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Fines Content of Granular Base Material

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16. Abstract

The influence of aggregate fines content and moisture content on the rapid shear strength of eight aggregate sources from throughout Arkansas was studied. The rapid shear strength, a dynamic triaxial test, is an indicator of aggregates' relative contribution to pavement performance. A pavement with a high shear strength base can be expected to resist heavier traffic loadings and be more rut resistant.

All specimens were compacted in a split mold using a vibratory force. Tests, conducted with a 5 psi chamber pressure, consisted of applying an axial load at a rate of two inches per second for one second.

Conclusions:

1. Fine grained material decreases the rapid shear strength of aggregate base material. All material fines through the No. 40 sieve (0.425 mm) affected the strength with strength decreasing as fines content increases.

2. Angular particles have higher rapid shear strength than rounded particles. Crushed stone is stronger than crushed gravel. Uncrushed gravel is weakest.

3. Base material is stronger when density is high and moisture content is low.

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FINES CONTENT OF GRANULAR BASE MATERIALS

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IMPLEMENTATION

The rapid shear test is a dynamic triaxial test which can be used to measure the relative strength of unbound granular base material. Because the strength is relative, a roadway designer, if given a choice of aggregates, can select the stronger aggregate for the base. In addition, the curves provided on the eight Arkansas aggregates tested (Figures 13 through 20) can be used as a relative indicator of "level of performance" for these aggregates.

The size range of fines which adversely affected rapid shear strength was found to extend to the No. 40 sieve (0.425)mm). This fact should be considered if and when specifications for SB-2 aggregate base material are reviewed for change.

GAINS, FINDINGS, AND CONCLUSIONS

The following list includes the primary gains and conclusions of this study.

1. Fine grained material decreases the rapid shear strength of aggregate base material. All material fines through the No. 40 sieve (0.425 mm) affected the strength with strength decreasing as fines content increases.

2. Angular particles have higher rapid shear strength than rounded particles. Crushed stone is stronger than crushed gravel. Uncrushed gravel is weakest.

3. Base material is stronger when density is high and moisture content is low.

SUMMARY OF IMPLEMENTATION

Practical Application:	Relative values of rapid shear strength give engineers a basis for evaluating aggregates for use in a highway base. The curves produced in this report (Figures 13 through 20) can be used as a relative "level of performance" for the aggregates.
Recommended Procedure:	a) Aggregate Evaluation - Compare the rapid shear strengths of possible aggregate sources for base material. Select the aggregate with the highest rapid shear strength. b) Level of Performance: Compare the rapid shear strengths of an aggregate at maximum density, optimum water content and maximum allowed fines content to the material provided.
Benefits:	Rapid shear strength is a dynamic test which approximates a "failure" traffic condition. Use of rapid shear strength may result in better pavement design.

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CHAPTER I

INTRODUCTION

A base course is the layer of material that lies immediately below the wearing surface of a pavement. Since the base course is close to the surface, it must possess high resistance to deformation in order to withstand the pressures imposed upon it.

Over the years, highway engineers have devoted considerable effort toward improving the pavement design process. The adverse effect of high fines content (percent passing the No. 200 sieve) in base course materials has long been recognized but is not well defined.

The objective of this study, "Fines in Base Course Materials TRC-8703", is to determine the effect of fines on the dynamic load behavior of aggregate sources from throughout Arkansas. The study results are expected to improve understanding of the behavior of road base materials. In turn, better and more economical road bases might be constructed.

In the research, the "rapid shear test" was used as a measure of the dynamic load behavior. The rapid shear test is a triaxial test in which a 6 inches diameter and 12 inches long sample is deformed two inches in one second. A five psi chamber pressure was used to simulate the confining pressure which typically exists in a highway base course.

Since the rapid shear test is not a standard test, the research was accomplished in three phases: Sample Preparation; Test Development and Production Testing. The Granite Mountain aggregate was tested to establish testing techniques and to find the effects of moisture, fines and dust ratio on rapid shear strength. Later, seven other aggregates were tested to find the effect of aggregate shape and stone type for typical Arkansas aggregates.

CHAPTER II

BACKGROUND

The literature review is separated into two parts for convenience. The Vibratory Compaction section covers the background for sample preparation. The Sample Variable section covers the effect of variables on the base material.

Vibratory Compaction

Two methods of vibratory compaction have been used to compact granular material (Forssbald, 1967): (a) vibrating in an open mold fixed on a vibrating table; (b) vibrating in a mold fixed on a vibrating table, with a loading weight on top of the material.

Vibrating devices for granular material compaction were developed at the Concrete and Soil Lab of AB Vibro-Verlcen, Solna, Sweden (Forssbald, 1967). The Concrete and Soil Lab of AB Vibro-Verlcen conducted a study on the use of vibrating tampers for granular material compaction. The study used two different tampers.

All samples in the Forssbald study were compacted in two lifts and vibrated for 2 minutes. Densities obtained in the study had good agreement with densities obtained by the AASHTO modified method (AASHTO T 180). The use of a heavy tamper (100 lb.) proved to be difficult to handle. Therefore, the light tamper (77 lb.) was recommended for compaction.

In the United States, the Bureau of Reclamation was the leading agency to use vibratory compaction in the laboratory (Pettibone and Hardin, 1965). The Bureau of Reclamation conducted an investigation to determine the factors affecting the maximum density of samples compacted by vibration. The investigation was conducted using two vibration tables with different mold sizes. The majority of the tests were run using oven-dried soil, but a few were performed with the soil initially saturated. All samples were compacted in one lift.

The amplitude of vibration was the most significant factor affecting soil density in the Bureau of Reclamation Study (Pettibone and Hardin, 1965). Maximum densities were generally obtained at higher amplitudes. The increase in density was not significant for times of vibration greater than 6 minutes. Both oven-dry and initially saturated soils had the same densities. When the surcharge load was applied by adding dead weight, soil density decreased when the total load (dead weight + soil + mold) on the vibrating table exceeded 200 lb.

Vibratory compaction was used to compact samples in a study conducted by Pappin (1979) at the University of Nottingham, England. Pappin anticipated fines migration during sample compaction. To compensate for the expected migration, the samples in the Pappin study were compacted in seven layers using three different gradations. The bottom layer contained mainly coarse aggregate, while the top layer contained mainly fines. Each layer was compacted for 90 seconds with a nominal surcharge on top to keep the surface level. The vibration for each layer was done in six consecutive periods of 15 seconds each, starting with the largest amplitude and decreasing to the smallest. Pappin did not report how effective this method was in compensating for the expected migration of fines.

Sample Variables

Moisture sensitivity is basically controlled by the quantity and characteristics of the fines and plasticity. Yoder and Witczak (1975) suggested that use of a more open-graded aggregate base would decrease moisture sensitivity and would drain water at a quicker rate (increased permeability). Krebs and Walker (p. 137) found that the presence of water in the base course may decrease the strength by reducing the cohesive properties of the fines and by reducing the friction between aggregate particles.

A base course material that contains little or no fines has stability from grain-to-grain interlock. An aggregate that contains no fines usually has a relatively low density but is pervious and non-frost susceptible. On the other hand, a base course material that contains a great amount of fines has no grain-to-grain interlock, and the aggregates merely "float" (dispersed matric orientation) in the soil (Yoder and Witczak, 1975). The aggregate has low density and is practically impervious, frost susceptible and greatly affected by adverse water conditions. A base course material that contains sufficient fines to fill all the voids between the aggregates grains will still gain strength from grain interlock which will increase shear resistance. The aggregate density will be high and permeability will be low but the material may be frost susceptible. This material is ideal from the standpoint of stability but is moderately difficult to compact.

Base course strength is important to pavement performance. Nichols (p. 58) indicates that flexible pavement performance is affected to a great extent by the degree of support offered by the underlying layers rather than by the thickness of asphaltic concrete in the upper portion of the structure.

According to Barksdale (p. 2), base course materials compacted to low densities will undergo more rutting than the well compacted sample. Furthermore, rutting is related to density but the mechanism which accounts for rutting appears to be shear distortion not densification.

Yoder and Witczak (1975) noted that pavement deformation is a manifestation of two different mechanisms and is a combination of densification (volume change) and repeated shear deformation (plastic flow with no volume change). Protection against excessive deformation, resulting from densification, is insured by proper compaction. The second mechanism, plastic flow, is one of the basic distress modes upon which pavement designs are based.

Under fixed conditions (density and moisture content), a given granular material tested for the permanent deformation response will be controlled by the magnitude of the repeated stress state (confining pressure and deviator stress). The factors (particularly increased density) that decrease permanent deformation accumulation will increase granular material shear strength. Moisture content is also an important factor relative to the shear strength and permanent deformation behavior of granular materials. Yoder and Witczak (1975) also noted that the shear strength of dense-graded base material cannot be maintained throughout the various seasons of the year in many climatic zones. Pavement sections generally experienced significant distress during those periods when base course moisture content is high and the subgrade is weak due to freeze-thaw softening.

Marshall Thompson (1984) suggested that the shear strength and permanent deformation behavior of dense-graded granular base materials with high fines content are strongly influenced by moisture content. Haynes and Yoder (1963) demonstrated that the crushed stone base used in the AASHO Road Test was quite sensitive to moisture content. Moisture sensitivity increased as the fines content increased from 6.2% to 11.5%. Moreover, permanent strain accumulated rapidly (Table 1) as the fines content increased.

Thompson (1984) found the strength of higher moisture content specimens to be less than the strength of the lower moisture content specimens at a 6.9% of fines. For example the rapid shear strength (confining pressure = 6 psi, dry density = 140.2 pcf) of a crushed stone base material at 4.6% moisture was approximately 222 psi (stress at failure). For the same crushed stone base material at 7.0% moisture (confining pressure = 6 psi, dry density = 140.3 pcf), the rapid shear strength was approximately 79 psi (Table 2). Marshall Thompson suggested that the moisture sensitivity of a granular base can be determined using the rapid shear strength as an indicator. Therefore, the rapid shear test was used to investigate the effects of fines of base course aggregates in this study.

Table 1

Total deflection crushed stone specimen
(Haynes & Yoder 1963)

Fines %	6.2	9.1	11.5
Degree of saturation	81	81	81
Air dry density, pcf	141	141	141
Confining pressure, psi	15	15	15
Deviator stress, psi	70	70	70
Relative density, %	80	80	80
Total deflection, in.	0.24	0.23	0.55

Table 2

Rapid shear strength*, crushed stone specimen
(Thompson 1984)

Fines, %	6.9	6.9
Moisture content, %	4.6	7.0
Density, pcf	140.2	140.3
Confining pressure, psi	6	6
Shear strength at failure, psi	222	79

*Deformation rate = 2"/sec.

CHAPTER III

SAMPLE PREPARATION

The aggregate material used to develop a sample preparation method was obtained from Granite Mountain Quarries at Granite Mountain, Arkansas. The gradation for SB-2 was modified because the maximum density of 135 pcf could not be achieved due to the large size and shape of the aggregate in relation to the size of the mold used for compaction. The modification was in accordance with procedures prescribed for maximum density determination in the Arkansas Standard Specifications for Highway Construction. Figure 1 and Table 3 contain the SB-2 gradation and modified gradation for the Granite Mountain Aggregate. The optimum moisture content provided by the AHTD is 6.7%, as determined by AASHTO T180.

TABLE 3, SB-2 gradation and the modified gradation.

	Crushed Stone Base Course Total Retained Percent by Weight	
SIEVE	SB-2	MODIFIED GRADATION (6% fines content)
1 1/2"	0	0
1"	---	0
3/4"	10-50	0
3/8"	---	34.5
No. 4	50-75	60.0
No. 40	70-90	85.0
No. 200	90-97	94.0

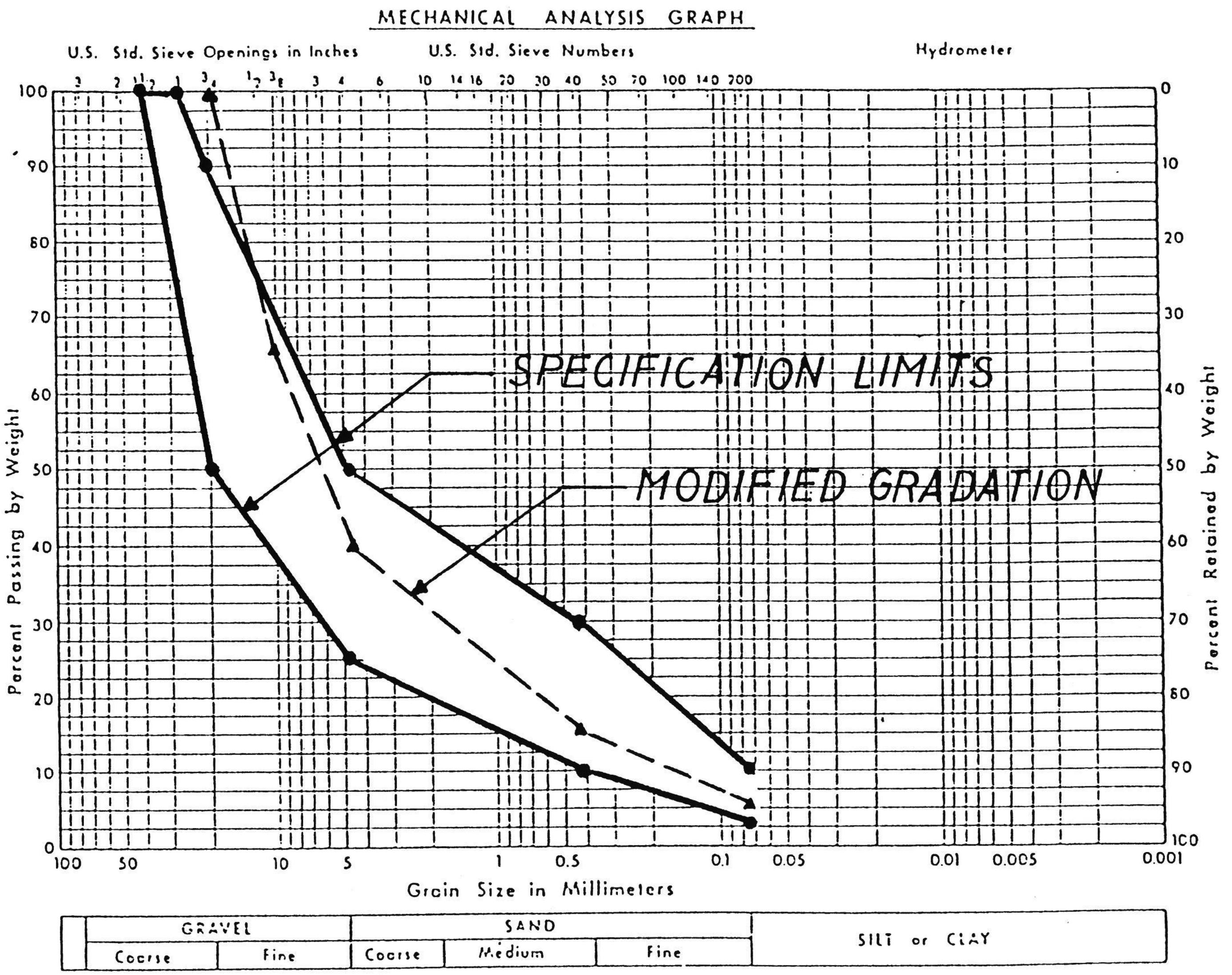


Figure 1. SB-2 gradation and the modified gradation.

Sample Mixing

The aggregate used in the research was sieved to various size fractions. The sieved aggregate was then recombined for each layer separately to maintain uniform gradation.

MTS Operation

Details of the MTS operation can be found in the M.S. thesis by Mr. Bashar Qedan (1987).

The MTS machine was chosen as a vibration source in order to eliminate the need to move the specimen for testing. Use of the machine required a special mechanical device to fit on the MTS loading frame (Figure 2). The mechanical device was rotated by hand during compaction.

Number of Layers

To determine the influence of the number of layers used in preparation samples were prepared using one, three and five layers. The one layer sample had serious migration of fines and moisture and the target density could not be achieved. The target dry density (133 pcf) also was not achieved with the three-layer samples, but density was achieved with the five-layer samples (Table 4). All subsequent samples were prepared using five layers.

TABLE 4 . Effect of number of layers on dry density

Number of Layers	Number of Samples	Dry Density (pcf)	
		First Sample	Second Sample
3	2	126.3	127.4
5	2	133.2	133.6

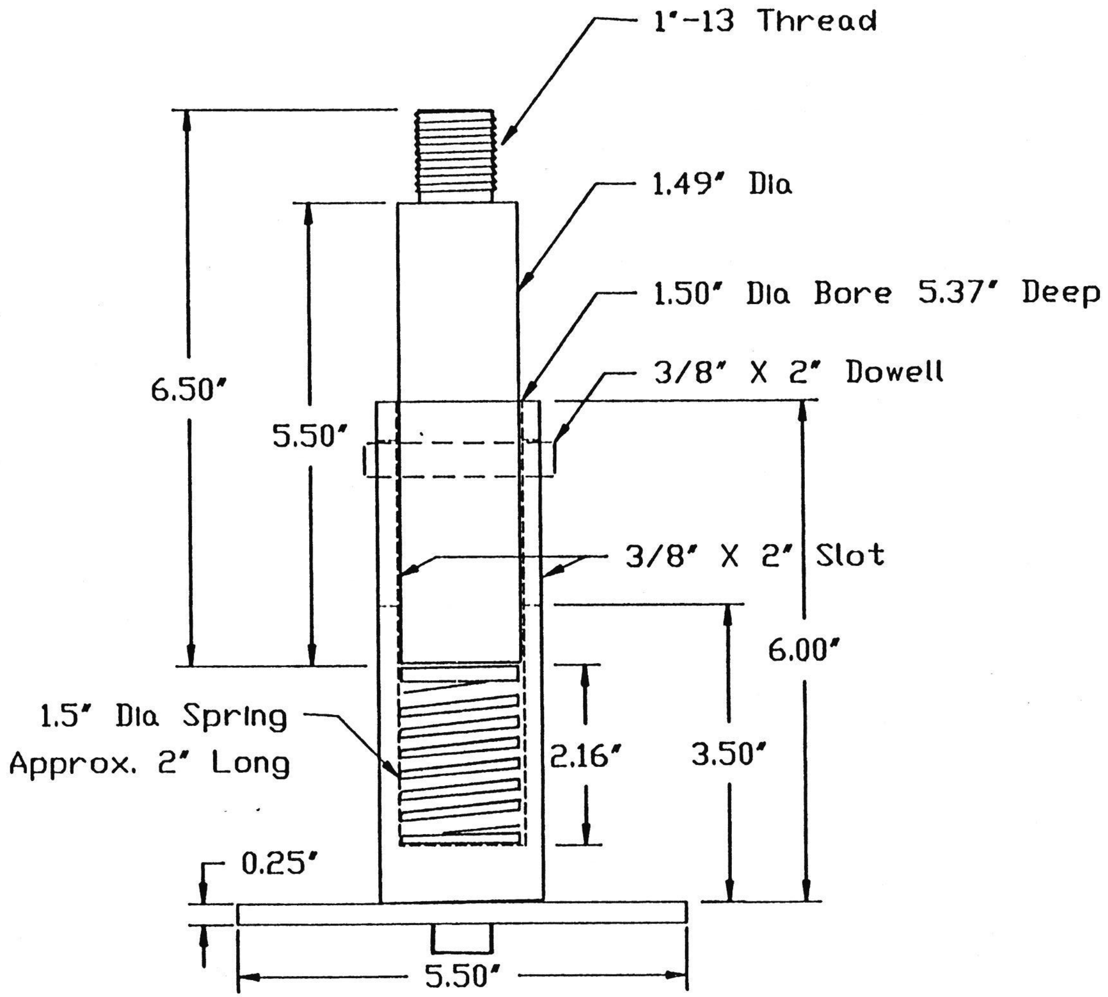


Figure 2. Engineering drawing of compaction device.

Fines Content

Different samples having fines contents (percent by weight passing the No. 200 sieve) of 3.0%, 6% and 10% were prepared. Each test was conducted with the following constants: (1) Moisture Content = 7.5%; (2) Number of Layers = 5; (3) Frequency = 10 HZ.

Target density was not achieved with 3% fines content, but was achieved with 6% and 10% fines contents. The migration of fines and moisture was not significant at any of the three fines contents.

Moisture Content

Samples having moisture contents of 0%, 5.0%, 7.5% and 10% were prepared. In each test the following variables were held constant: (1) Fines Content = 6%; (2) Number of Layers = 5; (3) Frequency = 10 HZ.

Dry density increased with the increase of moisture content. However, samples with moisture contents of 0% and 5% could not be compacted to target density. The dry sample had a serious migration of fines. The sample with 10% moisture content had a serious migration of both fines and moisture.

Frequency

Three vibration frequencies, 5 HZ., 10 HZ. and 30 HZ. were used to compact three different samples. The samples were constructed with the following constants: (1) Fines Content - 6.0%; (2) Moisture Content = 7.5%; (3) Number of Layers = 5.

The 5 HZ. and the 30 HZ. frequencies did not compact the samples to the target density. No further testing was done on the samples compacted using the 5 HZ and the 30 HZ frequencies.

For the sample compacted using 10 HZ. vibration frequency, the target dry density was achieved and the migration of fines and moisture was insignificant.

Number of Cycles

The number of cycles used for each layer was varied from 120 cycles/layer (2 minutes/layer) to 360 cycles/layer (6 minutes/layer). The increase in density was not significant for times of vibration greater than 2 minutes per layer (120 cycles/layer).

Recommendations

This phase of the study showed that the MTS machine can be used to compact test specimens to the target density without serious migration of fines or moisture. To accomplish this, the following requirements should be met:

1. Fines content should range between 5.0% and 15.0%.
2. Moisture content should be between 6.0% and 8.5%.
3. Number of layers should be five.
4. Vibration frequency should be 10 HZ.
5. Each layer should be vibrated 2 minutes (120 cycles).

CHAPTER IV

TEST DEVELOPMENT

The Granite Mountain aggregate was tested extensively to establish rapid shear procedures and define relationships between moisture, the amount of fines and strength.

Rapid Shear

The rapid shear test is conducted by deforming the specimen 2 inches in one second and measuring the load generated. The MTS machine plots the load (stress) applied versus deformation (strain) graph during the test Figure 3). The rapid shear strength normally is defined as the maximum load divided by the initial cross sectional area.

Two common types of failure were noted during the testing--shear and tension failure. Samples which failed on a diagonal plane (shear failure) were found to have a stress-strain relationship similar to that shown in Figure 4a with the peak load occurring at about 0.75 to 1.0 inches of deformation. Samples which failed by bulging (tension failure) have a shear strain relationship similar to that shown in Figure 4b with an increasing load throughout the test. Because of bulging, tension failure samples have a larger effective cross section (area) at the end of a test. The normal definition of shear strength seemed questionable for the tension failure samples due to the cross section increases and the fact that a peak load was not identified. To compensate for this effect, the test findings are reported both as maximum load at 0.75 inch vertical deformation.

The test results are also reported (Table 8) as the apparent internal friction angle. A vacuum gauge was used to measure the pressure during the testing at the base of the sample. This internal (vacuum)

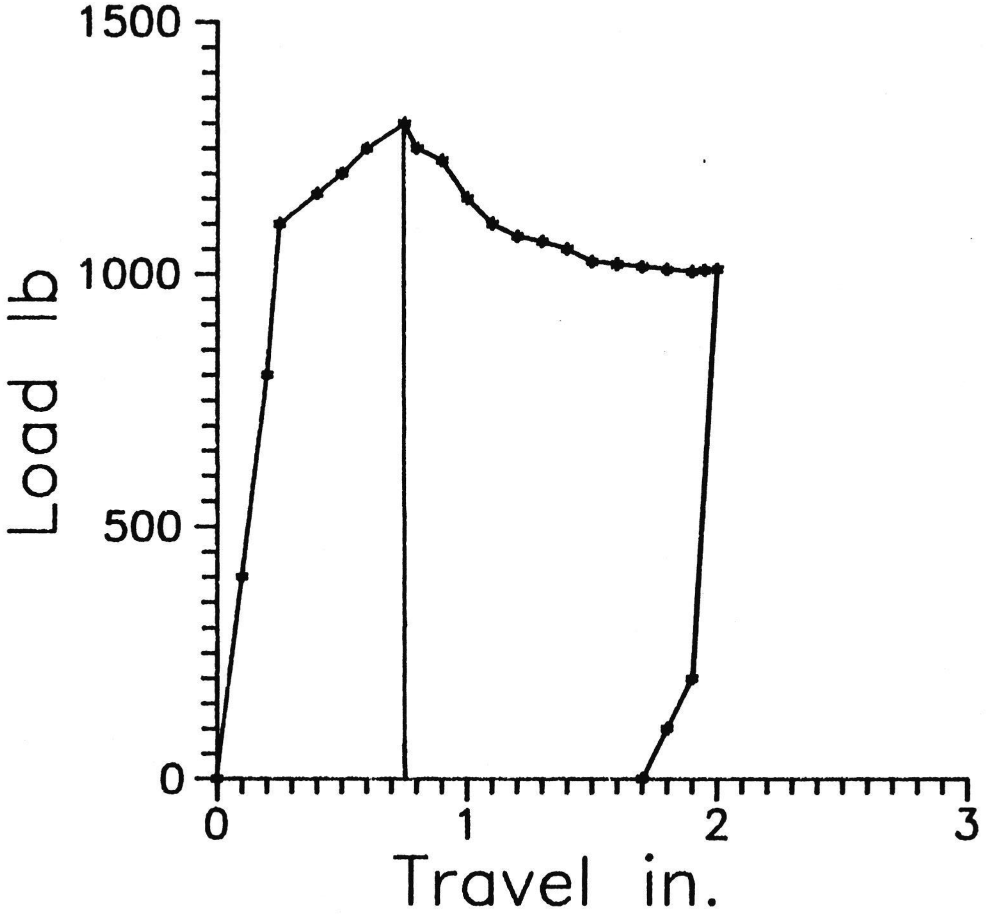
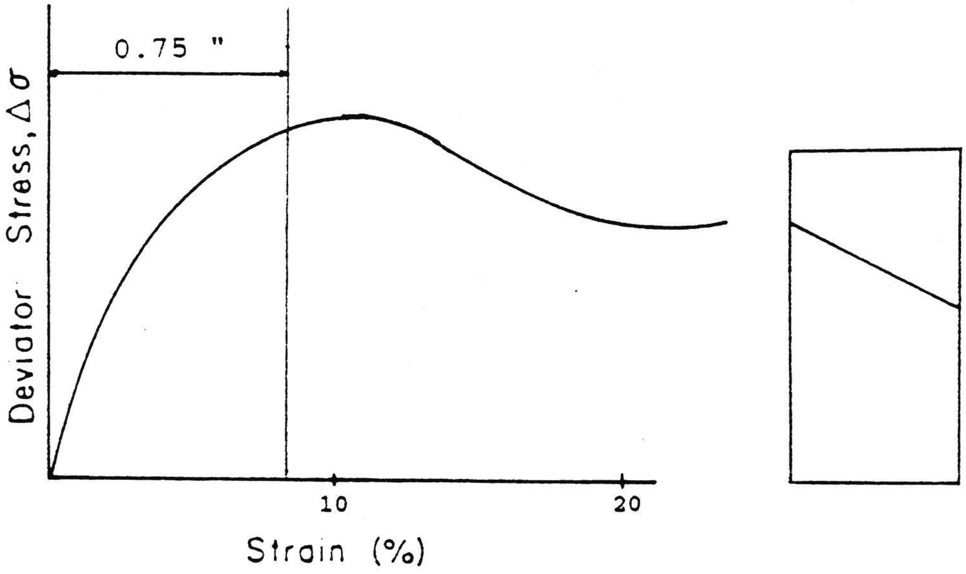
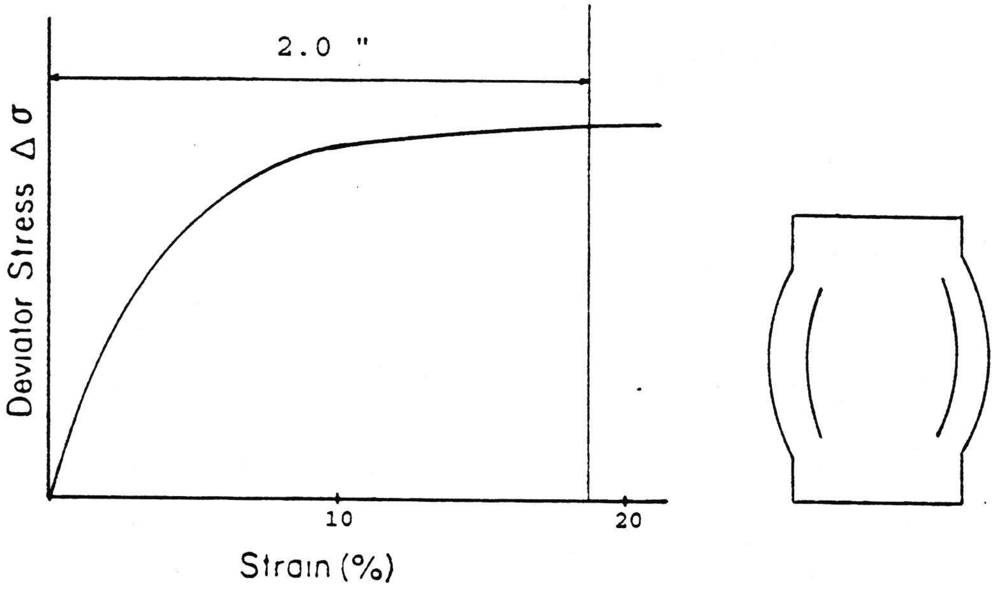


Figure 3. Typical Load vs. Deformation plot



(a) Shear failure



(b) Tension failure

Figure 4. **Idealized plot of Stress vs. Strain**

pressure was included in determination of the apparent friction angle. The friction angle is the line drawn tangent to the Mohr effective stress circle (Figure 5). A high friction angle means the soil has a larger shearing strength (Table 8).

Effect of Fines

Fines are normally defined as that fraction of material finer than 0.075 mm (No. 200 sieve). Test results on the Granite Mountain aggregate show that an increase in fines content decreases the rapid shear strength (Figure 6). The maximum rapid shear load (average) drops from 3095 lb. at 6% fines to 2520 lb. at 12% fines. For rapid shear loads at 0.75 inch deflection, the rapid shear load (average) drops from 2947 lb. at 6% fines to 2413 lb. at 12% fines.

A statistical analysis of the data (Table 5) was made using the Statistical Analysis System (SAS). The relation between the load and fines content was found to be statistically significant, having an R square of 0.72 (Table 6 and Figure 7).

Particles that are between the #40 and #200 sieves (0.425 mm and 0.075 mm) also were found to have an effect on the rapid shear strength. An increase from 10% to 20% in the amount of material between the #40 and #200 sieves was found to reduce the rapid shear load (Figure 8).

Effect of Moisture

An increase in fines content decreases the rapid shear strength of saturated samples (Figure 10) and partially saturated samples (Figure 6). However, for 6% fines content, shear strength was found to be higher at saturation than when partially saturated. The higher strength at low fines content is believed to be due to the higher negative pressure

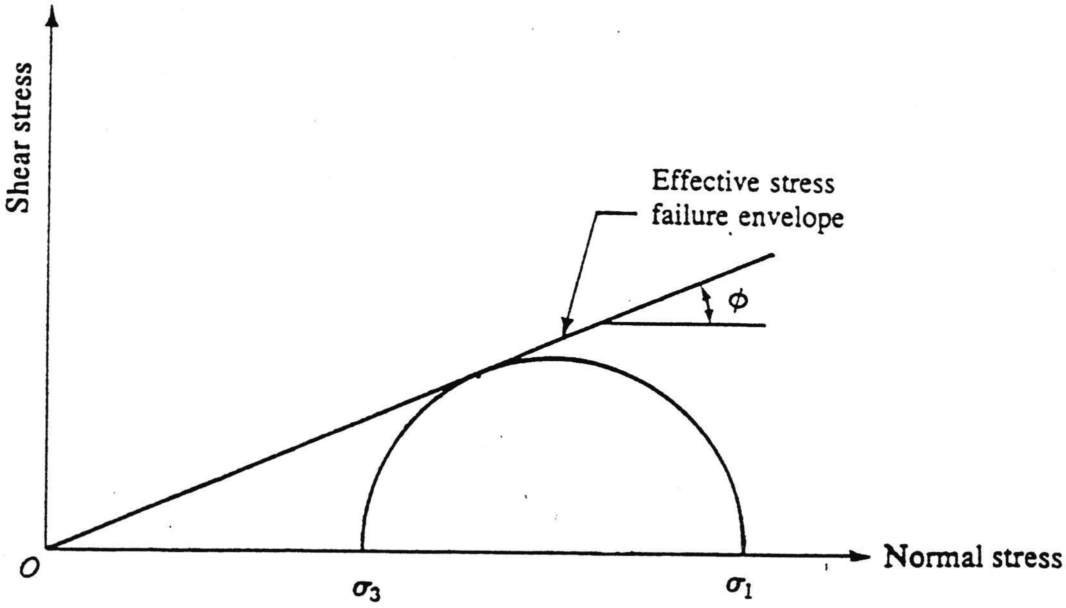


Figure 5. Plot of Mohr circle

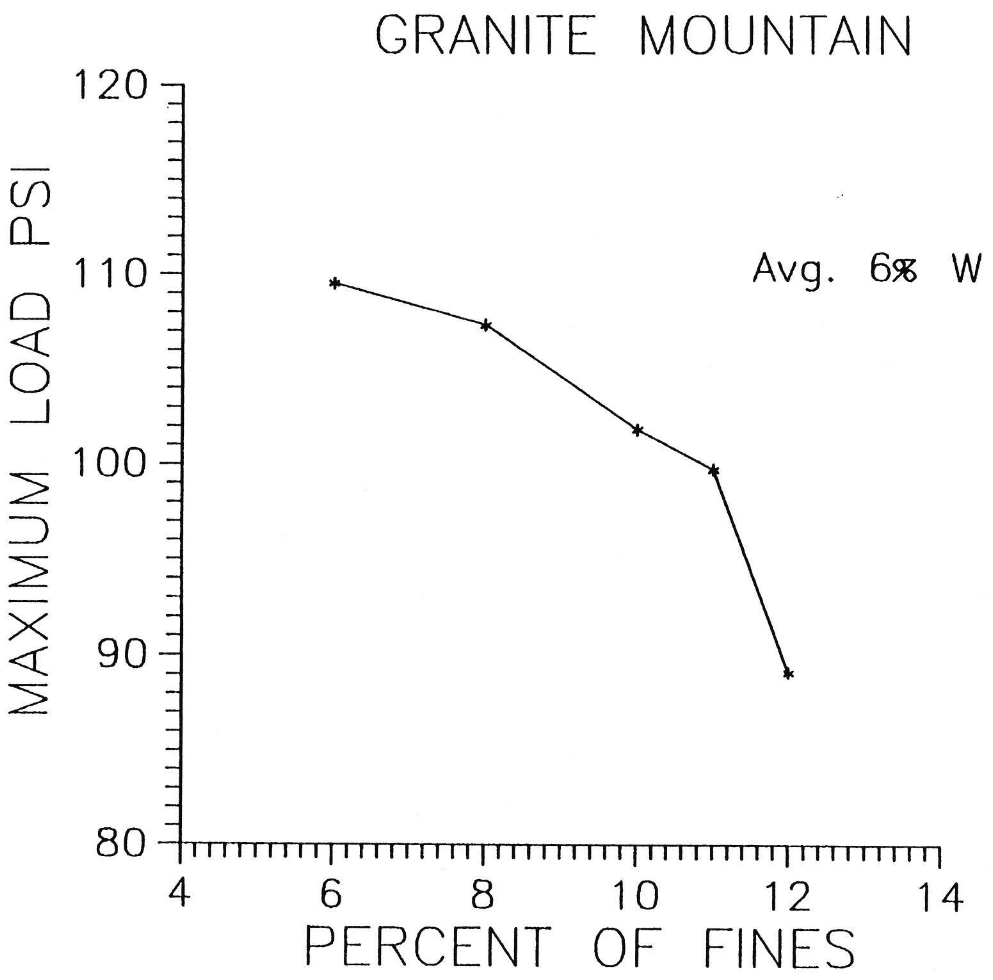


Figure 6. Maximum load vs. Fines

Table 5. Statistical Analysis Data

Water %	Max. load lb	0.75" load lb	Fines %	Vac in.	Net Press. psi
5.1	3265	3265	6	14	11.9
5.5	3243	3243	8	14.5	12.1
5.8	3219	3150	10	13	11.4
6.5	2820	2820	11	11	10.4
6.8	2730	2700	12	10.5	10.2
6.7	2511	2450	12	13	11.4
5.2	3060	2975	6	12	10.9
5.5	3166	3025	8	14	11.9
5.7	2916	2885	10	14	11.9
5.8	2521	2300	12	12	10.9
5.3	2959	2600	6	5	7.5
5.8	2697	2530	8	8	8.9
6.8	2501	2500	10	5	7.5
7.0	2317	2200	12	5	7.5
SAT	3408	3408	6	--	--
"	3028	3000	8	10	9.9
"	2640	2640	10	13	11.4
"	2606	2500	11	12	10.9
SAT	2427	2350	12	9	9.4

Table 6. Statistical Analysis of Fines Data

```
Model: MODEL1
Dep Variable: MAXLOAD

                           Analysis of Variance

                         Sum of         Mean
  Source       DF       Squares       Square       F Value       Prob>F

  Model         5 1140678.4390 228135.68780          7.265       0.0015
  Error        14 439652.11099  31403.72221
  C Total      19 1580330.5500

      Root MSE      177.21095     R-Square        0.7218
      Dep Mean     2749.35000     Adj R-Sq        0.6224
      C.V.            6.44556

                           Parameter Estimates

                      Parameter      Standard    T for H0:
 Variable  DF          Estimate         Error   Parameter=0    Prob > |T|

 INTERCEP   1        467.563606  2573.0748093         0.182        0.8584
 FINES      1        180.926826  231.89626499         0.780        0.4483
 FINES2     1        -12.793039   12.18845183        -1.050        0.3117
 NETPRESS   1        348.184186  459.69314914         0.757        0.4614
 NET2       1        -11.613648   22.19539838        -0.523        0.6090
 NETFINE    1         -5.001083   13.31278743        -0.376        0.7128

Dep Variable: LOAD75

                           Analysis of Variance

                         Sum of         Mean
  Source       DF       Squares       Square       F Value       Prob>F

  Model         5 1224145.3939 244829.07878          7.044       0.0017
  Error        14 486599.40612  34757.10044
  C Total      19 1710744.8000

      Root MSE      186.43256     R-Square        0.7156
      Dep Mean     2666.40000     Adj R-Sq        0.6140
      C.V.            6.99192

                           Parameter Estimates

                      Parameter      Standard    T for H0:
 Variable  DF          Estimate         Error   Parameter=0    Prob > |T|

 INTERCEP   1      -1988.565558  2706.9710982        -0.735        0.4747
 FINES      1        453.330758  243.96355863         1.858        0.0843
 FINES2     1        -21.486168   12.82270796        -1.676        0.1160
 NETPRESS   1        549.251900  483.61441504         1.136        0.2751
 NET2       1        -16.322204   23.35039063        -0.699        0.4960
 NETFINE    1        -14.749598   14.00555113        -1.053        0.3101
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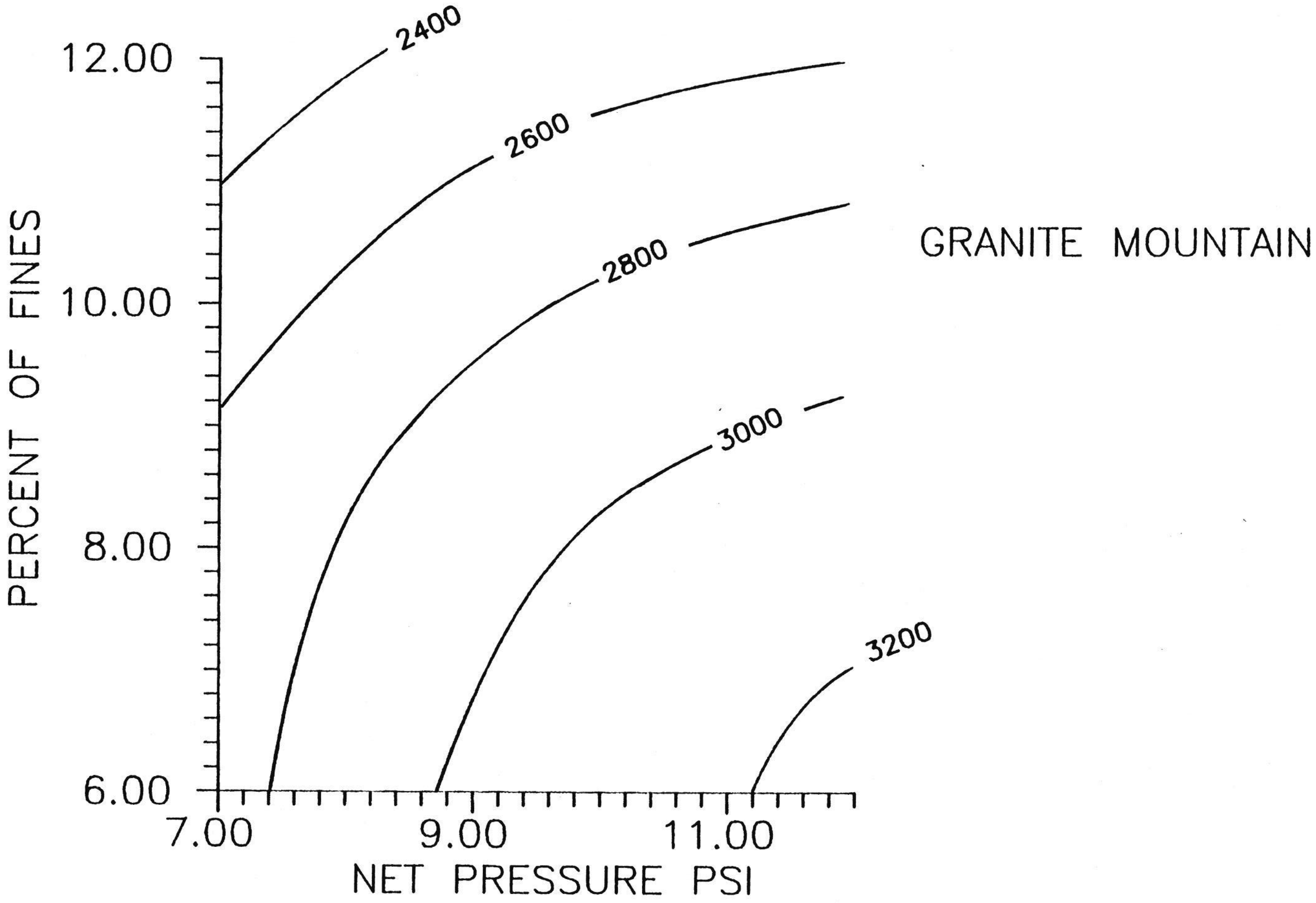

Figure 7. Fines vs. Net pressure for maximum load **1b.**

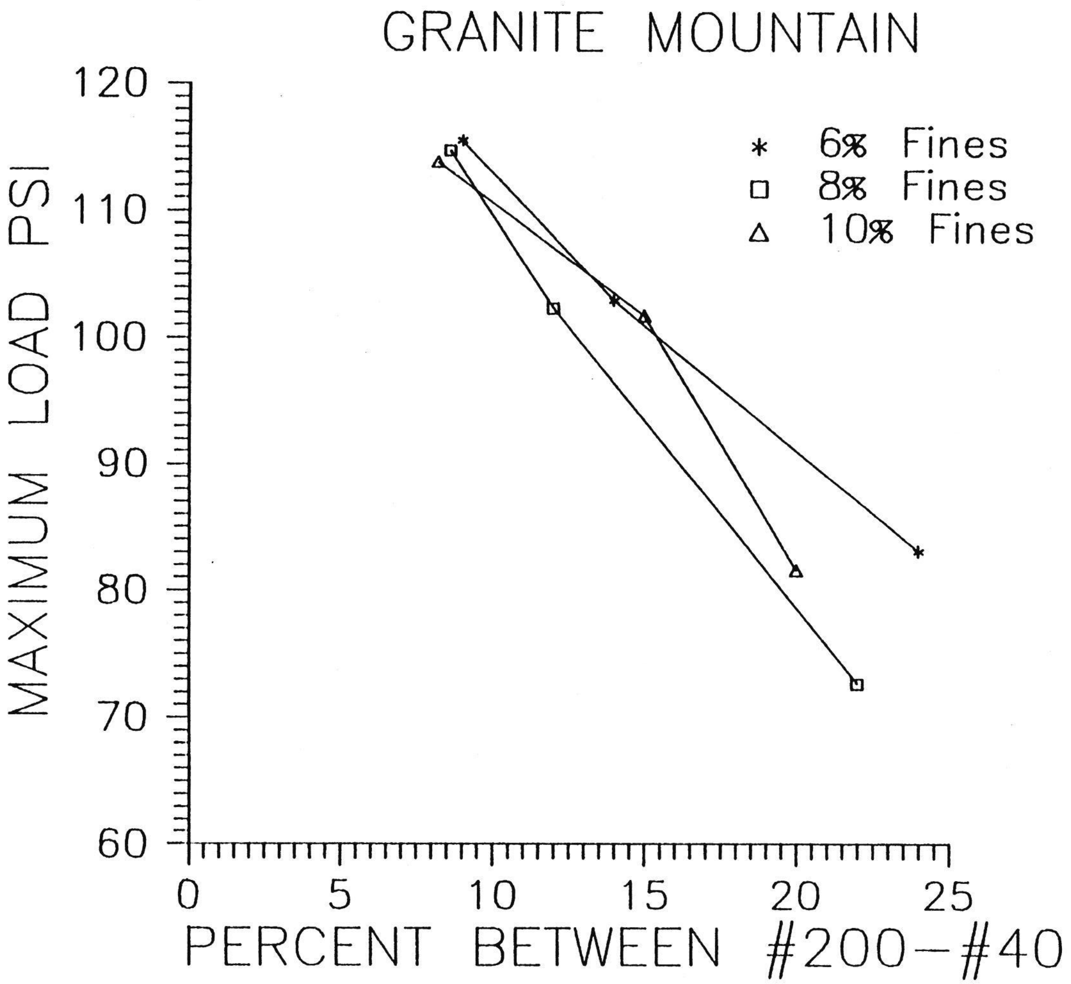

Figure 8. Maximum load vs. % passing #40-#200

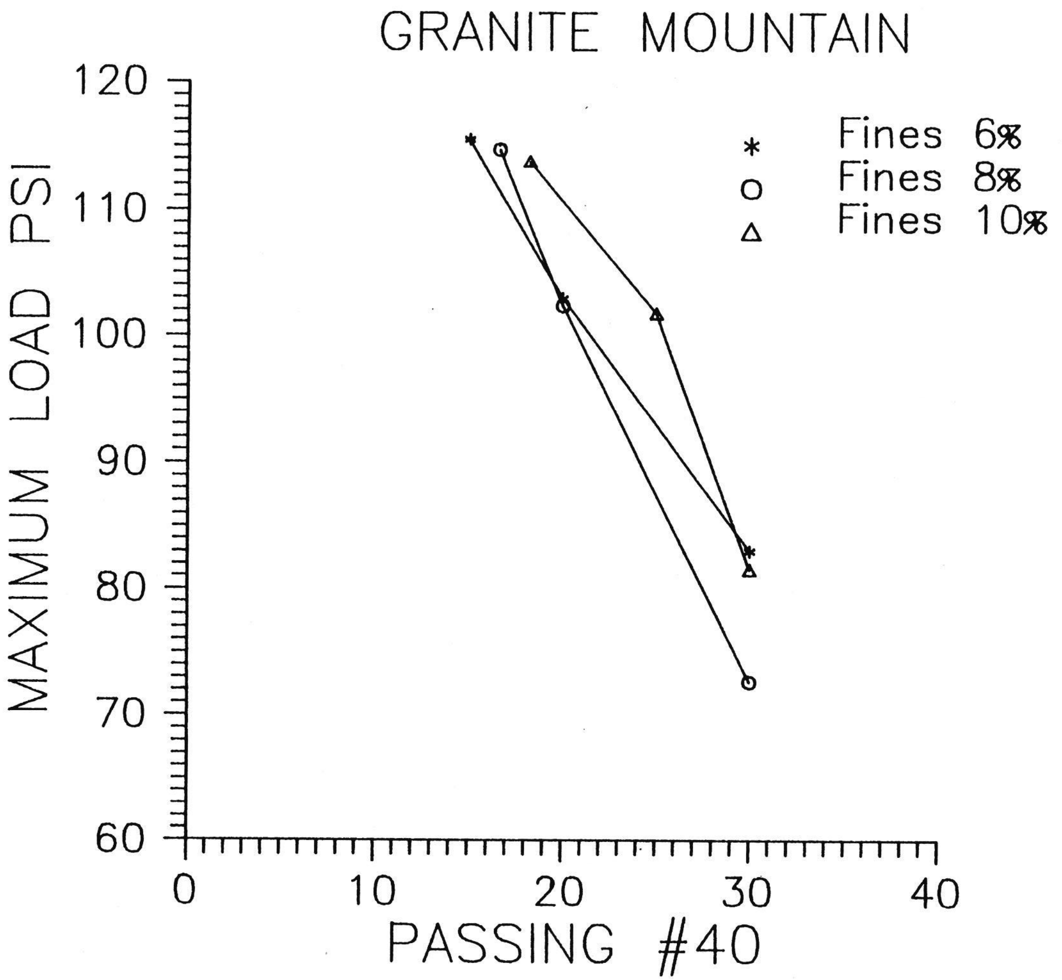

Figure 9. Maximum load vs. % passing #40

(vacuum) created in the saturated sample during the rapid shear. The negative pressure increases the effective confining pressure thereby increasing the vertical stress needed to cause shear.

Effect of Density

From time to time, a sample was prepared which did not meet target unit weight. These low unit weight samples were tested anyway to find the effect of not meeting target unit weight (Figure 11). The tests show that strength is reduced when unit weight is not achieved. The influence of unit weight appears to be greater as the amount of fines increases.

Effect of Net Pressure

At high net confining pressure (chamber pressure plus vacuum pressure), the shear strength is higher (Figure 12). The vacuum in the sample helps the aggregate to interlock more, acting in the same way as chamber pressure. This effect is shown at both maximum load (Figure 12) and load at 0.75 inches deflection.

The statistical analysis shows that the rapid shear strength is higher at low fines content and high vacuum pressure as compared to the low vacuum and high fines content (Figure 7). As expected, at low net confining pressure, the rapid shear strength is lower than at high net confining pressure. The influence of net confining pressure on rapid shear strength decreases as the fines content increases.

Because the vacuum is a part of the net confining pressure, a relationship also exists between vacuum and load. The R square between the variables is 0.72.

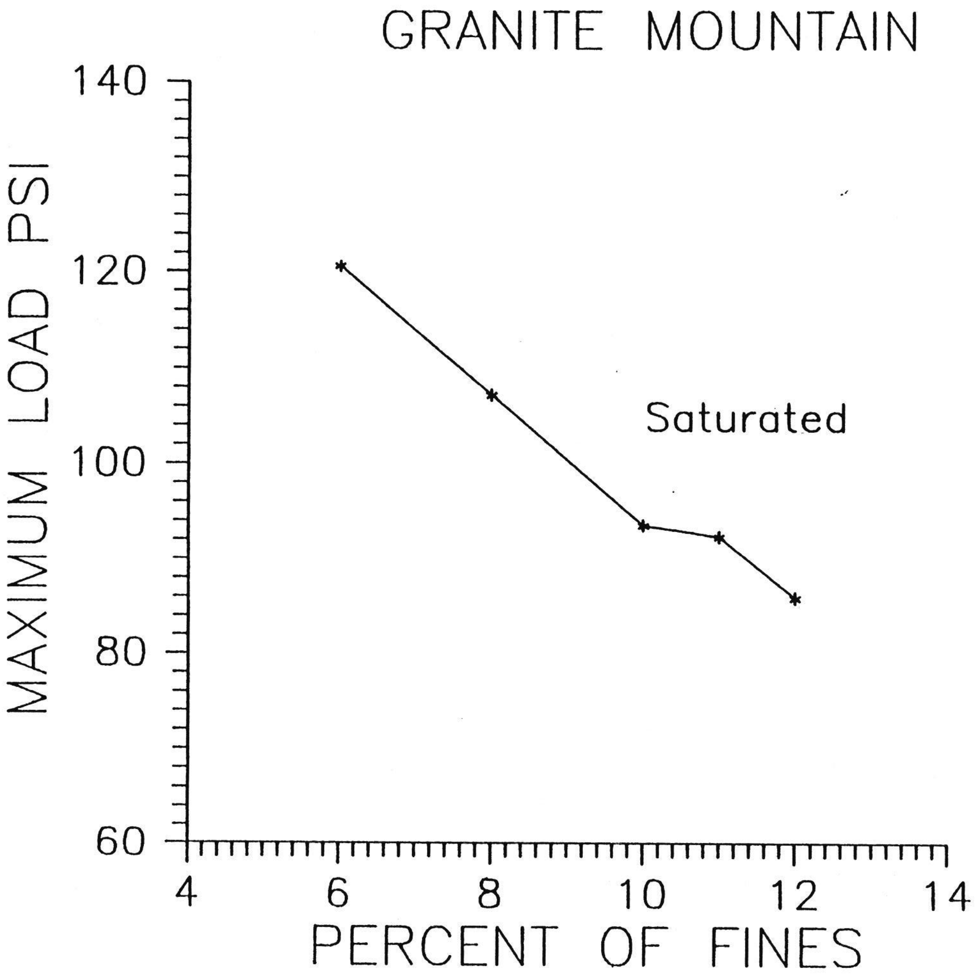

Figure 10. Maximum load vs. Fines for saturation

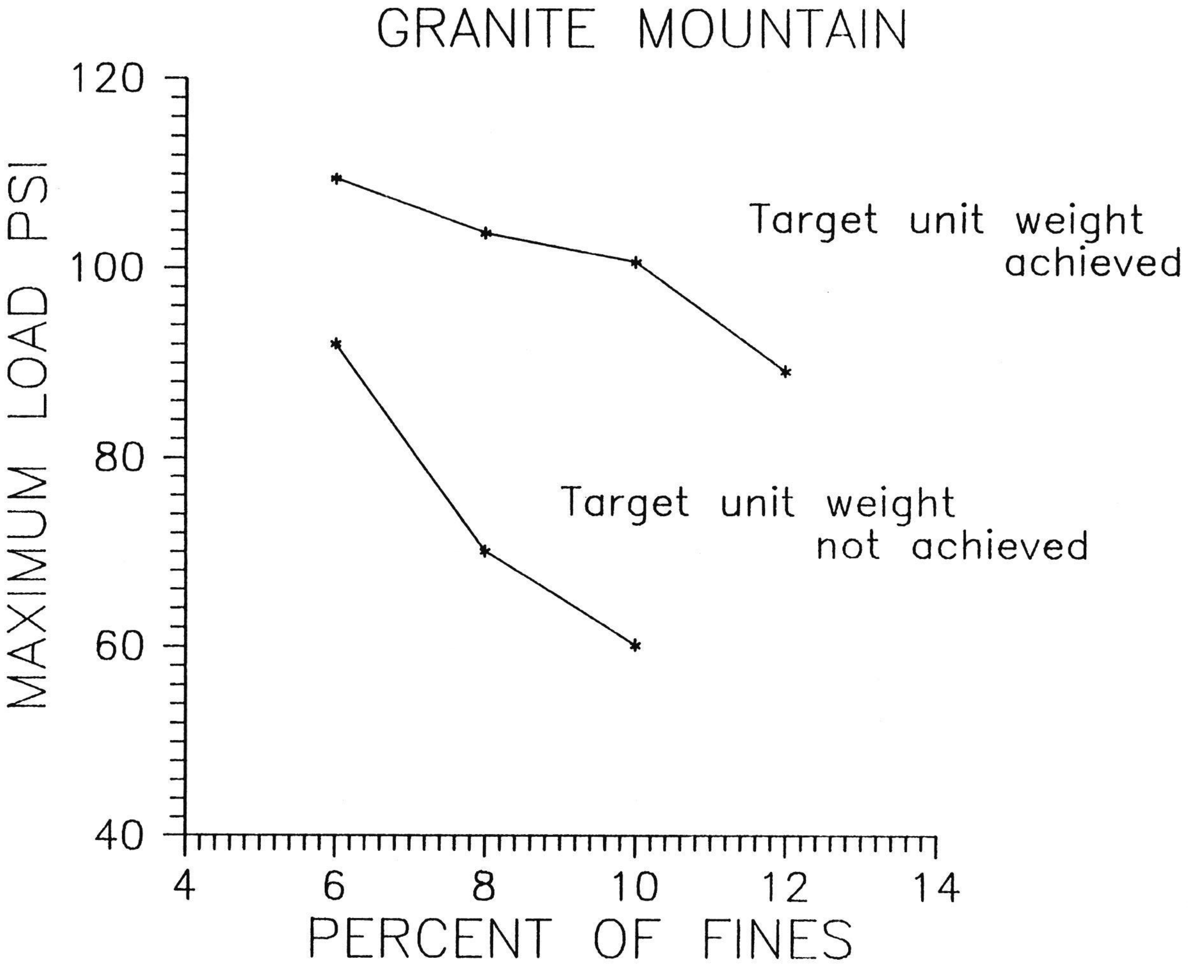

Figure 11. Effect of density

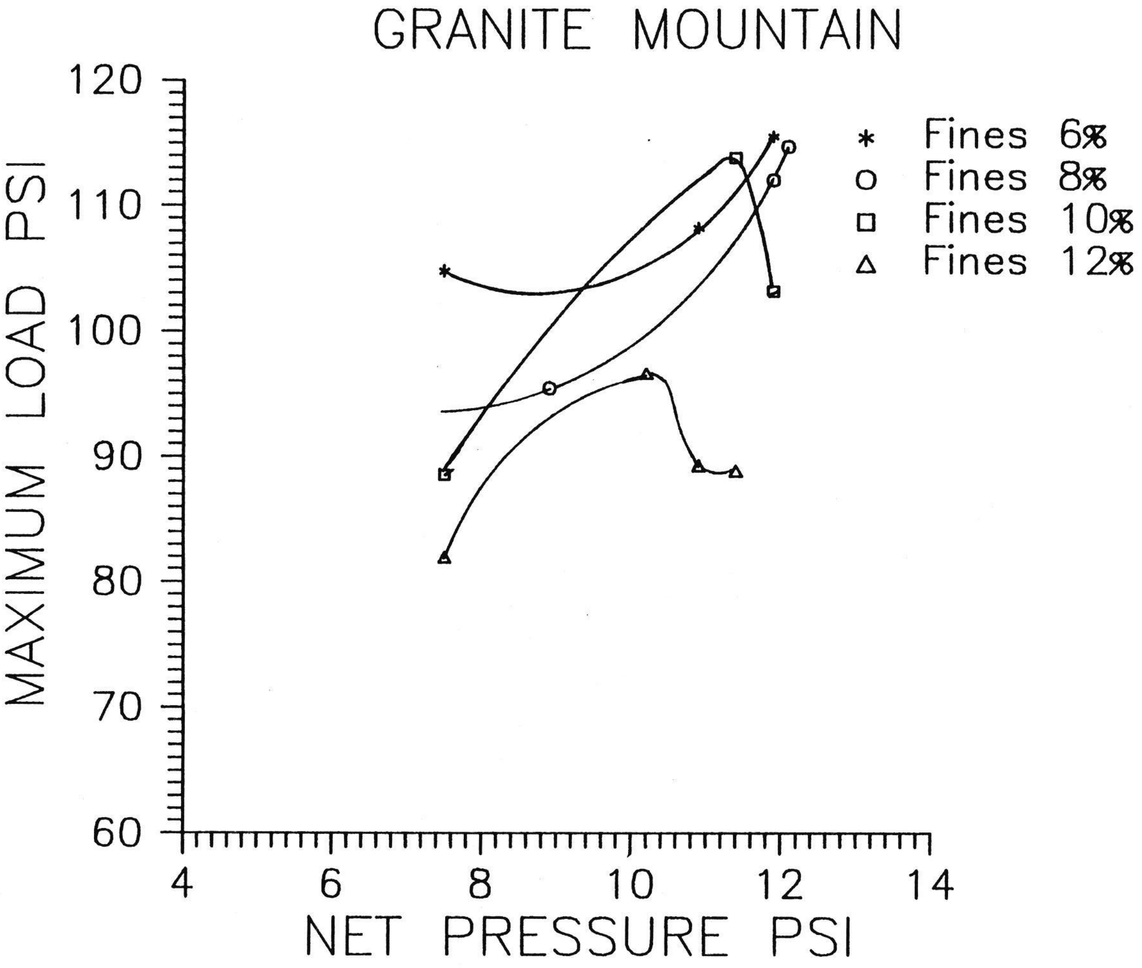

Figure 12. Maximum load vs. Net pressure for D.R.

CHAPTER V

PRODUCTION TESTING

Granular material from seven additional sources in Arkansas were tested to determine whether the findings from testing the Granite Mountain aggregate could be generally applied. The specific gravity, maximum density and optimum water content for each material are tabulated in Table 9. The dry density and the percent of maximum dry density achieved in the testing are also tabulated in Table 7. A summary of the data collected from the testing on all eight aggregates is given in Table 8.

Rapid shear strengths were plotted against the corresponding specimens' percent of fines and final water content. Then, contours of constant water contents were drawn to illustrate the trend or pattern of the effects of the variables. This was done because the data points are at different water contents.

Effect of fines

The rapid shear strengths of the granular base materials, are strongly influenced by the percent passing the No. 200 sieve (Figures 13 through 21). The Duffield sandstone (Figure 15) and the Delta #3 crushed gravel (Figure 19) have a significant drop in strength (steeper slope) as the percent of fines increased from 6 to 8%. The strength decreased a small amount as the percent of fines increased from 6 to 8% for the remaining materials.

Effect of moisture content

The effect of moisture on rapid shear strength depends on the amount of fines present. For some material, moisture content is not so important as the percent of fines are at the low end (8% moisture or less); but as

Table 7

Aggregate Properties

Material, Source	Spec. Gra.*	Max. Density*	Opt. % Water*	Dry Density*	% Max. Achieved
Syenite, Granite Mount.	2.62	137.0	6.7	135	98.5
Sandstone, Freshour	2.60	134.8	9.6	135	100.0
Sandstone, Duffield	2.57	138.4	7.0	131	94.7
Novaculite, State	na	133.7	7.9	130	97.2
Limestone, Anchor	2.67	137.4	7.8	131	95.3
Limestone, Midwest	2.68	143.8	6.5	135	93.9
Crushed Gravel, #3	2.53	137.8	5.8	135	98.0
Bank Gravel, Boorhem	2.53	135.8	5.7	135	99.4

* Data furnished by the Arkansas Highway & Transportation Department

Table 8

Rapid Shear Strength Data Summary

%Fines	MaxLoad(lb)	MaxStress(psi)	Vac(in)	%Water	Phi angle
Granite Mountain Syenite					
6	3265	115.48	13	5.1	56.6
8	3245	114.77	14.5	5.5	55.6
10	3219	113.85	13	5.8	56.4
12	2730	96.55	11	6.5	55.4
6	3408	120.53	--	10	--
8	3028	107.09	10	10	57.5
10	2640	93.37	13	10	53.5
12	2606	92.17	12	10	54.0
Freshour Sandstone					
6	3067	108.47	12	8.0	56.4
8	3024	106.95	11	8.0	56.8
10	2860	101.15	14	8.0	54.1
12	2247	79.47	14	8.0	50.3
6	3155	111.58	6	10.0	61.1
8	2855	100.97	14	10.0	54.0
10	2155	74.80	14	10.0	49.4
12	1881	66.53	13	10.2	48.2
Duffield Sandstone					
6	1896	67.06	1	8.1	59.2
8	1433	50.68	5	8.4	50.6
10	1267	44.81	0	8.5	54.8
12	1163	41.13	2	8.5	50.8
6	1158	40.96	0	10.2	53.5
8	1129	39.93	0	10.5	53.1
10	531	18.78	0	10.3	40.7
12	478	16.91	0	10.4	38.9
Mid State Novaculite					
6	2350	83.11	13	8.0	51.7
8	2297	81.24	11	7.8	52.8
10	2123	75.09	8.5	8.0	53.5
12	1750	61.89	5	8.0	53.7
6	2162	76.47	1	10.0	61.0
8	1824	64.51	4	11.6	55.3
10	1727	61.08	9	10.6	49.8
12	1289	45.59	2	10.7	52.4

Table 8 (cont'd)

%Fines	MaxLoad(lb)	MaxStress(psi)	Vac(in)	%Water	Phi angle
McClinton Anchor Limestone					
6	2756	97.47	11	6.7	55.5
8	2682	94.86	12	6.9	54.4
10	2619	92.62	4	6.9	60.4
12	1908	67.48	9	7.1	51.4
6	2748	97.19	0	9.5	65.1
8	2511	88.81	11	9.4	54.1
10	1815	64.19	8	10.2	51.5
12	1148	40.60	0	9.3	53.4
Midwest Limestone					
6	2703	95.60	13	4.3	53.9
8	1619	57.26	7	4.9	50.6
10	1610	56.94	6	4.5	51.4
12	1527	54.01	7	5.2	49.6
6	2409	85.20	9	6.3	55.0
8	2285	80.82	11	5.8	52.7
10	2057	72.75	10	7.9	51.8
12	1272	45.00	5	6.6	48.7
Delta #3 Crushed Gravel					
6	1020	36.08	6	8.2	44.0
8	763	27.00	0	8.8	46.9
10	689	24.37	0	8.5	45.2
12	531	18.78	0	8.4	40.7
6	661	23.38	1	10.7	42.9
8	586	20.73	1	10.4	40.8
10	402	14.22	0	10.3	36.0
12	321	11.35	0	9.5	32.1
Boorhem Fields Bank Gravel					
6	1185	41.91	2	6.5	51.1
8	1078	38.13	1	6.5	50.9
10	956	33.81	2.5	6.3	46.9
12	679	24.01	0	7.4	44.9
6	413	14.61	0	9.0	36.4
8	450	15.91	0	8.6	37.9
10	479	16.94	0	8.7	39.0
12	525	18.57	0	8.2	40.5

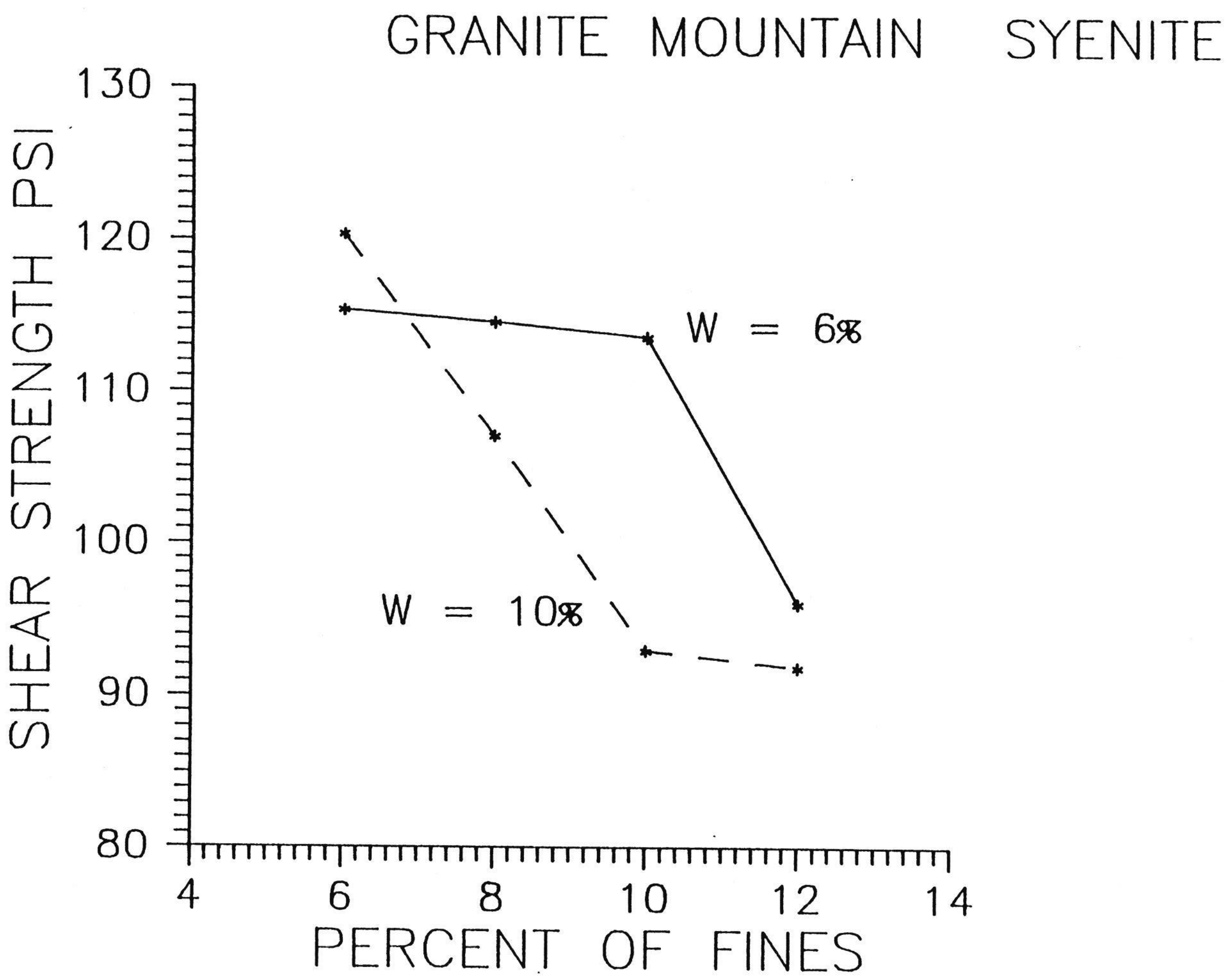

Figure 13. Effect of water on Granite Mountain Syenite

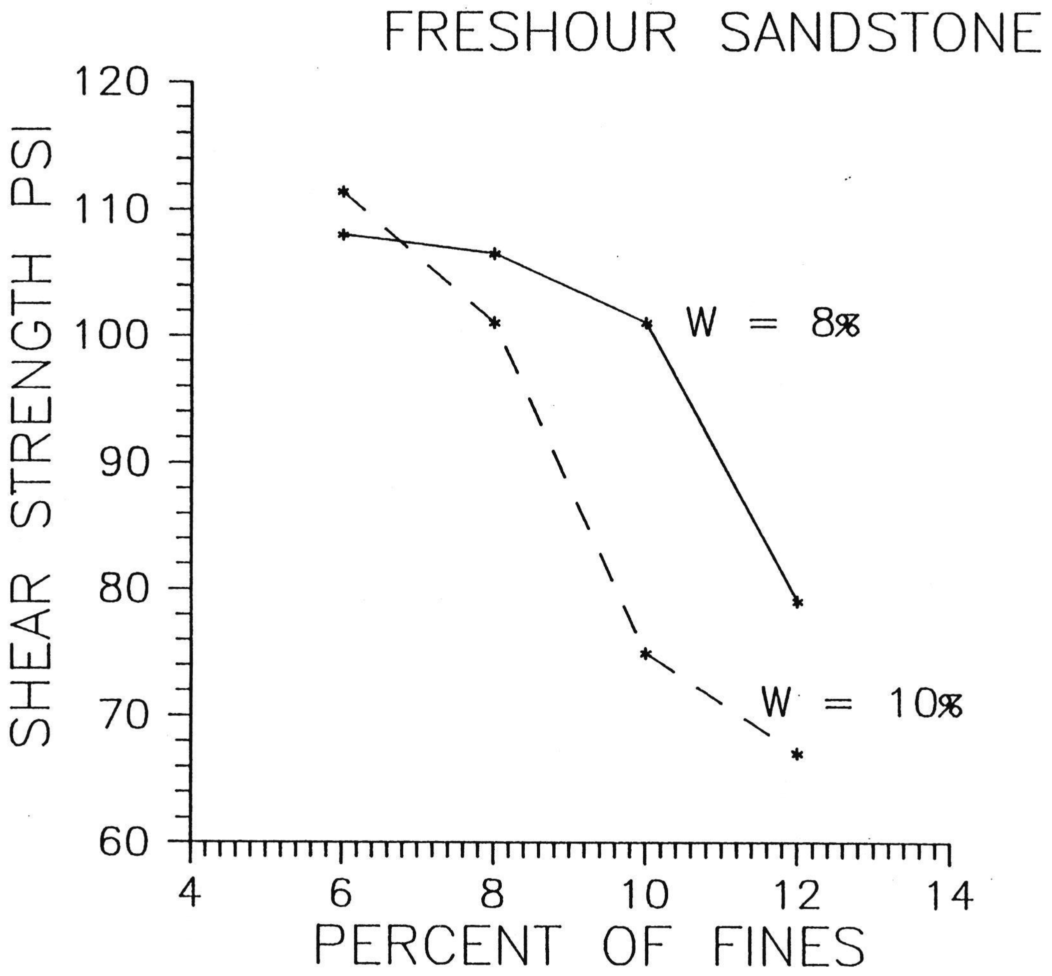

Figure 14. Effect of water on Freshour Sandstone

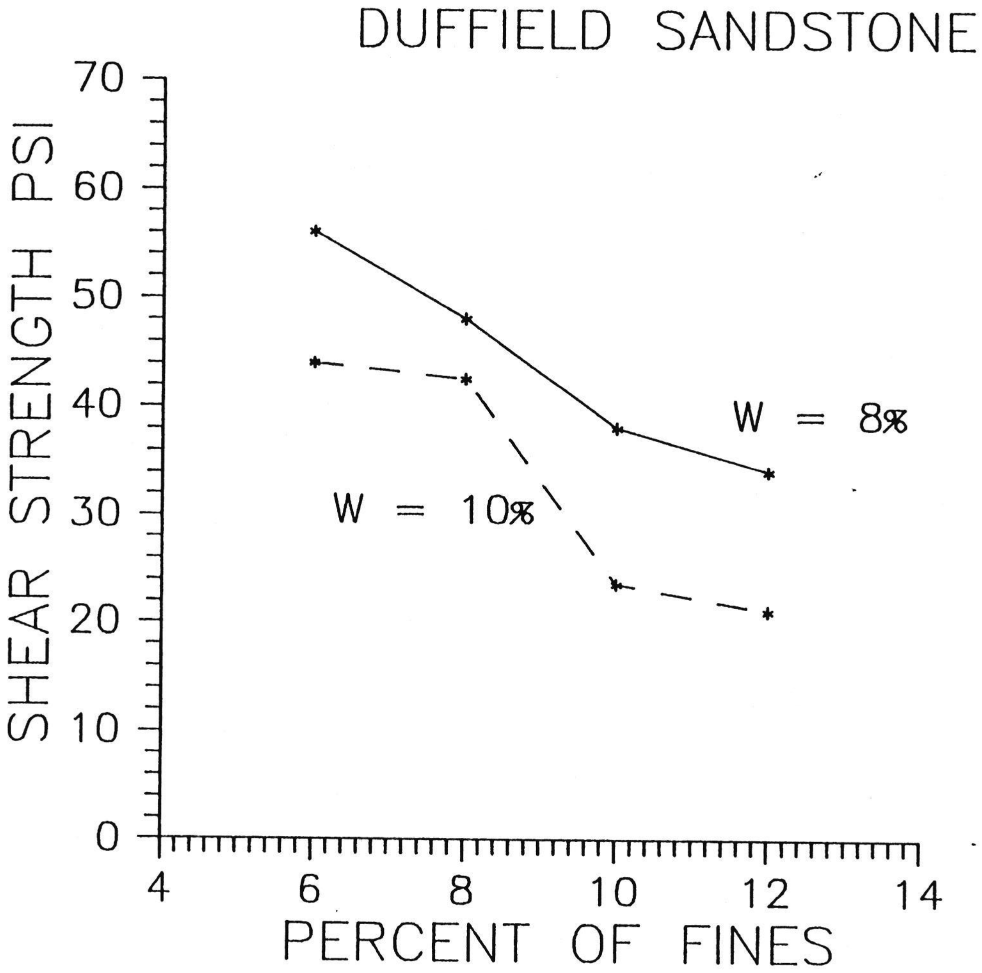

Figure 15. Effect of water on Duffield Sandstone

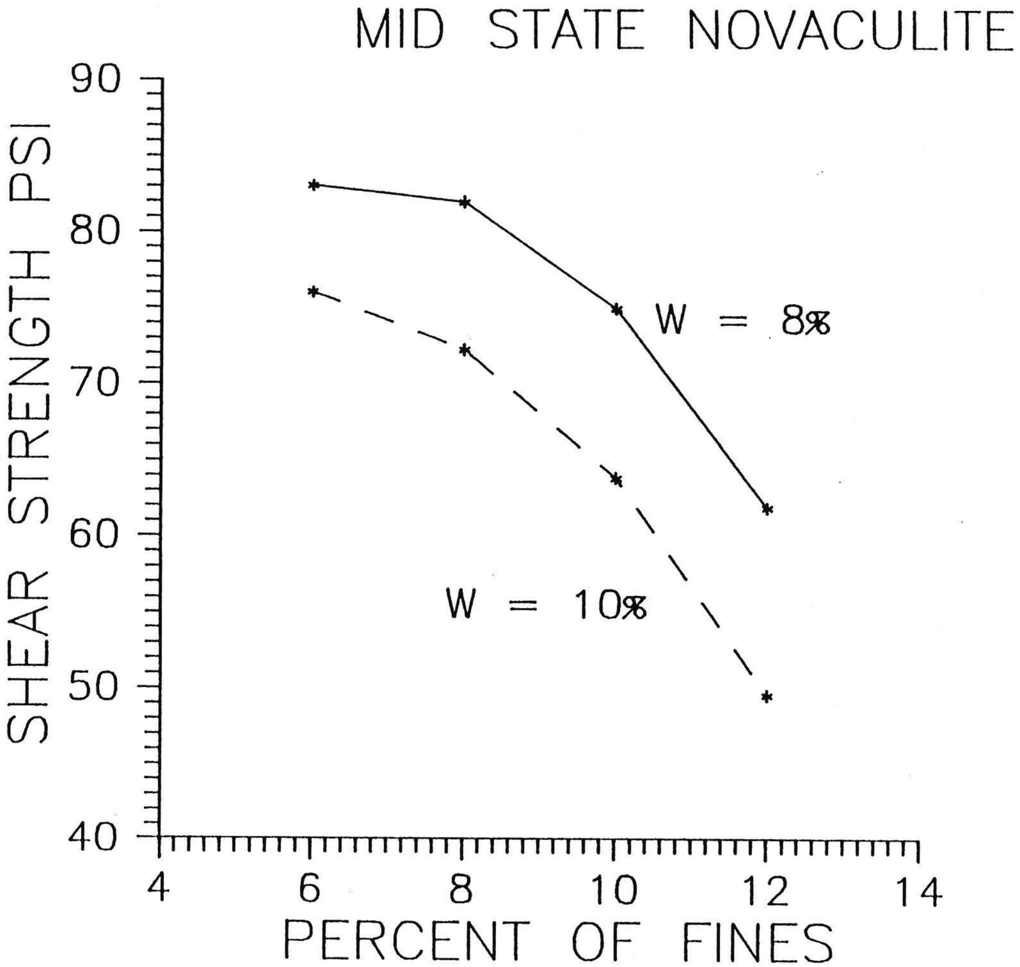

Figure 16. Effect of water on Mid State Novaculite

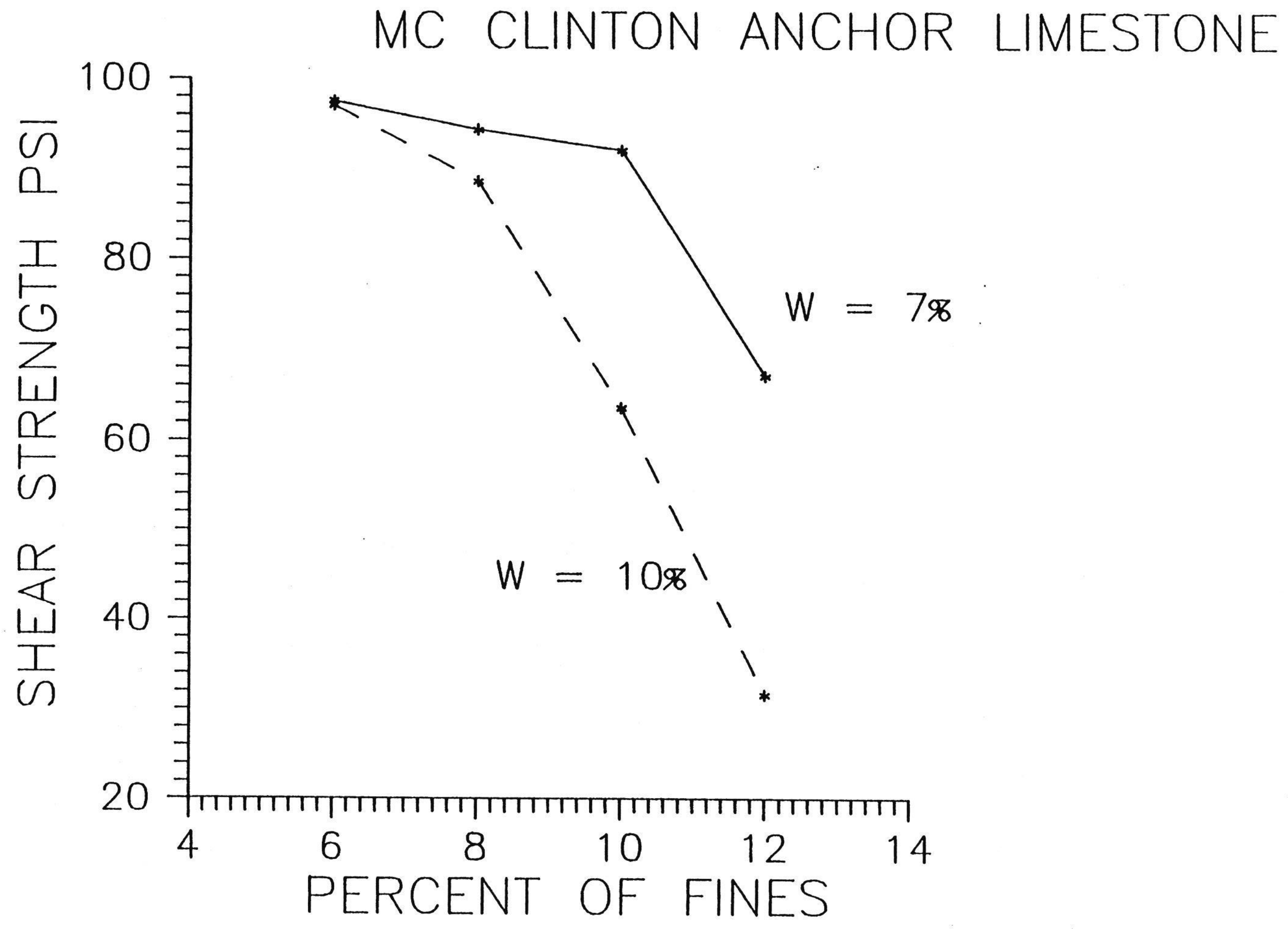

Figure 17. Effect of water on McClinton Anchor Limestone

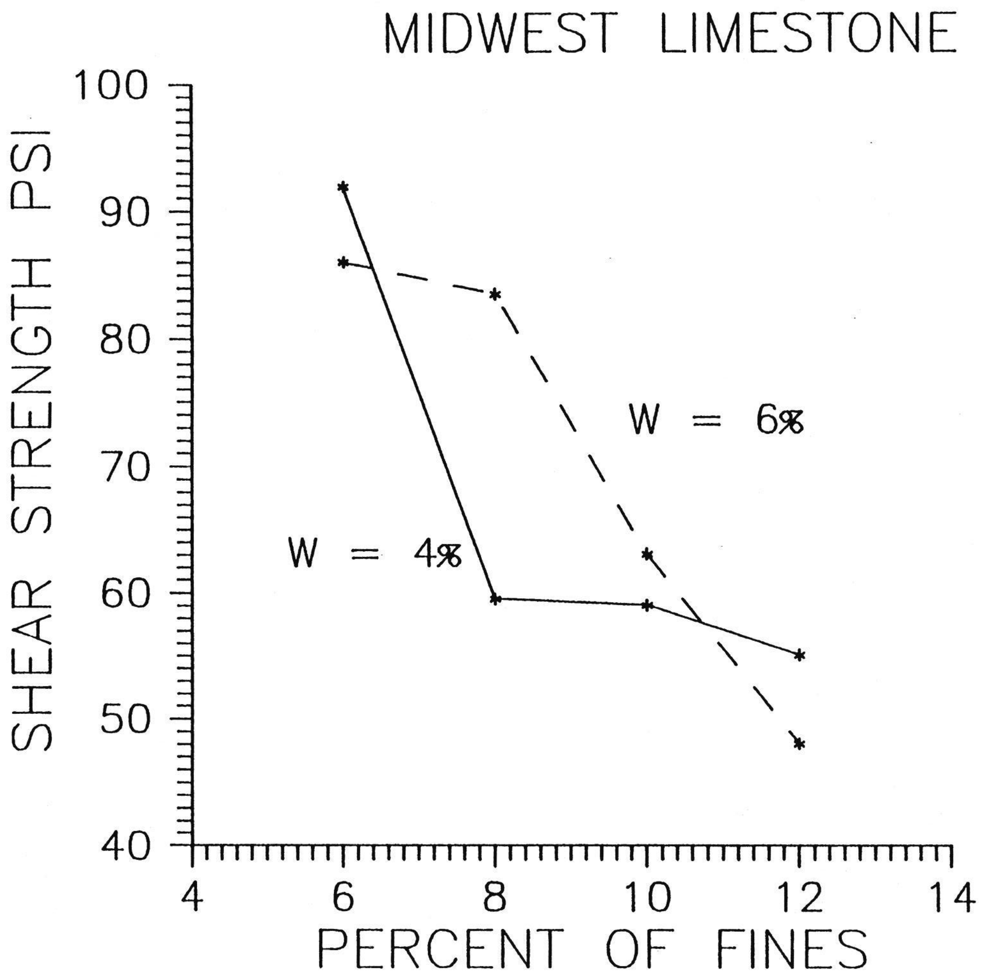

Figure 18. Effect of water on Midwest Limestone

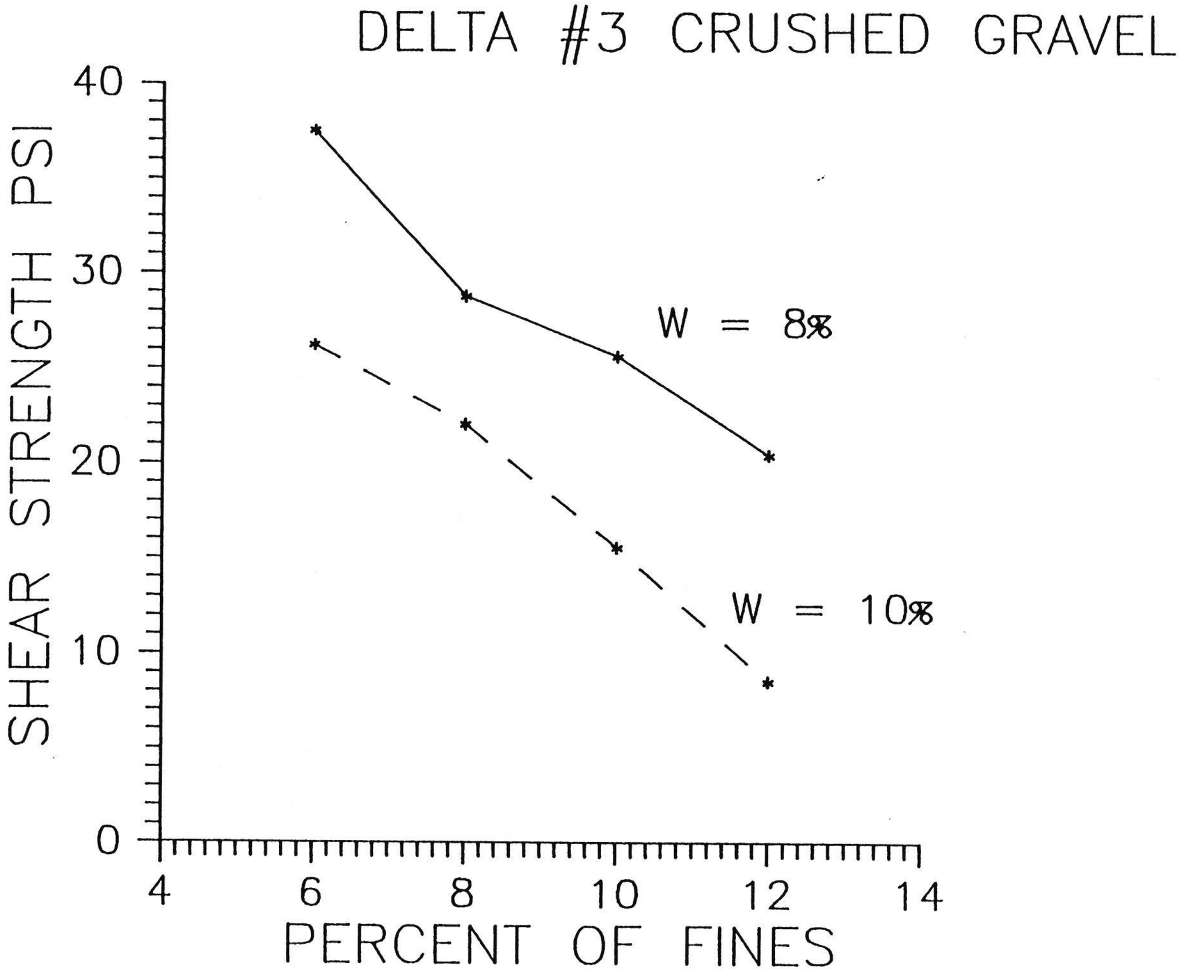

Figure 19. Effect of water on Delta #3 Crushed Gravel

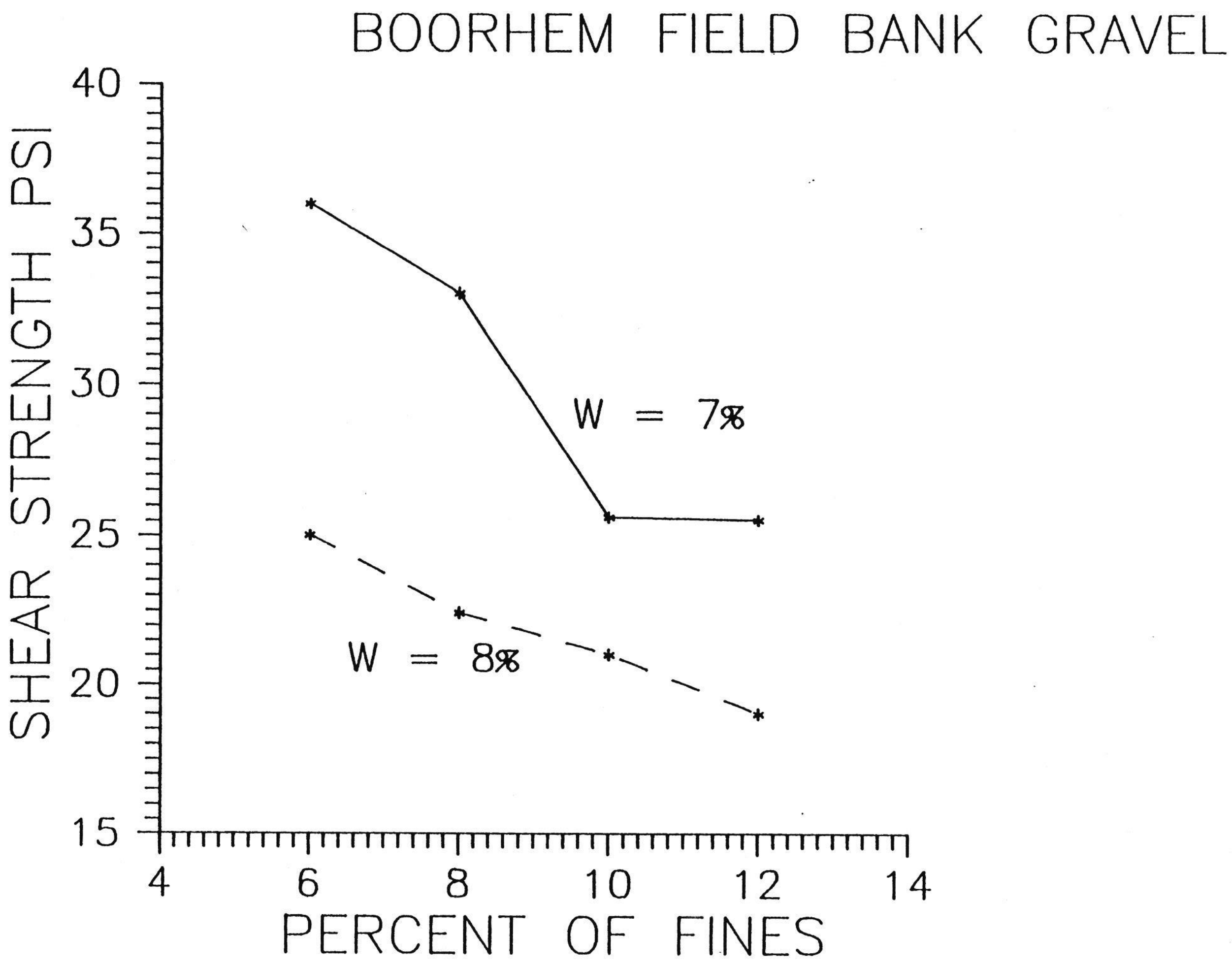

Figure 20. Effect of water on Boorhem Field Bank Gravel

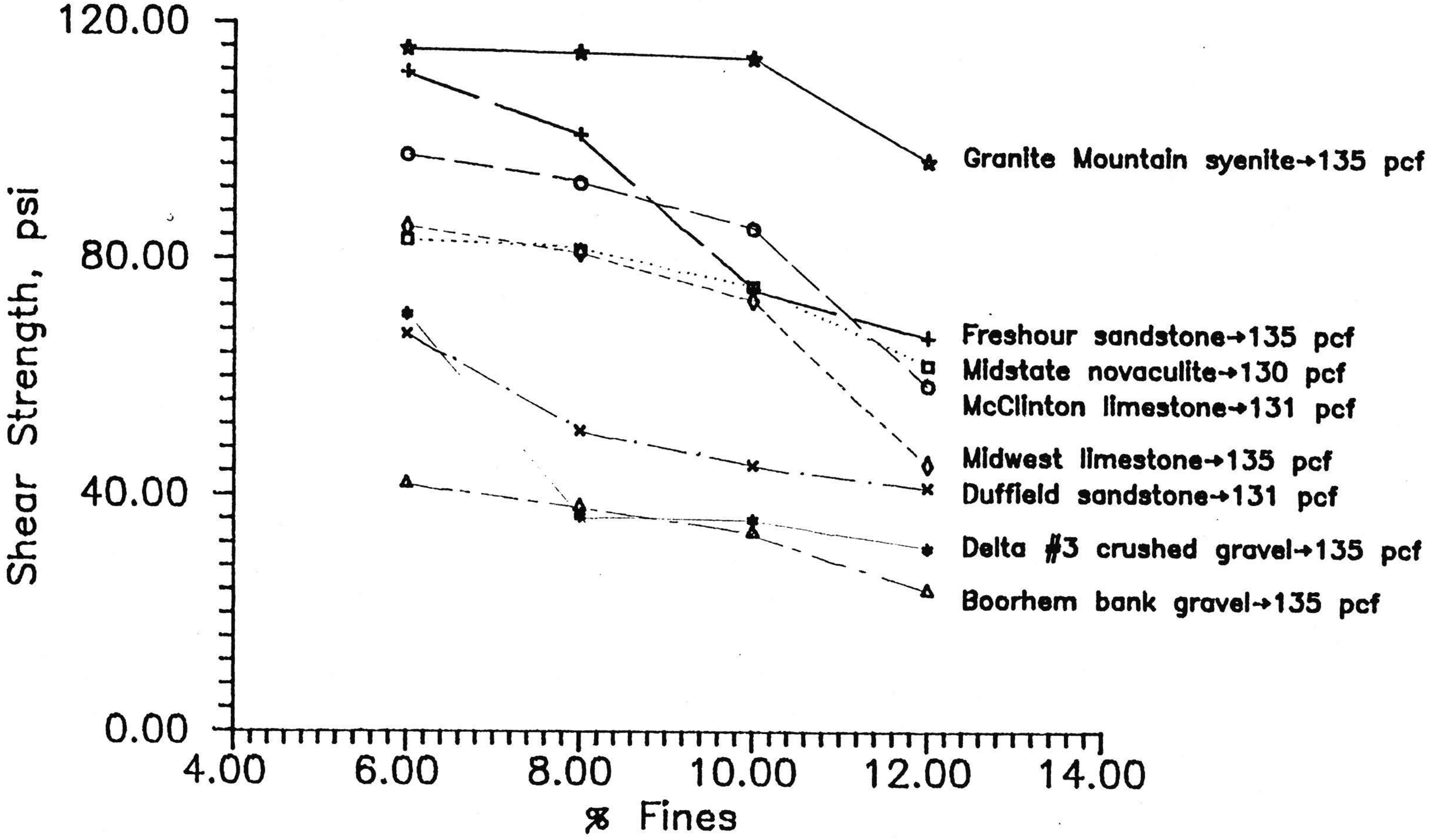

Figure 21. Rapid shear strength vs. % fines

the fines are increased, added moisture has a greater impact on strength reduction. This effect is shown in the Freshour sandstone (Figure 14), Granite Mountain syenite (Figure 13) McClinton Anchor limestone (Figure 17), and Midwest limestone (Figure 18). For the other materials moisture increases reduce the rapid shear strength about the same throughout the range of fines included in the test.

Figures 13 through 20 each show the relation between the strength and fines for two different water contents (interpolated data). The low water content was selected to be near the optimum water content for ease of compaction. In general the low water contents resulted in degrees of saturation of about 70% in the compacted specimens. The higher water content specimens were near 100% saturation. These two water contents were selected because they were, practically, the only water contents at which target unit weight could be attained.

Effect of crushed stone, crushed gravel, and gravel

Aggregate base material was stronger in rapid shear in the following order (Figure 21):

Crushed stone - strongest
Crushed gravel - medium
Uncrushed gravel - least strength

A direct comparison of one crushed stone (Freshour sandstone) and a crushed gravel (Delta #3) is given in Table 9. The crushed stone was found to be about three times as strong in rapid shear as the crushed gravel at both medium and high levels of fines and moisture content.

Table 10 shows a similar direct comparison between a crushed gravel (Delta #3) and a bank gravel (Boorhem Fields). The crushed gravel is approximately twice as strong as the uncrushed gravel. However, the uncrushed gravel shows less effect due to increased fines content.

Table 9

Rapid shear strength data of Freshour sandstone and Delta #3 crushed gravel

	Freshour		Delta #3	
Dry density, pcf	135	135	135	135
Relative density, pcf	100.0	100.0	98.0	98.0
Water content, %	9.0	10.2	8.2	9.5
Fines, %	6	12	6	12
Shear strength, lb.	3067	1881	1020	321

Table 10

Rapid shear strength data of Delta #3 crushed and Boorhem Fields bank gravel

	Delta #3		Boorhem Fields	
Dry density, pcf	135	135	135	135
Relative density, %	98.0	98.0	99.4	99.4
Fines, %	6	8	6	8
Water content, %	8.2	8.8	9.0	8.6
Shear strength, lb.	1020	763	413	450

CHAPTER VI

DUST RATIO

Dust ratio is the ratio of the amount of aggregate passing the No. 200 sieve to the amount passing No. 40 (D.R. = Weight Passing No. 200 / Weight Passing No. 40). To find the effect of dust ratio on rapid shear strength, the Granite Mountain sample was first tested and analyzed. Then all eight samples were tested to see if trends were consistent in the aggregates.

Granite Mountain

To examine the effect of dust ratio, fines content (passing No. 200 sieve) was held constant and percentages of the other size fractions were varied. Dust ratios tested ranged from 0.2 to 0.75. The test results relative to dust ratio are summarized in Table 11.

Except at the highest dust ratio (0.75), an increase in dust ratio is seen to increase the rapid shear strength (Figure 22). However, the highest dust ratio (0.75) resulted in an appreciable strength decrease. A complicating factor relative to the 0.75 dust ratio is the fact that target unit weight could not be achieved with that gradation. It is not clear whether the lower strength is the result of lower density, higher dust ratio, or both. The higher dust ratio may be responsible for both the lower density and the lower strength.

Eight Aggregates

All eight of the aggregate sources were tested at eight percent fines for rapid shear strength at dust ratios up to 0.75. Table 12 contains the results for the samples. Target unit weight could not be achieved at the

Table 11

Laboratory data for the rapid shear test

Dust Ratio	Water %	Max.load lb	0.75"load lb	Fines %	Vac in.	Net Press psi
0.2	6.4	2346	2187	6	9.5	9.7
0.3	5.72	2909	2850	6	12	10.9
0.4	5.1	3265	3265	6	13	11.4
0.27	6.4	2053	2000	8	9	9.4
0.4	5.6	2893	2780	8	12	10.9
0.48	5.5	3243	3243	8	14.5	12.1
0.75	5.4	1982	1900	8	13	11.4
0.33	6.45	2303	2303	10	12	10.9
0.4	5.94	2875	2765	10	11.5	10.6
0.55	5.8	3219	3150	10	12	10.9

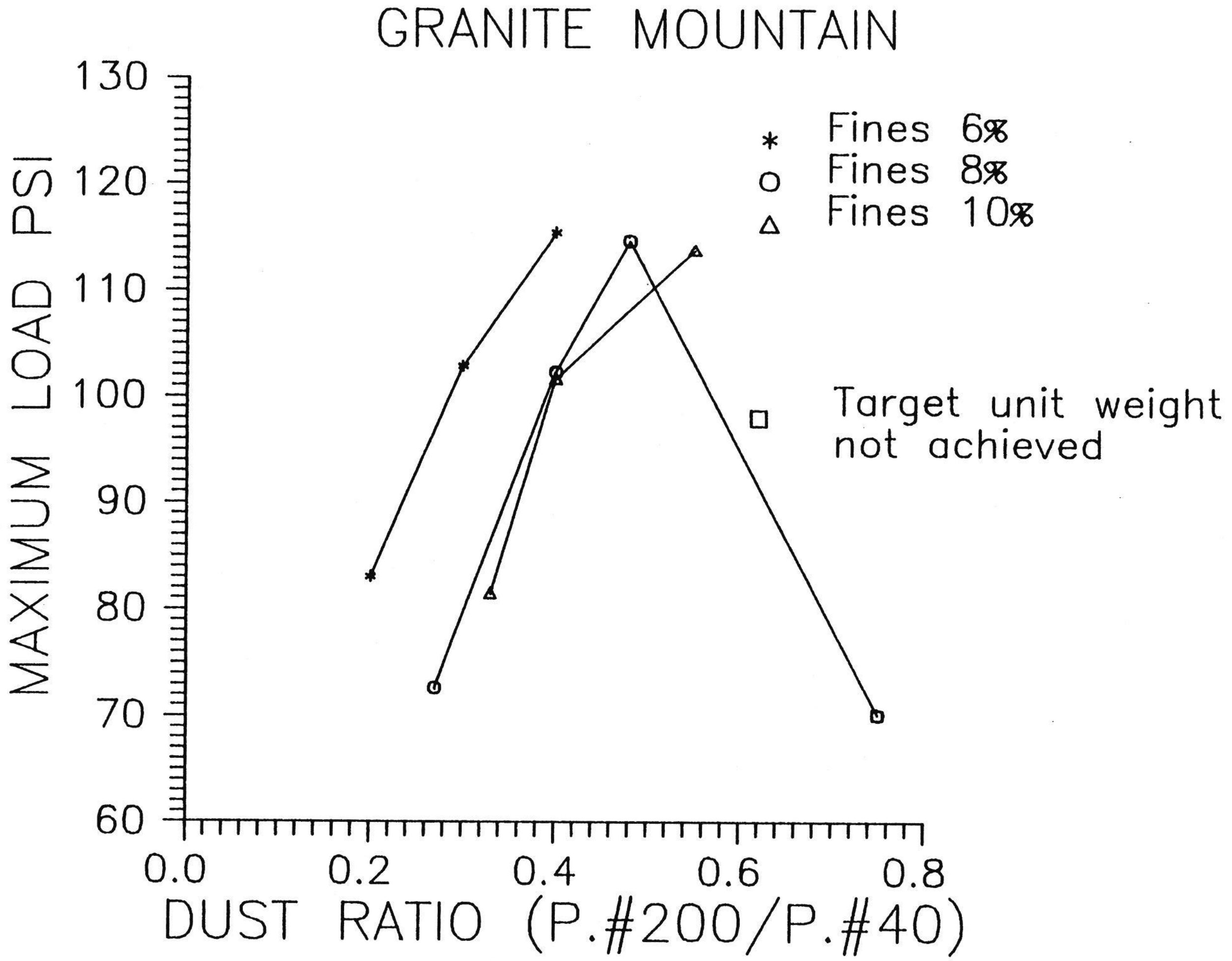

Figure 22. Maximum load vs. Dust Ratio

TABLE 12

Rapid shear strength data from the dust ratio testing

Sample	Dust Ratio	Max Load, LB	Max Stress, PSI
Syenite, Granite Mountain	0.27	2053	72.6
	0.40	2893	102.3
	0.48	3243	114.7
	0.75	1982	70.1
Sandstone, Freshour	0.48	3100	106.1
	0.60	2550	90.2
	0.75	1650	58.4
Sandstone, Duffield	0.48	1440	50.9
	0.60	1520	53.8
	0.75	1520	53.8
Novaculite, Midstate	0.48	2300	81.4
	0.60	2070	73.2
	0.75	1870	66.1
Limestone, McClinton Anchor	0.48	2682	94.9
	0.60	2947	104.2
	0.75	1910	67.6
Limestone, Midwest	0.48	2285	80.8
	0.60	1652	58.4
	0.75	1107	39.2
Crushed Gravel, Delta #3	0.48	763	27.0
	0.60	1207	42.7
	0.75	1420	50.2
Gravel, Boorham Field	0.40	1061	37.5
	0.48	1078	38.1
	0.60	1416	50.1
	0.75	1003	35.5

0.75 dust ratio except in the McClinton Anchor limestone. Plots of the results are contained in Figure 23 thru 30.

The test results show no consistent trend. The shear strength of some aggregates are seen to generally increase with increasing dust ratio while others generally decrease. The most consistent result is that for six (6) of the eight (8) aggregates shear strength is lowest at the highest dust ratio (0.75). However, the inability to achieve target unit weight at the 0.75 dust ratio makes it unclear as to whether the lower strength is a result of lower density, higher dust ratio, or both.

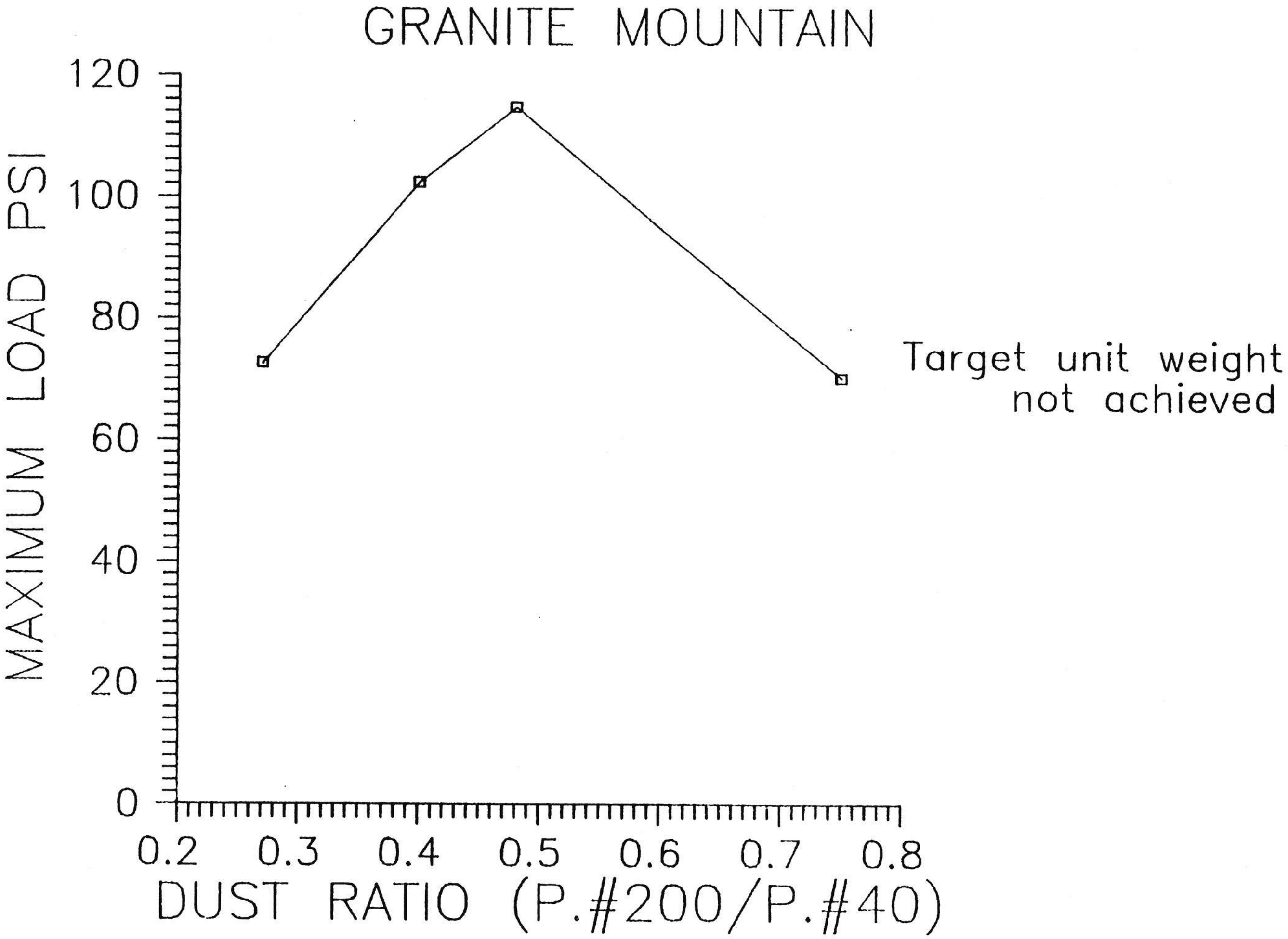

Figure 23. Effect of Dust Ratio on Granite Mountain Syenite

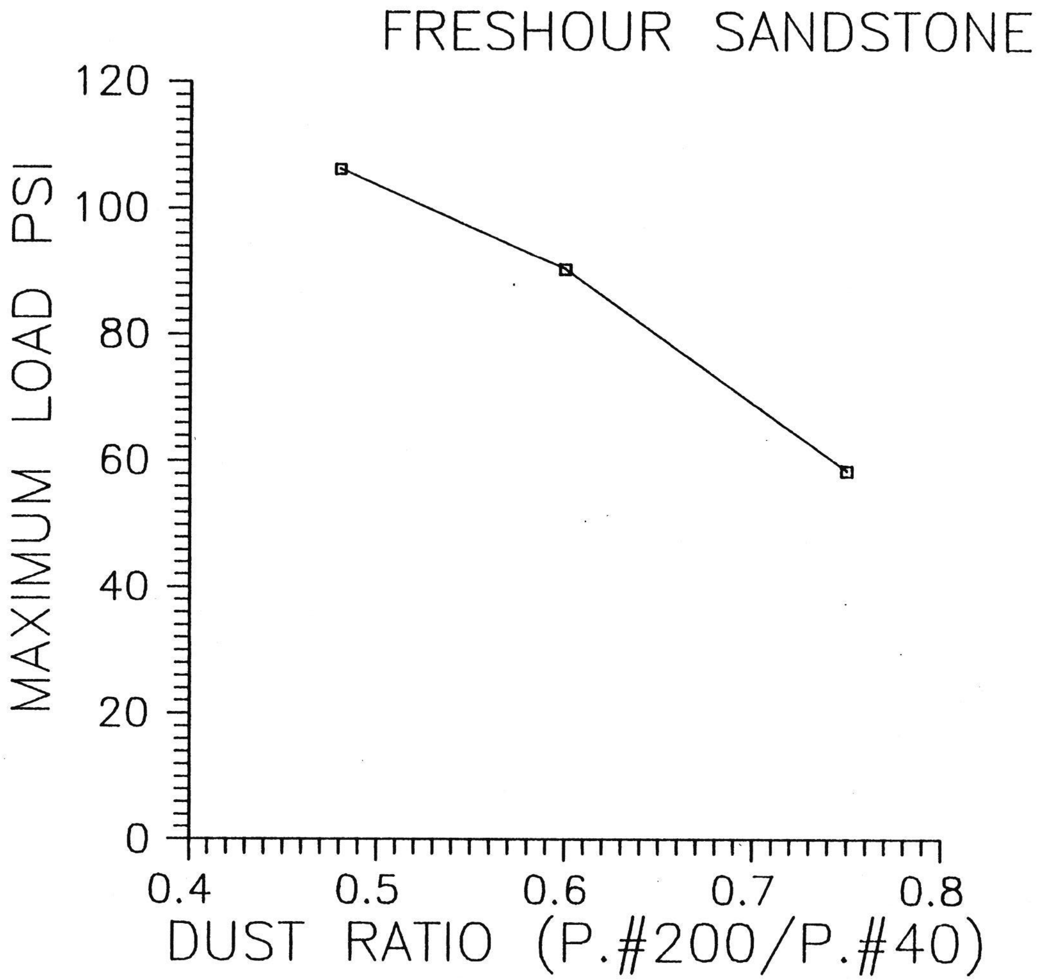

Figure 24. Effect of Dust Ratio on Freshour Sandstone

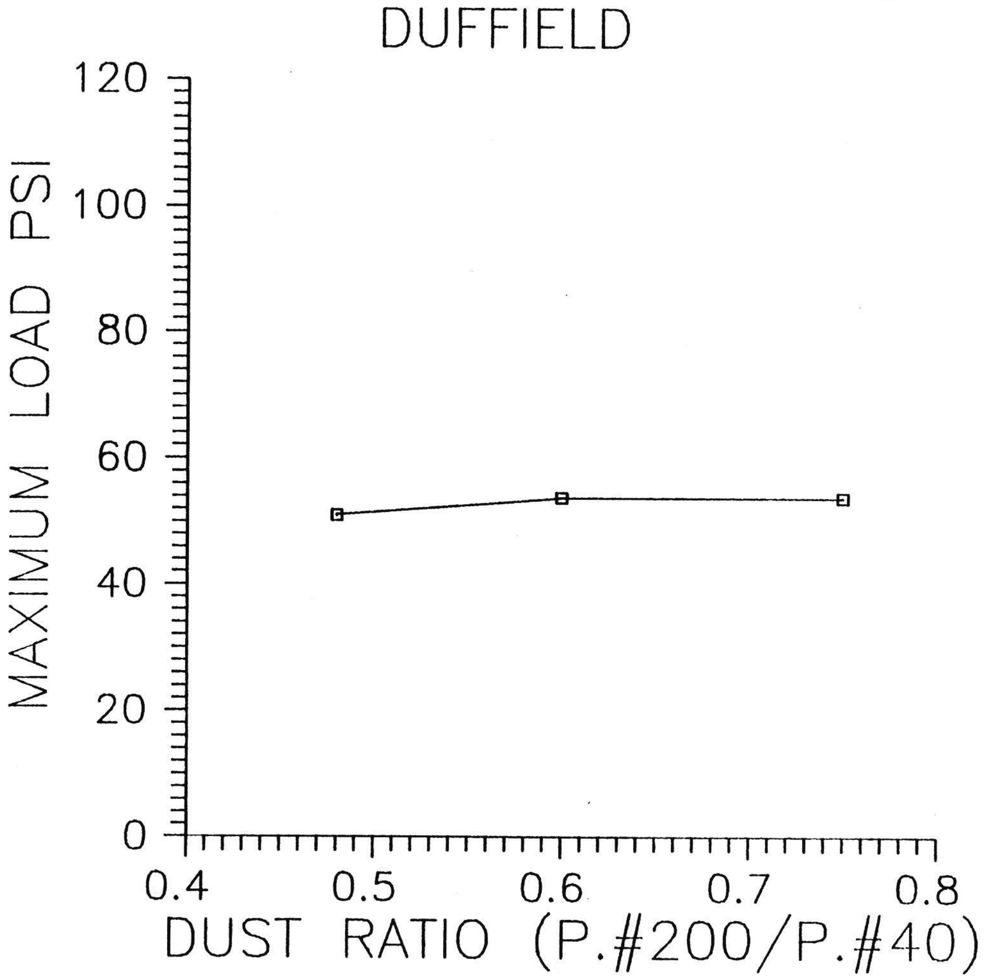

Figure 25. Effect of Dust Ratio on Duffield Sandstone

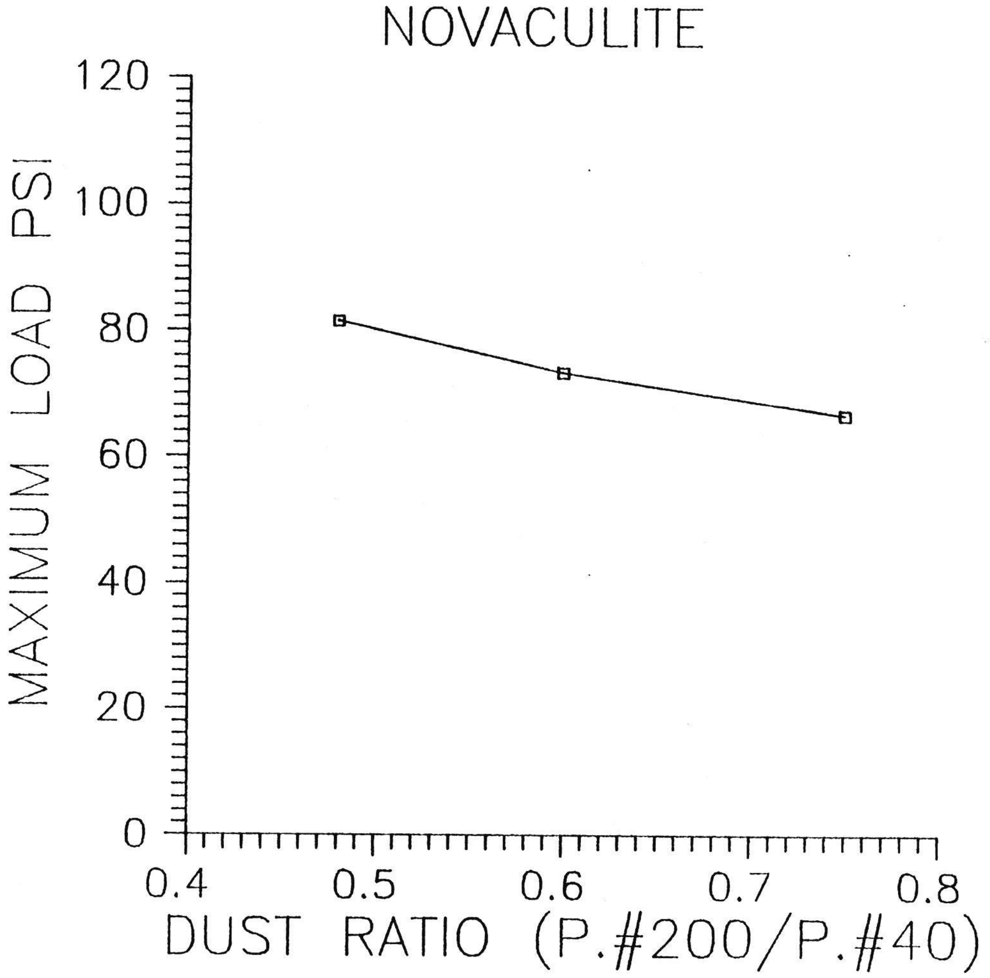

Figure 26. Effect of Dust Ratio on Mid State Novaculite

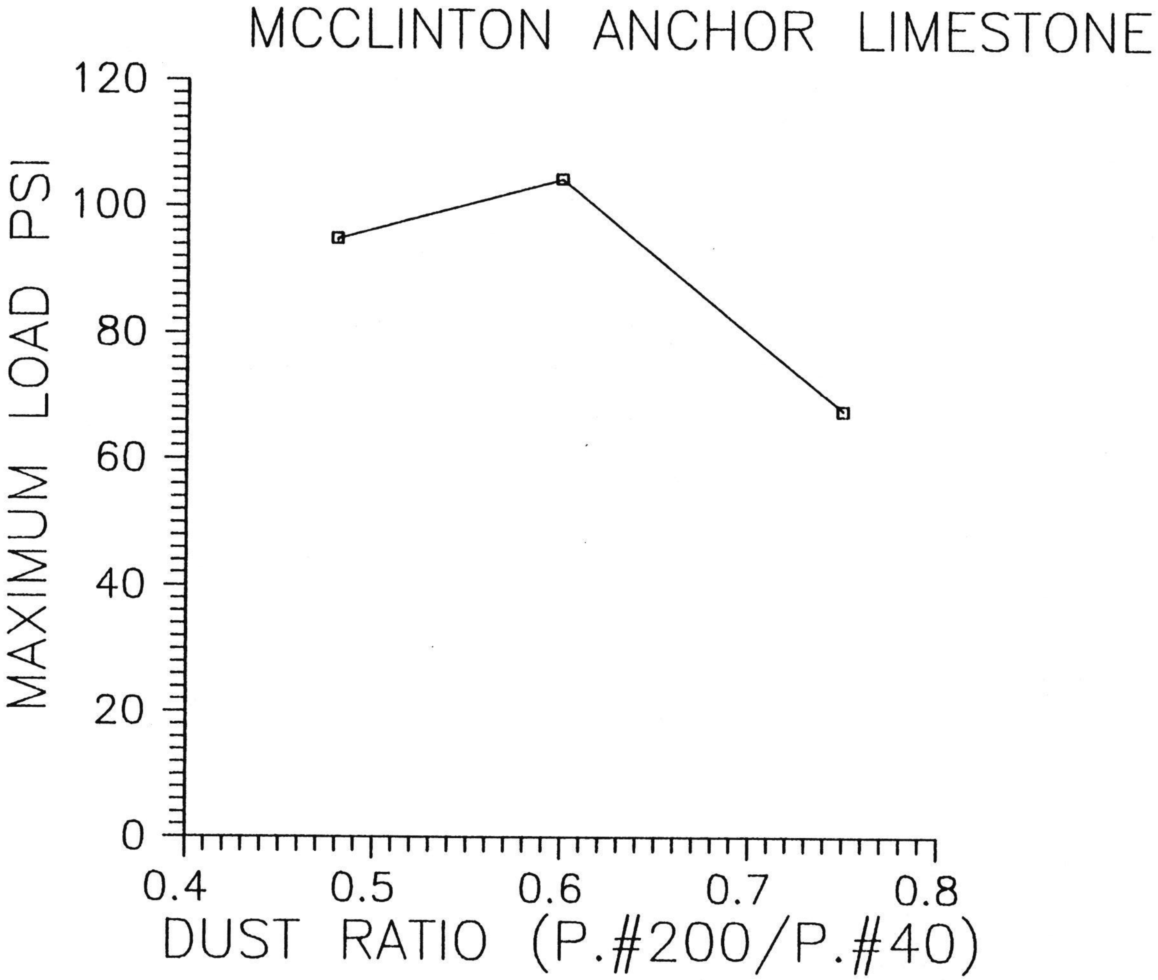

Figure 27. Effect of Dust Ratio on McClinton Anchor Limestone

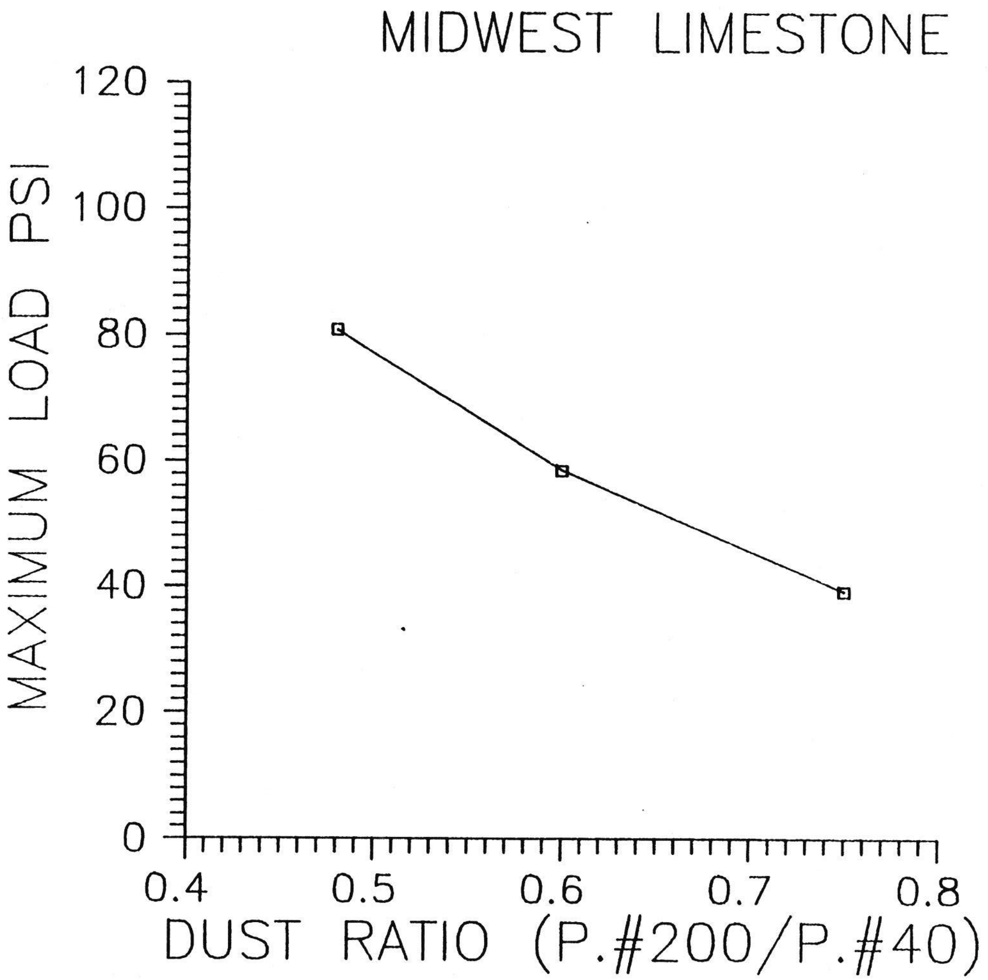

Figure 28. Effect of Dust Ratio on Midwest Limestone

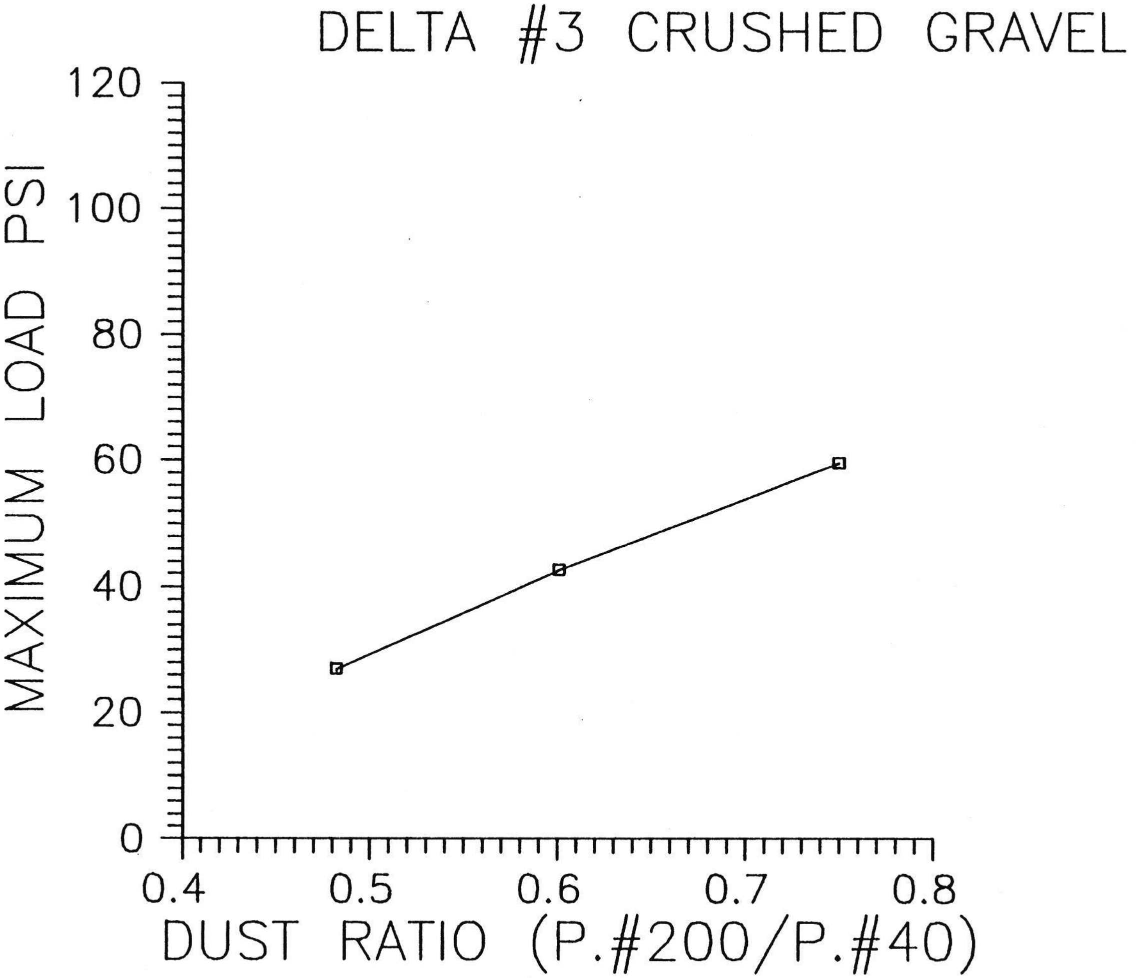

Figure 29. Effect of Dust Ratio on Delta #3 Crushed Gravel

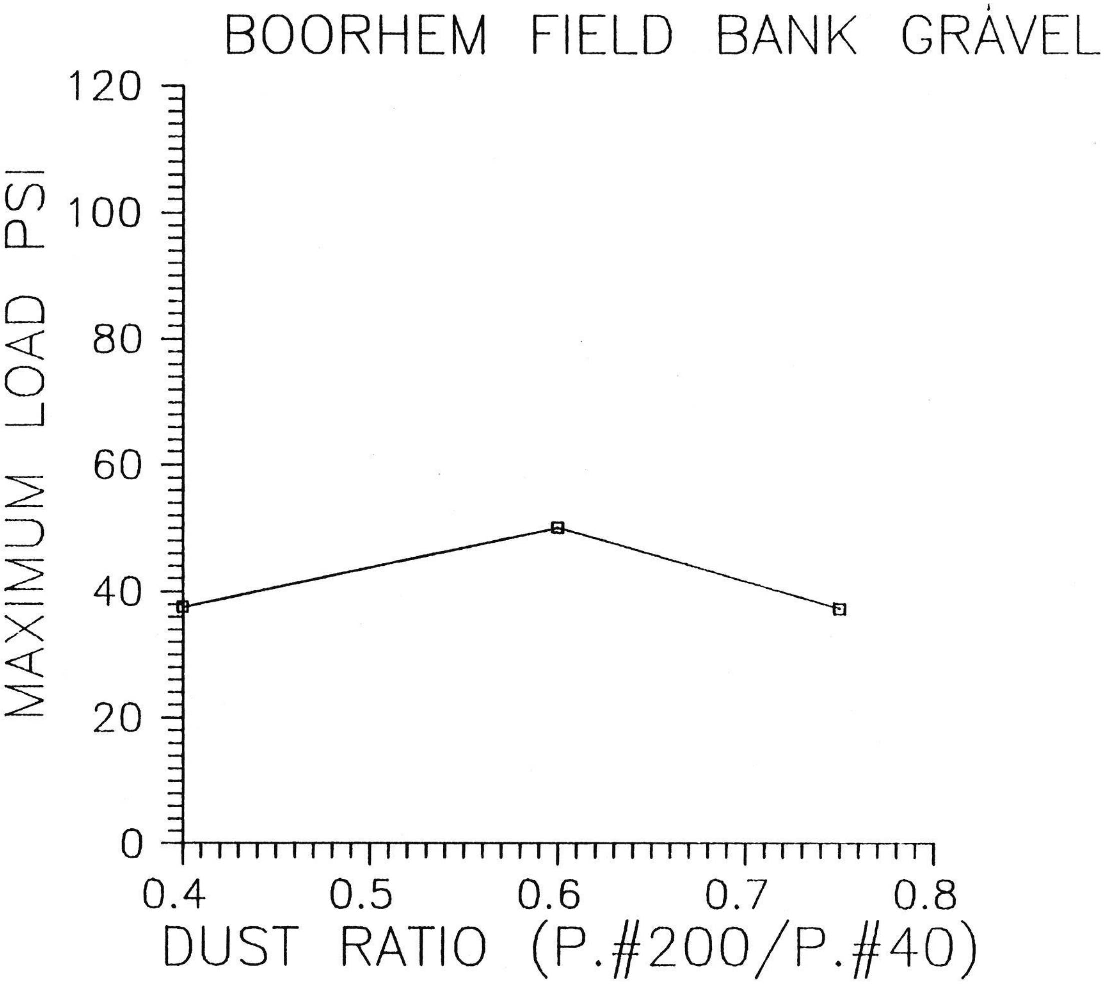

Figure 30. Effect of Dust Ratio on Boorhem Field Bank Gravel

CHAPTER VII

CONCLUSIONS

The following conclusions are based on the findings of the rapid shear strength study of Arkansas aggregates. Other studies are needed to relate rapid shear strength to pavement performance in order to incorporate the findings into pavement design and material specifications.

1. The strength of granular base materials, as measured in rapid shear, decreases with increases in the amount passing the #200 sieve.

2. Decreasing the water content from very wet (near saturation) to optimum water content significantly increases the strength.

3. The relative effect of fines and moisture content is not the same for all materials. For equal strengths, the fines content and moisture content differs from one material to another.

4. The rapid shear strength of 6 of the 8 aggregates was lowest at the highest dust ratio (0.75). However, the significance of this is affected by two facts: 1) that the other 2 aggregates exhibited their highest shear strength at this dust ratio and 2) that target unit weight could not be achieved at this dust ratio.

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