0816 73.92 10	-0.07324 76.57 10	-0.24028 30.34 10	0.35127 14.03 10	-0.08895 78.54 10	0.58895 91.54 10	0.67642 26.61 10	0.87042 4.93 10	0.316 3.16 10	-0.27768 65.11 10	0.85761 21.82 10	0.59511 30 10	0.81316 30.3 10	-0.64893 23.51 10	0.92603 2.38 10
T	-0.31853 18.36 10	0.11644 63.5 10	-0.0635 79.62 10	0.0689 77.93 10	-0.1844 82.91 10	-0.39181 12.82 10	0.31182 19.37 10	0.18189 50.84 10	0.24395 32.65 10	0.02527 90.78 10	-0.38887 34.15 10	-0.57328 31.23 10	0.14375 81.76 10	0.85212 6.67 10	0.89874 5.5 10	0.83161 25.3 10	-0.00861 3.38 10	0.20005 74.7 10
U	1 0 10	0.68904 0 10	-0.63173 0 10	0.20892 0 10	-0.67633 0 10	-0.1925 42.86 10	0.20253 40.57 10	-0.09153 80.24 10	0.42437 7.07 10	-0.15269 80.25 10	0.07684 5.5 10	0.07057 91.02 10	0.14375 81.76 10	0.85212 6.67 10	0.89874 5.5 10	0.83161 25.3 10	-0.00861 3.38 10	0.20005 74.7 10
V	0.68904 0.01 10	-0.68161 0 10	0.49376 0 10	-0.88441 3.58 10	-0.88441 3.58 10	-0.35525 13.55 10	0.34558 14.73 10	-0.02791 80.97 10	0.08022 3.62 10	-0.23839 64.1 10	-0.10072 40.13 10	-0.71585 17.36 10	-0.17948 77.27 10	0.10024 75.92 10	0.13907 82.24 10	-0.09637 87.75 10	-0.18804 85.01 10	-0.26989 46.99 10
W	-0.63173 0.37 10	-0.68161 0.13 10	0.49376 0 10	-0.88441 25.93 10	0.5423 1.65 10	0.0168 93.91 10	-0.012 98.11 10	0.05673 81.44 10	-0.72404 27.11 10	0.59353 29.14 10	0.31321 55.96 10	0.59133 28.36 10	0.0281 89.42 10	0.02657 86.92 10	0.03449 95.01 10	0.85559 22.97 10	-0.10987 86.04 10	0.4647 43.04 10
X	0.26982 8.92 10	0.49376 3.58 10	-0.27255 25.83 10	1 0 10	-0.48951 3.32 10	-0.1485 54.4 10	0.13702 57.59 10	-0.18587 44.61 10	0.31766 19.9 10	-0.58754 28.75 10	-0.00189 3.05 10	-0.67464 21.16 10	0.70943 17.06 10	-0.87467 21.14 10	-0.46384 43.13 10	-0.70873 18.02 10	0.51342 37.63 10	-0.68973 4.73 10
Y	-0.67633 0.01 10	-0.68161 0.01 10	0.49376 1.65 10	-0.88441 3.32 10	1 0 10	0.4034 8.68 10	-0.3939 8.52 10	0.01817 94.12 10	-0.50393 3.3 10	0.02844 86.35 10	0.14577 56.67 10	0.70409 42.38 10	0.1715 78.27 10	-0.20891 73.64 10	-0.15889 76.65 10	-0.10334 75.54 10	0.17 78.48 10	0.23381 70.8 10
Z	-0.1925 42.08 10	-0.35525 13.55 10	0.0168 93.91 10	-0.1485 54.4 10	0.4034 8.68 10	-0.3939 8.52 10	0.01817 94.12 10	-0.50393 3.3 10	0.02844 86.35 10	0.14577 56.67 10	0.70409 42.38 10	0.1715 78.27 10	-0.20891 73.64 10	-0.15889 76.65 10	-0.10334 75.54 10	0.17 78.48 10	0.23381 70.8 10	0.26989 46.99 10

Table 5.11. (Continued).

I.D. Code	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL
AA	0.20253 40.57 18	0.34550 14.73 18	-0.012 98.11 18	0.13702 57.50 18	-0.3638 0.52 18	-0.06817 0.01 18	1 0 18	0.42730 6.8 18	0.59233 0.08 18	-0.22378 71.75 18	-0.44344 45.45 18	-0.7311 16.05 18	-0.30337 54.77 18	-0.37311 53.82 18	-0.48128 41.18 18	-0.63771 24.7 18	0.5211 38.78 18	-0.51912 37.01 18
AB	-0.08153 80.24 18	-0.02781 90.87 18	0.05773 81.44 18	-0.16587 44.81 18	0.01817 84.12 18	-0.5287 2 18	0.42730 6.8 18	1 0 18	-0.03362 0.8848 18	0.35038 56.32 18	0.20195 74.54 18	-0.16028 78.08 18	-0.18158 7.69 18	-0.18158 70.52 18	-0.4118 48.09 18	-0.17177 78.24 18	0.40142 50.3 18	0.11334 85.8 18
AC	0.42437 7.92 18	0.46822 3.82 18	-0.27404 27.11 18	0.31765 19.9 18	-0.50383 3.3 18	-0.58618 1.02 18	0.59233 0.08 18	-0.03362 0.8848 18	1 0 18	-0.72981 27.02 18	-0.90341 10.83 18	-0.80071 0.06 18	0.4178 56.22 18	-0.38154 80.95 18	-0.27168 72.12 18	-0.48288 51.71 18	0.32544 87.48 18	-0.84108 15.89 18
AD	-0.15289 80.83 5	-0.28580 64.1 5	0.59353 28.14 5	-0.58754 28.75 5	0.02884 98.35 5	0.28271 84.40 5	-0.22378 71.75 5	0.35038 56.32 5	-0.72081 27.02 5	1 0 5	0.70308 10.84 5	0.72689 16.28 5	-0.73787 15.45 5	0.81175 96.5 5	-0.20077 73.40 5	0.83823 24.58 5	0.11808 85 5	0.8003 9.93 5
AE	0.07884 80.25 5	-0.40072 40.13 5	0.35321 55.98 5	-0.00169 3.95 5	0.34577 58.87 5	0.53021 34.84 5	-0.44344 45.45 5	0.20135 74.54 5	-0.00341 0.88 5	0.70308 10.84 5	1 0 5	0.01238 3.07 5	-0.82068 26.38 5	0.4384 45.43 5	0.2578 87.57 5	0.78035 13.57 5	-0.32875 53.01 5	0.08713 0.17 5
AF	0.07057 81.02 5	-0.71585 17.38 5	0.58133 28.38 5	-0.87484 21.16 5	0.70748 42.30 5	0.75480 14.02 5	-0.7311 16.05 5	-0.16028 78.08 5	-0.00071 10.83 5	0.72689 16.28 5	0.91238 3.07 5	1 0 5	-0.20548 82.84 5	0.31413 80.87 5	0.22455 71.85 5	0.74358 14.87 5	-0.28018 62.85 5	0.82104 2.63 5
AG	0.14375 81.78 5	-0.17948 77.27 5	0.0281 98.42 5	0.70943 17.08 5	0.1715 78.27 5	0.71811 72.45 5	-0.38337 34.77 5	-0.83718 7.69 5	0.4178 56.22 5	-0.18158 70.52 5	0.11735 80.86 5	-0.20548 45.43 5	1 0 5	-0.15871 76.75 5	0.13883 82.41 5	-0.38508 52.21 5	-0.08247 88.51 5	-0.5688 28.84 5
AH	0.85212 8.07 5	0.18024 75.92 5	0.02857 98.92 5	-0.67487 21.14 5	-0.20091 73.84 5	0.55035 32.68 5	-0.37211 53.82 5	-0.18158 70.52 5	-0.38154 80.86 5	0.11735 80.86 5	0.4384 45.43 5	-0.20548 45.43 5	1 0 5	0.05549 76.75 5	1 0 5	0.70370 18.47 5	-0.00789 0.80 5	0.50484 38.50 5
AI	0.88974 3.81 5	0.13897 82.24 5	0.03440 95.81 5	-0.40384 43.13 5	-0.15889 78.85 5	0.82483 25.07 5	-0.48128 41.18 5	-0.4118 48.09 5	-0.2708 72.12 5	-0.30077 73.40 5	0.2578 87.57 5	0.72689 16.28 5	0.13883 82.41 5	0.85540 1.12 5	1 0 5	0.50033 20.48 5	-0.09538 0.04 5	0.32887 58.82 5
AJ	0.83181 25.3 5	-0.08837 87.75 5	0.55550 22.97 5	-0.70373 16.02 5	-0.18334 75.54 5	0.78108 11.88 5	-0.83771 24.7 5	-0.17177 78.24 5	-0.48288 51.71 5	0.38023 24.58 5	0.76035 13.57 5	0.74358 14.07 5	-0.38508 52.21 5	0.70370 16.47 5	0.50033 28.48 5	1 0 5	-0.88508 22.08 5	0.85524 0.68 5
AK	-0.00881 3.38 5	-0.11604 85.01 5	-0.10087 86.04 5	0.51342 37.83 5	0.17 78.46 5	-0.87105 21.5 5	0.5211 38.78 5	0.40142 50.3 5	-0.32544 87.48 5	0.11808 85 5	-0.2818 3.07 5	-0.88247 86.51 5	-0.00789 0.80 5	-0.88538 0.04 5	1 0 5	-0.40544 22.00 5	0 48.83 5	1 0 5
AL	0.20005 74.7 5	-0.42000 48.00 5	0.4647 43.04 5	-0.89273 4.73 5	0.23381 70.5 5	0.62804 25.88 5	-0.61812 37.01 5	0.11334 85.8 5	-0.44108 15.89 5	0.8083 9.93 5	0.88713 0.17 5	0.92104 2.63 5	0.50484 38.50 5	0.50484 38.50 5	0.32887 58.82 5	0.85524 0.68 5	-0.40544 48.83 5	1 0 5

Table 5.12. Aggregate size gradation.

Sample	Sieve Size (Percent Passing)								Rock	Remarks
	1" 25mm	3/4" 19mm	1/2" 12.5mm	3/8" 9.5mm	No. 4 4.75mm	No. 8 2.36mm	No. 30 0.8mm	No. 200 0.075mm		
I.D.	100	100	100	75.0-95.0	10.0-30.0	0.0-10.0	0	0		
No. 11	100	100	100	78.7-83.5	18.2-22.9	1.4-2.8	0.1-0.2	0	Dolomite	No 11
D-001	100	100	100	38.5-52.0	2.9-7.7	0.2-0.5	0.1	0	"	"
D-002	100	99.6-100	98.7-99.8	72.5-77.8	13.8-20.0	1.0-1.7	0.2	0	"	"
D-003	100	100	99.8-100	82.6-86.1	6.4-9.9	0.1-0.3	0.1-0.2	0.0-0.2	"	"
D-004	100	100	100	74.3-77.4	15.3-18.3	1.3-1.7	0.2	0	"	"
D-005	100	100	99.8-100	90.0-93.0	29.3-37.8	1.6-2.9	0.2	0.0-0.1	"	"
D-006	100	100	99.8-100	85.6-90.8	6.9-17.3	0.4-4.1	0.3-1.8	0.2-0.8	"	"
D-007	100	100	99.7-100	86.3-89.5	16.5-25.7	0.4-1.5	0.1-0.2	0	"	"
D-008	100	100	100	69.6-78.8	9.1-15.4	0.5-1.4	0.2-0.4	0.1	"	"
D-009	100	100	100	89.8-90.5	22.6-26.5	2.4-2.5	0.5	0.1	"	"
D-010	100	100	100	82.4-87.5	17.8-26.5	2.5-4.3	0.1	0	"	"
D-011	100	100	99.9-100	86.6-89.9	29.5-37.3	7.9-9.4	1.3-1.7	0.3-0.5	"	"
D-012	100	100	100	92.5-94.0	25.9-28.7	0.5-1.2	0.1	0	"	"
D-013	100	100	100	82.2-85.2	19.5-24.4	1.1-1.6	0	0	"	"
D-014	100	100	99.7-100	88.2-89.8	34.4-38.2	8.8-10.3	0.1-0.2	0	"	"
D-015	100	100	100	81.5-82.3	9.9-16.3	2.2-7.0	1.8-5.1	1.3-3.0	"	"
D-016	100	100	100	85.1-87.9	15.8-22.6	0.3-0.8	0.1-0.2	0	"	"
D-017	100	100	99.8-99.8	77.5-84.8	6.5-14.4	0.5-1.5	0.2-0.3	0	"	"
D-018	100	100	100	84.1-89.9	23.9-31.4	2.6-5.0	0.2-0.3	0	"	"
D-019	100	100	100	81.2-82.9	7.1-14.5	0.5-2.6	0.3-0.4	0.0-0.2	"	"
D-020	100	100	100	80.5-82.9	17.4-19.2	1.9-2.0	0.5-0.6	0.4-0.5	Limestone	No 11
LS-001	100	100	99.4-99.9	98.2-98.4	22.3-24.8	0.8-2.3	0.2-0.4	0.2-0.3	"	"
S-001	100	100	100	96.5-97.2	23.3-26.8	1.9-3.7	0.9	0.7	Sandstone	No 11
S-002	100	100	83.9-90.1	59.9-63.8	16.9-21.1	1.7-4.2	0.2-0.7	0.2-0.3	"	No 9

Table 5.13. Petrographic analysis.

Sample I.D.	Grn Size (mm)	Mode (mm)	Grain Std Dev	Cement (%)	Matrix (%)	Grnd Ms (%)	Voids (%)	Grn Shp	Alt Gn Sh	Grains (%)
D-001	0.13	0.085	9.9	7	21.5	28.4	11.7	1.7	8.9	59.9
D-002	0.079	0.061	3.6	27.8	2.8	30.5	10.4	2.2	8.8	59.1
D-003	0.059	0.042	3	21.2	21.6	42.8	7.9	2.2	6.6	49.3
D-004	0.194	0.053	12	15.5	26.4	41.9	9.7	2.2		48.4
D-005	0.069	0.052	3.8	18	30.9	49	5.2	2.1		45.8
D-006	0.062	0.039	3.1	22.9	9.9	32.8	10.6	2.1		56.6
D-007	0.074	0.075	3.7	15.1	12.3	27.4	8.2	1.9		64.4
D-008	0.087	0.065	4.2	9.2	5.5	14.8	13.4	1.6		71.8
D-009	0.066	0.063	4.9	11.5	13.2	27.2	9.3	2.4	6.1	63.5
D-010	0.07	0.049	3.9	25.3	2.8	28.1	10.2	1.8		61.7
D-011	0.058	0.041	3.5	19.9	7.9	27.8	7.5	1.6		64.7
D-012	0.082	0.051	4.1	22.9	7.5	30.5	4.6	1.9	7	64.9
D-013										
D-014	0.057	0.043	4.9	17.3	47.5	64.8	4	1.9		31.2
D-015	0.116	0.085	7	12.1	24.8	36.9	4.6	2		58.5
D-016	0.096	0.09	5.9	13.3	29.1	42.4	7.6	2.1		50
D-017	0.119	0.114	8.7	15.7	9.4	25	7	1.6		68
D-018	0.063	0.058	3.6	13.2	47	60.7	3.5	2.5		35.8
D-019	0.059	0.046	7.4	11.5	7.4	12.6	9.8	2		77.6
D-020	0.085	0.068	4.2	21.5	13.2	34.7	10.3	1.9		55
S-001	0.058	0.049	0.06	8.9	22.7	31.6	3.4	2.3		65
S-002	0.051	0.026	0.02	20.9	35.7	56.6	6.3	2.1		37.1
LS-001	0.024	0.022	0.009	1.5	69.3	70.8	6		7.3	23.2
LS-002	0.04	0.027	0.02	4.6	90.6	95.1	0.1		7.3	4.8
Data From Second Observer										
D-001	0.094	0.09	0.05	0.3	55.7	56	13		8.9	31
D-002	0.059	0.06	0.03	0	15.4	15.4	9		8.8	75.6
D-003	0.035	0.032	0.02	2.9	44	47	9.5		6.6	43.5
D-009	0.038	0.054	1.1	10.7	30	40.7	8.4		6.1	50.9
D-012	0.064	0.054	0.03	0.6	38.3	38.9	8.3		7	52.8

Table 5.14. Compositional analysis.

Sample I.D.	Dolomite Peak	Cal/Dol Pk Ratio	X-ray Diff % Dol	Slb-Dol % Cal	Insol %	Soluble %	Elem %	Mg %	From %	Slb-Dol % Cal
D-001	71.5		98.30	0.00	1.70	98.30	12.4		94.1	4.2
D-002	85	0.044	93.23	6.06	0.71	99.29	12.9		97.9	1.4
D-003	62		96.87	0.00	3.13	96.87	11.3		85.7	11.1
D-004	42.5	0.14	82.72	15.17	2.11	97.89	11.3		85.7	12.2
D-005	54.5		90.18	0.00	9.82	90.18	11.6		88.0	2.2
D-006	76		94.71	0.00	5.29	94.71	12.4		94.1	0.6
D-007	69.5		98.66	0.00	1.34	98.66	12.9		97.9	0.8
D-008	87		99.78	0.00	0.22	99.78	13.1		99.4	0.4
D-009	54	0.066	84.53	8.05	7.42	92.58	10.7		81.2	11.4
D-010	66		95.84	0.00	4.16	95.84	12.6		95.6	0.2
D-011	57.5		93.69	0.00	6.31	93.69	12.2		92.6	1.1
D-012	53.5		92.35	0.00	7.65	92.35	11.9		90.3	2.1
D-013	36	0.19	76.40	18.04	5.56	94.44	10.1		76.6	17.8
D-014	51.5	0.065	86.68	8.05	5.27	94.73	11.2		85.0	9.8
D-015	76		99.50	0.00	0.50	99.50	12.8		97.1	2.4
D-016	80		99.92	0.00	0.08	99.92	12.9		97.9	2.0
D-017	80		99.65	0.00	0.35	99.65	12.9		97.9	1.8
D-018	70		97.85	0.00	2.15	97.85				
D-019	77	0.044	87.65	5.69	6.66	93.34				
D-020	73.5		94.10	0.00	5.90	94.10				
LS-001	11	1.35	29.76	59.09	11.15	88.85				
LS-002				95.98	4.02	95.98				
% Si & Cl % Cbnt										
S-001		2.79	11.50	34.00	54.50	45.50				
S-002		6.94	1.20	58.30	40.50	59.50				

Where a calcite/dolomite peak is not observed, calcite is assumed not to be present.
Information from x-ray diffraction using peak area for best fit curve and analysis

Table 5.15. Sieve gradation of acid-insoluble residue.

Sample	> No. 200 0.074mm	< No. 200 0.074mm	Total Ins	Ratio	No. 4 4.75mm	No. 8 2.36mm	No. 16 1.18mm	No. 30 0.6mm	No. 50 0.3mm	No. 100 0.150mm	No. 200 0.074mm
I.D.	(%)	(%)	(%)	<1/2	(%)	(%)	(%)	(%)	(%)	(%)	(%)
D-001	1.23	0.48	1.70	0.39	0.69	0.23	0.05	0.03	0.04	0.08	0.11
D-002	0.02	0.69	0.71	34.50	0	0	0	0.007	0	0	0.01
D-003	2.07	1.06	3.13	0.51	0.94	0.3	0.1	0.06	0.06	0.17	0.44
D-004	0.11	2.00	2.11	18.18	0.05	0.01	0	0	0.006	0.006	0.04
D-005	3.55	6.28	9.82	1.77	1.32	0.91	0.44	0.26	0.2	0.16	0.25
D-006	1.79	3.50	5.29	1.96	0.56	0.58	0.24	0.15	0.09	0.06	0.11
D-007	0.21	1.13	1.34	5.38	0.006	0.01	0.02	0.04	0.04	0.03	0.06
D-008	0.03	0.20	0.22	6.67	0	0	0	0	0.007	0.006	0.01
D-009	4.40	3.02	7.42	0.69	0.95	0.28	0.11	0.06	0.11	0.19	2.69
D-010	1.81	2.35	4.16	1.30	0.97	0.5	0.14	0.06	0.03	0.02	0.09
D-011	2.71	3.59	6.31	1.32	1.8	0.43	0.19	0.08	0.04	0.06	0.13
D-012	3.39	4.26	7.65	1.26	1.71	1.04	0.27	0.11	0.07	0.05	0.14
D-013	0.78	4.78	5.56	6.13	0.23	0.1	0.05	0.03	0.05	0.05	0.27
D-014	0.71	4.55	5.27	6.41	0.25	0.15	0.04	0.03	0.04	0.04	0.16
D-015	0.27	0.22	0.50	0.81	0.12	0.03	0.01	0.01	0.04	0.03	0.03
D-016	0.02	0.06	0.08	3.00	0.01	0	0.01	0	0	0	0
D-017	0.03	0.32	0.35	10.67	0	0	0.007	0	0	0.01	0.01
D-018	0.94	1.21	2.15	1.29	0.21	0.11	0.02	0.02	0.04	0.15	0.39
D-019	4.45	2.21	6.66	0.50	1.8	1.12	0.26	0.14	0.16	0.28	0.69
D-020	3.14	2.76	5.90	0.88	1.09	0.79	0.36	0.3	0.27	0.15	0.19
LS-001	6.53	4.62	11.15	0.71	0.45	1.46	0.26	0.07	0.06	0.06	0.17
LS-002	1.81	2.21	4.02	1.22	0.82	0.29	0.08	0.07	0.1	0.1	0.36
S-001	59.17	3.02	62.19	0.05	50.12	0.58	0.22	0.09	0.13	0.92	7.1
S-002	29.04	4.28	33.31	0.15	12.68	0.77	0.43	0.25	0.52	2.46	11.93

Table 5.16. Physical tests.

Sample I. D.	Specific Gravity	Absorption %	L.A. Abrasion % Loss	Sulfate Soundness % Loss
D-001	2.732	0.79	25.53	0.36
D-002	2.599	2.39	28.59	
D-003	2.605	2.64	27.05	9.57
D-004	2.39	6.25	29.36	9.86
D-005	2.616	2.02	29.19	7.3
D-006	2.626	1.56	26.62	2.24
D-007	2.583	3.05	32.43	4.79
D-008	2.594	2.38	31.73	0.76
D-009	2.671	1.21	22.47	5.59
D-010	2.489	3.76	36.98	3.29
D-011	2.632	2.02	24.75	5.99
D-012	2.588	2.74	29.5	2.24
D-013				
D-014	2.48	4	30.28	13.18
D-015	2.669	1.03	29.76	2.56
D-016	2.614	1.86	32.62	0.55
D-017	2.718	1	25.69	0.31
D-018	2.619	2.48	27.25	3.62
D-019	2.648	1.59	30.75	6.45
D-020	2.59	2.95	28.54	5.33
S-001	2.592	1.19	26.8	7.51
Data were not available for S-002, LS-001 and LS-002				

Table 6.1. BPN vs. time data for standard and reference aggregates (D-001).

I.D.	0 hr	STDV	1 hr	STDV	3 hr	STDV	6 hr	STDV	10 hr	STDV
1	41.3	1.1	30.7	0.9	27.3	0.7	24.9	0.6	23.6	0.7
2	39.8	1.8	27.9	1.7	26.1	2.0	24.2	1.6	23.2	2.5
3	42.4	1.2	30.1	0.6	26.9	0.7	24.4	0.6	25.8	0.6
4	40.4	1.5	29.4	0.9	27.0	0.8	25.4	1.0	23.6	1.2
5	41.3	1.4	29.3	1.6	26.9	1.5	25.6	1.9	25.2	1.6
6	40.6	1.2	30.2	1.9	27.7	2.1	24.8	2.2	25.7	2.0
7	41.1	0.4	29.8	1.1	27.3	1.3	26.8	0.5	26.7	2.3
8	40.5	0.5	28.1	1.0	24.8	1.5	23.8	1.5	21.3	0.9
9	40.3	0.9	28.7	0.9	26.5	1.0	24.6	0.6	23.7	1.0
10	40.1	1.5	29.9	0.6	27.3	1.5	25.3	1.4	25.3	1.2
11	41.3	1.9	31.6	1.6	27.7	1.7	26.6	1.5	24.5	0.9
12	40.7	1.8	30.0	2.2	27.1	2.7	26.5	3.1	24.9	3.2
13	38.5	1.0	28.2	0.3	26.0	0.4	23.4	0.8	22.5	0.6
14	40.4	1.4	28.9	1.2	26.5	0.9	25.5	0.9	25.4	1.4
15	40.9	1.8	30.3	2.3	26.8	2.2	25.6	2.8	22.7	2.8
16	40.4	1.1	30.2	1.2	26.1	2.3	24.8	2.2	22.7	2.2
17	40.8	2.7	31.6	3.1	27.9	3.4	26.7	3.5	24.3	3.5
18	40.9	1.0	33.2	1.8	28.7	0.7	28.4	1.2	29.2	1.0
19	39.9	0.7	30.7	0.9	28.2	1.8	26.5	1.9	25.2	2.5
20	39.8	1.1	30.4	1.2	27.8	1.4	26.0	1.7	24.5	1.9
21	41.0	1.5	31.9	2.3	29.7	3.2	27.8	3.3	26.9	3.9
22	42.0	1.4	32.9	1.0	30.6	0.9	29.2	0.8	28.8	1.3
23	41.9	0.8	29.5	3.0	27.3	1.6	25.9	1.8	25.1	2.1
24	41.9	1.2	31.3	2.9	28.5	2.5	27.1	2.9	26.1	3.2
25	42.5	0.4	32.5	0.9	30.2	1.4	28.2	0.8	27.5	0.8
26	41.8	1.2	31.3	2.5	27.0	2.0	25.5	2.5	25.1	2.4
27	42.6	1.9	31.3	1.2	28.8	2.1	27.3	1.0	26.6	1.0

Average
of Standard
Aggregate
(D-001)

40.9 1.3 30.4 1.5 27.5 1.6 26.0 1.7 25.0 1.8

Reference
Aggregate
(D-001)

40.0 30.4 27.8 25.6 24.9

Table 6.2. Results of the British Wheel test for dolomite sources.

I.D.	IFV	STDV	Rank	PV	STDV	Rank	WI	STDV	Rank	Remark
D-004	46.9	1.8	2	35.3	1.8	1	11.6		19	District A
D-013	43.5	2.5	11	32.7	2.6	2	10.8		20	District C
D-014	46.7	2.6	3	32.0	0.8	3	14.7		13	District C
<hr/>										
D-002	43.3	2.4	12	25.0	1.8	16	18.3		1	District A
D-003	41.8	0.5	15	27.3	1.5	14	14.5		15	District A
D-005	44.0	2.0	8	27.7	2.6	13	16.3		5	District A
D-006	42.7	1.4	13	26.8	1.6	15	15.9		8	District A
D-007	44.0	3.2	9	28.8	1.8	8	15.2		10	District A
D-008	44.6	1.5	7	28.7	1.2	9	15.9		9	District A
D-018	43.6	0.5	10	28.4	0.9	10	15.2		11	District A
D-019	41.6	1.6	16	28.0	0.9	12	13.6		18	District A
D-020	41.9	0.8	14	28.1	1.5	11	13.8		17	District A
TOTAL	43.1	1.1		27.6	1.2		15.4	1.4		
<hr/>										
D-009	44.8	2.0	6	31.0	2.3	6	13.8		16	District B
D-010	45.9	1.2	5	31.3	1.3	4	14.6		14	District B
D-011	46.2	1.6	4	30.0	1.0	7	16.2		7	District B
D-012	47.6	2.0	1	31.3	2.6	5	16.3		6	District B
TOTAL	46.1	1.2		30.9	0.6		15.2	1.2		
<hr/>										
D-001	40.0	1.2	20	24.9	1.9	17	15.1		12	District C
D-015	40.5	1.7	18	24.1	1.7	19	16.4		3	District C
D-016	40.1	1.5	19	23.6	1.0	20	16.5		2	District C
D-017	41.3	1.7	17	24.9	1.0	18	16.4		4	District C
TOTAL	40.5	0.2		24.4	0.5		16.1	0.7		

Table 6.3 Empirical equations based on the regression analysis of laboratory parameters.

Method I			
<u>18 Observations:</u> Step 6, R ² =0.86 (P<0.05)	Equation 6.1		
IFV = 84.341 + 0.146(N)(AA) - 0.016(V)(W) - 0.884(Z)(AB) + 0.034(AB) ²			
<u>18 Observations:</u> Step 4, R ² =0.92 (P<0.05)	Equation 6.2		
PV = 64.233 - 0.119(J)(Z) - 3.057(Q)(AC) + 0.032(Y)(AA) - 0.129(Z)(AB)			
<u>19 Observations:</u> Step 5, R ² =0.98 (P<0.05)	Equation 6.3		
IFV = 52.145 + 0.273(N)(AA) - 0.003(T)(Y) - 0.022(U)(W) + 0.021(Y)(AA) - 0.100(Z)(AB)			
<u>19 Observations:</u> Step 6, R ² =0.97 (P<0.05)	Equation 6.4		
PV = 75.479 - 0.049(J)(Z) - 0.003(P) ² - 0.012(V)(W) + 0.020(Y)(AA) - 0.756(Z)(AB) + 0.026(AB) ²			
Method II			
<u>18 Observations:</u> Step 1, R ² =0.55 (P<0.05)	Equation 6.5		
IFV = 41.618 + 0.342(N)(AA)			
<u>18 Observations:</u> Step 2, R ² =0.78 (P<0.05)	Equation 6.6		
PV = 22.569 + 2.042(AA) + 0.186(M) ²			
<u>19 Observations:</u> Step 1, R ² =0.54 (P<0.05)	Equation 6.7		
IFV = 41.724 + 0.333(N)(AA)			
<u>19 Observations:</u> Step 2, R ² =0.77 (P<0.05)	Equation 6.8		
PV = 21.947 + 2.051(AA) + 0.328(M)(Z)			
Limits			
0.11≤N*AA≤12.69	123.5≤V*W≤406.4	60.02≤Z*AB≤92.04	504.90≤AB*AB≤1367.52
197.70≤J*Z≤270.85	0.05≤Q*AC≤1.91	60.3≤Y*AA≤232.0	419.3≤T*Y≤1643.0
28.6≤U*W≤256.1	0.15≤P*P≤1190.3	0.05≤M*Z≤11.78	0.79≤AA≤6.25

Table 6.4. Stepwise regression analysis of laboratory parameters.

Method I: IFV based on 18 Observations				Method I: PV Based on 18 Observations			
Variable	Parameter Estimate	Probability %	R-square	Variable	Parameter Estimate	Probability %	R-square
Step 1				Step 1			
Intercept	41.618	0.01	0.55	Intercept	61.93	0.01	0.74
NAA	0.342	0.04		JZ	-0.137	0.01	
Step 2				Step 2			
Intercept	40.256	0.01	0.66	Intercept	50.962	0.01	0.84
NAA	0.262	0.44		JZ	-0.101	0.02	
YAA	0.014	4.67		AA	0.018	0.96	
Step 3				Step 3			
Intercept	42.171	0.01	0.74	Intercept	52.09	0.01	0.87
NAA	0.272	0.19		JZ	-0.083	0.14	
VW	-0.009	5.4		YAA	0.024	0.2	
YAA	0.016	1.44		ZAB	-0.086	7.06	
Step 4				Step 4			
Intercept	49.469	0.01	0.81	Intercept	64.233	0.01	0.92
NAA	0.24	0.24		JZ	-0.119	0.01	
VW	-0.011	1.15		QAC	-3.057	1.37	
YAA	0.022	0.19		YAA	0.032	0.01	
ZAB	-0.096	3.98		ZAB	-0.129	0.55	
Step 5				Step 5			
Intercept	75.034	0.01	0.88	Intercept	63.757	0.01	0.95
NAA	0.153	3.07		JZ	-0.112	0.01	
VW	-0.015	0.1		QAC	-4.16	0.09	
YAA	0.01	15.12		UU	0.001	1.46	
ZAB	-0.67	1.03		YAA	0.041	0.01	
ABAB	0.024	2.19		ZAB	-0.162	0.04	
Step 6				Step 6			
Intercept	84.341	0.01	0.86	Intercept	63.57	0.01	0.97
NAA	0.146	4.45		JZ	-0.108	0.01	
VW	-0.016	0.1		QAC	-2.469	4.17	
ZAB	-0.884	0.03		UU	0.002	0.22	
ABAB	0.034	0.03		XAA	-0.85	2.3	
Step 7				YAA	0.069	0.01	
Intercept	93.475	0.01	0.9	ZAB	-0.185	0.01	
KN	-0.057	5.29					
NAA	0.172	1.32					
VW	-0.017	0.03					
ZAB	-0.074	0.01					
ABAB	0.041	0.01					
Step 8							
Intercept	102.604	0.01	0.93				
KN	-0.11	0.94					
NAA	0.262	0.28					
TAB	-0.005	6.51					
VW	-0.017	0.01					
ZAB	-1.265	0.01					
ABAB	0.049	0.01					
Step 9							
Intercept	103.092	0.01	0.95				
KN	-0.094	1.18					
NAA	0.264	0.11					
TT	0.02	4.29					
TAB	-0.027	1.99					
VW	-0.018	0.01					
ZAB	-1.286	0.01					
ABAB	0.056	0.01					

Table 6.4. (Continued).

Method I: PV Based on 19 Observations							
Variable	Parameter Estimate	Probability %	R-square	Variable	Parameter Estimate	Probability %	R-square
Step 1				Step 9			
Intercept	61.331	0.01	0.67	Intercept	69.062	0.01	0.98
JZ	-0.135	0.01		NS	11.068	0.07	
				PP	-0.002	1.28	
Step 2				ST	-1.611	0.36	
Intercept	50.552	0.01	0.76	VW	-0.011	0.01	
JZ	-0.1	0.09		YAA	0.023	0.01	
YAA	0.017	2.85		ZAB	-0.898	0.01	
				ABAB	0.032	0.01	
Step 3				Step 10			
Intercept	51.676	0.01	0.85	Intercept	66.002	0.01	0.99
JZ	-0.105	0.01		NN	-0.073	0.2	
PP	-0.003	0.81		NS	22.837	0.02	
YAA	0.019	0.48		PP	-0.001	1.2	
Step 4				ST	-2.459	0.01	
Intercept	53.075	0.01	0.9	VW	-0.011	0.01	
JZ	-0.084	0.07		YAA	0.019	0.01	
PP	-0.004	0.2		ZAB	-0.828	0.01	
YAA	0.027	0.05		ABAB	0.03	0.01	
ZAB	-0.1	2.87					
Step 5				Step 11			
Intercept	56.1	0.01	0.93	Intercept	67.901	0.01	0.99
JZ	-0.084	0.03		NN	-0.059	2.53	
PP	-0.003	0.22		NS	22.141	0.02	
VW	-0.007	4.08		PP	-0.001	4.06	
YAA	0.03	0.01		RS	136.196	12.17	
ZAB	-0.12	0.66		ST	-3.263	0.04	
Step 6				VW	-0.011	0.01	
Intercept	75.479	0.01	0.97	YAA	0.022	0.01	
JZ	-0.049	0.55		ZAB	-0.877	0.01	
PP	-0.003	0.08		ABAB	0.032	0.01	
VW	-0.012	0.05					
YAA	0.02	0.09		Step 12			
ZAB	-0.756	0.05		Intercept	67.115	0.01	1
ABAB	0.026	0.16		NN	-0.079	1	
Step 7				NS	27.003	0.03	
Intercept	77.039	0.01	0.98	PP	-0.001	1.78	
JZ	-0.05	0.23		RS	364.262	4.76	
PP	-0.002	0.09		ST	-4.827	0.22	
ST	-0.99	5.48		TX	0.034	13.64	
VW	-0.01	0.04		VW	-0.012	0.01	
YAA	0.023	0.02		YAA	0.023	0.01	
ZAB	-0.776	0.02		ZAB	-0.882	0.01	
ABAB	0.027	0.07		ABAB	0.032	0.01	
Step 8				Step 13			
Intercept	71.131	0.01	0.98	Intercept	65.884	0.01	1
JZ	-0.02	32.13		NN	-0.105	0.35	
NS	7.74	7.93		NS	32.404	0.02	
PP	-0.002	1.15		PP	-0.005	3.98	
ST	-1.431	1.22		PW	0.011	9.33	
VW	-0.011	0.02		RS	470.624	1.42	
YAA	0.023	0.01		ST	-5.901	0.1	
ZAB	-0.827	0.01		TX	0.064	2.96	
ABAB	0.029	0.02		VW	-0.013	0.01	
				YAA	0.02	0.02	
				ZAB	-0.872	0.01	
				ABAB	0.032	0.01	

Table 6.4. (Continued).

Method I: IFV Based on 19 Observations								
Variable	Parameter Estimate	Probability %	R-square	Variable	Parameter Estimate	Probability %	R-square	
Step 1				Step 9				
Intercept	41.724	0.01	0.54	Intercept	76.984	0.01	0.94	
NAA	0.333	0.04		NN	0.066	1.02		
Step 2				TY				
Intercept	40.284	0.01	0.65	UW	-0.016	0.43	0.03	
NAA	0.255	0.36		WAA	-0.127	1.15		
YAA	0.014	3.44	0.73	YAA	0.039	0.03	0.15	
Step 3				ZAB	-0.717	0.04		
Intercept	41.562	0.01		ABAB	0.026	0.15		
NAA	0.281	0.11	0.79	Step 10				
UW	-0.009	6.63		Intercept	77.766	0.01	0.95	
YAA	0.012	4.65	MW	-0.025	7.94			
Step 4				NN	0.076	0.31	0.94	
Intercept	47.533	0.01	TY	-0.002	0.94			
NAA	0.258	0.13	0.85	UW	-0.018	0.16	1.18	
UW	-0.011	2.27		WAA	-0.117	1.18		
YAA	0.016	1.15	0.88	YAA	0.037	0.11	0.02	
ZAB	-0.082	7.16		ZAB	-0.715	0.02		
Step 5				ABAB	0.025	0.1	0.98	
Intercept	52.145	0.01	0.85	Step 11				
NAA	0.273	0.03		Intercept	82.364	0.01	0.16	
TY	-0.003	3.23	MW	-0.038	0.16			
UW	-0.022	0.25	0.88	NN	0.082	0.01	0.24	
YAA	0.021	0.15		TY	-0.002	0.24		
ZAB	-0.1	1.89	0.92	UW	-0.013	0.16	0.01	
Step 6				WW	0.018	0.27		
Intercept	66.43	0.01		0.88	WAA	-0.24	0.01	0.01
NAA	0.224	0.32	YAA		0.053	0.01		
TY	-0.003	2.61	0.92	ZAB	-0.872	0.01	0.01	
UW	-0.023	0.14		ABAB	0.031	0.01		
YAA	0.013	9.58	0.94	Step 12				
ZAB	-0.43	6.9		Intercept	76.333	0.01	0.43	
ABAB	0.014	13	0.94	MW	-0.171	0.43		
Step 7				NN	-0.107	12.12	1.49	
Intercept	72.83	0.01		OZ	0.413	1.49		
NAA	0.142	0.81	0.92	TY	-0.002	0.02	0.02	
TY	-0.002	3.24		UW	-0.013	0.02		
UW	-0.017	0.79	0.94	WW	0.018	0.04	0.76	
WAA	-0.119	4.36		WAA	-0.146	0.76		
YAA	0.034	1.1	0.94	YAA	0.032	0.41	0.01	
ZAB	-0.609	0.94		ZAB	-0.752	0.01		
ABAB	0.021	2.4	0.94	ABAB	0.028	0.01		
Step 8				Step 13				
Intercept	77.821	0.01	0.94	Intercept	78.402	0.01	1	
NN	0.072	11.64		MW	-0.204	0.15		
NAA	-0.019	86.61	0.94	MY	0.007	8.41	1.8	
TY	-0.002	2.08		NN	-0.089	14.19		
UW	-0.016	0.92	0.94	OZ	0.359	1.8	0.03	
WAA	-0.131	2.25		TY	-0.002	0.03		
YAA	0.039	0.42	0.94	UW	-0.013	0.02	0.03	
ZAB	-0.738	0.36		WW	0.018	0.03		
ABAB	0.026	0.83	0.94	WAA	-0.125	1.12	0.84	
				YAA	0.027	0.84		
				ZAB	-0.8	0.01	0.01	
				ABAB	0.03	0.01		

Table 6.4. (Continued).

Method II: IFV Based on 18 Observations				Method II: PV Based on 18 Observations			
Variable	Parameter Estimates	Probability %	R-square	Variable	Parameter Estimates	Probability %	R-square
Step 1				Step 1			
Intercept	41.618	0.01	0.55	Intercept	24.098	0.01	0.63
NAA	0.342	0.04		AA	1.81	0.01	
				Step 2			
				Intercept	22.569	0.01	0.78
				AA	2.042	0.01	
				MZ	0.186	0.48	
				Step 3			
				Intercept	28.564	0.01	0.82
				AA	2.106	0.01	
				MM	0.167	0.8	
				ZAB	-0.08	9.67	
				Step 4			
				Intercept	42.83	0.01	0.88
				AA	-3.97	12.58	
				MM	0.163	0.36	
				ZAB	-0.264	0.7	
				AAAB	0.198	2.59	

Method II: IFV Based on 19 Observations				Method II: PV Based on 19 Observations			
Variable	Parameter Estimates	Probability %	R-square	Variable	Parameter Estimates	Probability %	R-square
Step 1				Step 1			
Intercept	41.724	0.01	0.54	Intercept	23.913	0.01	0.58
NAA	0.333	0.04		AA	1.814	0.01	
				Step 2			
				Intercept	21.947	0.01	0.77
				AA	2.051	0.01	
				MZ	0.328	0.24	
				Step 3			
				Intercept	21.573	0.01	0.82
				AA	2.231	0.01	
				MZ	1.188	1.66	
				MAB	-0.082	6.66	

Table 6.5. Comparative results between actual and predicted BPN values.

Equation 6.1				Equation 6.2			
I.D.	Actual	Predicted	Residual	I.D.	Actual	Predicted	Residual
D-001	40.0	39.7	0.3	D-001	24.9	24.7	0.2
D-002	43.3			D-002	25.0		
D-003	41.8	42.1	-0.3	D-003	27.3	27.6	-0.3
D-004	46.9	47.1	-0.2	D-004	35.3	35.6	-0.3
D-005	44.0	43.7	0.3	D-005	27.7	27.8	-0.1
D-006	42.7	42.0	0.7	D-006	26.9	28.1	-1.2
D-007	44.0	43.1	0.9	D-007	28.8	28.4	0.4
D-008	44.6	42.8	1.8	D-008	28.7	28.1	0.6
D-009	44.8	45.0	-0.2	D-009	31.0	31.0	0.0
D-010	45.9	46.3	-0.4	D-010	31.3	30.8	0.5
D-011	46.2	45.4	0.8	D-011	30.0	29.7	0.3
D-012	47.6	46.0	1.6	D-012	31.3	31.1	0.2
D-013	43.5			D-013	32.7		
D-014	46.7	47.8	-1.1	D-014	32.0	30.7	1.3
D-015	40.5	41.6	-1.1	D-015	24.1	23.4	0.7
D-016	40.1	40.2	-0.1	D-016	23.6	25.0	-1.4
D-017	41.3	42.4	-1.1	D-017	24.9	25.1	-0.2
D-018	43.6	43.6	0.0	D-018	28.4	26.7	1.7
D-019	41.6	43.1	-1.5	D-019	28.0	28.9	-0.9
D-020	41.9	42.3	-0.4	D-020	28.1	29.6	-1.5

Equation 6.3				Equation 6.4			
I.D.	Actual	Predicted	Residual	I.D.	Actual	Predicted	Residual
D-001	40.0	39.7	0.3	D-001	24.9	23.9	1.0
D-002	43.3	42.9	0.4	D-002	25.0	24.8	0.2
D-003	41.8	42.0	-0.2	D-003	27.3	27.8	-0.5
D-004	46.9	47.2	-0.3	D-004	35.3	35.8	-0.5
D-005	44.0	44.2	-0.2	D-005	27.7	27.5	0.2
D-006	42.7	42.6	0.1	D-006	26.9	26.8	0.1
D-007	44.0	43.9	0.1	D-007	28.8	28.5	0.3
D-008	44.6	44.2	0.4	D-008	28.7	28.0	0.7
D-009	44.8	44.1	0.7	D-009	31.0	30.9	0.1
D-010	45.9	45.2	0.7	D-010	31.3	31.3	0.0
D-011	46.2	45.5	0.7	D-011	30.0	30.4	-0.4
D-012	47.6	46.5	1.1	D-012	31.3	30.8	0.5
D-013	43.5			D-013	32.7		
D-014	46.7	46.6	0.1	D-014	32.0	31.6	0.3
D-015	40.5	41.1	-0.6	D-015	24.1	24.9	-0.8
D-016	40.1	39.0	1.1	D-016	23.6	24.3	-0.7
D-017	41.3	42.3	-1.0	D-017	24.9	25.8	-0.9
D-018	43.6	42.8	0.8	D-018	28.4	27.8	0.6
D-019	41.6	43.5	-1.9	D-019	28.0	28.4	-0.4
D-020	41.9	44.1	-2.2	D-020	28.1	28.2	-0.1

Table 6.5. (Continued).

Equation 6.5				Equation 6.6			
I.D.	Actual	Predicted	Residual	I.D.	Actual	Predicted	Residual
D-001	40.0	41.7	-1.7	D-001	24.9	24.5	0.4
D-002	43.3			D-002	25.0		
D-003	41.8	42.6	-0.8	D-003	27.3	28.8	-1.5
D-004	46.9	45.9	1.0	D-004	35.3	35.3	0.0
D-005	44.0	46.0	-2.0	D-005	27.7	29.0	-1.3
D-006	42.7	43.5	-0.8	D-006	26.9	26.4	0.5
D-007	44.0	42.8	1.2	D-007	28.8	28.8	0.0
D-008	44.6	41.8	2.8	D-008	28.7	27.4	1.3
D-009	44.8	42.9	1.9	D-009	31.0	28.7	2.3
D-010	45.9	44.6	1.3	D-010	31.3	30.9	0.4
D-011	46.2	44.1	2.1	D-011	30.0	28.1	1.9
D-012	47.6	45.6	2.0	D-012	31.3	30.3	1.0
D-013	43.5			D-013	32.7		
D-014	46.7	47.8	-1.1	D-014	32.0	30.8	1.2
D-015	40.5	41.7	-1.2	D-015	24.1	24.7	-0.6
D-016	40.1	41.7	-1.6	D-016	23.6	26.4	-2.8
D-017	41.3	41.7	-0.4	D-017	24.9	24.6	0.3
D-018	43.6	42.6	1.0	D-018	28.4	27.8	0.6
D-019	41.6	42.8	-1.2	D-019	28.0	29.5	-1.5
D-020	41.9	44.4	-2.5	D-020	28.1	30.4	-2.3

Equation 6.7				Equation 6.8			
I.D.	Actual	Predicted	Residual	I.D.	Actual	Predicted	Residual
D-001	40.0	41.9	-1.9	D-001	24.9	24.7	0.2
D-002	43.3	42.3	1.0	D-002	25.0	26.9	-1.9
D-003	41.8	42.7	-0.9	D-003	27.3	29.1	-1.8
D-004	46.9	45.9	1.0	D-004	35.3	34.8	0.5
D-005	44.0	45.9	-1.9	D-005	27.7	29.1	-1.4
D-006	42.7	43.5	-0.8	D-006	26.9	26.7	0.2
D-007	44.0	42.9	1.1	D-007	28.8	28.4	0.4
D-008	44.6	41.9	2.7	D-008	28.7	26.9	1.8
D-009	44.8	42.9	1.9	D-009	31.0	28.3	2.7
D-010	45.9	44.7	1.2	D-010	31.3	31.1	0.2
D-011	46.2	44.1	2.1	D-011	30.0	28.4	1.6
D-012	47.6	45.6	2.0	D-012	31.3	30.4	0.9
D-013	43.5			D-013	32.7		
D-014	46.7	47.8	-1.1	D-014	32.0	30.7	1.3
D-015	40.5	41.8	-1.3	D-015	24.1	24.3	-0.2
D-016	40.1	41.8	-1.7	D-016	23.6	25.8	-2.2
D-017	41.3	41.8	-0.5	D-017	24.9	24.0	0.9
D-018	43.6	42.7	0.9	D-018	28.4	27.8	0.6
D-019	41.6	42.9	-1.3	D-019	28.0	29.1	-1.1
D-020	41.9	44.4	-2.5	D-020	28.1	30.7	-2.6

Table 6.6. Field data.

Sample I.D.	Ribbed Tire AFN (FNR)	Smooth Tire AFN (FNR)	Macro Depth MATXd	Coupon IFV	Coupon PV	Core Surface BPN	Specific Gravity	Absorption %	L.A. Abrasion % Loss	Sulfate Soundness % Loss	Aggregate Type
RS-17264	48.4	36.3	22.7	43.6	31.4	63.5	2.317	0.84	24.29	0.5	Dolomite
RS-17254	45.3	38.3	24.5	42.2	28.6		2.381				Dolomite
RS-16084B	49	36.1	19.1	40.7	25.9	60.2	2.361				Dolomite & Sand
RS-13478	57.9	49.3	21.4			69.3	2.292	0.7	23.37	0.55	Dolomite
RS-18593	48.8	37.9	22.5			61.9	2.362	1.52	28.05	5.70	Gravel
R-13019	38.8	32.5	28.4	40.2	31.1		2.386	1.11	22.91	3.14	Gravel
RS-17320	50.5	43.5	31.4			63.6	2.299	1.49	22.38	5.03	Gravel
RS-17694	38.2	41.2	78.8			69.4	2.333	1.57	23.37	5.42	Gravel
R-10577	41.6	39.5	45.6				2.343	2.06	27.16	4.72	Gravel
RS-11048	33.6	27.7	26.9	38.8	25.5		2.359				Limestone
RS-11776	29.8	29.5	55.8	36.2	26.4		2.298	1.18	28.72	0.74	Limestone
R-12810	25.4	19.8	22.4				2.362	0.81	27.14	6.68	Limestone
R-12812	34.5	29.8	31.7	39.4	29.6		2.391	0.85	24.98	3.63	Limestone
RS-14940	41	36	33.7	41.8	30.8		2.361				Limestone
RS-18045	58.2	42	18.0	47.3	30.2	67.6	2.302	2.01	19.09	0.38	Limestone
R-15310	50.4	35.9	17.4	41.8	27.1		2.309	3.67	43.31	0.79	Slag
R-14456	51.8	30.2	11.9	42.1	27.1		2.31				Slag
RS-16076	51.1	41.2	25.0			65.9	2.322	2.32	26.01	2.42	Slag
RS-16094C	37.2	27.9	20.0	37.2		61.3	2.39	4.29		4.97	Slag & Sand
R-19478	54.2	37.4	18.2			67.5	2.356	1.19	26.8	7.51	Sandstone
R-17111	44.3	41.8	44.5			65.1	2.301				Sandstone
R-16957	45.8	42.1	40.1			65.7	2.342	0.68	26.86	2.81	Sandstone
RS-17450	59.5	57	47.3			63.6	2.339	0.85	24.21	2.42	Sandstone

Table 6.7. Matrix arrangement of correlation coefficients, significance level in percent and observations for field parameters.

I.D.	Correlation coefficient/significance level/observations											
	Ribbed Tire AFN (FNR)	Smooth Tire AFN (FNS)	Macrotexture Depth	Coupons IFV	Coupons PV	Coupons BPN	Specific Gravity	Absorption %	L.A. Abrasion % Loss	Sulfate Soundness % Loss		
Ribbed Tire AFN (FNR)	1 0 23	0.78 0.01 23	-0.32 14.13 23	0.88 0.04 11	0.15 66.1 11	0.23 43.97 13	-0.41 5.47 23	0.02 95.08 17	-0.11 66.76 16	-0.31 23.34 17		
Smooth Tire AFN (FNS)	0.78 0.01 23	1 0 23	0.27 20.93 23	0.84 0.12 11	0.45 16.52 11	0.38 19.61 13	-0.42 4.8 23	-0.2 45.26 17	-0.25 34.35 16	-0.3 76.28 17		
Macrotexture Depth	-0.32 14.13 23	0.27 20.93 23	1 0 23	-0.7 1.76 11	-0.03 92.17 11	0.34 25.33 13	-0.14 52.44 23	-0.24 38.16 17	-0.14 60.27 16	0.06 82.76 17		
Coupons IFV	0.88 0.04 11	0.84 0.12 11	-0.7 1.76 11	1 0 11	0.5 12.02 11	1 0.48 3	-0.28 44.33 11	0.29 57.09 6	-0.29 58.25 6	-0.41 41.74 6		
Coupons PV	0.15 66.1 11	0.45 16.52 11	-0.7 92.17 11	0.5 12.02 11	1 0 11	0.7 50.61 3	0.2 55.97 11	-0.48 33.19 8	-0.7 12.42 6	0.28 59.09 6		
Cores BPN	0.23 43.97 13	0.36 19.61 13	0.34 25.33 13	1 0.48 3	0.7 50.61 3	1 0 13	-0.58 4.44 13	-0.39 23.52 11	-0.25 48.14 10	-0.18 60.52 11		
Bulk Specific Gravity	-0.41 5.47 23	-0.42 4.8 23	-0.14 52.44 23	-0.26 44.33 11	0.2 55.97 11	-0.56 4.44 13	1 0 13	0.08 81.37 17	-0.08 77.12 16	0.8 1.04 17		
Absorption %	0.02 95.08 17	-0.2 45.26 17	-0.24 36.16 17	0.29 57.09 6	-0.48 33.19 6	-0.39 23.52 11	0.06 81.37 17	1 0 17	0.63 0.95 16	-0.01 96.87 17		
L.A. Abrasion % Loss	-0.12 66.76 16	-0.25 34.35 18	-0.14 60.27 16	-0.29 58.25 6	-0.7 12.42 10	-0.25 48.14 16	-0.08 77.12 16	0.63 0.95 16	1 0 16	-0.11 69.13 16		
Sulfate Soundness % Loss	-0.31 23.34 17	-0.3 23.72 17	0.08 82.76 17	-0.41 41.74 6	0.28 59.09 8	-0.18 60.52 11	0.6 1.04 17	-0.01 98.87 17	-0.11 69.13 16	1 0 17		

Appendix A

Count and weight of each lithologic type retained on each sieve size, and percentage based
on count and weight

Table A.1 G-001 (1 1/2 inch to + 3/8 inch).

Rock Type	1st Trial		2nd Trial		3rd Trial		Total	
	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)
Limestone	67	110.51	78	132.93	80	133.56	225	377.00
Dolomite	68	108.60	81	136.93	69	121.26	218	366.79
Carbonates	135	219.11	159	269.86	149	254.82	443	743.79
Chert	5	6.99	5	6.80	13	17.53	23	31.32
Sandstone	5	6.88	3	4.54	6	8.63	14	20.05
Siltstone	12	15.24	9	14.25	11	14.63	32	44.12
Shale	0	0.00	2	2.59	0	0.00	2	2.59
Clay ironstone	0	0.00	2	3.49	0	0.00	2	3.49
Other Sedimentary	22	29.11	21	31.67	30	40.79	73	101.57
Diorite	16	26.41	14	20.67	9	16.42	39	63.50
Granite	17	26.90	29	48.32	28	44.02	74	119.24
Gabbro	9	16.56	9	17.11	12	18.25	30	51.92
Felsite	7	10.74	4	6.15	8	13.03	19	29.92
Basalt	11	18.25	31	52.77	16	25.18	58	96.20
Igneous	60	98.86	87	145.02	73	116.9	220	360.78
Gneiss	2	4.07	5	8.10	7	12.77	14	24.94
Quartzite	46	77.05	26	40.34	41	71.73	113	189.12
Schist	0	0.00	2	2.33	0	0.00	2	2.33
Metamorphic	48	81.12	33	50.77	48	84.5	129	216.39
TOTAL	265	428.20	300	497.32	300	497.01	865	1422.53

Rock Type	1st Trial (%)		2nd Trial (%)		3rd Trial (%)		Average (%)	
	Count	Wt.	Count	Wt.	Count	Wt.	Count	Wt.
Limestone	25.3	25.8	26.0	26.7	26.7	26.9	26.0	26.5
Dolomite	25.7	25.4	27.0	27.5	23.0	24.4	25.2	25.8
Carbonates	50.9	51.2	53.0	54.3	49.7	51.3	51.2	52.2
Chert	1.9	1.6	1.7	1.4	4.3	3.5	2.6	2.2
Sandstone	1.9	1.6	1.0	0.9	2.0	1.7	1.6	1.4
Siltstone	4.5	3.6	3.0	2.9	3.7	2.9	3.7	3.1
Shale	0.0	0.0	0.7	0.5	0.0	0.0	0.2	0.2
Clay ironstone	0.0	0.0	0.7	0.7	0.0	0.0	0.2	0.2
Other Sedimentary	8.3	6.8	7.0	6.4	10.0	8.2	8.4	7.1
Diorite	6.0	6.2	4.7	4.2	3.0	3.3	4.6	4.5
Granite	6.4	6.3	9.7	9.7	9.3	8.9	8.5	8.3
Gabbro	3.4	3.9	3.0	3.4	4.0	3.7	3.5	3.7
Felsite	2.6	2.5	1.3	1.2	2.7	2.6	2.2	2.1
Basalt	4.2	4.3	10.3	10.6	5.3	5.1	6.6	6.6
Igneous	22.6	23.1	29.0	29.2	24.3	23.5	25.3	25.3
Gneiss	0.8	1.0	1.7	1.6	2.3	2.6	1.6	1.7
Quartzite	17.4	18.0	8.7	8.1	13.7	14.4	13.2	13.5
Schist	0.0	0.0	0.7	0.5	0.0	0.0	0.2	0.2
Metamorphic	18.1	18.9	11.0	10.2	16.0	17.0	15.0	15.4
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table A.2. G-001 (- 3/8 inch to + No. 4).

Rock Type	1st Trial		2nd Trial		3rd Trial		Total	
	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)
Limestone	91	44.45	68	45.75	68	36.96	227	127.16
Dolomite	66	29.93	80	53.96	83	42.75	229	126.64
Carbonates	157	74.38	148	99.71	151	79.71	456	253.80
Chert	10	4.75	6	2.27	10	5.41	26	12.43
Sandstone	9	3.61	2	0.44	4	1.98	15	6.03
Siltstone	3	1.23	11	6.97	10	5.11	24	13.31
Shale	0	0.00	4	6.16	1	0.29	5	6.45
Clay ironstone	0	0.00	1	0.40	0	0.00	1	0.40
Other Sedimentary	22	9.59	24	16.24	25	12.79	71	38.62
Diorite	16	8.16	11	6.96	17	9.48	44	24.60
Granite	23	9.24	18	8.83	21	10.52	62	28.59
Gabbro	12	3.70	10	5.75	11	7.01	33	16.46
Felsite	2	1.68	7	5.96	3	1.63	12	9.27
Basalt	32	14.05	34	21.45	30	19.73	96	55.23
Igneous	85	36.83	80	48.95	82	48.37	247	134.15
Gneiss	0	0.00	2	1.45	0	0.00	2	1.45
Quartzite	35	14.22	46	31.72	42	23.41	123	69.35
Schist	1	0.99	0	0.00	0	0.00	1	0.99
Metamorphic	36	15.21	48	33.17	42	23.41	126	71.79
TOTAL	300	136.01	300	198.07	300	164.28	900	498.36

Rock Type	1st Trial (%)		2nd Trial (%)		3rd Trial (%)		Average (%)	
	Count	Wt.	Count	Wt.	Count	Wt.	Count	Wt.
Limestone	30.3	32.7	22.7	23.1	22.7	22.5	25.2	26.1
Dolomite	22.0	22.0	26.7	27.2	27.7	26.0	25.4	25.1
Carbonates	52.3	54.7	49.3	50.3	50.3	48.5	50.7	51.2
Chert	3.3	3.5	2.0	1.1	3.3	3.3	2.9	2.6
Sandstone	3.0	2.7	0.7	0.2	1.3	1.2	1.7	1.4
Siltstone	1.0	0.9	3.7	3.5	3.3	3.1	2.7	2.5
Shale	0.0	0.0	1.3	3.1	0.3	0.2	0.6	1.1
Clay ironstone	0.0	0.0	0.3	0.2	0.0	0.0	0.1	0.1
Other Sedimentary	7.3	7.1	8.0	8.2	8.3	7.8	7.9	7.7
Diorite	5.3	6.0	3.7	3.5	5.7	5.8	4.9	5.1
Granite	7.7	6.8	6.0	4.5	7.0	6.4	6.9	5.9
Gabbro	4.0	2.7	3.3	2.9	3.7	4.3	3.7	3.3
Felsite	0.7	1.2	2.3	3.0	1.0	1.0	1.3	1.7
Basalt	10.7	10.3	11.3	10.8	10.0	12.0	10.7	11.1
Igneous	28.3	27.1	26.7	24.7	27.3	29.4	27.4	27.1
Gneiss	0.0	0.0	0.7	0.7	0.0	0.0	0.2	0.2
Quartzite	11.7	10.5	15.3	16.0	14.0	14.3	13.7	13.6
Schist	0.3	0.7	0.0	0.0	0.0	0.0	0.1	0.2
Metamorphic	12.0	11.2	16.0	16.7	14.0	14.3	14.0	14.1
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table A.3. G-002 (- 1 1/2 inch to +3/8 inch).

Rock Type	1st Trial		2nd Trial		3rd Trial		Total	
	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)
Limestone	98	145.85	58	90.45	52	79.84	208	316.14
Dolomite	117	172.55	121	185.95	149	222.04	387	580.54
Carbonates	215	318.40	179	276.4	201	301.88	595	896.68
Chert	1	0.92	2	2.31	1	1.12	4	4.35
Sandstone	0	0.00	0	0.00	2	2.27	2	2.27
Siltstone	0	0.00	0	0.00	0	0.00	0	0.00
Shale	0	0.00	0	0.00	0	0.00	0	0.00
Clay ironstone	0	0.00	0	0.00	0	0.00	0	0.00
Other Sedimentary	1	0.92	2	2.31	3	3.39	6	6.62
Diorite	5	6.61	5	9.98	6	10.84	16	27.43
Granite	2	4.03	7	8.98	5	7.12	14	20.13
Gabbro	6	11.16	4	7.36	1	2.45	11	20.97
Felsite	0	0.00	0	0.00	0	0.00	0	0.00
Basalt	10	16.00	1	1.16	3	4.56	14	21.72
Igneous	23	37.8	17	27.48	15	24.97	55	90.25
Gneiss	0	0.00	0	0.00	0	0.00	0	0.00
Quartzite	7	8.07	8	11.73	7	9.90	22	29.70
Schist	0	0.00	0	0.00	0	0.00	0	0.00
Metamorphic	7	8.07	8	11.73	7	9.9	22	29.70
TOTAL	246	365.19	206	317.92	226	340.14	678	1023.25

Rock Type	1st Trial (%)		2nd Trial (%)		3rd Trial (%)		Average (%)	
	Count	Wt.	Count	Wt.	Count	Wt.	Count	Wt.
Limestone	39.8	39.9	28.2	28.5	23.0	23.5	30.3	30.6
Dolomite	47.6	47.2	58.7	58.5	65.9	65.3	57.4	57.0
Carbonates	87.4	87.2	86.9	86.9	88.9	88.8	87.7	87.6
Chert	0.4	0.3	1.0	0.7	0.4	0.3	0.6	0.4
Sandstone	0.0	0.0	0.0	0.0	0.9	0.7	0.3	0.2
Siltstone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Shale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Clay ironstone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Sedimentary	0.4	0.3	1.0	0.7	1.3	1.0	0.9	0.7
Diorite	2.0	1.8	2.4	3.1	2.7	3.2	2.4	2.7
Granite	0.8	1.1	3.4	2.8	2.2	2.1	2.1	2.0
Gabbro	2.4	3.1	1.9	2.3	0.4	0.7	1.6	2.0
Felsite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Basalt	4.1	4.4	0.5	0.4	1.3	1.3	2.0	2.0
Igneous	9.3	10.4	8.3	8.6	6.6	7.3	8.1	8.8
Gneiss	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Quartzite	2.8	2.2	3.9	3.7	3.1	2.9	3.3	2.9
Schist	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Metamorphic	2.8	2.2	3.9	3.7	3.1	2.9	3.3	2.9
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table A.4 G-002 (- 3/8 inch to + No. 4).

Rock Type	1st	Trial	2nd	Trial	3rd	Trial	Total	
	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)
Limestone	101	56.05	89	49.96	105	69.06	295	175.07
Dolomite	149	86.40	152	87.57	154	92.90	455	266.87
Carbonates	250	142.45	241	137.53	259	161.96	750	441.94
Chert	6	2.55	4	1.72	2	0.65	12	4.92
Sandstone	4	1.03	3	1.34	3	1.78	10	4.15
Siltstone	0	0.00	0	0.00	0	0.00	0	0.00
Shale	0	0.00	0	0.00	0	0.00	0	0.00
Clay ironstone	0	0.00	0	0.00	0	0.00	0	0.00
Other Sedimentary	10	3.58	7	3.06	5	2.43	22	9.07
Diorite	4	2.83	11	8.32	2	2.06	17	13.21
Granite	4	2.19	5	3.49	8	5.11	17	10.79
Gabbro	1	1.11	1	0.26	3	2.95	5	4.32
Felsite	0	0.00	0	0.00	2	1.68	2	1.68
Basalt	8	4.26	10	6.47	5	2.37	23	13.10
Igneous	17	10.39	27	18.54	20	14.17	64	43.10
Gneiss	0	0.00	0	0.00	0	0.00	0	0.00
Quartzite	23	11.32	24	10.27	16	8.25	63	29.84
Schist	0	0.00	1	0.34	0	0.00	1	0.34
Metamorphic	23	11.32	25	10.61	16	8.25	64	30.18
TOTAL	300	167.74	300	169.74	300	186.81	900	524.29

Rock Type	1st	Trial (%)	2nd	Trial (%)	3rd	Trial (%)	Average (%)	
	Count	Wt.	Count	Wt.	Count	Wt.	Count	Wt.
Limestone	33.7	33.4	29.7	29.4	35.0	37.0	32.8	33.3
Dolomite	49.7	51.5	50.7	51.6	51.3	49.7	50.6	50.9
Carbonates	83.3	84.9	80.3	81.0	86.3	86.7	83.3	84.2
Chert	2.0	1.5	1.3	1.0	0.7	0.3	1.3	1.0
Sandstone	1.3	0.6	1.0	0.8	1.0	1.0	1.1	0.8
Siltstone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Shale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Clay ironstone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Sedimentary	3.3	2.1	2.3	1.8	1.7	1.3	2.4	1.7
Diorite	1.3	1.7	3.7	4.9	0.7	1.1	1.9	2.6
Granite	1.3	1.3	1.7	2.1	2.7	2.7	1.9	2.0
Gabbro	0.3	0.7	0.3	0.2	1.0	1.6	0.6	0.8
Felsite	0.0	0.0	0.0	0.0	0.7	0.9	0.2	0.3
Basalt	2.7	2.5	3.3	3.8	1.7	1.3	2.6	2.5
Igneous	5.7	6.2	9.0	10.9	6.7	7.6	7.1	8.2
Gneiss	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Quartzite	7.7	6.7	8.0	6.1	5.3	4.4	7.0	5.7
Schist	0.0	0.0	0.3	0.2	0.0	0.0	0.1	0.1
Metamorphic	7.7	6.7	8.3	6.3	5.3	4.4	7.1	5.8
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table A.5 G-003 (- 1 inch to + 1/2 inch).

Rock Type	1st Trial		2nd Trial		3rd Trial		Total	
	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)
Limestone	60	394.72	64	373.99	74	503.75	198	1272.46
Dolomite	90	662.19	84	582.25	62	480.34	236	1724.78
Cabonates	150	1056.91	148	956.24	136	984.09	434	2997.24
Chert	6	40.02	9	35.10	10	52.93	25	128.05
Sandstone	0	0.00	1	17.23	1	3.56	2	20.79
Siltstone	3	18.58	0	0.00	0	0.00	3	18.58
Shale	0	0.00	1	8.58	0	0.00	1	8.58
Clay ironstone	0	0.00	0	0.00	0	0.00	0	0.00
Other Sedimentary	9	58.60	11	60.91	11	56.49	31	176.00
Diorite	2	9.87	2	17.57	2	14.69	6	42.13
Granite	4	22.13	1	6.44	2	20.44	7	49.01
Gabbro	14	123.11	7	54.53	6	50.17	27	227.81
Felsite	5	25.66	0	0.00	1	3.26	6	28.92
Basalt	16	154.53	8	51.32	14	116.36	38	322.21
Igneous	41	335.30	18	129.86	25	204.92	84	670.08
Gneiss	13	92.71	13	107.70	6	42.83	32	243.24
Quartzite	14	90.99	17	123.38	5	38.82	36	253.19
Schist	1	5.19	0	0.00	0	0.00	1	5.19
Metamorphic	28	188.89	30	231.08	11	81.65	69	501.62
TOTAL	228	1639.70	207	1378.09	183	1327.15	618	4344.94

Rock Type	1st Trial (%)		2nd Trial (%)		3rd Trial (%)		Average (%)	
	Count	Wt.	Count	Wt.	Count	Wt.	Count	Wt.
Limestone	26.3	24.1	30.9	27.1	40.4	38.0	32.6	29.7
Dolomite	39.5	40.4	40.6	42.3	33.9	36.2	38.0	39.6
Cabonates	65.8	64.5	71.5	69.4	74.3	74.2	70.5	69.3
Chert	2.6	2.4	4.3	2.5	5.5	4.0	4.1	3.0
Sandstone	0.0	0.0	0.5	1.3	0.5	0.3	0.3	0.5
Siltstone	1.3	1.1	0.0	0.0	0.0	0.0	0.4	0.4
Shale	0.0	0.0	0.5	0.6	0.0	0.0	0.2	0.2
Clay ironstone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Sedimentary	3.9	3.6	5.3	4.4	6.0	4.3	5.1	4.1
Diorite	0.9	0.6	1.0	1.3	1.1	1.1	1.0	1.0
Granite	1.8	1.3	0.5	0.5	1.1	1.5	1.1	1.1
Gabbro	6.1	7.5	3.4	4.0	3.3	3.8	4.3	5.1
Felsite	2.2	1.6	0.0	0.0	0.5	0.2	0.9	0.6
Basalt	7.0	9.4	3.9	3.7	7.7	8.8	6.2	7.3
Igneous	18.0	20.4	8.7	9.4	13.7	15.4	13.4	15.1
Gneiss	5.7	5.7	6.3	7.8	3.3	3.2	5.1	5.6
Quartzite	6.1	5.5	8.2	9.0	2.7	2.9	5.7	5.8
Schist	0.4	0.3	0.0	0.0	0.0	0.0	0.1	0.1
Metamorphic	12.3	11.5	14.5	16.8	6.0	6.2	10.9	11.5
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table A.6 G-003 (-1/2 inch to + 3/8 inch).

Rock Type	1st Trial		2nd Trial		3rd Trial		Total	
	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)
Limestone	77	185.25	70	155.58	64	134.12	211	474.95
Dolomite	117	272.93	126	272.22	109	247.01	352	792.16
Cabonates	194	458.18	196	427.8	173	381.13	563	1267.11
Chert	8	15.23	12	23.35	12	27.23	32	65.81
Sandstone	1	1.14	5	9.45	0	0.00	6	10.59
Siltstone	1	1.43	6	13.12	5	12.57	12	27.12
Shale	1	1.44	1	1.44	0	0.00	2	2.88
Clay ironstone	1	1.44	0	0.00	0	0.00	1	1.44
Other Sedimentary	12	20.68	24	47.36	17	39.8	53	107.84
Diorite	6	13.13	4	7.90	3	6.03	13	27.06
Granite	11	26.19	9	22.80	3	7.79	23	56.78
Gabbro	8	17.22	9	24.12	4	9.03	21	50.37
Felsite	2	3.40	3	5.39	3	5.34	8	14.13
Basalt	22	54.60	26	60.04	28	60.99	76	175.63
Igneous	49	114.54	51	120.25	41	89.18	141	323.97
Gneiss	2	4.24	6	12.00	5	11.39	13	27.63
Quartzite	7	15.26	23	56.88	14	30.59	44	102.73
Schist	0	0.00	0	0.00	0	0.00	0	0.00
Metamorphic	9	19.5	29	68.88	19	41.98	57	130.36
TOTAL	264	612.9	300	664.29	250	552.09	814	1829.28

Rock Type	1st Trial (%)		2nd Trial (%)		3rd Trial (%)		Average (%)	
	Count	Wt.	Count	Wt.	Count	Wt.	Count	Wt.
Limestone	29.2	30.2	23.3	23.4	25.6	24.3	26.0	26.0
Dolomite	44.3	44.5	42.0	41.0	43.6	44.7	43.3	43.4
Cabonates	73.5	74.8	65.3	64.4	69.2	69.0	69.3	69.4
Chert	3.0	2.5	4.0	3.5	4.8	4.9	3.9	3.6
Sandstone	0.4	0.2	1.7	1.4	0.0	0.0	0.7	0.5
Siltstone	0.4	0.2	2.0	2.0	2.0	2.3	1.5	1.5
Shale	0.4	0.2	0.3	0.2	0.0	0.0	0.2	0.2
Clay ironstone	0.4	0.2	0.0	0.0	0.0	0.0	0.1	0.1
Other Sedimentary	4.5	3.4	8.0	7.1	6.8	7.2	6.4	5.9
Diorite	2.3	2.1	1.3	1.2	1.2	1.1	1.6	1.5
Granite	4.2	4.3	3.0	3.4	1.2	1.4	2.8	3.0
Gabbro	3.0	2.8	3.0	3.6	1.6	1.6	2.5	2.7
Felsite	0.8	0.6	1.0	0.8	1.2	1.0	1.0	0.8
Basalt	8.3	8.9	8.7	9.0	11.2	11.0	9.4	9.7
Igneous	18.6	18.7	17.0	18.1	16.4	16.2	17.3	17.6
Gneiss	0.8	0.7	2.0	1.8	2.0	2.1	1.6	1.5
Quartzite	2.7	2.5	7.7	8.6	5.6	5.5	5.3	5.5
Schist	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Metamorphic	3.4	3.2	9.7	10.4	7.6	7.6	6.9	7.1
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table A.7 G-003 (- 3/8 inch to + No. 4 inch).

Rock Type	1st Trial		2nd Trial		3rd Trial		Total	
	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)
Limestone	98	87.40	83	74.71	83	58.66	264	220.77
Dolomite	120	104.17	117	109.59	128	93.61	365	307.37
Carbonates	218	191.57	200	184.30	211	152.27	629	528.14
Chert	11	8.58	17	11.34	15	11.29	43	31.21
Sandstone	4	2.27	4	3.42	0	0.00	8	5.69
Siltstone	2	2.20	5	6.01	3	0.99	10	9.20
Shale	0	0.00	1	1.82	1	0.24	2	2.06
Clay ironstone	0	0.00	0	0.00	1	0.93	1	0.93
Other Sedimentary	17	13.05	27	22.59	20	13.45	64	49.09
Diorite	3	2.13	4	1.95	5	4.54	12	8.62
Granite	2	0.94	8	4.49	9	6.13	19	11.56
Gabbro	10	11.09	3	3.07	1	2.05	14	16.21
Felsite	0	0.00	0	0.00	1	0.39	1	0.39
Basalt	24	23.62	38	34.99	33	21.60	95	80.21
Igneous	39	37.78	53	44.50	49	34.71	141	116.99
Gneiss	9	7.35	6	6.78	2	2.08	17	16.21
Quartzite	17	14.20	14	13.33	18	10.09	49	37.62
Schist	0	0.00	0	0.00	0	0.00	0	0.00
Metamorphic	26	21.55	20	20.11	20	12.17	66	53.83
TOTAL	300	263.95	300	271.50	300	212.60	900	748.05

Rock Type	1st Trial (%)		2nd Trial (%)		3rd Trial (%)		Average (%)	
	Count	Wt.	Count	Wt.	Count	Wt.	Count	Wt.
Limestone	32.7	33.1	27.7	27.5	27.7	27.6	29.3	29.4
Dolomite	40.0	39.5	39.0	40.4	42.7	44.0	40.6	41.3
Carbonates	72.7	72.6	66.7	67.9	70.3	71.6	69.9	70.7
Chert	3.7	3.3	5.7	4.2	5.0	5.3	4.8	4.2
Sandstone	1.3	0.9	1.3	1.3	0.0	0.0	0.9	0.7
Siltstone	0.7	0.8	1.7	2.2	1.0	0.5	1.1	1.2
Shale	0.0	0.0	0.3	0.7	0.3	0.1	0.2	0.3
Clay ironstone	0.0	0.0	0.0	0.0	0.3	0.4	0.1	0.1
Other Sedimentary	5.7	4.9	9.0	8.3	6.7	6.3	7.1	6.5
Diorite	1.0	0.8	1.3	0.7	1.7	2.1	1.3	1.2
Granite	0.7	0.4	2.7	1.7	3.0	2.9	2.1	1.6
Gabbro	3.3	4.2	1.0	1.1	0.3	1.0	1.6	2.1
Felsite	0.0	0.0	0.0	0.0	0.3	0.2	0.1	0.1
Basalt	8.0	8.9	12.7	12.9	11.0	10.2	10.6	10.7
Igneous	13.0	14.3	17.7	16.4	16.3	16.3	15.7	15.7
Gneiss	3.0	2.8	2.0	2.5	0.7	1.0	1.9	2.1
Quartzite	5.7	5.4	4.7	4.9	6.0	4.7	5.4	5.0
Schist	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Metamorphic	8.7	8.2	6.7	7.4	6.7	5.7	7.3	7.1
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table A.8 G-004 (- 1/2 inch to + 3/8 inch)

Rock Type	1st Trial		2nd Trial		3rd Trial		Total	
	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)
Limestone	64	111.02	42	78.85	74	129.04	180	318.91
Dolomite	83	150.57	46	83.35	61	109.12	190	343.04
Carbonates	147	261.59	88	162.2	135	238.16	370	661.95
Chert	3	4.70	5	7.29	9	12.56	17	24.55
Sandstone	1	1.51	0	0.00	1	0.97	2	2.48
Siltstone	0	0.00	0	0.00	0	0.00	0	0.00
Shale	3	5.43	0	0.00	2	3.02	5	8.45
Clay ironstone	1	1.27	0	0.00	2	5.03	3	6.30
Other Sedimentary	8	12.91	5	7.29	14	21.58	27	41.78
Diorite	13	25.08	16	32.37	12	21.99	41	79.44
Granite	8	12.58	8	17.20	13	22.18	29	51.96
Gabbro	10	18.93	4	9.10	4	8.38	18	36.41
Felsite	2	3.83	0	0.00	2	3.08	4	6.91
Basalt	12	21.56	21	38.96	30	55.17	63	115.69
Igneous	45	81.98	49	97.63	61	110.8	155	290.41
Gneiss	1	2.33	1	2.05	0	0.00	2	4.38
Quartzite	26	43.80	8	12.14	27	46.30	61	102.24
Schist	4	6.98	4	9.21	3	5.29	11	21.48
Metamorphic	31	53.11	13	23.4	30	51.59	74	128.10
TOTAL	231	409.59	155	290.52	240	422.13	626	1122.24

Rock Type	1st Trial (%)		2nd Trial (%)		3rd Trial (%)		Average (%)	
	Count	Wt.	Count	Wt.	Count	Wt.	Count	Wt.
Limestone	27.7	27.1	27.1	27.1	30.8	30.6	28.5	28.27
Dolomite	35.9	36.8	29.7	28.7	25.4	25.8	30.3	30.43
Carbonates	63.6	63.9	56.8	55.8	56.3	56.4	58.9	58.71
Chert	1.3	1.1	3.2	2.5	3.8	3.0	2.8	2.21
Sandstone	0.4	0.4	0.0	0.0	0.4	0.2	0.3	0.20
Siltstone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
Shale	1.3	1.3	0.0	0.0	0.8	0.7	0.7	0.68
Clay ironstone	0.4	0.3	0.0	0.0	0.8	1.2	0.4	0.50
Other Sedimentary	3.5	3.2	3.2	2.5	5.8	5.1	4.2	3.59
Diorite	5.6	6.1	10.3	11.1	5.0	5.2	7.0	7.49
Granite	3.5	3.1	5.2	5.9	5.4	5.3	4.7	4.75
Gabbro	4.3	4.6	2.6	3.1	1.7	2.0	2.9	3.25
Felsite	0.9	0.9	0.0	0.0	0.8	0.7	0.6	0.55
Basalt	5.2	5.3	13.5	13.4	12.5	13.1	10.4	10.58
Igneous	19.5	20.0	31.6	33.6	25.4	26.2	25.5	26.62
Gneiss	0.4	0.6	0.6	0.7	0.0	0.0	0.4	0.42
Quartzite	11.3	10.7	5.2	4.2	11.3	11.0	9.2	8.61
Schist	1.7	1.7	2.6	3.2	1.3	1.3	1.9	2.04
Metamorphic	13.4	13.0	8.4	8.1	12.5	12.2	11.4	11.08
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.00

Table A.9 G-004 (- 3/8 inch to No. 4).

Rock Type	1st	Trial	2nd	Trial	3rd	Trial	Total	
	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)
Limestone	107	62.62	98	47.50	122	68.09	327	178.21
Dolomite	93	58.86	75	36.50	74	37.53	242	132.89
Cabonates	200	121.48	173	84.00	196	105.62	569	311.10
Chert	8	3.01	10	5.61	12	3.55	30	12.17
Sandstone	0	0.00	0	0.00	0	0.00	0	0.00
Siltstone	0	0.00	1	0.29	3	0.59	4	0.88
Shale	0	0.00	1	0.26	0	0.00	1	0.26
Clay ironstone	0	0.00	1	0.87	0	0.00	1	0.87
Other Sedimentary	8	3.01	13	7.03	15	4.14	36	14.18
Diorite	18	10.41	16	7.80	15	6.70	49	24.91
Granite	10	5.68	7	3.97	12	6.52	29	16.17
Gabbro	11	7.53	19	9.40	13	7.23	43	24.16
Felsite	4	2.97	2	2.10	1	0.43	7	5.50
Basalt	26	15.40	32	17.62	21	12.17	79	45.19
Igneous	69	41.99	76	40.89	62	33.05	207	115.93
Gneiss	0	0.00	0	0.00	0	0.00	0	0.00
Quartzite	22	12.30	38	19.58	27	14.86	87	46.74
Schist	1	1.83	0	0.00	0	0.00	1	1.83
Metamorphic	23	14.13	38	19.58	27	14.86	88	48.57
TOTAL	300	180.61	300	151.50	300	157.67	900	489.78

Rock Type	1st	Trial (%)	2nd	Trial (%)	3rd	Trial (%)	Average (%)	
	Count	Wt.	Count	Wt.	Count	Wt.	Count	Wt.
Limestone	35.7	34.7	32.7	31.4	40.7	43.2	36.3	36.40
Dolomite	31.0	32.6	25.0	24.1	24.7	23.8	26.9	26.83
Cabonates	66.7	67.3	57.7	55.4	65.3	67.0	63.2	63.23
Chert	2.7	1.7	3.3	3.7	4.0	2.3	3.3	2.54
Sandstone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
Siltstone	0.0	0.0	0.3	0.2	1.0	0.4	0.4	0.19
Shale	0.0	0.0	0.3	0.2	0.0	0.0	0.1	0.06
Clay ironstone	0.0	0.0	0.3	0.6	0.0	0.0	0.1	0.19
Other Sedimentary	2.7	1.7	4.3	4.6	5.0	2.6	4.0	2.98
Diorite	6.0	5.8	5.3	5.1	5.0	4.2	5.4	5.05
Granite	3.3	3.1	2.3	2.6	4.0	4.1	3.2	3.30
Gabbro	3.7	4.2	6.3	6.2	4.3	4.6	4.8	4.99
Felsite	1.3	1.6	0.7	1.4	0.3	0.3	0.8	1.10
Basalt	8.7	8.5	10.7	11.6	7.0	7.7	8.8	9.29
Igneous	23.0	23.2	25.3	27.0	20.7	21.0	23.0	23.73
Gneiss	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
Quartzite	7.3	6.8	12.7	12.9	9.0	9.4	9.7	9.72
Schist	0.3	1.0	0.0	0.0	0.0	0.0	0.1	0.34
Metamorphic	7.7	7.8	12.7	12.9	9.0	9.4	9.8	10.06
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.00

Table A.10 G-005 (- 1/2 inch to + 3/8 inch).

Rock Type	1st Trial		2nd Trial		3rd Trial		Total	
	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)
Limestone	84	145.10	78	139.30	73	129.90	235	414.30
Dolomite	114	210.30	123	226.90	96	177.90	333	615.10
Cabonates	198	355.40	201	366.20	169	307.80	568	1029.40
Chert	13	18.60	15	26.40	26	42.80	54	87.80
Sandstone	1	1.80	1	1.60	1	1.60	3	5.00
Siltstone	1	2.20	3	4.30	2	2.60	6	9.10
Shale	1	1.00	0	0.00	0	0.00	1	1.00
Clay ironstone	0	0.00	0	0.00	0	0.00	0	0.00
Other Sedimentary	16	23.60	19	32.30	29	47.00	64	102.90
Diorite	4	7.20	3	7.10	8	13.00	15	27.30
Granite	15	23.60	12	20.80	7	10.90	34	55.30
Gabbro	6	11.60	12	21.10	11	22.50	29	55.20
Felsite	0	0.00	0	0.00	0	0.00	0	0.00
Basalt	34	59.80	24	43.90	34	62.90	92	166.60
Igneous	59	102.20	51	92.90	60	109.30	170	304.40
Gneiss	14	27.70	11	19.20	13	24.40	38	71.30
Quartzite	13	25.10	18	27.80	29	46.50	60	99.40
Schist	0	0.00	0	0.00	0	0.00	0	0.00
Metamorphic	27	52.80	29	47.00	42	70.90	98	170.70
TOTAL	300	534.00	300	538.40	300	535.00	900	1607.40

Rock Type	1st Trial (%)		2nd Trial (%)		3rd Trial (%)		Average (%)	
	Count	Wt.	Count	Wt.	Count	Wt.	Count	Wt.
Limestone	28.0	27.2	26.0	25.9	24.3	24.3	26.1	25.8
Dolomite	38.0	39.4	41.0	42.1	32.0	33.3	37.0	38.3
Cabonates	66.0	66.6	67.0	68.0	56.3	57.5	63.1	64.0
Chert	4.3	3.5	5.0	4.9	8.7	8.0	6.0	5.5
Sandstone	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Siltstone	0.3	0.4	1.0	0.8	0.7	0.5	0.7	0.6
Shale	0.3	0.2	0.0	0.0	0.0	0.0	0.1	0.1
Clay ironstone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Sedimentary	5.3	4.4	6.3	6.0	9.7	8.8	7.1	6.4
Diorite	1.3	1.3	1.0	1.3	2.7	2.4	1.7	1.7
Granite	5.0	4.4	4.0	3.9	2.3	2.0	3.8	3.4
Gabbro	2.0	2.2	4.0	3.9	3.7	4.2	3.2	3.4
Felsite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Basalt	11.3	11.2	8.0	8.2	11.3	11.8	10.2	10.4
Igneous	19.7	19.1	17.0	17.3	20.0	20.4	18.9	18.9
Gneiss	4.7	5.2	3.7	3.6	4.3	4.6	4.2	4.4
Quartzite	4.3	4.7	6.0	5.2	9.7	8.7	6.7	6.2
Schist	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Metamorphic	9.0	9.9	9.7	8.7	14.0	13.3	10.9	10.6
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table A.11 G-005 (- 3/8 inch to + No. 4).

Rock Type	1st Trial		2nd Trial		3rd Trial		Total	
	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)	Count	Wt.
Limestone	90	74.40	78	60.10	88	71.60	256	206.10
Dolomite	83	62.50	85	66.00	84	68.20	252	196.70
Carbonates	173	136.90	163	126.10	172	139.80	508	402.80
Chert	14	8.00	25	18.50	21	15.00	60	41.50
Sandstone	1	1.10	1	0.60	3	3.20	5	4.90
Siltstone	1	0.40	0	0.00	0	0.00	1	0.40
Shale	2	0.40	4	2.10	0	0.00	6	2.50
Clay ironstone	1	0.60	1	1.50	0	0.00	2	2.10
Other Sedimentary	19	10.50	31	22.70	24	18.20	74	51.40
Diorite	8	6.00	4	2.40	5	5.80	17	14.20
Granite	13	8.90	10	7.70	15	7.70	38	24.30
Gabbro	14	11.20	4	3.40	4	3.40	22	18.00
Felsite	1	0.90	0	0.00	0	0.00	1	0.90
Basalt	26	19.50	44	35.50	34	27.70	104	82.70
Igneous	62	46.50	62	49.00	58	44.60	182	140.10
Gneiss	18	17.30	11	8.40	9	7.90	38	33.60
Quartzite	28	24.30	33	25.80	36	29.50	97	79.60
Schist	0	0.00	0	0.00	1	1.50	1	1.50
Metamorphic	46	41.60	44	34.20	46	38.90	136	114.70
TOTAL	300	235.50	300	232.00	300	241.50	900	709.00

Rock Type	1st Trial (%)		2nd Trial (%)		3rd Trial (%)		Average (%)	
	Count	Wt.	Count	Wt.	Count	Wt.	Count	Wt.
Limestone	30.0	31.6	26.0	25.9	29.3	29.6	28.4	29.0
Dolomite	27.7	26.5	28.3	28.4	28.0	28.2	28.0	27.7
Carbonates	57.7	58.1	54.3	54.4	57.3	57.9	56.4	56.8
Chert	4.7	3.4	8.3	8.0	7.0	6.2	6.7	5.9
Sandstone	0.3	0.5	0.3	0.3	1.0	1.3	0.6	0.7
Siltstone	0.3	0.2	0.0	0.0	0.0	0.0	0.1	0.1
Shale	0.7	0.2	1.3	0.9	0.0	0.0	0.7	0.4
Clay ironstone	0.3	0.3	0.3	0.6	0.0	0.0	0.2	0.3
Other Sedimentary	6.3	4.5	10.3	9.8	8.0	7.5	8.2	7.3
Diorite	2.7	2.5	1.3	1.0	1.7	2.4	1.9	2.0
Granite	4.3	3.8	3.3	3.3	5.0	3.2	4.2	3.4
Gabbro	4.7	4.8	1.3	1.5	1.3	1.4	2.4	2.5
Felsite	0.3	0.4	0.0	0.0	0.0	0.0	0.1	0.1
Basalt	8.7	8.3	14.7	15.3	11.3	11.5	11.6	11.7
Igneous	20.7	19.7	20.7	21.1	19.3	18.5	20.2	19.8
Gneiss	6.0	7.3	3.7	3.6	3.0	3.3	4.2	4.7
Quartzite	9.3	10.3	11.0	11.1	12.0	12.2	10.8	11.2
Schist	0.0	0.0	0.0	0.0	0.3	0.6	0.1	0.2
Metamorphic	15.3	17.7	14.7	14.7	15.3	16.1	15.1	16.2
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table A.12 G-006 (- 1 inch to + 1/2 inch).

Rock Type	1st Trial		2nd Trial		3rd Trial		Total	
	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)
Limestone	63	353.40	43	268.80	51	350.40	157	972.60
Dolomite	67	431.90	77	452.50	68	429.00	212	1313.40
Carbonates	130	785.30	120	721.30	119	779.40	369	2286.00
Chert	3	19.40	0	0.00	0	0.00	3	19.40
Sandstone	2	12.60	2	9.10	2	10.30	6	32.00
Siltstone	2	5.60	0	0.00	0	0.00	2	5.60
Shale	0	0.00	1	11.80	1	12.20	2	24.00
Clay ironstone	1	2.00	0	0.00	2	7.00	3	9.00
Other Sedimentary	8	39.60	3	20.90	5	29.50	16	90.00
Diorite	3	13.50	7	52.40	4	24.50	14	90.40
Granite	13	77.00	11	79.90	15	79.90	39	236.80
Gabbro	11	102.70	10	72.90	10	66.90	31	242.50
Felsite	0	0.00	0	0.00	3	19.00	3	19.00
Basalt	47	276.10	52	294.50	45	261.50	144	832.10
Igneous	74	469.30	80	499.70	77	451.80	231	1420.80
Gneiss	19	125.60	23	69.40	9	49.60	51	244.60
Quartzite	24	173.80	25	162.90	24	173.60	73	510.30
Schist	0	0.00	0	0.00	0	0.00	0	0.00
Metamorphic	43	299.40	48	232.30	33	223.20	124	754.90
TOTAL	255	1593.60	251	1474.20	234	1483.90	740	4551.70

Rock Type	1st Trial (%)		2nd Trial (%)		3rd Trial (%)		Average (%)	
	Count	Wt.	Count	Wt.	Count	Wt.	Count	Wt.
Limestone	24.7	22.2	17.1	18.2	21.8	23.6	21.2	21.3
Dolomite	26.3	27.1	30.7	30.7	29.1	28.9	28.7	28.9
Carbonates	51.0	49.3	47.8	48.9	50.9	52.5	49.9	50.2
Chert	1.2	1.2	0.0	0.0	0.0	0.0	0.4	0.4
Sandstone	0.8	0.8	0.8	0.6	0.9	0.7	0.8	0.7
Siltstone	0.8	0.4	0.0	0.0	0.0	0.0	0.3	0.1
Shale	0.0	0.0	0.4	0.8	0.4	0.8	0.3	0.5
Clay ironstone	0.4	0.1	0.0	0.0	0.9	0.5	0.4	0.2
Other Sedimentary	3.1	2.5	1.2	1.4	2.1	2.0	2.2	2.0
Diorite	1.2	0.8	2.8	3.6	1.7	1.7	1.9	2.0
Granite	5.1	4.8	4.4	5.4	6.4	5.4	5.3	5.2
Gabbro	4.3	6.4	4.0	4.9	4.3	4.5	4.2	5.3
Felsite	0.0	0.0	0.0	0.0	1.3	1.3	0.4	0.4
Basalt	18.4	17.3	20.7	20.0	19.2	17.6	19.5	18.3
Igneous	29.0	29.4	31.9	33.9	32.9	30.4	31.3	31.3
Gneiss	7.5	7.9	9.2	4.7	3.8	3.3	6.8	5.3
Quartzite	9.4	10.9	10.0	11.1	10.3	11.7	9.9	11.2
Schist	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Metamorphic	16.9	18.8	19.1	15.8	14.1	15.0	16.7	16.5
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table A.13 G-006 (- 1/2 inch to + 3/8 inch).

Rock Type	1st Trial		2nd Trial		3rd Trial		Total	
	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)	Count	Wt.
Limestone	62	128.00	56	106.80	55	112.20	173	347.00
Dolomite	51	108.40	60	107.60	56	110.30	167	326.30
Carbonates	113	236.40	116	214.40	111	222.50	340	673.30
Chert	2	3.00	0	0.00	0	0.00	2	3.00
Sandstone	5	10.60	9	16.50	5	11.30	19	38.40
Siltstone	2	2.90	1	1.20	0	0.00	3	4.10
Shale	4	5.60	2	4.30	1	3.60	7	13.50
Clay ironstone	0	0.00	2	3.00	1	2.90	3	5.90
Other Sedimentary	13	22.10	14	25.00	7	17.80	34	64.90
Diorite	2	4.20	8	17.70	7	19.50	17	41.40
Granite	22	44.10	14	30.10	15	34.80	51	109.00
Gabbro	14	28.00	14	32.50	18	39.60	46	100.10
Felsite	0	0.00	0	0.00	0	0.00	0	0.00
Basalt	41	81.20	62	111.30	73	135.00	176	327.50
Igneous	79	157.50	98	191.60	113	228.90	290	578.00
Gneiss	7	12.70	6	12.80	6	11.10	19	36.60
Quartzite	34	54.30	42	76.40	51	95.70	127	226.40
Schist	0	0.00	0	0.00	0	0.00	0	0.00
Metamorphic	41	67.00	48	89.20	57	106.80	146	263.00
TOTAL	246	483.00	276	520.20	288	576.00	810	1579.20

Rock Type	1st Trial (%)		2nd Trial (%)		3rd Trial (%)		Average (%)	
	Count	Wt.	Count	Wt.	Count	Wt.	Count	Wt.
Limestone	25.2	26.5	20.3	20.5	19.1	19.5	21.5	22.0
Dolomite	20.7	22.4	21.7	20.7	19.4	19.1	20.6	20.9
Carbonates	45.9	48.9	42.0	41.2	38.5	38.6	42.2	42.9
Chert	0.8	0.6	0.0	0.0	0.0	0.0	0.3	0.2
Sandstone	2.0	2.2	3.3	3.2	1.7	2.0	2.3	2.4
Siltstone	0.8	0.6	0.4	0.2	0.0	0.0	0.4	0.3
Shale	1.6	1.2	0.7	0.8	0.3	0.6	0.9	0.8
Clay ironstone	0.0	0.0	0.7	0.6	0.3	0.5	0.4	0.3
Other Sedimentary	5.3	4.6	5.1	4.8	2.4	3.1	4.3	3.9
Diorite	0.8	0.9	2.9	3.4	2.4	3.4	2.0	2.2
Granite	8.9	9.1	5.1	5.8	5.2	6.0	6.4	6.7
Gabbro	5.7	5.8	5.1	6.2	6.3	6.9	5.7	6.1
Felsite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Basalt	16.7	16.8	22.5	21.4	25.3	23.4	21.5	21.2
Igneous	32.1	32.6	35.5	36.8	39.2	39.7	35.6	36.2
Gneiss	2.8	2.6	2.2	2.5	2.1	1.9	2.4	2.4
Quartzite	13.8	11.2	15.2	14.7	17.7	16.6	15.6	14.5
Schist	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Metamorphic	16.7	13.9	17.4	17.1	19.8	18.5	17.9	16.9
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table A.14 G-006 (- 3/8 inch to No.4).

Rock Type	1st Trial		2nd Trial		3rd Trial		Total	
	Count	Wt. (g)	Count	Wt. (g)	Count	Wt. (g)	Count	Wt.
Limestone	63	55.10	57	45.10	61	49.10	181	149.30
Dolomite	70	57.10	70	53.30	68	53.90	208	164.30
Carbonates	133	112.20	127	98.40	129	103.00	389	313.60
Chert	1	0.50	1	0.80	0	0.00	2	1.30
Sandstone	2	2.50	7	5.80	5	3.70	14	12.00
Siltstone	0	0.00	2	1.30	3	3.60	5	4.90
Shale	1	0.50	1	0.90	1	1.20	3	2.60
Clay ironstone	3	3.10	3	1.90	3	1.60	9	6.60
Other Sedimentary	7	6.60	14	10.70	12	10.10	33	27.40
Diorite	5	4.70	6	2.60	9	7.90	20	15.20
Granite	22	18.60	19	14.90	4	2.80	45	36.30
Gabbro	9	4.50	21	15.40	28	19.40	58	39.30
Felsite	1	0.10	1	1.60	4	3.30	6	5.00
Basalt	87	62.70	61	42.10	60	50.40	208	155.20
Igneous	124	90.6	108	76.6	105	83.80	337	251.00
Gneiss	0	0.00	0	0.00	0	0.00	0	0.00
Quartzite	36	21.80	51	32.20	54	40.10	141	94.10
Schist	0	0.00	0	0.00	0	0.00	0	0.00
Metamorphic	36	21.8	51	32.2	54	40.10	141	94.10
TOTAL	300	231.2	300	217.9	300	237.00	900	686.10

Rock Type	1st Trial (%)		2nd Trial (%)		3rd Trial (%)		Average (%)	
	Count	Wt.	Count	Wt.	Count	Wt.	Count	Wt.
Limestone	21.0	23.8	19.0	20.7	20.3	20.7	20.1	21.7
Dolomite	23.3	24.7	23.3	24.5	22.7	22.7	23.1	24.0
Carbonates	44.3	48.5	42.3	45.2	43.0	43.5	43.2	45.7
Chert	0.3	0.2	0.3	0.4	0.0	0.0	0.2	0.2
Sandstone	0.7	1.1	2.3	2.7	1.7	1.6	1.6	1.8
Siltstone	0.0	0.0	0.7	0.6	1.0	1.5	0.6	0.7
Shale	0.3	0.2	0.3	0.4	0.3	0.5	0.3	0.4
Clay ironstone	1.0	1.3	1.0	0.9	1.0	0.7	1.0	1.0
Other Sedimentary	2.3	2.9	4.7	4.9	4.0	4.3	3.7	4.0
Diorite	1.7	2.0	2.0	1.2	3.0	3.3	2.2	2.2
Granite	7.3	8.0	6.3	6.8	1.3	1.2	5.0	5.4
Gabbro	3.0	1.9	7.0	7.1	9.3	8.2	6.4	5.7
Felsite	0.3	0.0	0.3	0.7	1.3	1.4	0.7	0.7
Basalt	29.0	27.1	20.3	19.3	20.0	21.3	23.1	22.6
Igneous	41.3	39.2	36.0	35.2	35.0	35.4	37.4	36.6
Gneiss	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Quartzite	12.0	9.4	17.0	14.8	18.0	16.9	15.7	13.7
Schist	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Metamorphic	12.0	9.4	17.0	14.8	18.0	16.9	15.7	13.7
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Appendix B

Graph showing results of the British Wheel test for individual aggregate.

B.1. British Pendulum test results (D-001 and D-016).

B.2. British Pendulum test results (D-002 and D-003).

B.3. British Pendulum test results (D-004 and D-020).

B.4. British Pendulum test results (D-005 and D-006).

B.5. British Pendulum test results (D-007 and D-008).

B.6. British Pendulum test results (D-009 and D-010).

B.7. British Pendulum test results (D-011 and D-012).

B.8. British Pendulum test results (D-013 and D-014).

B.9. British Pendulum test results (D-015 and D-017).

B.10. British Pendulum test results (D-018 and D-019).

B.11. British Pendulum test results (G-001-DO and G-002-DO).

B.12. British Pendulum test results (G-003-DO and G-006-DO).

B.13. British Pendulum test results (G-004-DO and G-005-DO).

B.14. British Pendulum test results (G-001-LS and G-006-LS).

B.15. British Pendulum test results (G-002-LS and G-005-LS).

B.16. British Pendulum test results (G-003-LS and G-004-LS).

B.17. British Pendulum test results (SL-001 and Basalt).

B.18. British Pendulum test results (Diorite and Gabbro).

B.19. British Pendulum test results (Granite and Gneiss).

B.20. British Pendulum test results (LS-001 and LS-002).

B.21. British Pendulum test results (S-001 and S-002).

B.22. British Pendulum test results (MIX73 and MIX100).

B.23. British Pendulum test results (MIX37 and MIX55).

B.24. British Pendulum test results (R-10577 and R-13019).

B.25. British Pendulum test results (R-11046 and RS-17254).

B.26. British Pendulum test results (R-11776 and RS-16084).

B.27. British Pendulum test results (R-12812 and RS-14940).

B.28. British Pendulum test results (R-14456 and R-15310).

Appendix C.

List of Abbreviation

Appendix C. List of Abbreviation

AASHTO -- American Association of State Highway and Transportation Officials
AFN -- Average Friction Number
ASTM -- American Society for Testing and Materials
AWI -- Aggregate Wear Index
BPN -- British Pendulum Number
EDTA -- Disodium Dihydrogenethylenediamine Tetraacetate
FNR -- Friction Number Ribbed
FNS -- Friction Number Smooth
IFV -- Initial Friction Value
INDOT -- Indiana Department of Transportation
ITM -- Indiana Test Method
ISM -- Indiana Standard Method
MATXd x 10³ -- Macrotexture Depth
MDOT -- Michigan Department of Transportation
MEKP -- Methyl Ethyl Ketone Peroxide
MTM -- Michigan Test Method
MgO -- Magnesium Oxide
NCSU -- North Carolina State University
PV -- Polished Value
SMA -- Stone Mastic Asphalt
WI -- Wear Index

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