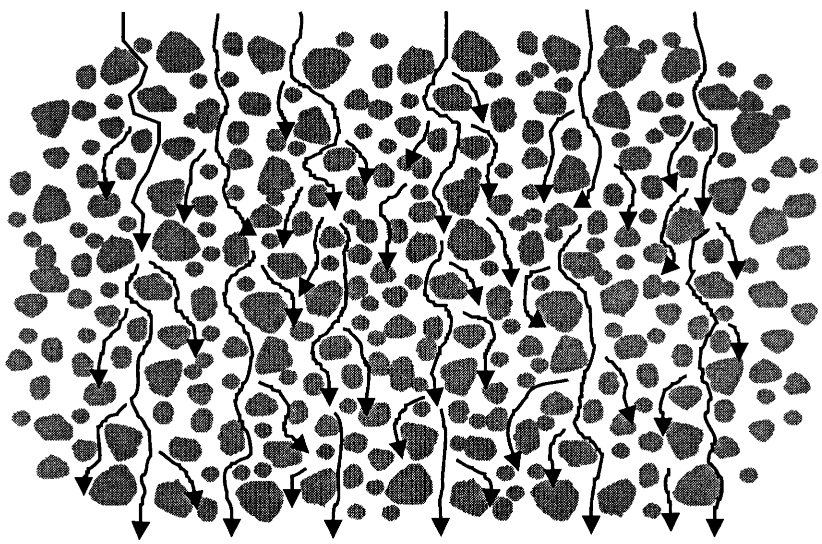
FINAL REPORT

THE INFLUENCE OF FINES ON STRENGTH AND DRAINAGE CHARACTERISTICS OF AGGREGATE BASES



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Supplementary Notes

Abstract

One of the most commonly used dense-graded aggregate mixes in Virginia is designated as Type 21B. In an effort to improve drainage characteristics of the 21B material it was proposed to decrease the maximum allowable percentage of fines from 7% to 5% while retaining the existing percentage ranges for course particles. Prior to implementing this modification, the Virginia Department of Transportation (VDOT) conducted a series of laboratory tests to assess the potential impact of the revised material specifications. Samples of 21B aggregates produced by 19 quarries located throughout Virginia and North Carolina were analyzed. The results showed no statistically significant relationship between the percentage of fines and the coefficient of permeability. It can be concluded that the proposed decrease in the maximum allowable percentage of fines from 7% to 5% would not result in a significant improvement in roadway drainage.

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(A Cooperative Organization Sponsored Jointly by the
Virginia Department of Transportation and
the University of Virginia)

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ABSTRACT

Type 21B is one of the most commonly used dense-graded aggregate mixes in Virginia. To improve the drainage characteristics of the 21B material, a decrease in the maximum allowable percentage of fines from 7% to 5% was proposed, while retaining the existing percentage ranges for coarse particles. Before implementing this modification, the Virginia Department of Transportation (VDOT) conducted a series of laboratory tests to assess the potential impact of the revised material specifications. Samples of 21B aggregates produced by 19 quarries in Virginia and in North Carolina were analyzed. The results showed no statistically significant relationship between the percentage of fines and the coefficient of permeability. It can be concluded that the proposed decrease in the maximum allowable percentage of fines from 7% to 5% would not result in a significant improvement in roadway drainage.

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INTRODUCTION

It has long been recognized that pavement service life largely depends on the stability and permeability of the underlying base material. To improve the drainability of aggregate bases, various state DOTs have been experimenting with open-graded mixes (Mathis, 1990). Open-graded aggregates (OGA) are characterized by a relatively narrow range of particle sizes. Typically, it is required that the particle size of OGA for which 85% is finer should be less than 4 times the size for which 15% is finer (Cedergren, 1974). In contrast, dense-graded aggregates have a relatively broad particle size distribution.

There has been some concern that, while assuring excellent drainage characteristics, OGA may not provide adequate long term support (compacting OGA is like attempting to compact equal size marbles). Currently, OGA utilized in Virginia must be treated with asphalt or cement to ensure stability. Unstabilized OGA is not recommended for general use under any VDOT pavement (VDOT, 1990).

VDOT routinely uses dense graded aggregates due to their excellent load carrying capacity, derived from the interlocking of various particle sizes which creates a stable foundation base. There has been some concern, however, that in situations involving very high water infiltration a dense matrix may not allow sufficiently rapid drainage. As a result, water trapped in the pavement section for a prolonged time may cause significant structural damage under traffic loads.

One of the most commonly used dense-graded aggregate mixes in Virginia is designated as Type 21B. Current VDOT gradation requirements for the 21B mix, as stated in Section 208c of the Road and Bridge Specifications (VDOT, 1991) are as follows:

Sieve Opening	% Finer by Weight
2 in	100
1 in	85-95
3/8 in	50-69
No. 10	20-36
No. 40	9-19
No. 200	4-7

In an effort to improve drainage characteristics of the Type 21B material, VDOT has been reviewing current gradation requirements. Some previous studies indicate that the percentage of fines (material passing the No. 200 sieve) is one of the most significant factors affecting the overall permeability of the base material (Crovetti and Dempsey, 1993; Persing et al., 1978). A change in gradation specifications, reducing the percentage of fines to a 4-5% range, was proposed. Before implementing this modification, VDOT decided to conduct laboratory tests designed to assess its impact.

PURPOSE AND SCOPE

The purpose of this study was to evaluate the influence of fines on drainage and strength characteristics of the VDOT Type 21B dense-graded aggregate. Statistical relationships between the percentage of fines, coefficient of permeability and the California Bearing Ratio (CBR) were sought.

Laboratory tests were conducted on a number of currently supplied Type 21B mixes. Analysis of the particle size distribution of aggregates sampled from various quarries indicated significant variations in the fines content, sometimes exceeding the allowable range. The purpose of laboratory tests was to answer the question, "Can we relate the permeability and CBR values to the fines content of the currently produced Type 21B material?"

Nineteen quarries located throughout Virginia and North Carolina were sampled. Tests were conducted on samples obtained from the following locations:

QUARRY	VDOT DISTRICT
Pounding Mill Quarry Corp. Bluefield Plant	Bristol
Cardinal Stone Grayson Quarry	Bristol

Wilson Quarries Horsepasture Quarry	Salem
Rockydale Quarries Inc. Rockydale Quarry	Salem
Blue Ridge Stone Corp. Blue Ridge Plant	Salem
Luck Stone Corp. Augusta Plant	Staunton
C. S. Mundy, Inc. Flat Rock Quarry	Staunton
Martin Marietta Aggregates Culpeper Quarry	Culpeper
Luck Stone Corp. Charlottesville Plant	Culpeper
Vulcan Materials Co. South Boston Quarry	Lynchburg
Vulcan Materials Co. Shelton Quarry (Shelton, N.C.)	Lynchburg
Tarmac Mid-Atlantic, Inc. Dale Quarry	Richmond
Tidewater Quarries, Inc. Deepwater Terminal	Richmond
Martin Marietta Aggregates Carmel Church	Fredericksburg
Martin Marietta Aggregates Spotsylvania Quarry	Fredericksburg
Luck Stone Corp. Fairfax Plant	Northern Virginia

Vulcan Materials Co. Occoquan Quarry	Northern Virginia
Loudoun Quarries, Inc Shaw Road Plant	Northern Virginia
Vulcan Materials Co. Skippers Plant	Suffolk

METHODS

Samples of the 21B material were collected from 19 quarries by VDOT District Materials personnel. Laboratory testing was conducted at the Virginia Transportation Research Council. The following tests were performed on each aggregate sample in accordance with the Virginia Test Methods (VDOT, 1995) and ASTM (1993) standards:

1. Grain size analysis (VTM-25)
2. Atterberg Limits (VTM-7)
3. Specific Gravity (ASTM D854)
4. Standard Proctor (VTM-1)
5. CBR (VTM-8)
6. Permeability - Falling Head or Constant Head Test

In accordance with the VTM-25 test procedure, the percentage of fine particles passing the No. 200 sieve was determined by the wet wash method. It accounts for fines that may be adhering to coarse particles. Atterberg Limit tests were conducted primarily to check for the presence of plastic fines, which could significantly affect the overall permeability. Specific gravity tests were done to obtain adjusted theoretical maximum density of a mixture containing particles larger than the No. 4 sieve opening. Each of the Standard Proctor tests performed for a density determination consisted of a minimum of four samples, conditioned at different moisture contents. Permeability and CBR samples were subsequently prepared at the optimum moisture content. Uniform moisture distribution in a sample was assured through mechanical mixing. Compaction of aggregates was conducted using an automatic proctor hammer (ELE) to deliver a consistent amount of energy. Permeability and CBR samples were compacted in 5 layers, at 45 blows per layer, to 152 mm diameter by 152 mm high specimens in CBR molds, using the entire material gradation. Specimens were then allowed to soak in water for a minimum of 4 days, while subjected to a 4.54 kg surcharge. Care was taken to assure that permeability and CBR sample sets were prepared and conditioned in an identical manner prior to testing.

At the end of the soaking period CBR samples were tested in a hydraulic press (HUMBOLDT) following a standard procedure. Load versus piston penetration relationship was continuously recorded using an automated data acquisition system (HUMBOLDT). Permeability samples were subjected to a constant head or a falling head test, depending on the magnitude of outflow. Hydraulic gradient was kept at a maximum value not exceeding 1.0 to simulate field conditions (Cedergren, 1974). De-ionized and de-aired water was used as a permeant in all tests.

RESULTS

Laboratory test results for individual samples are presented in Appendix A.

DISCUSSION

Statistical analysis was performed to determine which variables might exert a significant influence on the coefficient of permeability and CBR of an aggregate mix. The following variables were considered as potential influences on permeability and strength:

- Percent passing the No.4 sieve
- Percent passing the No. 40 sieve
- Percent passing the No. 200 sieve
- D_{10}
- D_{15}
- D_{60}
- D_{85}
- D_{85}/D_{15}
- Coefficient of uniformity $C_u=D_{60}/D_{10}$
- Void ratio
- Ratio of particle principal dimensions (Min/Max)

The strength of a linear association between variables is commonly expressed by the Pearson correlation coefficient r (SPSS, Inc., 1993), defined as:

$$r = \frac{\sum_{i=1}^{N} \left(X_i - \bar{X}\right)\left(Y_i - \bar{Y}\right)}{\left(N - 1\right) S_x S_y} \qquad \text{(Eqn. 1)}$$

where N is the number of cases, and S_x and S_y are the standard deviations of the two variables. The absolute value of r indicates the strength of a linear relationship, ranging from 0 (no association) to 1 (full association) and provides an indicator of which variables may be likely influences on permeability.

Initially, Pearson coefficients were computed by correlating the coefficient of permeability and CBR with each of the above listed variables. It was recognized that some associations may not be linear. Thus, correlations were also performed using transformed variables. Log, square root, square, and reciprocal transformations were utilized.

By itself, the percentage of material passing the No. 200 sieve was found to bear little relationship to the coefficient of permeability and CBR. Correlation coefficients of 0.04 and 0.17 were computed for the logarithm of the coefficient of permeability versus the percentage of fines and CBR versus the percentage of fines, respectively. A cumulative plot of the permeability versus the percentage of fines is shown in Figure 1. A plot of CBR versus the percentage of fines is shown in Figure 2.

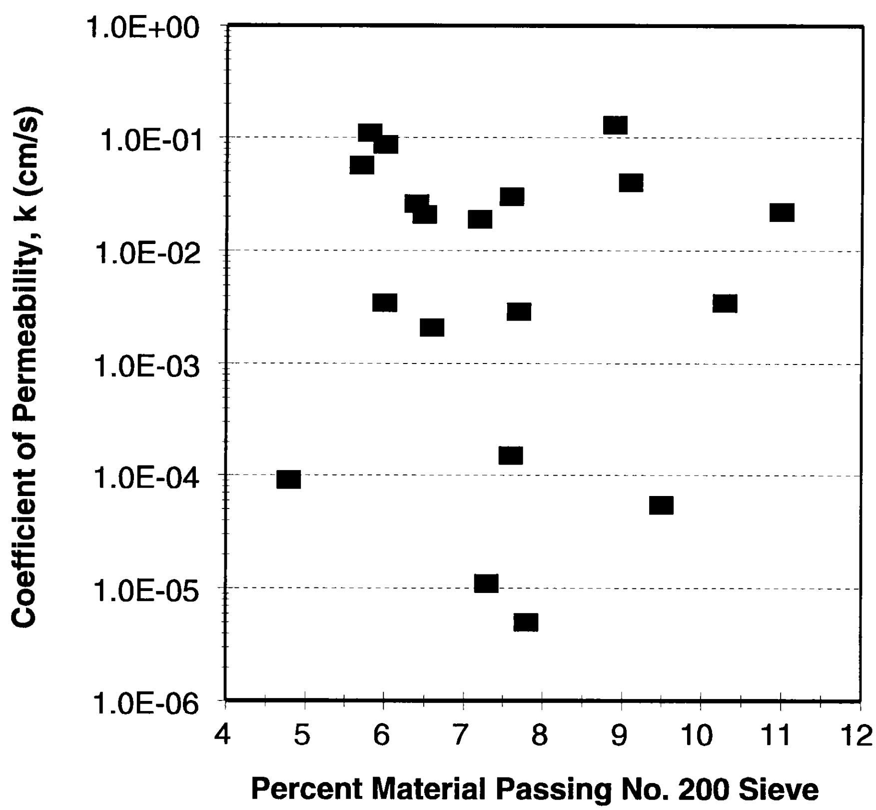

Figure 1. Influence of fines on permeability.

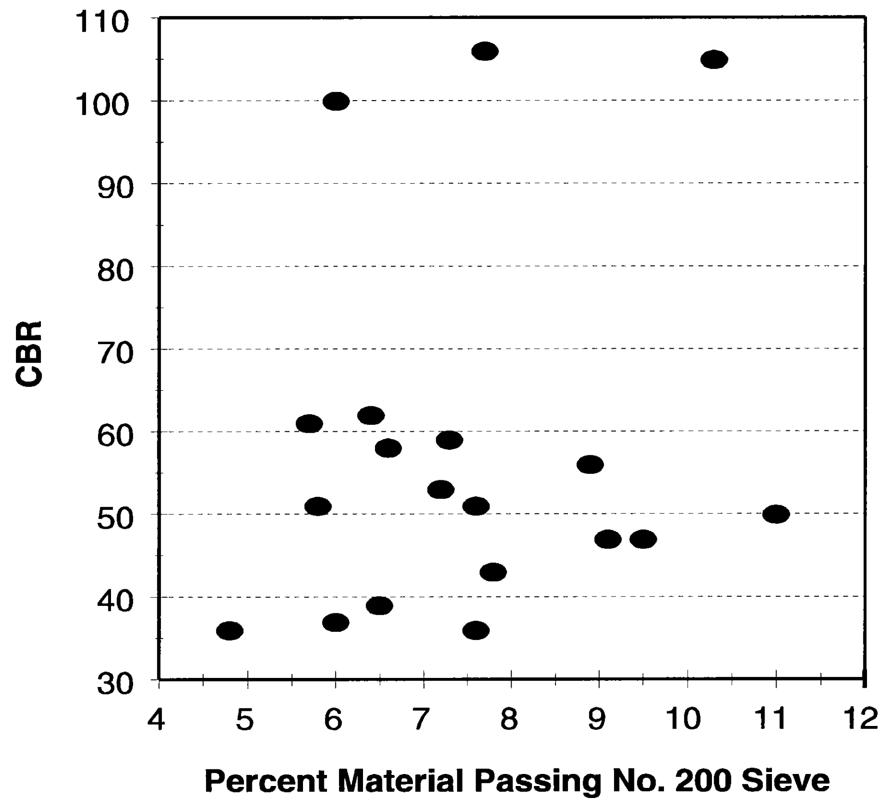

Figure 2. Influence of fines on CBR.

Subsequently, it was decided to employ multiple regression to evaluate the influence of fines collectively with other independent variables. Multiple regression analyses were performed using two different dependent variables: the coefficient of permeability and CBR. The regression model involved analyzing the dependent variable as a linear function of one or several independent variables and a constant term. Correlation coefficients between independent variables were computed to check for the presence of interrelated terms. In such cases, one of the variables was removed from the multiple regression model to avoid the problem of multicollinearity.

Contrary to what one might expect, the results of regression analyses indicated that the fines content does not exert a statistically significant influence on permeability. Two other variables were found to be strong predictors (better than a 0.01 level of significance, indicating a probability of arriving at an erroneous conclusion) of permeability. One was the coefficient of uniformity $C_u = D_{60}/D_{10}$. The other was the ratio of D_{85}/D_{15}. Both of these variables describe the particle size distribution of a material. They were found to explain between 65% and 70% of the variability in the coefficient of permeability. This is a significant finding and suggests new avenues to explore for the establishment of aggregate specifications.

Figure 3 indicates a general trend of decreasing permeability with increasing C_u. Stated another way, permeability increases as the particle size distribution becomes more uniform. This relationship is not surprising, since uniform particles contain larger voids, allowing greater permeability. The influence of the particle size distribution on the coefficient of uniformity is shown in Figure 4. What the results indicate is that a material with a small C_u (Figure 4, curve 1) is significantly more permeable than a material with a large C_u (Figure 4, curve 2), despite containing same percentages of fines.

Regression analyses indicated that CBR values are most strongly influenced by the ratio of particle principal dimensions (Min/Max). For each sample material the ratio was calculated from an average of 20 representative particle measurements performed with calipers. The highest coefficient of 0.53 was computed for the CBR^2 vs $(Min/Max)^2$ relationship, as shown in Figure 5.

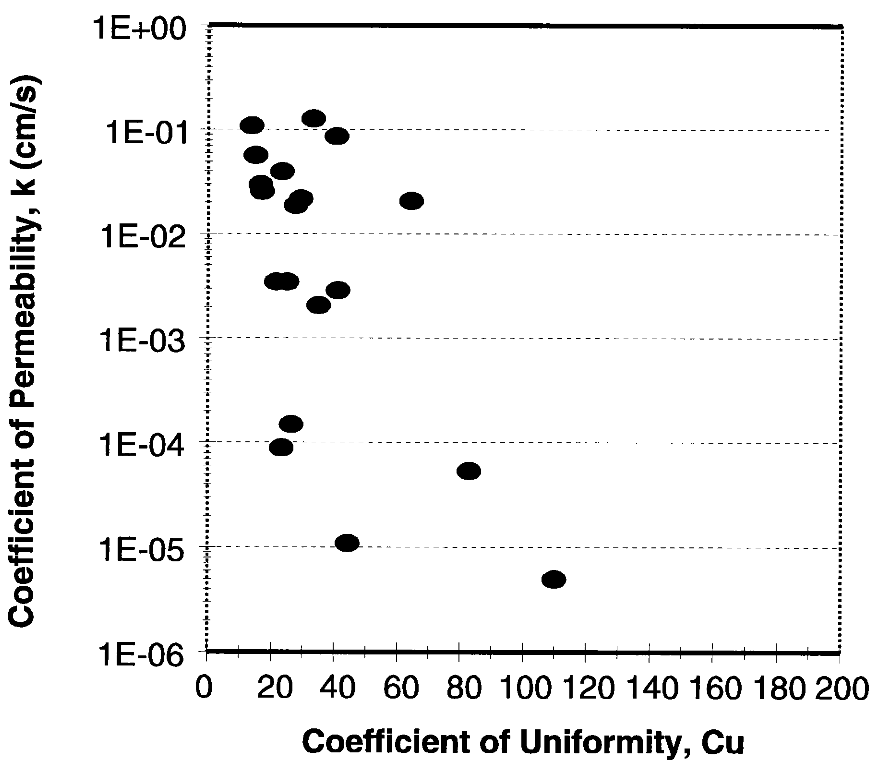

Figure 3. Influence of C_u on permeability.

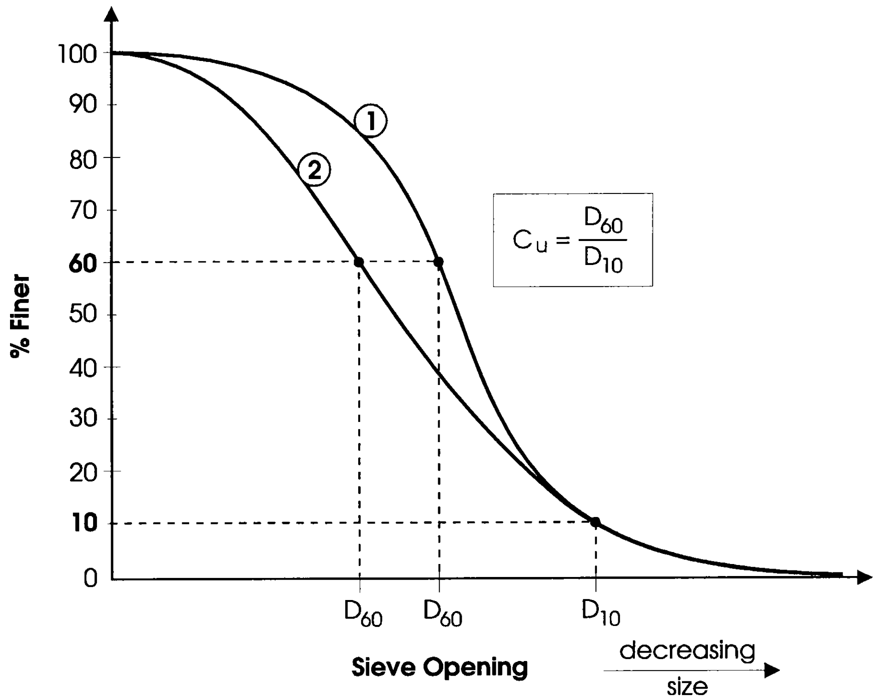

Figure 4. Coefficient of uniformity.

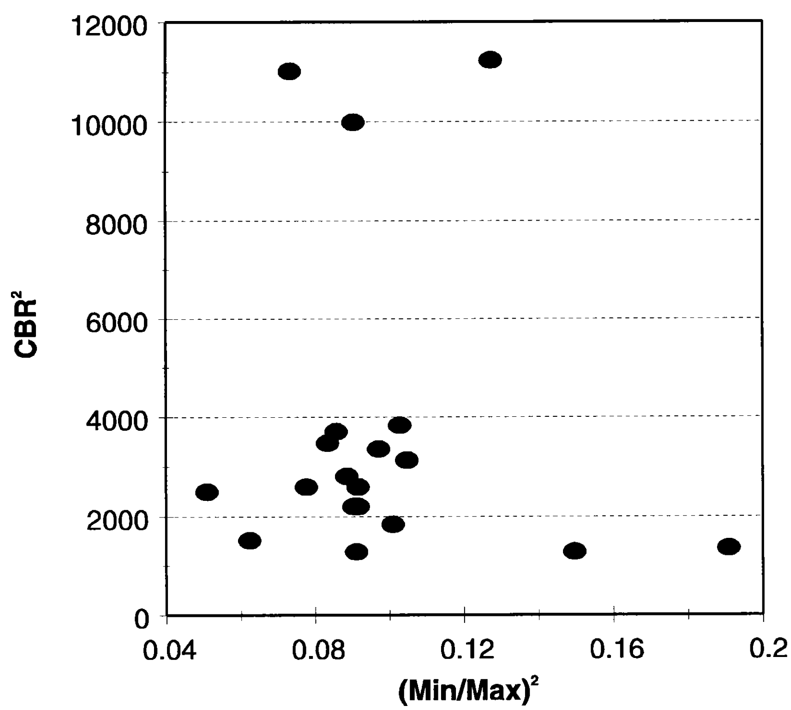

Figure 5. Influence of particle shape on CBR.

Virginia specifications for the Type 21B material were compared to those for similar dense-graded aggregates used elsewhere. Table 1 indicates allowable limits on the fines content. It appears that the current upper limit imposed on the fines portion of the 21B mix in Virginia is relatively stringent, compared with some other states.

Table 1. Gradation Limits on the Percent Passing the No. 200 Sieve

Virginia	4-7
North Carolina	4-12 (unless otherwise specified in the special provisions) 4-10 (when specified in the special provisions)
Kentucky	4-13 (dense graded aggregate base) 0-8 (crushed stone base)
West Virginia	0-10
Maryland	0-8
Indiana	5-10

Gradation specifications used by Indiana further stipulate that "the fraction passing the No. 200 sieve shall not exceed 2/3 the fraction passing the No. 30 sieve." Moreover, laboratory tests on aggregates performed by the Indiana Department of Highways (INDOT, 1990) did not indicate a significant relationship between the fines content and permeability.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations apply only to the range of 21B gradations tested in this study. While the total percentage of fines contained in a dense-graded mix cannot be ignored, it should not be relied upon as the controlling single factor in the expected base drainability. Very weak statistical association was detected between the permeability of the currently produced Type 21B aggregate mix and its fines content. The dominant influence on permeability was found to be exerted by the entire particle size distribution, as represented by the coefficient of uniformity C_u or the ratio of D_{85}/D_{15}. In the observed C_u range of approximately 10 to 115, improved drainage may be achieved by using a low C_u gradation, with no adverse impact on strength. Therefore, drainage characteristics of a dense-graded aggregate mix can be more effectively enhanced by controlling the uniformity of the particle size distribution. Laboratory results indicate that no significant benefit will be realized by decreasing the current maximum allowable fines content from 7% to 5%, while keeping the remaining gradation limits unchanged.

ACKNOWLEDGMENTS

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APPENDIX A

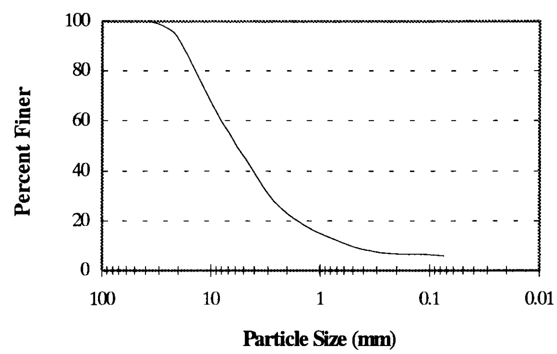
Laboratory Test Results

SUMMARY OF LABORATORY TEST RESULTS
21B Study

Sample Location — **Pounding Mill Quarry Corp.**
Bluefield Plant

Gradation Analysis (VTM-25)

% Finer than	50.8 mm	[2 in]	
	38.1	[1 1/2 in]	100.0
	25.4	[1 in]	97.4
	19.05	[3/4 in]	91.3
	9.525	[3/8 in]	65.7
	4.76	[No. 4]	44.4
	2	[No. 10]	23.0
	0.42	[No. 40]	8.7
	0.074	[No. 200]	5.8



Atterberg Limits (VTM-7)

Liquid Limit	14
Plastic Limit	12
Plasticity Index	2

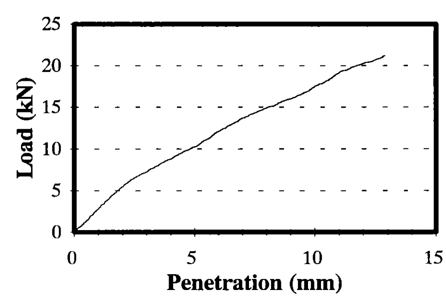
Standard Proctor (VTM-1)
(- No. 4 Material)

Maximum Dry Unit Weight (kN/m^3)	20.3
Optimum Moisture Content (%)	6.0

Specific Gravity (ASTM D854)
(All Material) — 2.72

California Bearing Ratio (VTM-8)
(All Material)

CBR	51
Swell (%)	0.003
Final Moisture Content (%)	4.6
Final Dry Unit Weight (kN/m^3)	20.4



Permeability Test Data

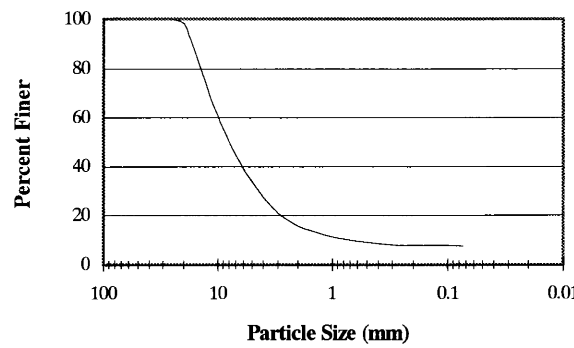
Type of Test	Constant Head
Hydraulic Gradient	0.50
Permeability [@ 20 C] (cm/s)	1.1E -1

SUMMARY OF LABORATORY TEST RESULTS
21B Study

Sample Location — **Cardinal Stone Grayson Quarry**

Gradation Analysis (VTM-25)

% Finer than	50.8 mm	[2 in]	
	38.1	[1 1/2 in]	
	25.4	[1 in]	100.0
	19.05	[3/4 in]	96.9
	9.525	[3/8 in]	58.4
	4.76	[No. 4]	32.3
	2	[No. 10]	15.7
	0.42	[No. 40]	8.8
	0.074	[No. 200]	7.6



Atterberg Limits (VTM-7)

Liquid Limit	Non-
Plastic Limit	Plastic
Plasticity Index	

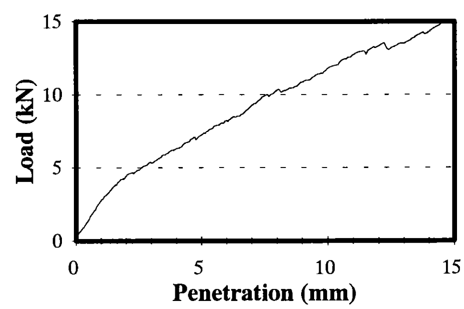
Standard Proctor (VTM-1)
(- No. 4 Material)

Maximum Dry Unit Weight (kN/m^3)	20.4
Optimum Moisture Content (%)	8.0

Specific Gravity (ASTM D854)
(All Material) — 2.83

California Bearing Ratio (VTM-8)
(All Material)

CBR	36
Swell (%)	0
Final Moisture Content (%)	4.8
Final Dry Unit Weight (kN/m^3)	20.4



Permeability Test Data

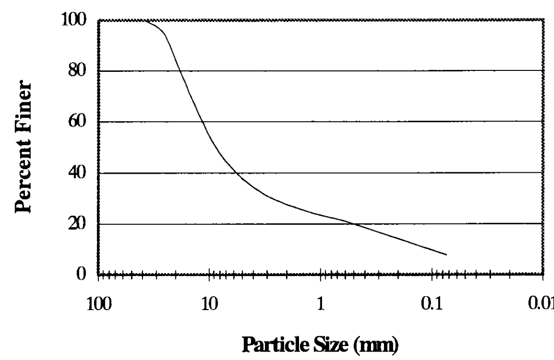
Type of Test	Constant Head
Hydraulic Gradient	0.64
Permeability [@ 20 C] (cm/s)	3.0E -2

SUMMARY OF LABORATORY TEST RESULTS
21B Study

Sample Location — **Wilson Quarries Horsepasture Quarry**

Gradation Analysis (VTM-25)

% Finer than	50.8 mm	[2 in]	
	38.1	[1 1/2 in]	100.0
	25.4	[1 in]	94.5
	19.05	[3/4 in]	81.7
	9.525	[3/8 in]	52.8
	4.76	[No. 4]	37.0
	2	[No. 10]	27.4
	0.42	[No. 40]	18.8
	0.074	[No. 200]	7.8



Atterberg Limits (VTM-7)

Liquid Limit	Non-
Plastic Limit	Plastic
Plasticity Index	

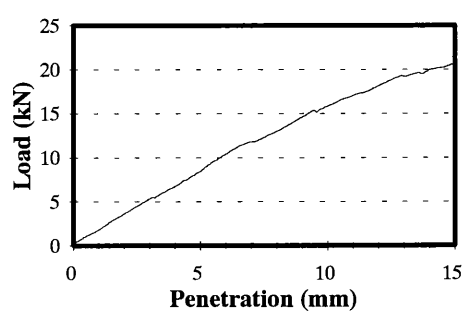
Standard Proctor (VTM-1)
(- No. 4 Material)

Maximum Dry Unit Weight (kN/m^3)	20.3
Optimum Moisture Content (%)	9.2

Specific Gravity (ASTM D854)
(All Material) — 2.86

California Bearing Ratio (VTM-8)
(All Material)

CBR	43
Swell (%)	0.025
Final Moisture Content (%)	5.4
Final Dry Unit Weight (kN/m^3)	22.3



Permeability Test Data

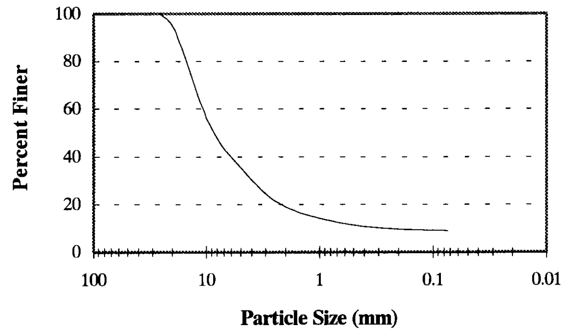
Type of Test	Falling Head
Hydraulic Gradient	0.95 - 0.83
Permeability [@ 20 C] (cm/s)	5.0E -6

SUMMARY OF LABORATORY TEST RESULTS
21B Study

Sample Location — **Rockydale Quarries, Inc.**
Rockydale Quarry

Gradation Analysis (VTM-25)

% Finer than	50.8 mm	[2 in]	
	38.1	[1 1/2 in]	
	25.4	[1 in]	100.0
	19.05	[3/4 in]	93.2
	9.525	[3/8 in]	54.2
	4.76	[No. 4]	34.2
	2	[No. 10]	19.0
	0.42	[No. 40]	10.9
	0.074	[No. 200]	8.9



Atterberg Limits (VTM-7)

Liquid Limit	17
Plastic Limit	15
Plasticity Index	2

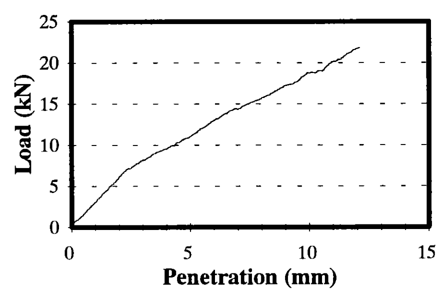
Standard Proctor (VTM-1)
(- No. 4 Material)

Maximum Dry Unit Weight (kN/m^3)	22
Optimum Moisture Content (%)	7.8

Specific Gravity (ASTM D854)
(All Material) 2.85

California Bearing Ratio (VTM-8)
(All Material)

CBR	56
Swell (%)	0.003
Final Moisture Content (%)	4.0
Final Dry Unit Weight (kN/m^3)	20.7



Permeability Test Data

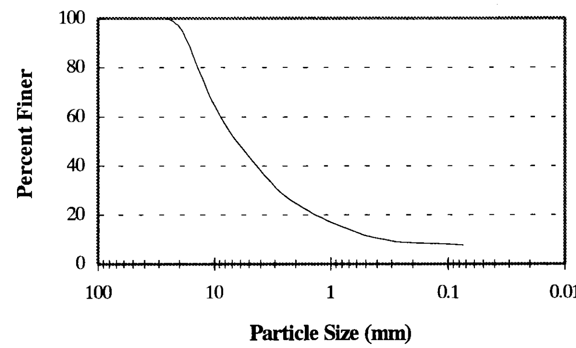
Type of Test	Constant Head
Hydraulic Gradient	0.28
Permeability [@ 20 C] (cm/s)	1.3E -1

SUMMARY OF LABORATORY TEST RESULTS
21B Study

Sample Location — **Blue Ridge Stone Corp.**
Blue Ridge Plant

Gradation Analysis (VTM-25)

% Finer than	50.8 mm	[2 in]	
	38.1	[1 1/2 in]	
	25.4	[1 in]	100.0
	19.05	[3/4 in]	95.0
	9.525	[3/8 in]	62.9
	4.76	[No. 4]	42.6
	2	[No. 10]	24.7
	0.42	[No. 40]	10.8
	0.074	[No. 200]	7.6



Atterberg Limits (VTM-7)

Liquid Limit	18
Plastic Limit	14
Plasticity Index	4

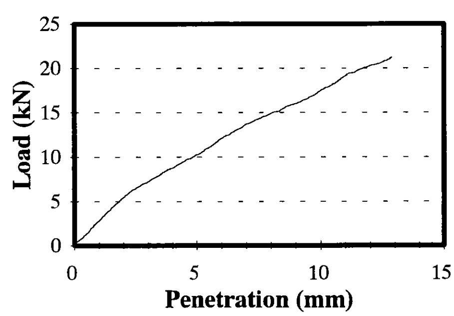
Standard Proctor (VTM-1)
(- No. 4 Material)

Maximum Dry Unit Weight (kN/m^3)	21
Optimum Moisture Content (%)	9.9

Specific Gravity (ASTM D854)
(All Material) — 2.76

California Bearing Ratio (VTM-8)
(All Material)

CBR	51
Swell (%)	0.025
Final Moisture Content (%)	5.9
Final Dry Unit Weight (kN/m^3)	21.3



Permeability Test Data

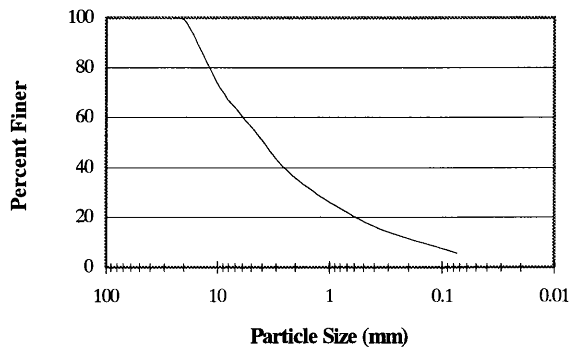
Type of Test	Falling Head
Hydraulic Gradient	0.99 - 0.66
Permeability [@ 20 C] (cm/s)	1.5E -4

SUMMARY OF LABORATORY TEST RESULTS
21B Study

Sample Location — **Luck Stone Corp. Augusta Plant**

Gradation Analysis (VTM-25)

% Finer than	50.8 mm	[2 in]	
	38.1	[1 1/2 in]	
	25.4	[1 in]	100.0
	19.05	[3/4 in]	98.0
	9.525	[3/8 in]	72.1
	4.76	[No. 4]	55.2
	2	[No. 10]	35.7
	0.42	[No. 40]	16.7
	0.074	[No. 200]	5.7



Atterberg Limits (VTM-7)

Liquid Limit	Non-
Plastic Limit	Plastic
Plasticity Index	

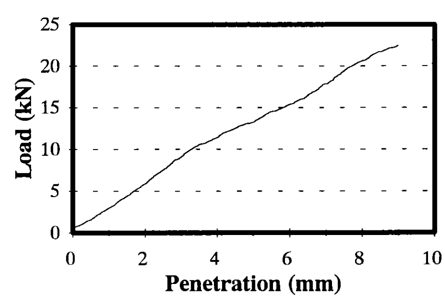
Standard Proctor (VTM-1)
(- No. 4 Material)

Maximum Dry Unit Weight (kN/^m^3)	20.6
Optimum Moisture Content (%)	9.1

Specific Gravity (ASTM D854)
(All Material) — 2.73

California Bearing Ratio (VTM-8)
(All Material)

CBR	61
Swell (%)	0
Final Moisture Content (%)	4.8
Final Dry Unit Weight (kN/m^3)	20.7



Permeability Test Data

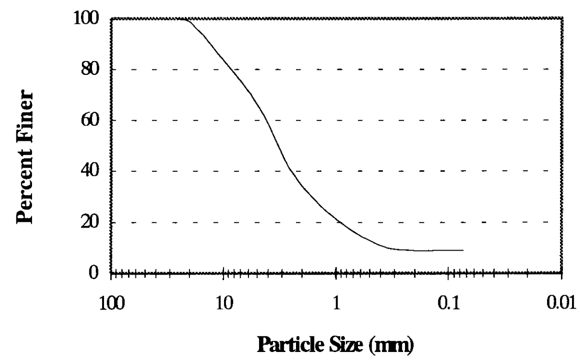
Type of Test	Constant Head
Hydraulic Gradient	0.5
Permeability [@ 20 C] (cm/s)	5.7E -2

SUMMARY OF LABORATORY TEST RESULTS
21B Study

Sample Location — **C.S. Mundy, Inc.**
Flat Rock Quarry

Gradation Analysis (VTM-25)

% Finer than	50.8 mm	[2 in]	
	38.1	[1 1/2 in]	
	25.4	[1 in]	100.0
	19.05	[3/4 in]	98.1
	9.525	[3/8 in]	82.5
	4.76	[No. 4]	64.7
	2	[No. 10]	34.1
	0.42	[No. 40]	11.3
	0.074	[No. 200]	9.1



Atterberg Limits (VTM-7)

Liquid Limit	18
Plastic Limit	14
Plasticity Index	4

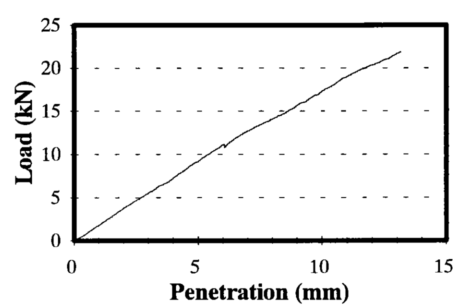
Standard Proctor (VTM-1)
(- No. 4 Material)

Maximum Dry Unit Weight (kN/m^3)	20.6
Optimum Moisture Content (%)	12.0

Specific Gravity (ASTM D854)
(All Material) — 2.74

California Bearing Ratio (VTM-8)
(All Material)

CBR	47
Swell (%)	0.017
Final Moisture Content (%)	8.2
Final Dry Unit Weight (kN/m^3)	21.4



Permeability Test Data

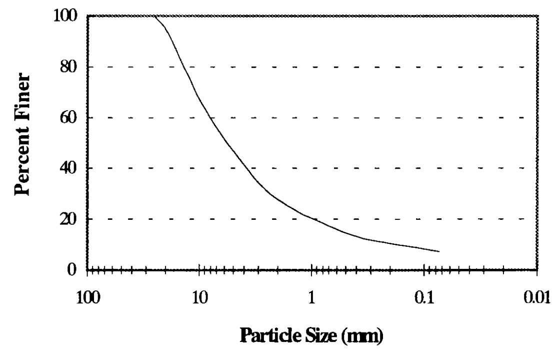
Type of Test	Constant Head
Hydraulic Gradient	0.50
Permeability [@ 20 C] (cm/s)	4.0E -2

SUMMARY OF LABORATORY TEST RESULTS
21B Study

Sample Location — **Martin Marietta Aggregates**
Culpeper Quarry

Gradation Analysis (VTM-25)

% Finer than	50.8 mm	[2 in]	
	38.1	[1 1/2 in]	
	25.4	[1 in]	100.0
	19.05	[3/4 in]	93.3
	9.525	[3/8 in]	65.5
	4.76	[No. 4]	45.6
	2	[No. 10]	27.8
	0.42	[No. 40]	13.6
	0.074	[No. 200]	7.2



Atterberg Limits (VTM-7)

Liquid Limit	Non-
Plastic Limit	Plastic
Plasticity Index	

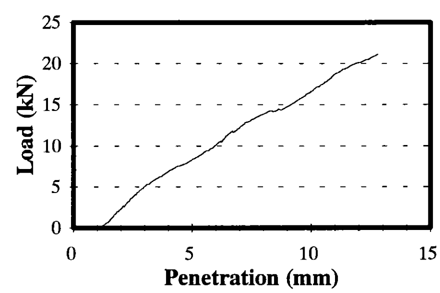
Standard Proctor (VTM-1)
(- No. 4 Material)

Maximum Dry Unit Weight (kN/m^3)	20.8
Optimum Moisture Content (%)	8.8

Specific Gravity (ASTM D854)
(All Material) — 2.82

California Bearing Ratio (VTM-8)
(All Material)

CBR	53
Swell (%)	0
Final Moisture Content (%)	5.9
Final Dry Unit Weight (kN/m^3)	21



Permeability Test Data

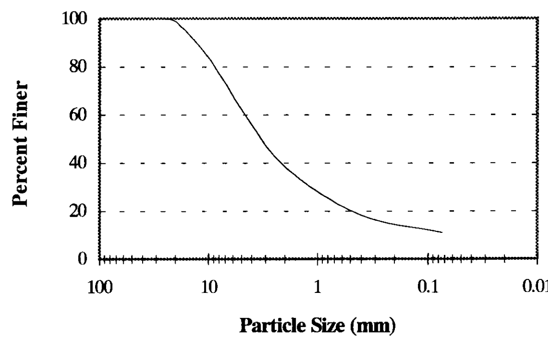
Type of Test	Constant Head
Hydraulic Gradient	0.45
Permeability [@ 20 C] (cm/s)	1.9E -2

SUMMARY OF LABORATORY TEST RESULTS
21B Study

Sample Location — **Luck Stone Corp. Charlottesville Plant**

Gradation Analysis (VTM-25)

% Finer than	50.8 mm	[2 in]	
	38.1	[1 1/2 in]	
	25.4	[1 in]	100.0
	19.05	[3/4 in]	98.2
	9.525	[3/8 in]	82.6
	4.76	[No. 4]	60.8
	2	[No. 10]	38.3
	0.42	[No. 40]	18.6
	0.074	[No. 200]	11.0



Atterberg Limits (VTM-7)

Liquid Limit	19
Plastic Limit	17
Plasticity Index	2

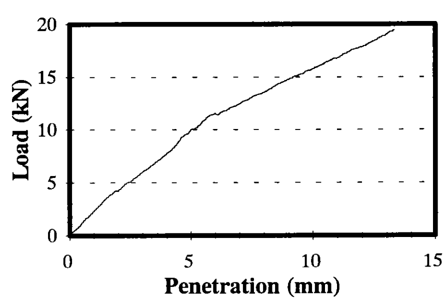
Standard Proctor (VTM-1)
(- No. 4 Material)

Maximum Dry Unit Weight (kN/m^3)	22.2
Optimum Moisture Content (%)	9.0

Specific Gravity (ASTM D854)
(All Material) 2.95

California Bearing Ratio (VTM-8)
(All Material)

CBR	50
Swell (%)	0
Final Moisture Content (%)	6.0
Final Dry Unit Weight (kN/m^3)	21.7



Permeability Test Data

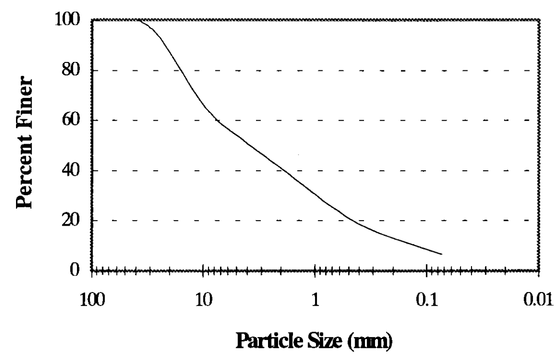
Type of Test	Constant Head
Hydraulic Gradient	0.41
Permeability [@ 20 C] (cm/s)	2.2E -2

SUMMARY OF LABORATORY TEST RESULTS
21B Study

Sample Location — **Vulcan Materials Co. South Boston Quarry**

Gradation Analysis (VTM-25)

% Finer than	50.8 mm	[2 in]	
	38.1	[1 1/2 in]	100.0
	25.4	[1 in]	93.8
	19.05	[3/4 in]	
	9.525	[3/8 in]	64.9
	4.76	[No. 4]	53.3
	2	[No. 10]	41.1
	0.42	[No. 40]	19.1
	0.074	[No. 200]	6.6



Atterberg Limits (VTM-7)

Liquid Limit	Non-
Plastic Limit	Plastic
Plasticity Index	

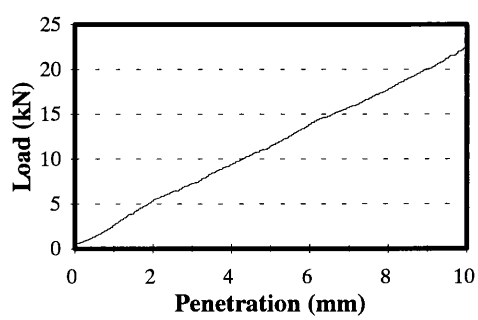
Standard Proctor (VTM-1)
(- No. 4 Material)

Maximum Dry Unit Weight (kN/m^3)	21.5
Optimum Moisture Content (%)	8.5

Specific Gravity (ASTM D854)
(All Material) — 2.84

California Bearing Ratio (VTM-8)
(All Material)

CBR	58
Swell (%)	0.012
Final Moisture Content (%)	7.6
Final Dry Unit Weight (kN/m^3)	21



Permeability Test Data

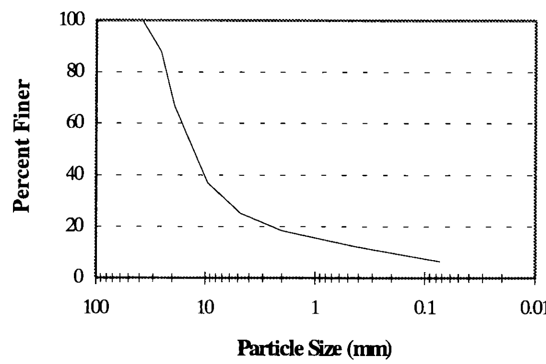
Type of Test	Falling Head
Hydraulic Gradient	1.02 - 0.69
Permeability [@ 20 C] (cm/s)	2.1E -3

SUMMARY OF LABORATORY TEST RESULTS
21B Study

Sample Location — **Vulcan Materials Co.**
Shelton Quarry

Gradation Analysis (VTM-25)

% Finer than	50.8 mm	[2 in]	
	38.1	[1 1/2 in]	100.0
	25.4	[1 in]	87.8
	19.05	[3/4 in]	66.6
	9.525	[3/8 in]	36.8
	4.76	[No. 4]	25.1
	2	[No. 10]	18.3
	0.42	[No. 40]	12.2
	0.074	[No. 200]	6.5



Atterberg Limits (VTM-7)

Liquid Limit	Non-
Plastic Limit	Plastic
Plasticity Index	

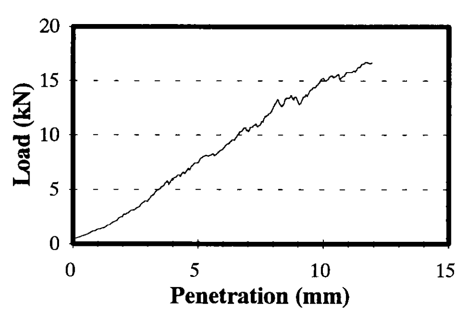
Standard Proctor (VTM-1)
(- No. 4 Material)

Maximum Dry Unit Weight (kN/m^3)	19.8
Optimum Moisture Content (%)	8.0

Specific Gravity (ASTM D854)
(All Material) — 2.64

California Bearing Ratio (VTM-8)
(All Material)

CBR	39
Swell (%)	0.023
Final Moisture Content (%)	4.8
Final Dry Unit Weight (kN/m^3)	21.5



Permeability Test Data

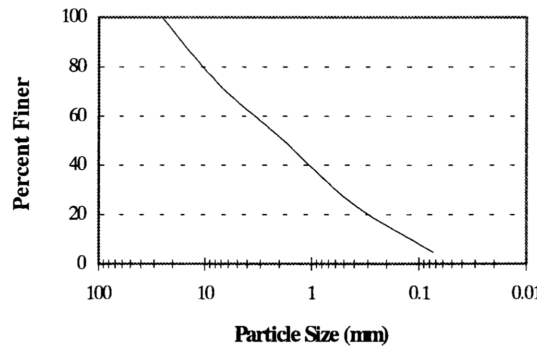
Type of Test	Constant Head
Hydraulic Gradient	0.41
Permeability [@ 20 C] (cm/s)	2.1E -2

SUMMARY OF LABORATORY TEST RESULTS
21B Study

Sample Location — **Tarmac Mid-Atlantic, Inc. Dale Quarry**

Gradation Analysis (VTM-25)

% Finer than	50.8 mm	[2 in]	
	38.1	[1 1/2 in]	
	25.4	[1 in]	100.0
	19.05	[3/4 in]	
	9.525	[3/8 in]	78.1
	4.76	[No. 4]	65.1
	2	[No. 10]	51.6
	0.42	[No. 40]	24.6
	0.074	[No. 200]	4.8



Atterberg Limits (VTM-7)

Liquid Limit	Non-
Plastic Limit	Plastic
Plasticity Index	

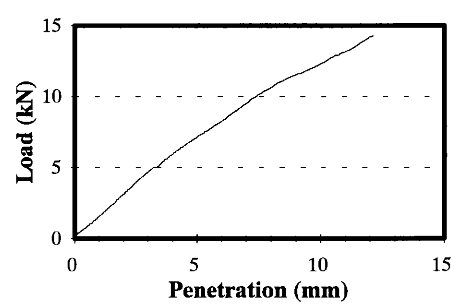
Standard Proctor (VTM-1)
(- No. 4 Material)

Maximum Dry Unit Weight (kN/m^3)	19.4
Optimum Moisture Content (%)	9.0

Specific Gravity (ASTM D854)
(All Material) 2.67

California Bearing Ratio (VTM-8)
(All Material)

CBR	36
Swell (%)	0.092
Final Moisture Content (%)	8.8
Final Dry Unit Weight (kN/m^3)	20.4



Permeability Test Data

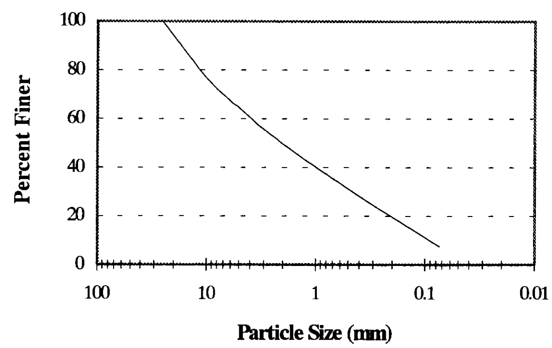
Type of Test	Falling Head
Hydraulic Gradient	1.02 - 0.69
Permeability [@ 20 C] (cm/s)	9.0E -5

SUMMARY OF LABORATORY TEST RESULTS
21B Study

Sample Location — **Tidewater Quarries, Inc. Deepwater Terminal**

Gradation Analysis (VTM-25)

% Finer than	50.8 mm	[2 in]	
	38.1	[1 1/2 in]	
	25.4	[1 in]	100.0
	19.05	[3/4 in]	
	9.525	[3/8 in]	75.5
	4.76	[No. 4]	63.5
	2	[No. 10]	49.6
	0.42	[No. 40]	28.7
	0.074	[No. 200]	7.3



Atterberg Limits (VTM-7)

Liquid Limit	Non-
Plastic Limit	Plastic
Plasticity Index	

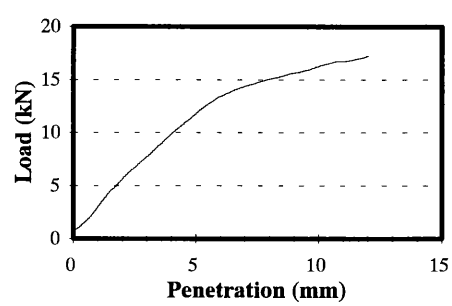
Standard Proctor (VTM-1)
(- No. 4 Material)

Maximum Dry Unit Weight (kN/m^3)	20.6
Optimum Moisture Content (%)	9.8

Specific Gravity (ASTM D854)
(All Material) 2.86

California Bearing Ratio (VTM-8)
(All Material)

CBR	59
Swell (%)	0.035
Final Moisture Content (%)	7.7
Final Dry Unit Weight (kN/m^3)	21.9



Permeability Test Data

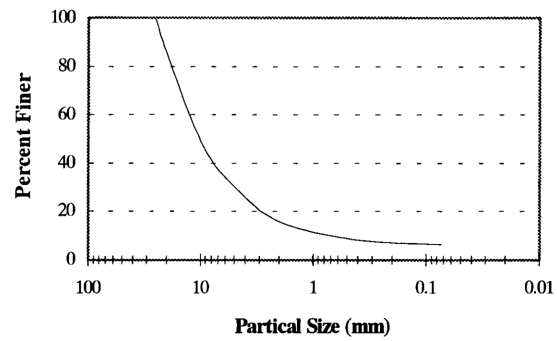
Type of Test	Falling Head
Hydraulic Gradient	0.39 - 0.24
Permeability [@ 20 C] (cm/s)	1.1E -5

SUMMARY OF LABORATORY TEST RESULTS
21B Study

Sample Location — **Martin Marietta Aggregates Carmel Church**

Gradation Analysis (VTM-25)

% Finer than	50.8 mm	[2 in]	
	38.1	[1 1/2 in]	
	25.4	[1 in]	100.0
	19.05	[3/4 in]	82.9
	9.525	[3/8 in]	47.2
	4.76	[No. 4]	29.1
	2	[No. 10]	15.7
	0.42	[No. 40]	8.3
	0.074	[No. 200]	6.4



Atterberg Limits (VTM-7)

Liquid Limit	Non-
Plastic Limit	Plastic
Plasticity Index	

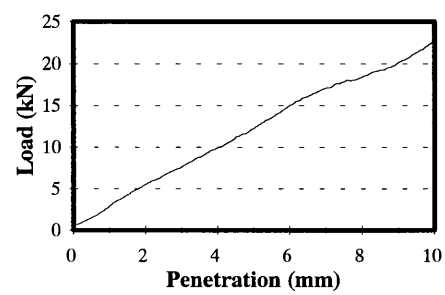
Standard Proctor (VTM-1)
(- No. 4 Material)

Maximum Dry Unit Weight (kN/m^3)	20.8
Optimum Moisture Content (%)	10.8

Specific Gravity (ASTM D854)
(All Material) 2.77

California Bearing Ratio (VTM-8)
(All Material)

CBR	62
Swell (%)	0.023
Final Moisture Content (%)	5.4
Final Dry Unit Weight (kN/m^3)	20



Permeability Test Data

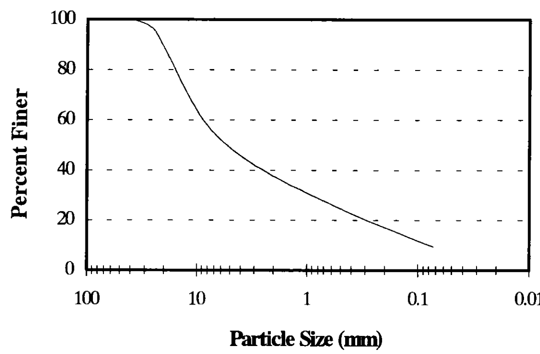
Type of Test	Constant Head
Hydraulic Gradient	0.36
Permeability [@ 20 C] (cm/s)	2.6E -2

SUMMARY OF LABORATORY TEST RESULTS
21B Study

Sample Location — **Martin Marietta Aggregates Spotsylvania Quarry**

Gradation Analysis (VTM-25)

% Finer than	50.8 mm	[2 in]	
	38.1	[1 1/2 in]	100.0
	25.4	[1 in]	96.4
	19.05	[3/4 in]	87.5
	9.525	[3/8 in]	62.1
	4.76	[No. 4]	48.2
	2	[No. 10]	37.6
	0.42	[No. 40]	22.9
	0.074	[No. 200]	9.5



Atterberg Limits (VTM-7)

Liquid Limit	25
Plastic Limit	22
Plasticity Index	3

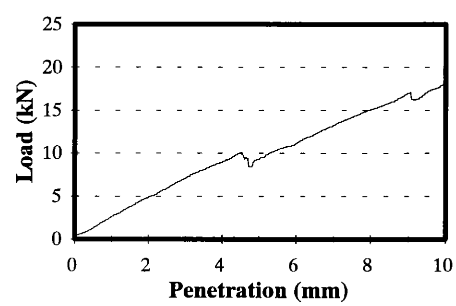
Standard Proctor (VTM-1)
(- No. 4 Material)

Maximum Dry Unit Weight (kN/m^3)	20
Optimum Moisture Content (%)	10.0

Specific Gravity (ASTM D854)
(All Material) — 2.72

California Bearing Ratio (VTM-8)
(All Material)

CBR	47
Swell (%)	0.248
Final Moisture Content (%)	7.4
Final Dry Unit Weight (kN/m^3)	21



Permeability Test Data

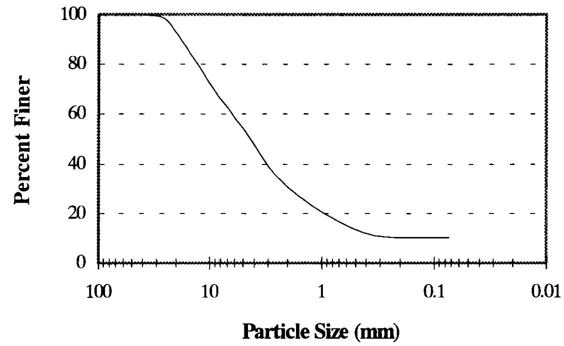
Type of Test	Falling Head
Hydraulic Gradient	1.66 - 1.33
Permeability [@ 20 C] (cm/s)	5.4E -5

SUMMARY OF LABORATORY TEST RESULTS
21B Study

Sample Location	**Luck Stone Corp. Fairfax Plant**

Gradation Analysis (VTM-25)

% Finer than	50.8 mm	[2 in]	
	38.1	[1 1/2 in]	100.0
	25.4	[1 in]	98.4
	19.05	[3/4 in]	91.5
	9.525	[3/8 in]	70.9
	4.76	[No. 4]	52.7
	2	[No. 10]	30.7
	0.42	[No. 40]	12.0
	0.074	[No. 200]	10.3



Atterberg Limits (VTM-7)

Liquid Limit	20
Plastic Limit	18
Plasticity Index	2

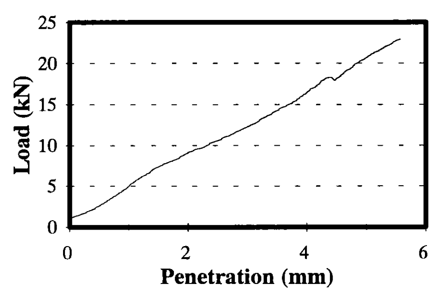
Standard Proctor (VTM-1)
(- No. 4 Material)

Maximum Dry Unit Weight (kN/m^3)	21.4
Optimum Moisture Content (%)	9.9

Specific Gravity (ASTM D854)
(All Material) 2.88

California Bearing Ratio (VTM-8)
(All Material)

CBR	105
Swell (%)	0.018
Final Moisture Content (%)	6.3
Final Dry Unit Weight (kN/m^3)	22.1



Permeability Test Data

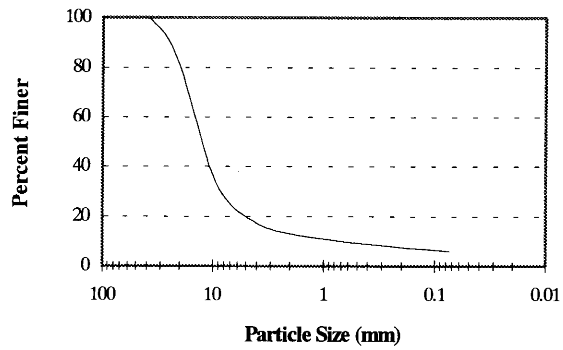
Type of Test	Constant Head
Hydraulic Gradient	0.43
Permeability [@ 20 C] (cm/s)	2.9E -3

SUMMARY OF LABORATORY TEST RESULTS
21B Study

Sample Location — **Vulcan Materials Co. Occoquan Quarry**

Gradation Analysis (VTM-25)

% Finer than	50.8 mm	[2 in]	
	38.1	[1 1/2 in]	100.0
	25.4	[1 in]	90.8
	19.05	[3/4 in]	77.4
	9.525	[3/8 in]	34.2
	4.76	[No. 4]	19.3
	2	[No. 10]	13.0
	0.42	[No. 40]	9.0
	0.074	[No. 200]	6.0



Atterberg Limits (VTM-7)

Liquid Limit	Non-
Plastic Limit	Plastic
Plasticity Index	

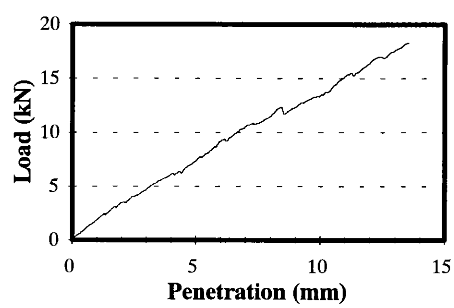
Standard Proctor (VTM-1)
(- No. 4 Material)

Maximum Dry Unit Weight (kN/m^3)	20.6
Optimum Moisture Content (%)	8.2

Specific Gravity (ASTM D854)
(All Material) — 2.68

California Bearing Ratio (VTM-8)
(All Material)

CBR	37
Swell (%)	0.015
Final Moisture Content (%)	6.0
Final Dry Unit Weight (kN/m^3)	20.6



Permeability Test Data

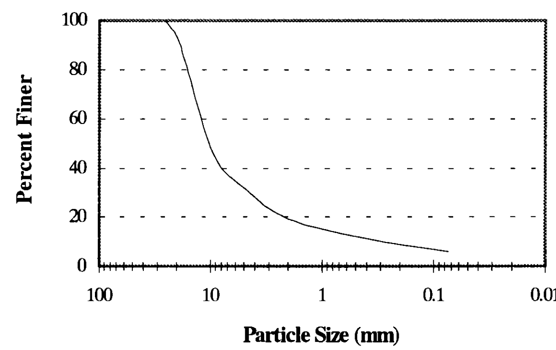
Type of Test	Constant Head
Hydraulic Gradient	0.43
Permeability [@ 20 C] (cm/s)	3.5E -3

SUMMARY OF LABORATORY TEST RESULTS
21B Study

Sample Location — **Loudoun Quarries, Inc.**
Shaw Road Plant

Gradation Analysis (VTM-25)

% Finer than	50.8 mm	[2 in]	
	38.1	[1 1/2 in]	
	25.4	[1 in]	100.0
	19.05	[3/4 in]	91.0
	9.525	[3/8 in]	46.2
	4.76	[No. 4]	31.2
	2	[No. 10]	19.4
	0.42	[No. 40]	11.4
	0.074	[No. 200]	6.0



Atterberg Limits (VTM-7)

Liquid Limit	Non-
Plastic Limit	Plastic
Plasticity Index	

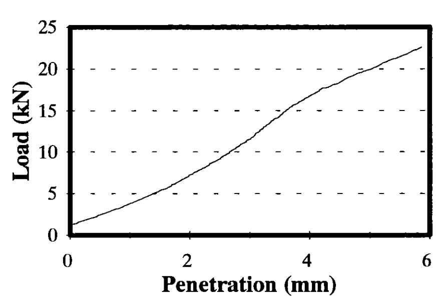
Standard Proctor (VTM-1)
(- No. 4 Material)

Maximum Dry Unit Weight (kN/m^3)	22.1
Optimum Moisture Content (%)	9.0

Specific Gravity (ASTM D854)
(All Material) 3.03

California Bearing Ratio (VTM-8)
(All Material)

CBR	100
Swell (%)	0
Final Moisture Content (%)	4.9
Final Dry Unit Weight (kN/m^3)	23.4



Permeability Test Data

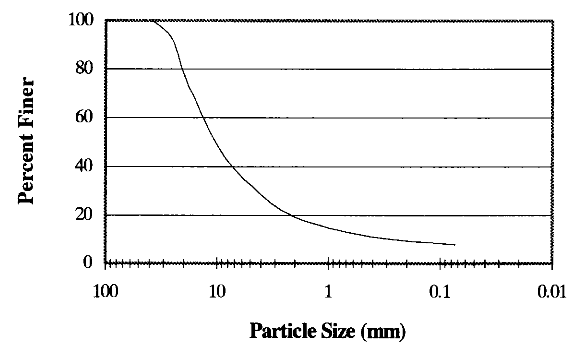
Type of Test	Constant Head
Hydraulic Gradient	0.52
Permeability [@ 20 C] (cm/s)	8.7E -2

SUMMARY OF LABORATORY TEST RESULTS
21B Study

Sample Location — **Vulcan Materials Co.**
Skippers Plant

Gradation Analysis (VTM-25)

% Finer than	50.8 mm	[2 in]	
	38.1	[1 1/2 in]	100.0
	25.4	[1 in]	92.5
	19.05	[3/4 in]	76.4
	9.525	[3/8 in]	47.2
	4.76	[No. 4]	31.6
	2	[No. 10]	19.2
	0.42	[No. 40]	11.1
	0.074	[No. 200]	7.7



Atterberg Limits (VTM-7)

Liquid Limit	20
Plastic Limit	19
Plasticity Index	1

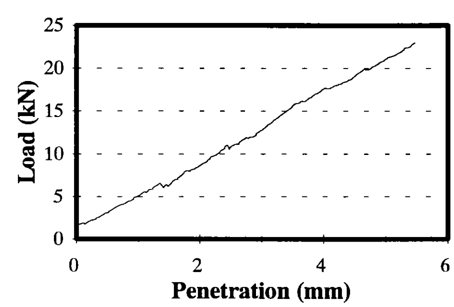
Standard Proctor (VTM-1)
(- No. 4 Material)

Maximum Dry Unit Weight (kN/m^3)	20.7
Optimum Moisture Content (%)	8.5

Specific Gravity (ASTM D854)
(All Material) 2.68

California Bearing Ratio (VTM-8)
(All Material)

CBR	106
Swell (%)	0
Final Moisture Content (%)	4.5
Final Dry Unit Weight (kN/m^3)	20.2



Permeability Test Data

Type of Test	Constant Head
Hydraulic Gradient	0.43
Permeability [@ 20 C] (cm/s)	3.5E -3