EFFECT OF CHANGES IN GRADATION ON STRENGTH AND UNIT WEIGHT OF CRUSHED STONE BASE

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ABRIDGMENT

•THIS report gives information on the changes in unit weight and strength for a crushed granite base when changes are made in the gradation.

The tests performed included compacted unit weight, CBR, and triaxial shear tests. The results of the tests indicate that crushed granite with a gradation inside the ASTM specification band included in the new ASTM Specification D 2940 71T, Graded Aggregate Material for Bases or Subbases for Highway or Airports, produces satisfactory shear strengths. The shear strength variation for gradations within the specification band was small. The highest shear strength was obtained on specimens conforming to an ASTM down-the-middle gradation. The results tended to show that increasing the percentage of material passing the No. 200 sieve causes a decrease in shear strength. The data appear to confirm the need to limit the percentage passing the No. 200 sieve to less than 10 percent and the percentage passing the No. 4 sieve to less than approximately 50 percent for a 2-in. topsized aggregate. Test results showed that the shear strength, as determined by the California bearing ratio test, was increased by a factor of slightly less than 2 when the compactive effort was increased from AASHO T 99 to AASHO T 180.

LABORATORY WORK

The tests were performed on a granite aggregate having a 2-in. topsize. This aggregate came from the Red Oak, Georgia, quarry owned by Vulcan Materials Company. The material properties as evaluated by the State Highway Department of Georgia using standard GHD test methods were as follows:

Property	Value
Los Angeles abrasion loss, percent	36
Specific gravity	
Bulk	2.64
Sat. surf. dry	2.66
Apparent	2.68
Absorption, percent	0.44
Magnesium sulfate roundness loss, percent	0.53

The initial testing program consisted of performing the standard AASHO T 99 and modified compaction AASHO T 180 tests on specimens with a laboratory-prepared gradation simulating the middle of the ASTM D 2940 71T grading band. CBR and triaxial tests were performed on specimens with this gradation in accordance with ASTM D 1883 and AASHO T 212 respectively. The same tests as mentioned above were performed on various laboratory-prepared gradations simulating a number of gradations meeting and not meeting ASTM and Georgia specifications, as follows:

Sponsored by Committee on Strength and Deformation Characteristics of Pavement Sections.

Gradation	Number
ASTM middle	2-B
ASTM fine	2-C
ASTM coarse	2-D
Georgia fine	2-E
70 percent passing No. 4	2-F
80 percent passing No. 4	2-J
ASTM 0 percent passing No. 200	2-K
ASTM 10 percent passing No. 200	2-L
ASTM 15 percent passing No. 200	2-M
ASTM 20 percent passing No. 200	2-N

Table 1 gives the gradations and the test results.

The gradation of the material was determined after each strength test was performed. The Texas triaxial test was slightly modified by increasing the compactive effort to make it similar to ASTM T 180 compactive effort. When possible, moisture tests were performed on the specimens after each test. The coarse material was very difficult to compact in the mold. Also, the specimens made with the coarse material would not stay together when it was extruded from the compaction cylinder. This was first solved by using rubber membranes. Later, a split cylinder mold was used to solve this problem. Several other changes or innovations or both were made in the laboratory equipment and testing procedures as follows:

1. No capillary pressure was used (1-psi lateral pressure required by AASHO T 212);
2. No capillary surcharge except a porous stone was used;
3. The specimens were compacted with the bottom porous stone in place and in a saturated condition so as not to remove water from the specimen during compaction;
4. Each specimen was prepared individually to conform to the specified gradation for that test; and
5. A 0-psi lateral pressure was used when the specimens were tested, while encased in the Texas triaxial cell, with the air valve open.

An analysis of the unit weights indicates that within the ASTM gradation band, if well-graded aggregates are compared, the unit weight of the gradation down-the-middle of the ASTM grading band is the highest. It also shows that moving to the coarse side of the ASTM gradation band reduces the density.

Attempts to compact samples of aggregates representing smooth gradations or well-graded aggregates outside the ASTM band on the coarse side were not possible because of the coarseness of the material. It is assumed that it would also be extremely difficult to compact such a base in the field. Figure 1 shows what happens to the unit weight of a base if the gradation curve remains parallel to a midpoint gradation but is continuously made finer. The results of the unit weights of the ASTM down-the-middle gradation, with the percentage passing the No. 200 sieve varied, are shown in Figure 2. It shows a distinct increase in unit weight as the percengage of material passing the No. 200 sieve increases. The results show that, if the topsize of an aggregate gradation is held constant and the fines are increased, the unit weight will likewise increase up to some point. This trend changed when the percentage of aggregate passing the No. 200 sieve was increased from 15 to 20 percent. Evidently at this point the fines, after filling all the voids, began to replace the coarse aggregate and thereby reduced the unit weight. The maximum compacted unit weight for the ASTM down-the-middle gradation appears to be its highest when the percentage of material passing the No. 200 sieve is increased to about 15 percent.

The data indicate that, for a gradation simulating ASTM down-the-middle, as material finer than the No. 200 sieve is added, the CBR strength of the material tends to decrease. This is shown in Figure 3.

The down-the-middle ASTM gradation increased from 206 to 377 or about 183 percent when the compaction effort was changed from AASHO T 99 to AASHO T 180. The CBR strength increased as the binder or percentage of material passing the No. 4 sieve

Table 1. Density, CBR, and maximum triaxial shear strength.

Item	ASTM Spec.	2-D	2-B	2-C	2-E	2-F	2-J	2-K	2-L	2-M	2-N
Gradation, cumulative percent passing											
2 in.	100	100	100	100	100	100	100	100	100	100	100
1½ in.	88-100	88.0	94.0	100	95.0	100	100	94.0	94.0	94.0	94.0
¾ in.	60-100	60.0	80.0	100	75.0	100	100	80.0	80.0	80.0	80.0
⅜ in.	40-77	40.0	58.5	77.0	62.5	87.0	89.0	58.5	58.5	58.5	58.5
No. 4	25-60	25.0	42.5	60.0	53.0	70.0	80.0	42.5	42.5	42.5	42.5
No. 10	—	15.0	—	41.0	45.0	51.0	61.0	—	—	—	—
No. 30	7-24	7.0	15.5	24.0	26.0	31.0	41.0	15.5	15.5	15.5	27.0
No. 200	0-10	0.0	5.0	10.0	10.0	13.0	25.0	0.0	10.0	15.0	20.0
Density (AASHO T-180), pcf		136	141[a]	138	139	137	134	142	144	146	142
Solid volume, percent		82	85	84	84	83	82	86	87	88	86
CBR values (AASHO T-180), percent		284	377	301	332	247	207	441	383	368	257
Maximum stress (AASHO T-212 at T-180 compaction), psi[b]											
Normal		146	254	229	217	158	102	159	159	186	125
Shear		68	123	103	104	73	46	74	74	88	57

[a]AASHO T-99 compaction also performed on this gradation resulted in density = 138 pcf; solid volume = 83 percent, and CBR = 206 percent.
[b]At 10-psi lateral pressure.

Figure 1. ASTM gradations parallel to grading bands.

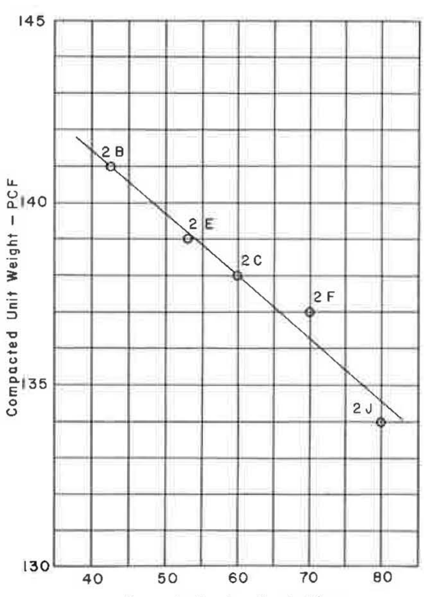


Figure 2. ASTM middle gradation except percentage passing No. 200 sieve.

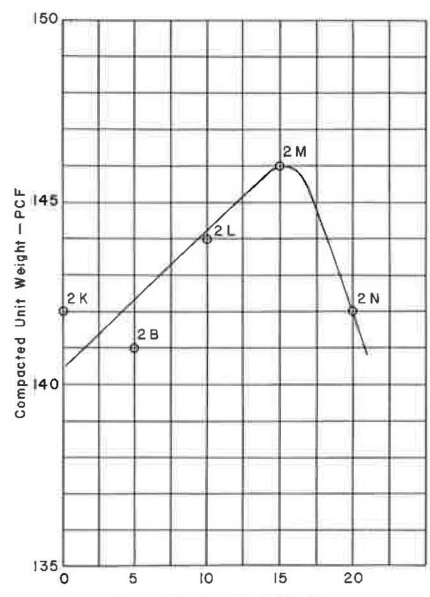


Figure 3. CBR and triaxial shear strengths versus percentage passing No. 200 sieve, ASTM middle gradation.

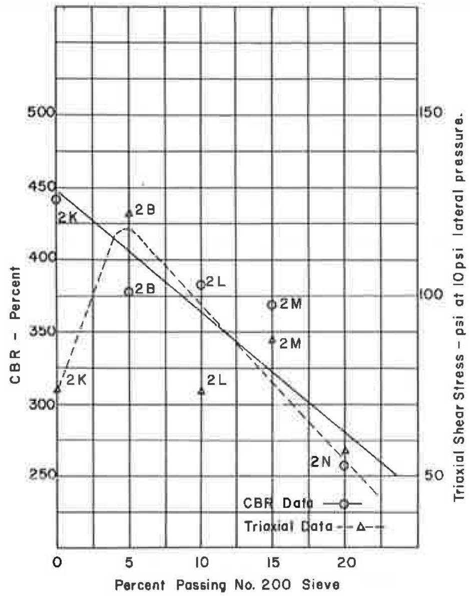
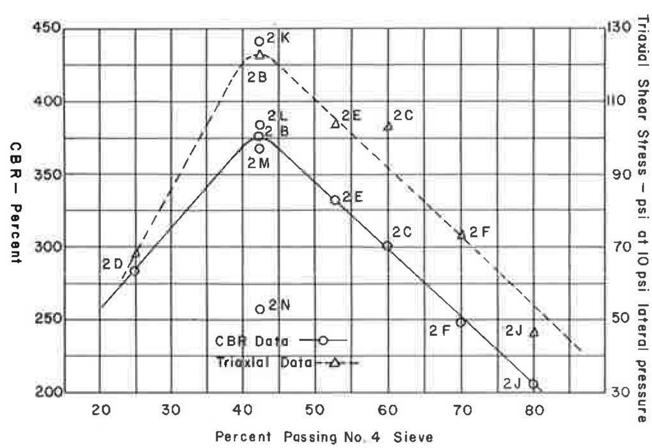


Figure 4. CBR and triaxial shear strengths versus percentage passing No. 4 sieve, all gradations.



went from 25 to 42.5, the midpoint of the ASTM grading band, but then rapidly decreased as the binder was further increased. This is shown in Figure 4.

As expected, the triaxial test results showed that, as the lateral pressure increased, the maximum normal stress, the normal stress at 2 percent strain, and the maximum shear stress all increased. There is a general tendency for the triaxial strength to decrease slightly as the gradation curves move away from the ASTM midpoint. There is also a decrease in triaxial shear strength as the percentage of material passing the No. 200 sieve is increased for a down-the-middle ASTM specification (Fig. 3). There is a more definite trend of the decrease in triaxial strength as the percentage of material passing the No. 4 sieve is increased above the ASTM midpoint gradation of 42.5 percent (Fig. 4).

CONCLUSIONS AND SUGGESTIONS

The results of this research indicate that strengths considered satisfactory by current practice standards were obtained on the crushed stone granite that had gradations within the allowable limits of the new ASTM Specification D 2940 71T.

The midpoint of the ASTM specification appears to produce the highest strengths. The data showed that strengths decrease as the material passing the No. 200 sieve is increased above approximately 5 percent, the ASTM midpoint. The data confirm the limit of 10 percent used by the Corps of Engineers and specified in the ASTM D 2940. (These tests were accomplished by wet sieving.) Material with 40 to 50 percent passing the No. 4 sieve provided maximum strengths for this material. A good target for maximum strength appears to be the midpoint of the ASTM band, 42.5 percent. These suggestions are based on 2-in. topsized aggregate.

Gradations should not be designed for maximum unit weight because, as the fines are increased, the strength of the base may begin to decrease. Maximum laboratory unit weights were obtained when about 15 percent of the material passed the No. 200 sieve.

The results and suggestions given above are based on laboratory prepared and controlled gradations. To help ensure that field gradations simulate laboratory or specified gradations or both, highway departments and material suppliers can develop a statistical quality control program with the objective of establishing the accurate job mix tolerances. The strength of a stone base is highly dependent on its state of compaction, which can be accurately controlled and measured only when a consistent gradation is utilized.

The degree of compactive effort used on a base is very important to its strength. Increasing the compactive effort from AASHO T 99 to AASHO T 180 almost doubled the CBR strength for the material being tested. It is suggested that all crushed stone bases be compacted to the maximum possible density with 100 percent of AASHO T 180 set as a minimum acceptable value.

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