SHEAR STRENGTH OF SURFACE-MINE SPOILS MEASURED BY TRIAXIAL AND DIRECT SHEAR METHODS

by Michael J. Superfesky and George P. Williams, Jr.

FOREST SERVICE GENERAL TECHNICAL REPORT NE-39
1978
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
NORTHEASTERN FOREST EXPERIMENT STATION
370 REED ROAD, BROOMALL, PA. 19008

THE AUTHORS

MICHAEL J. SUPERFESKY received B.S. and M.S. degrees in civil engineering from West Virginia University in 1967 and 1968, respectively. He joined the U.S. Forest Service as a Civil Engineer at the Monongahela National Forest, Elkins, West Virginia, from 1968 to 1973, and served as a Research Civil Engineer at the Forest Products Laboratory, Madison, Wisconsin, from 1973 to 1976. Currently, he is a Research Civil Engineer at the Northeastern Forest Experiment Station's Surface-Mined Area Reclamation Research Project at Berea, Kentucky.

GEORGE P. WILLIAMS, JR., who received a B.S. degree from North Carolina University in 1960, joined the Forest Service in 1962 as a Civil Engineer at the North Carolina National Forest, Asheville, N.C. He later worked on the Lincoln National Forest, Alamogordo, N.M., and on the Carson National Forest in Taos, N.M. Since 1966 he has worked as a Research Civil Engineer at the Northeastern Station's Surface- Mined Area Reclamation Research Project at Berea.

MANUSCRIPT RECEIVED FOR PUBLICATION 25 AUGUST 1977

ABSTRACT

Results of measurements of seven surface-mine spoils by triaxial and direct shear methods indicated that the direct shear method may be used for evaluating the shear strength parameters of surface-mine spoils. The average angle of internal friction determined by direct shear testing was 38.6°; the average value for the triaxial method was 33.4°. The average value of cohesion determined by direct shear testing of dry materials was .077 bar; the average value of cohesion determined for the triaxial method was .100 bar.

Soaking specimens immediately before direct shear testing reduced the average angle of internal friction by 8.2°; there was no significant change in cohesion. The methods used to sample, blend materials, and prepare specimens caused two distinct populations for triaxial test results. The ratio of freshly crushed materials to weathered materials in a specimen affected triaxial results more than direct shear results.

INTRODUCTION

THE STABILITY of outslopes, head-of-hollow fills, and other embankments associated with surface mining depends on the shear strength of the spoil materials that comprise these structures. A knowledge of the shear strength parameters—cohesion and the angle of internal friction—is necessary to analyze and design embankments that are compatible with reclamation goals. But the variety of geologic materials produced during a mining operation indicates that considerable testing also is required to describe these parameters adequately.

The prinicipal methods for measuring the shear strength of soils in the laboratory are the direct shear test and the triaxial test. The triaxial shear test consists of confining a cylindrical soil sample in a rubber membrane under fluid pressure, and then applying an axial compressive load (Fig. 1). The confining pressure, axial deformation, axial stress, and water pressure (pore pressure) are then measured. These measurements are used to determine the shear strength parameters.

The direct shear test consists of confining a thin sample of material between parallel blocks, applying a normal load, and shearing it along a predetermined plane (Fig. 2). The normal stress and the maximum shearing stress are used to determine cohesion and the angle of internal friction.

Each method has advantages and limitations. The more sophisticated triaxial shear test is more difficult to perform and interpret; however, it allows better simulation of field conditions. The advantages of the direct shear method are that the test apparatus is less complicated, and the test is

Figure 1.—Schematic of triaxial test apparatus (from Lambe and Whitman 1969).

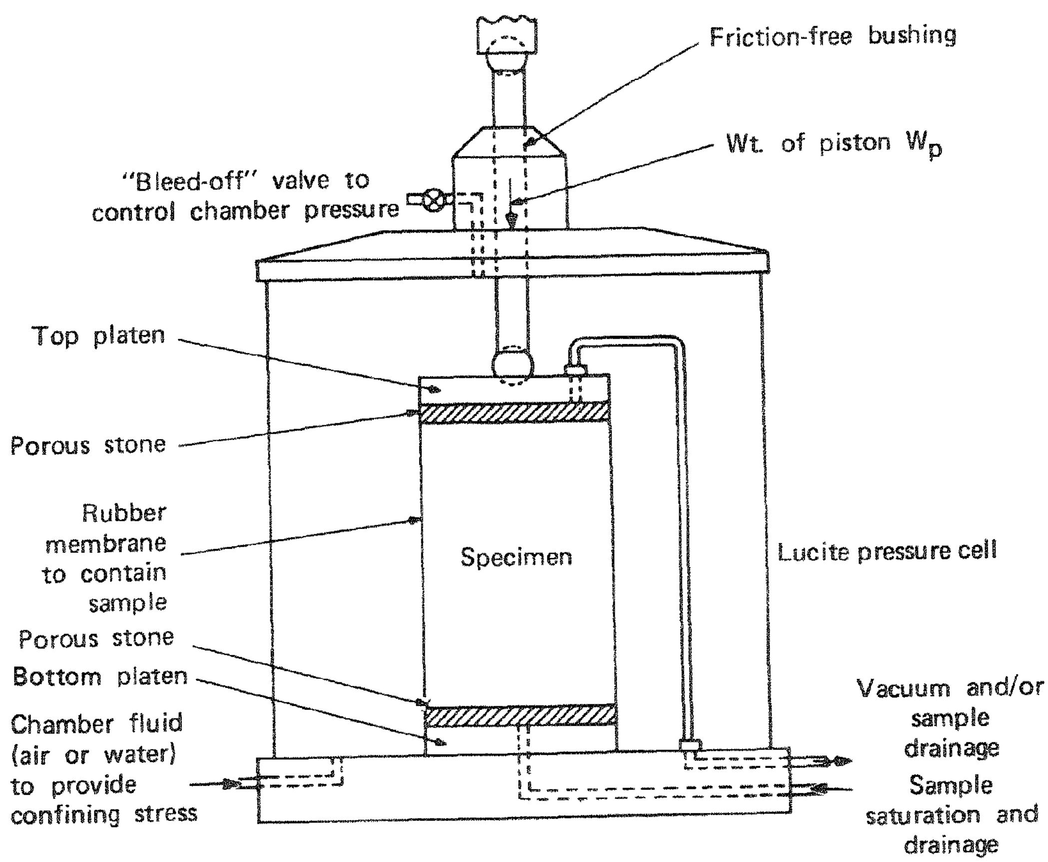
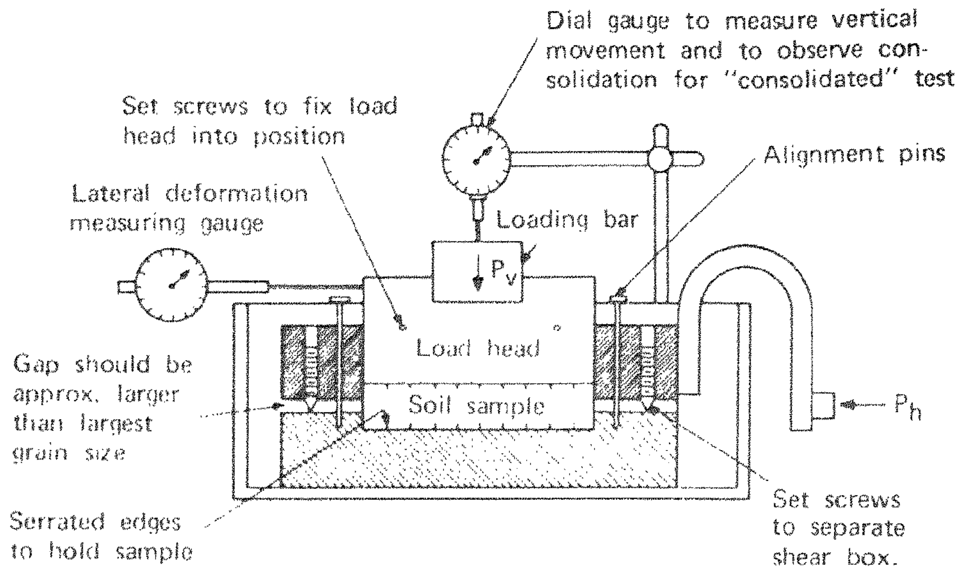


Figure 2.—Schematic of direct shear test apparatus (from Lambe and Whitman 1969).



less time consuming. Although the direct shear test imposes boundary conditions that seldom exist in the field, this method provides a good indication of the shear strength of many soils (Bowles 1970).

Because of the variety of surface-mine spoil materials to be investigated, direct shear testing seems more desirable than triaxial testing for characterizing shear strength parameters. However the user of the direct shear method must demonstrate how direct shear results compare with triaxial results. This paper evaluates the shear strength parameters of seven surface-mine spoil materials measured by triaxial and direct shear methods. In the direct shear tests, both dry and moist specimens were tested.

MATERIALS AND METHODS

The seven spoil materials used in direct shear tests were the same as those that had previously been measured by triaxial methods (Drnevich et al. 1976). Descriptions and classes (according to the Unified Classification System) of Materials G, H, I, J, MS1, MS2, and MS3 are listed in Table 1. Materials G, H, I, J, and MS1 were blends of equal proportions (by dry weight) of three of the following: an acid shale, a siltstone, a sandstone, and a calcareous shale. All materials were obtained from surface mines in eastern Kentucky. Except for the 1-day-old sandstone spoil, all were obtained from talus at the foot of highwalls, where mining had been terminated 12 to 18 months earlier.

The calcareous shale was dark gray, soft, and contained many fine grains of iron oxides. The approximate mineral composition was: quartz: 66 percent; illite: 19 percent; and kaolinite plus chlorite: 15 percent. There were traces of feldspars. The siltstone was yellowish gray, soft, and had iron oxide bands that contained sand grains. The approximate mineral composition was: quartz: 36 percent; illite: 36 percent; plagioclase feldspar: 20 percent; and kaolinite: 7 percent. There were traces of K-feldspars. The sandstone was hard, light gray, and contained abundant limonitic flecks. Quartz made up 86 percent of the rock. Minor constitutents were: K-feldspars: 3 percent; plagioclase feldspar: 2 percent; kaolinite: 5 percent; and illite: 4 percent. The acid shale was dark gray and was slightly silty and micaceous. Quartz made up 50 percent of this rock; the re-

Table 1.—Description and class (by Unified Soil Classification) of spoil materials

Spoil material	Description	Triaxial shear		Direct shear	
		As tested	After test	As received	As tested
G	1/3 sandstone, 1/3 siltstone, and 1/3 acid shale	SP-SC[a]	—	SP	SP
H	1/3 sandstone, 1/3 siltstone, and 1/3 calcareous shale	SW-SM[a] or SP SM		SW	SW
I	1/3 sandstone, 1/3 acid shale, and 1/3 calcareous shale	SP SC[a]	—	SP	SP
J	1/3 siltstone, 1/3 acid shale & 1/3 calcareous shale	SP-SC[a]	—	SP	SP
MS 1	Similar to J but different batch and gradation	GW[a]	SW	SW	SW
MS 2	Shale from 10-foot thick stratum	GW	SW	SW	SW
MS 3	Sands and silty shales from several overburden strata; as blended during mining and grading operations	SP	SP-SM	SP	SP

[a] From composite of constituents

mainder was illite: 20 percent; K-feldspars: 5 percent; plagioclase feldspar: 7.5 percent; kaolinite plus chlorite: 11.5 percent; and pyrite: 3 percent.

Material MS1 had the same composition as material J, but differed in the distribution of particle sizes. MS2 was a light brown to light gray shale that had been obtained from a 10-foot (3.05-m) thick stratum in Breathitt County, Kentucky. The stratum had been exposed for about 6 months when sampled. MS3, obtained from a spoil bench at the same location, was a mixture of shale and sandstone spoils developed from all strata disturbed by mining activities at that Breathitt County site.

The largest size of particles of materials tested in triaxial shear tests was ¾ inch (19.1 mm). Larger particles are likely to cause errors in test results due to bridging between adjacent particles and direct interaction with the test apparatus. For Materials G, H, I, and J, particles that remained on a ¾-inch sieve were wasted. For Materials MS1, MS2, and MS3, particles that remained on the ¾-inch sieve were passed through a ¾-inch crusher. The crushed particles that passed through the ¾-inch sieve but that remained on a No. 4 sieve (4.76-mm openings) were blended into the test material. Figure 3 is a diagram of the crushing and blending procedures for triaxial and direct shear testing.

The maximum particle size that could be accommodated by the 4-inch (10.16-cm) diameter direct shear box used in this study was approximately ¼ inch (6.4 mm) (Bowles 1970). So, for the direct shear tests, material that remained on the No. 4 sieve was passed through a crusher with a 5-mm opening. The crushed material that passed through the No. 4 sieve but that remained on a No. 10 sieve (2-mm openings) was blended into the test material (Fig. 3). Percentages of freshly crushed particles incorporated into each spoil material are listed in Table 2.

Table 2.—Percentages of freshly crushed particles in blended test materials

Spoil material	Triaxial	Direct shear
G	0	18
H	0	12.5
I	0	23.2
J	0	18
MS1	25	48.1
MS2	15	35.8
MS3	15	24.4

The time between the triaxial and direct shear tests was approximately 1 year for Materials MS1, MS2, and MS3, and about 2 years for Materials G, H, I, and J. During storage, all materials were sealed in plastic bags. At the beginning of storage, the moisture contents of six of the spoil materials approximated those of the samples prepared for triaxial tests. Moisture contents averaged 13.8 percent and ranged from 13.4 to 14.2 percent. All of Material MS1 used during direct shear testing was taken from previously tested triaxial specimens. The average moisture content of MS1 triaxial specimens at failure was 14.4 percent.

The distribution of particle sizes for the seven materials is shown in Figures 4 through 10. Six of the charts show four distributions: as sampled, as tested in triaxial shear, as received for direct shear tests, and as tested in direct shear. For MS1, there is a fifth distribution that represents a sieve analysis that was done immediately after the triaxial tests.

All material ¾ inch or larger was removed in preparing triaxial samples. The same batches were used for direct shear tests, so direct shear samples did not include material larger than ¾ inch before crushing.

Triaxial shear testing

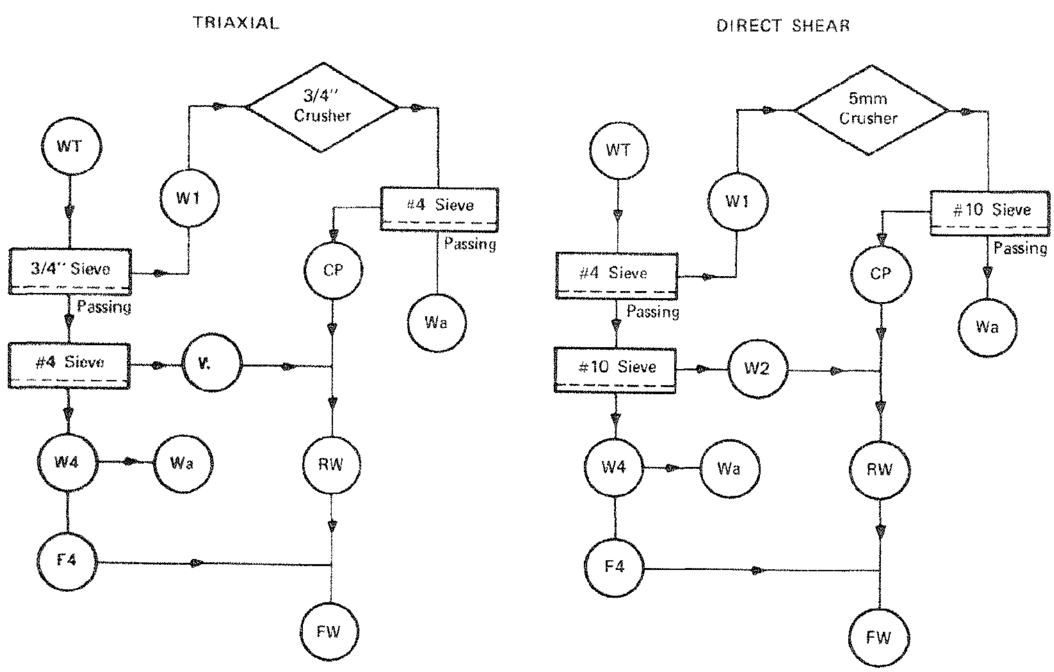
The shear strength parameters can be described in terms of effective stress or total stress. Effective stress is the stress carried by the soil particles. Effective-stress analysis is used whenever stable conditions have existed over a long period and pore pressure can be assumed to have dissipated (U. S. Department of the Navy 1971). Total-stress analysis is usually used to simulate conditions of stability immediately after construction or if pore pressures have not dissipated or are not known.

The triaxial shear test apparatus allows measurements for a variety of degrees of confinement, consolidation, and drainage. Triaxial data were obtained from consolidated-undrained tests. Specimens from Materials G, H, I, and J were 4 inches in diameter by 8 inches (20.32 cm) and were compacted to a maximum dry density at optimum moisture content in accordance with American Society for Testing and Materials D-698-7 (Method D) (ASTM 1976). After compacting but before testing, the void spaces were saturated. Effective confining stresses of 1.03, 2.07, and 4.14 bars were used to simulate stresses at different depths within a spoil bank. Each test was conducted three times on similar specimens.

Specimens of Materials MS1, MS2, and MS3 were compacted by three methods: standard, modified, and low-energy compaction (Drnevich 1976). Specimens were 4 inches in diameter by 8 inches and were saturated before testing. Twelve specimens from each material group were tested using effective confining stresses of 1.03 and 4.14 bars. During all tests, drainage from the speci-

Text continues on page 12.

Figure 3.—Diagram of crushing and blending procedures for triaxial and direct shear testing.



Initial total sample = WT
Final total sample = FW
Initial ratio of gravels to fines (constant) = $\frac{W1 + W2}{W4}$ = RI
Waste = Wa
Amount of W4 to be used = F4
Amount of crushed particles > small sieve opening = CP
New amount > small sieve opening = W2 + CP = RW

To maintain RI after crushing, the amount of fines must be reduced to compensate for material wasted in the crushing process. The amount of W4 to be used is calculated by the following:

$$RI = \frac{RW}{F4} \longrightarrow F4 = \frac{RW}{RI}$$

Figure 4.—Distribution of particle sizes for Material G.

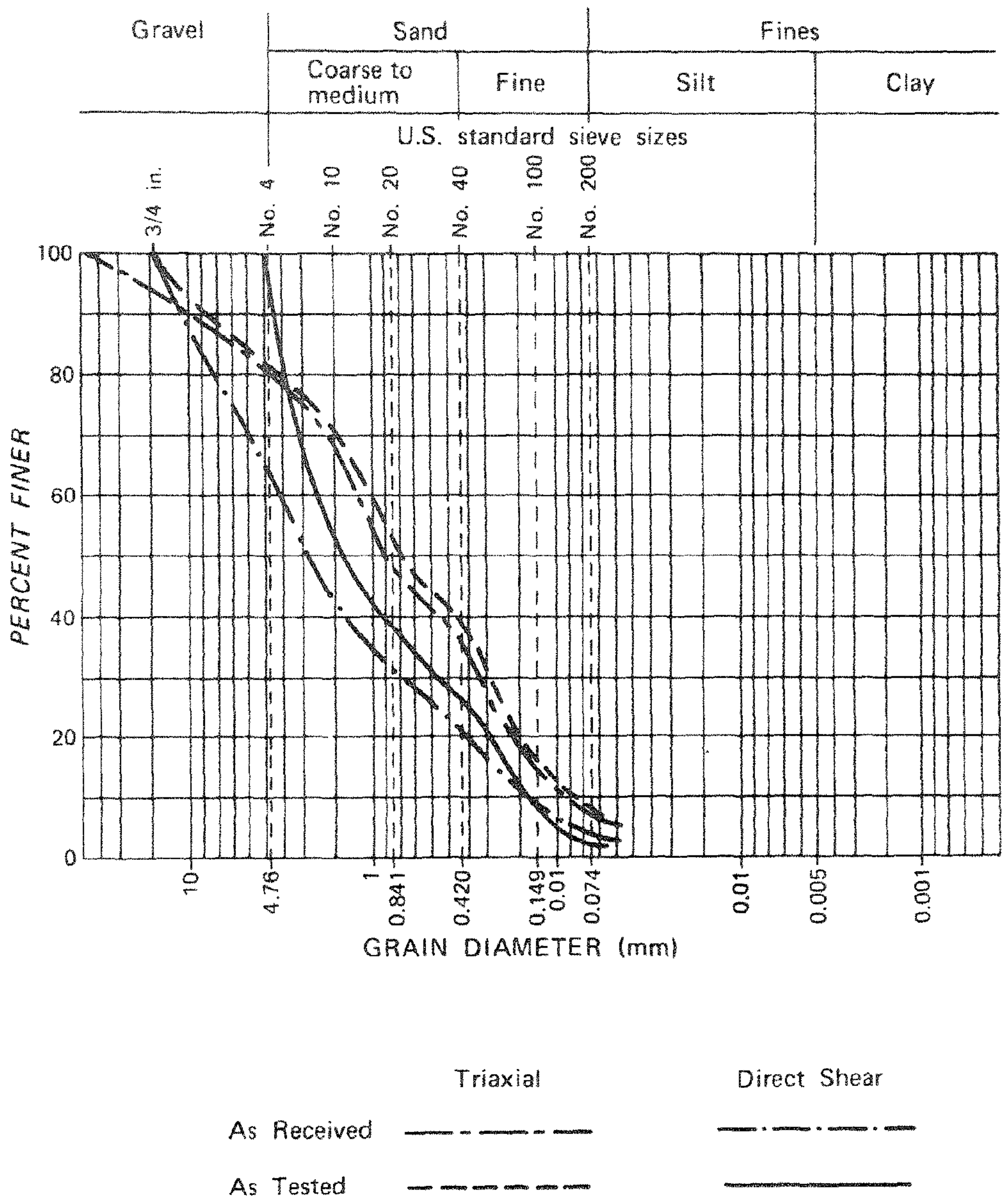


Figure 5.—Distribution of particle sizes for Material H.

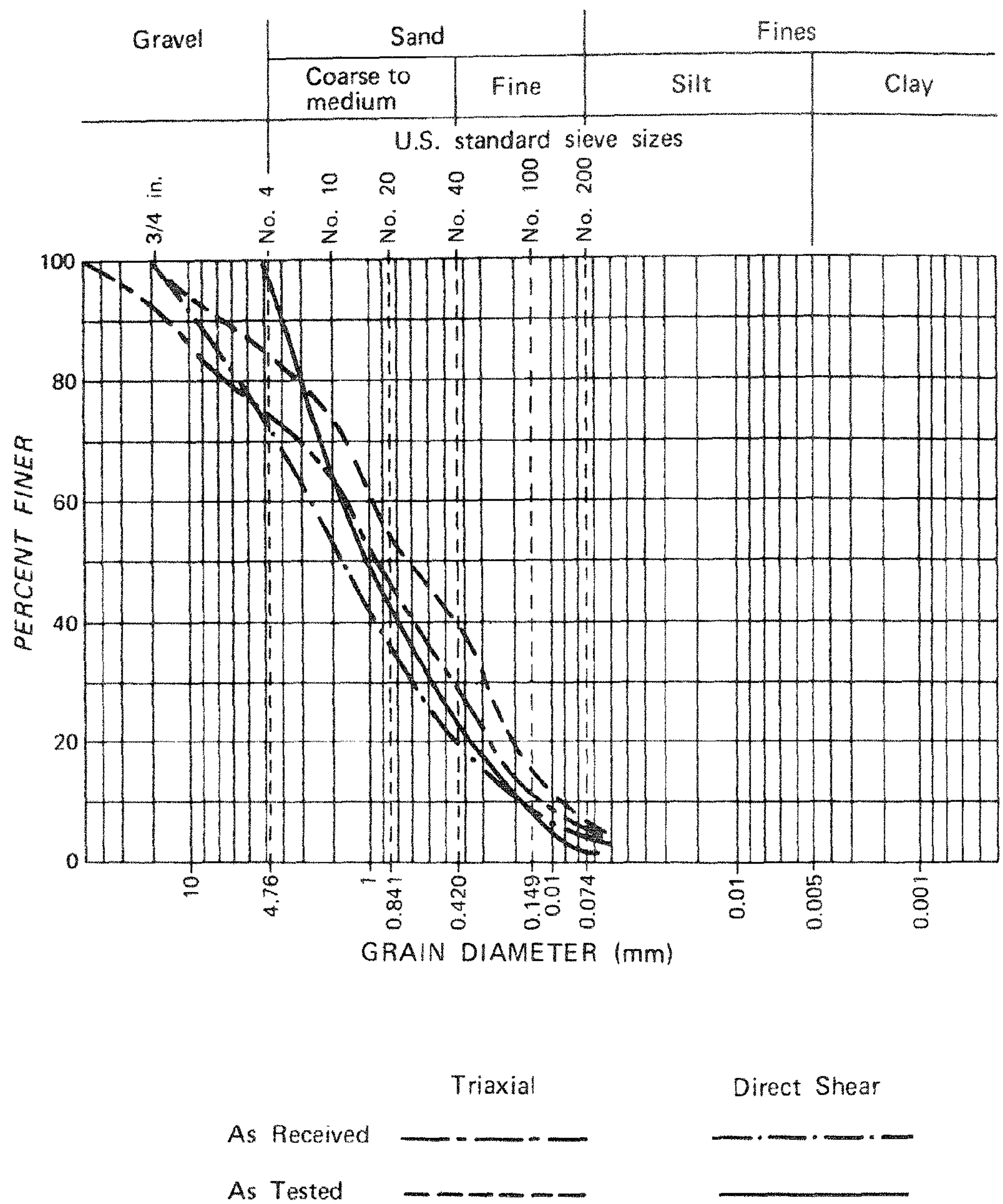


Figure 6.—Distribution of particle sizes for Material I.

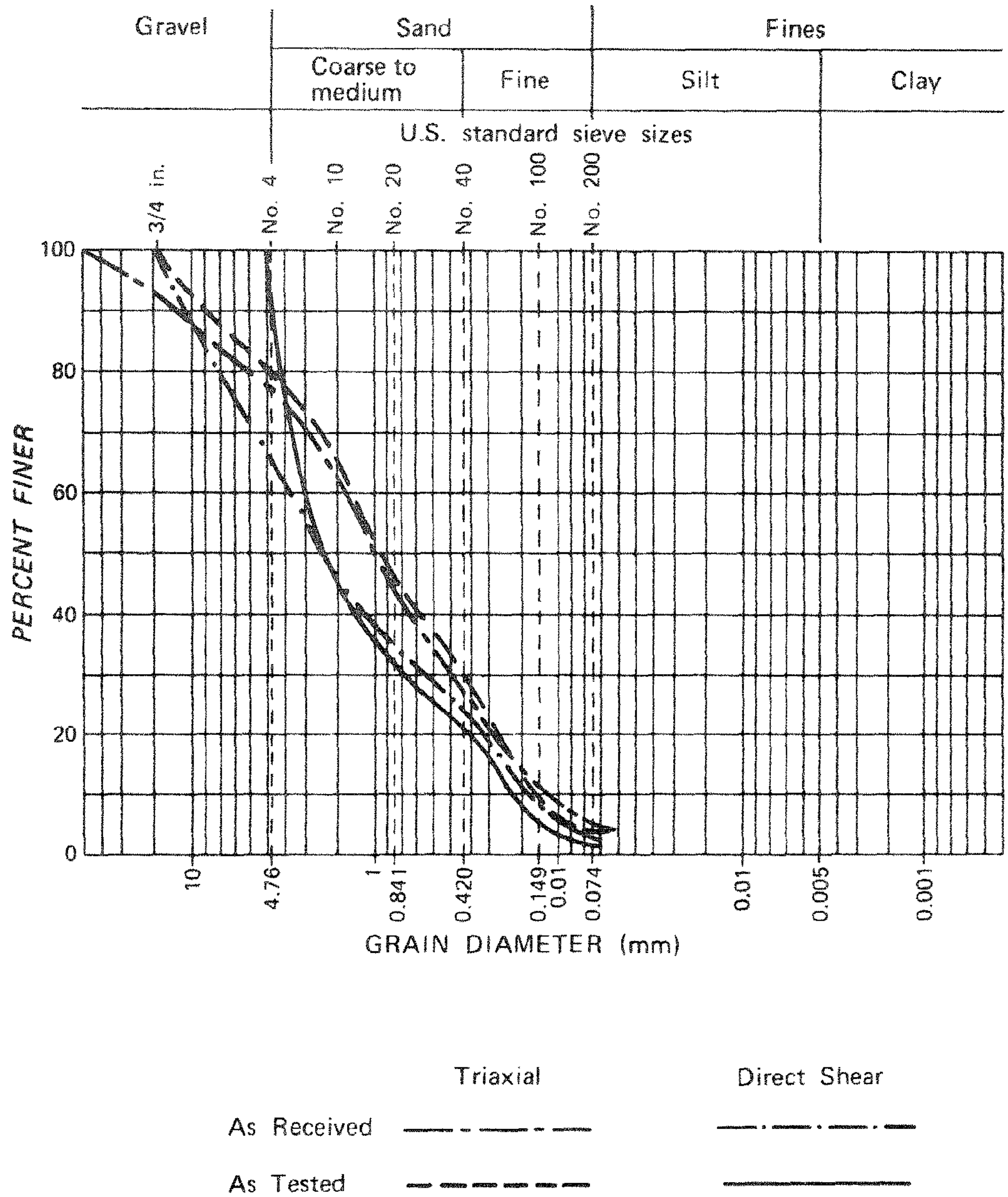


Figure 7.—Distribution of particle sizes for Material J.

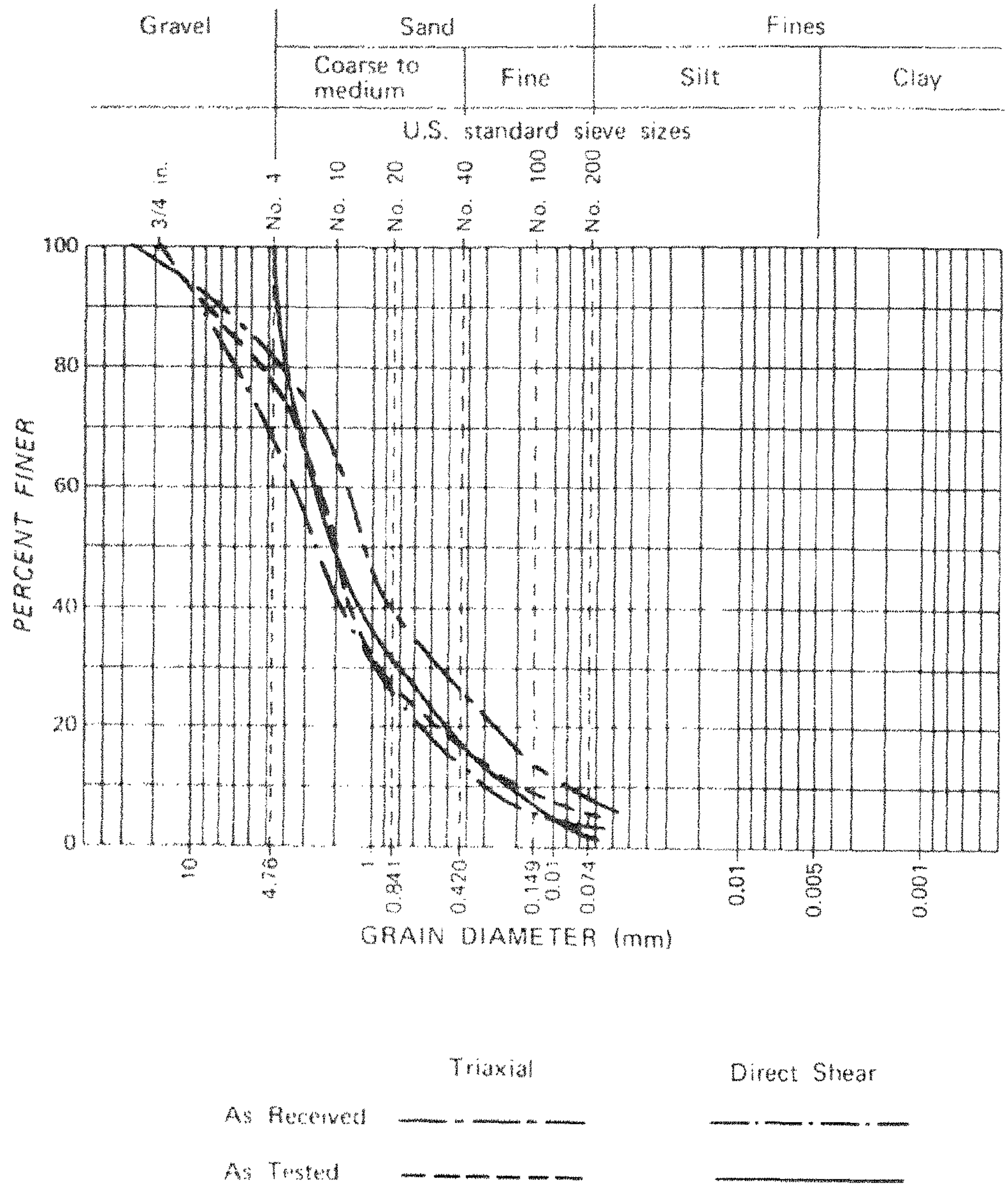


Figure 8.—Distribution of particle sizes for Material MS1.

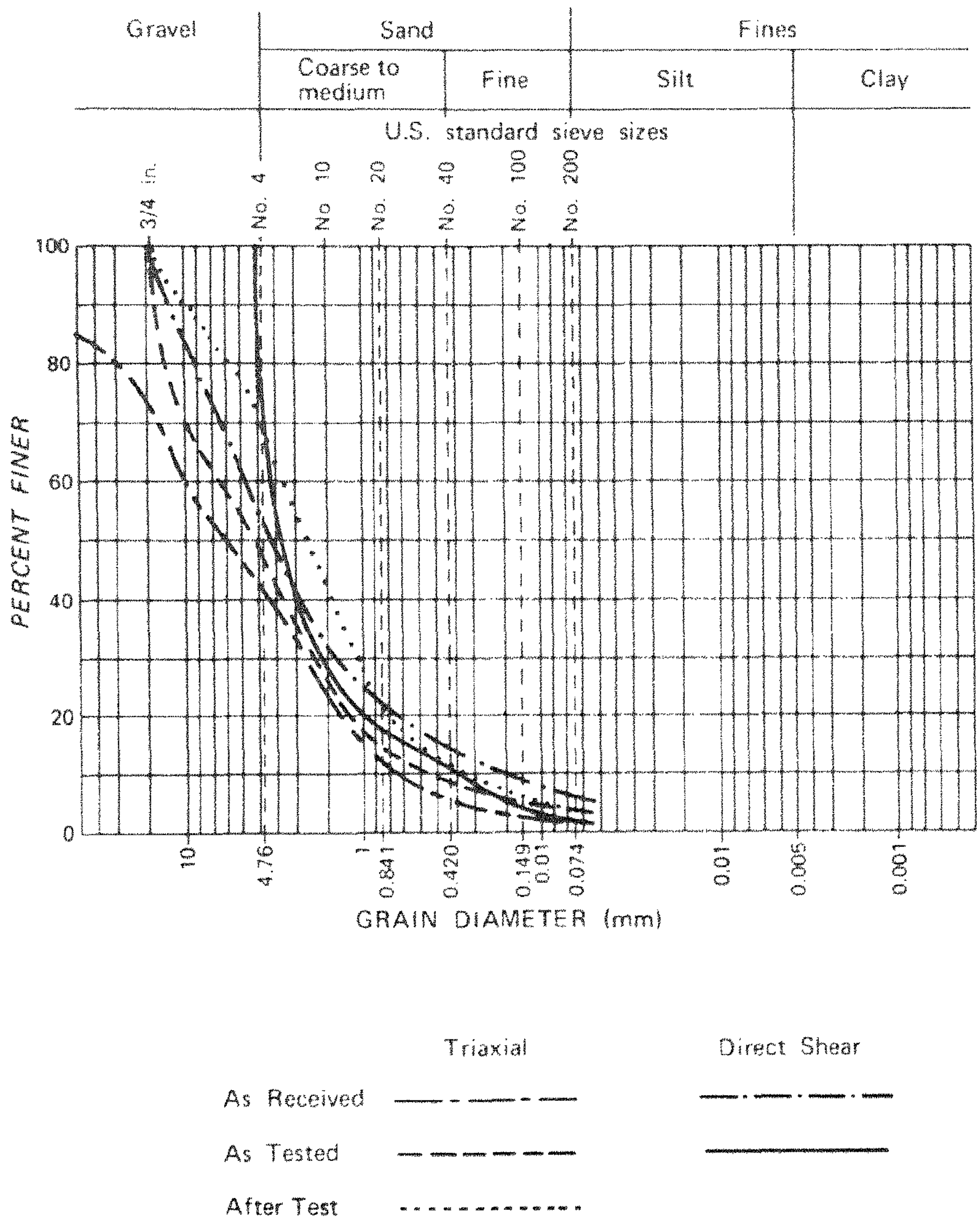


Figure 9.—Distribution of particle sizes for Material MS2.

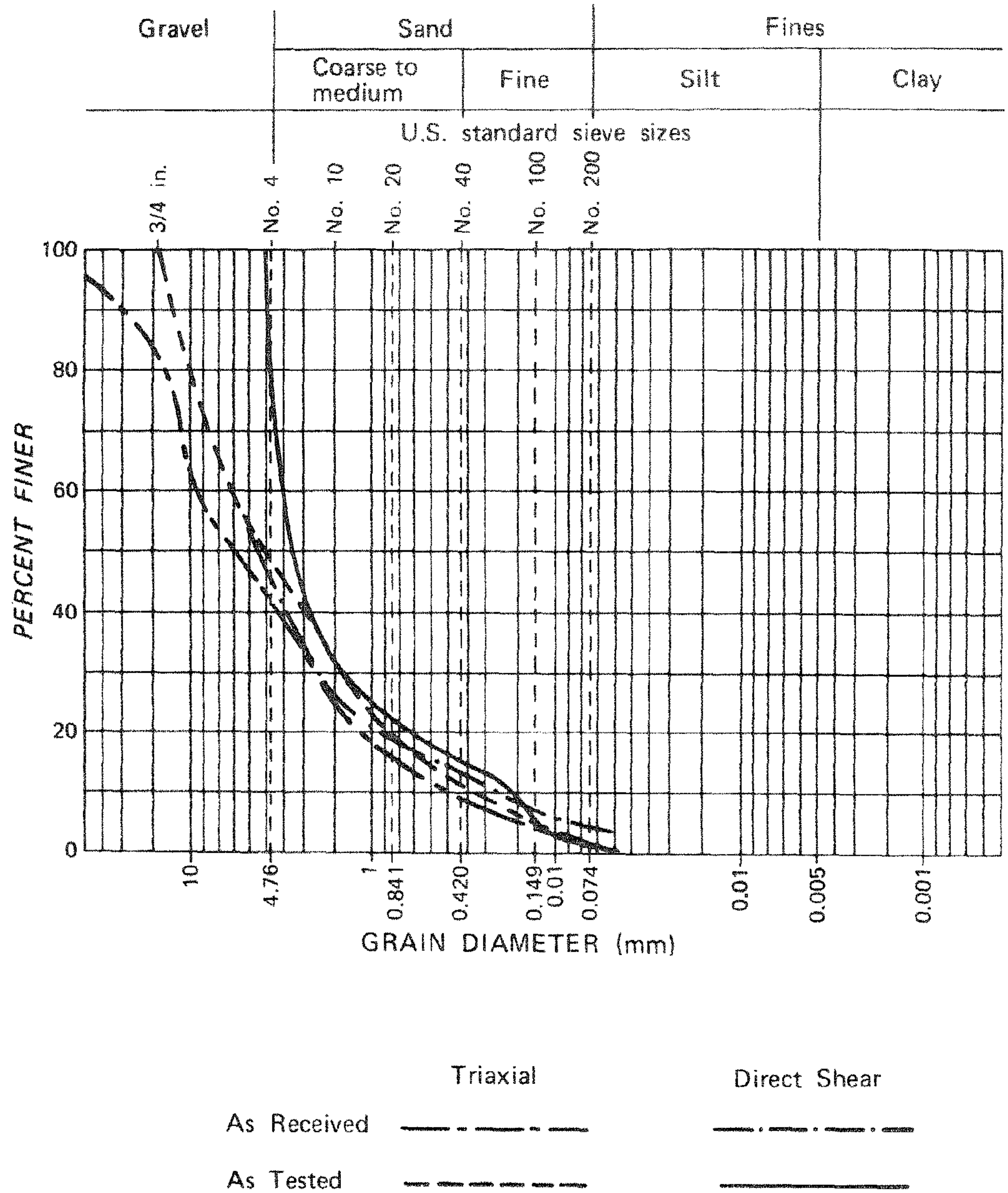
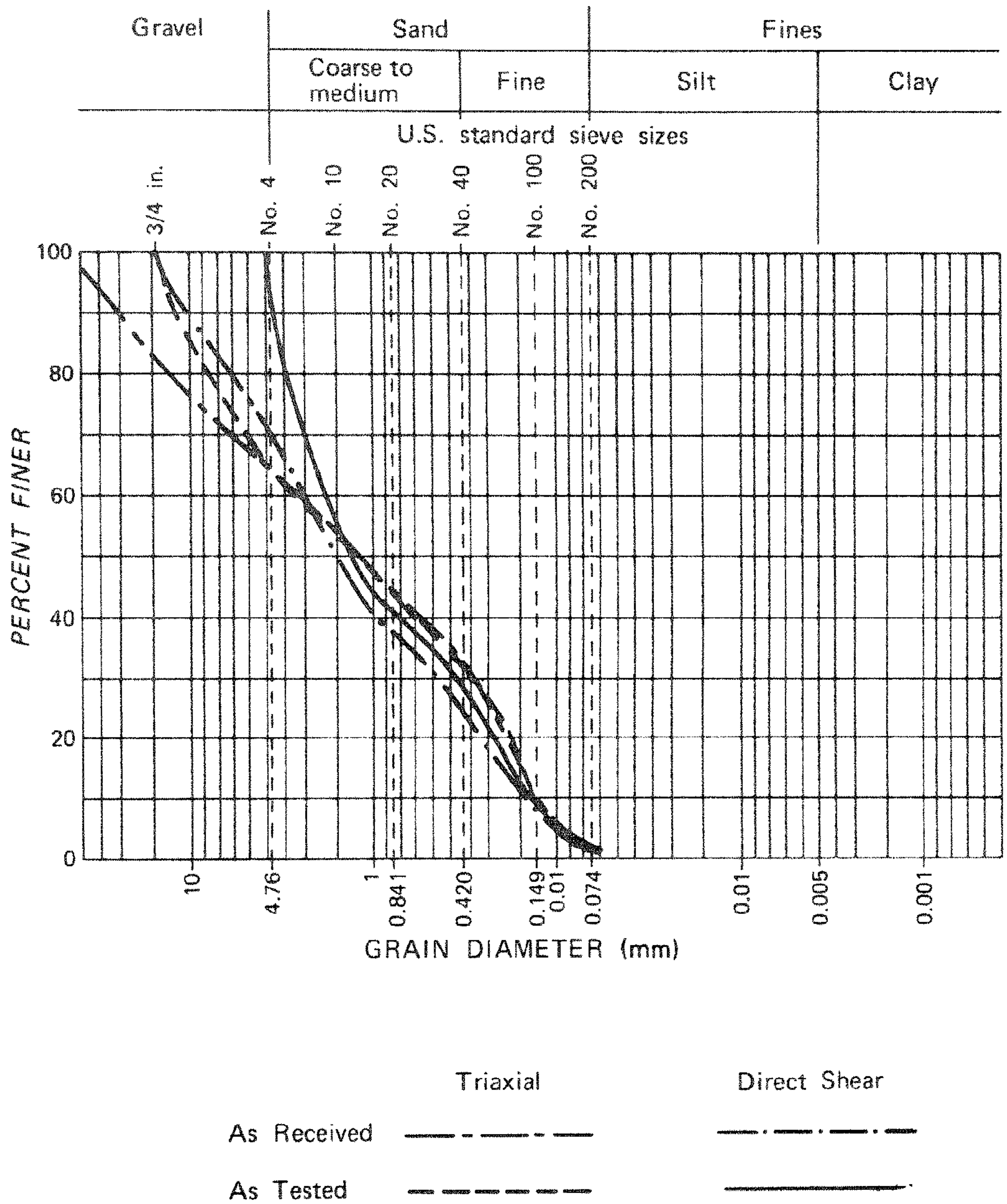


Figure 10.—Distribution of particle sizes for Material MS3.



mens was prohibited and pore pressures were monitored.

Direct shear testing

Direct shear tests were conducted at a constant rate of strain on both wet and dry samples. In the dry test, the shear box was filled to about 3/16 inch (4.76 mm) of the top with uncompacted, oven-dried material. Specimens were about 1-inch thick and 4 inches in diameter. Normal stresses of .46, 1.07, and 1.67 bars were applied and each specimen was sheared at a rate of 0.048 inch (1.22 mm) per minute. All direct shear specimens failed 5 to 10 minutes after loading. Shearing force and horizontal displacement were measured during each test.

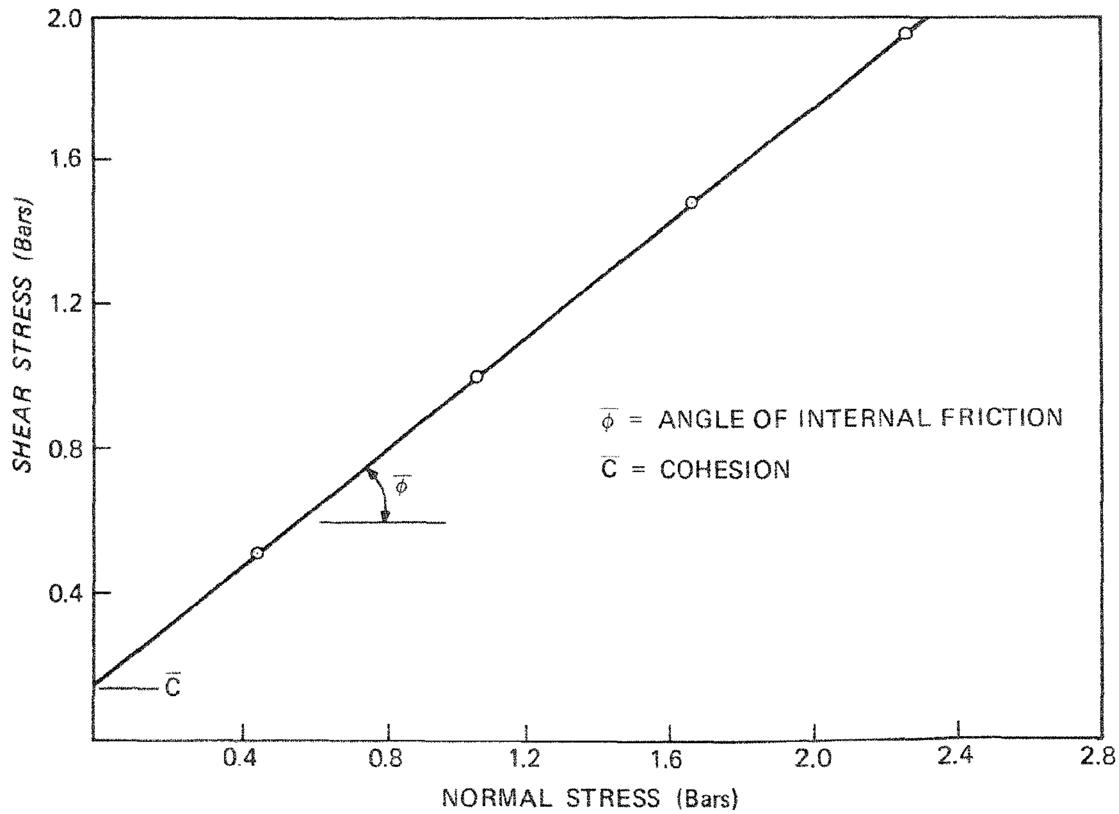
Wet tests were conducted by the same procedures except that after placing the material in the shear box, a piece of filter paper was placed on the top of the soil and 125 ml of water were poured over the paper. After 15 minutes, the normal stress was applied. After each test, the moisture content of the wet specimen was determined.

All direct shear parameters were based on three tests, each conducted at a different normal stress. To determine if a test result could be reproduced, each set of three dry tests was repeated for Materials G, H, I, and J. The results of these tests correlated well with those of the initial tests. Typical direct shear test results are shown in Figure 11.

RESULTS

The effective angle of internal friction ($\bar{\phi}$) and effective cohesion ($\bar{C}$), for triaxial and direct shear tests are presented in Table 3. The direct shear tests on dry material yielded a greater value of $\bar{\phi}$ than the triaxial tests for each of the spoil materials except MS3. The average value of $\bar{\phi}$ determined by the direct shear method was 38.6°; the average

Figure 11.—Typical direct shear test results.



value for the seven materials determined by the triaxial method was 33.4°. The average value of $\bar{C}$ determined by direct shear testing of dry materials was .077 bar; the average value of $\bar{C}$ determined by triaxial testing was .100 bar.

Triaxial results varied considerably more than direct shear results. The coefficient of variation of ϕ for the triaxial tests was 12.6 percent compared to 2.1 percent for direct shear results. The coefficient of variation of $\bar{C}$ was 87.4 percent for the triaxial method and 65.6 percent for the direct shear method. For all seven materials, the average value of $\bar{\phi}$ for the direct shear method exceeded by 5.2° the average value determined for the triaxial method. A paired t test indicated that the 95 percent confidence interval for the mean difference is 1.3 to 9.1°. However when only materials MS1, MS2, and MS were considered, there was no significant difference between the $\bar{\phi}$ values for the triaxial method and those for the direct shear method.

Values of $\bar{C}$ ranged from .200 to 0 bar for the triaxial tests, and from .146 to 0 bar for direct shear testing of dry materials. The average value of $\bar{C}$ for the direct shear method was .077 bar with a coefficient of variation of 65.6 percent. The average value of $\bar{C}$ for the triaxial method was .100 bar with a coefficient of variation of 87.4 percent. There was no significant difference between the means of triaxial and direct shear $\bar{C}$ values at the 95 percent confidence level.

For the spoil materials tested, the triaxial results strongly indicated the presence of two populations (Table 3). Analysis of data substantiated the finding that triaxial shear strength parameters for Materials G, H, I and J (group 1) differed significantly from those of Materials MS1, MS2, and MS3 (group 2). This is somewhat contrary to the fact that Material J from group 1 and Material MS1 from group 2 were from the same source; that is, they were from the same field sample. However the preparation procedures for Material J (and other materials in group 1) differed from those for Material MS1 (and other materials in group 2).

In preparing Materials G, H, I and J for triaxial testing, all spoil particles larger than ¾ inch were wasted. For materials MS1, MS2, and MS3, the larger particles were crushed and blended with the smaller particles. Also, Materials, G, H, I, and J had been subjected to 12 to 18 months of field weathering, while Materials MS2 and MS3 experienced very little weathering. These differences are also indicated by the Unified Soil Classification of the two groups. All "as tested" group 1 materials were classified as poorly graded sands (SP-SM or SP-SC); "as tested" group 2 materials were classified as well-graded gravels or poorly graded sands (GW and SP) (Table 1).

All "as tested" direct shear specimens were classified as poorly graded sands (SP) or well-graded sands (SW). Analysis of direct shear data indicated that the materials represented a single population, in spite of the fact that the amount of freshly crushed particles ranged from 12.5 percent for Material H to 48.1 percent for Material MS1. Therefore it seems that the ratio of freshly crushed materials to weathered materials in a specimen has a greater effect on triaxial results than on direct shear results.

The separation of the triaxial results into two distinct populations, and the better correlation of triaxial results and direct shear results for Materials MS1, MS2, and MS3 may have been due to the use of different methods for molding and compacting specimens. In all direct shear tests, materials were placed in the shear box in a loose, uncompacted state; but the triaxial tests were performed on materials compacted to different densities.

Triaxial specimens of Materials G, H, I, and J were compacted using only standard compaction methods. The dry density of those 36 specimens (9 from each material) ranged from 1.95 to 2.01 gm/cm^3; the average was 1.98. By contrast, the dry density of 72 specimens of Materials MS1, MS2, and MS3 (24 from each material) compacted using standard, modified, and low energy methods ranged from 1.68 to 2.20 gm/cm^3; the average was 1.96.

Effect of moisture on direct shear results

To determine the effect of moisture on direct shear properties a second group of tests was conducted on wetted samples; the procedures used were the same as those described earlier. Wetting the material before testing reduced the average angle of internal friction by 8.2°. The effect of moisture on cohesion was not as definitive; in four cases cohesion increased. The overall average and variability were approximately the same as for the dry tests (Table 3). Moisture contents of the wetted direct shear specimens determined by weight after testing ranged from 15 to 20 percent.

Table 3.—Comparison of shear strength parameters for triaxial tests and wet and dry direct shear tests

Spoil material	Triaxial (consolidated undrained)		Direct shear			
			Dry		Wet	
	Angle of internal friction	Cohesion	Angle of internal friction	Cohesion	Angle of internal friction	Cohesion
	degrees	*bars*	*degrees*	*bars*	*degrees*	*bars*
			GROUP 1			
G	30.8	0.190	37.9	0.113	32.2	0.030
H	31.5	.170	37.3	.053	26.9	.091
I	31.3	.090	38.4	.075	33.7	.037
J	28.6	.200	39.8	.112	30.8	.016
Mean	30.6	.163	38.4	.088	30.9	.044
SD	1.33	.050	1.07	.029	2.92	.033
Coefficient of variance (%)	4.4	30.7	2.8	33.3	9.4	75.5
			GROUP 2			
MS1	33.2	0.049	38.7	0.146	27.4	0.116
MS2	38.7	-0-	38.8	.039	30.1	.106
MS3	39.8	-0-	39.1	-0-	31.5	.063
Mean	37.2	.016	38.9	.062	29.7	.095
SD	3.54	.028	0.21	.076	2.08	.028
Coefficient of variance (%)	9.5	173.	0.5	123.	7.0	29.6
			ALL MATERIALS			
Mean	33.4	0.100	38.6	0.077	30.4	0.066
SD	4.22	.087	0.81	.050	2.47	.040
Coefficient of variance (%)	12.6	87.4	2.1	65.6	8.2	60.3

Drainage was allowed in these tests and the lower moisture contents were associated with the large normal loads.

It is emphasized that shear strength parameters—cohesion, and angle of internal friction—determined by the wet direct shear method are not the same parameters as the total stress parameters determined by the triaxial method. Total stress includes the stress carried by both the soil particles and the pore water. If drainage is prevented during a test, excessive pore water pressure will develop and the total stress parameters will differ from the effective stress parameters. For the wet direct shear tests, some drainage was allowed but the rapid rate of loading probably did not allow complete drainage. The incomplete drainage probably caused some excess pore pressures. Although the pore pressures were not monitored, it is believed that they did not develop to the degree that would occur during the consolidated undrained triaxial test (Taylor 1952). However the wet direct shear test does provide an indication of the effect of moisture of shear strength parameters.

In addition to changes in strength parameters which may result from a buildup of pore pressure, the addition of moisure to a test specimen might also cause other changes. The mineralogic analyses of three basic constituents of Materials G, H, I, J, and MS1 showed high proportions of clay minerals. The addition of moisture to these clay-rich materials could have altered their strength characteristics through mechanisms that have little direct relationship to the buildup of pore pressure. The mechanics of this alteration could well be disaggregation of clay mineral conglomerates in the presence of moisture.

SUMMARY

Shear strength parameters of surface-mine spoils can be estimated by direct shear testing. For seven surface-mine spoils, the angle of internal friction determined by direct shear tests of dry materials exceeded by 5.2° the value determined by consolidated undrained triaxial tests. The average value of cohesion for all materials measured by the triaxial method was .100 bar compared to .077 bar for those measured in dry direct shear tests. There was considerable variability in cohesion for both test methods.

Wetting the direct shear samples in the shear box immediately before testing reduced the average angle of internal friction by 8.2°; but the effect of moisture on cohesion was not as definitive. In four cases cohesion was reduced and in three cases it was increased. The overall average for all seven materials and the variability was about the same.

Field sampling, material blending, and specimen properties affect both triaxial and direct shear results. When the percentages of freshly crushed material in the spoil blends were increased, the triaxial tests showed significant increases in the angles of internal friction. For the materials tested here, these increases resulted in two distinct populations. The percentage of freshly crushed materials did not significantly affect the results of direct shear tests. Triaxial results for materials that contained freshly crushed particles and that were compacted to three densities correlated best with those of the dry direct shear tests.

It is generally agreed that the shear strength of granular soils increases as the size of the particle increases. However the particle size that can be handled by shear testing equipment is limited. Neither of the test methods used in this study, nor the procedures used to interpret the data, can totally quantify the impact of larger particles typical of mine spoils on the shear strength of a spoil mass. Usually, such tests will yield shear strength values that tend to be conservative with respect to the shear strength of an actual mine spoil. There is a need for testing equipment and analytical procedures that will allow us to measure the influence of large particles commonly found in mine spoil dumps on the shear strength of spoil masses.

ACKNOWLEDGMENT

We thank Thomas L. Despard, Research Geologist, for his analysis and classification of materials used in this study.

LITERATURE CITED

American Society for Testing and Materials.
1976. **Soil and rock; building stones; peat: part 19.** Am. Soc. Test Mater. 846 p.

Bowles, Joseph E.
1970. **Engineering properties of soils and their measurements.** McGraw-Hill, New York.

Drnevich, Vincent P., Ronald J. Ebelhar, and G. Perry Williams.
1976. **Geotechnical properties of some eastern Kentucky surface mine spoils.** *In* Proc. 7th Ohio River Val. Soils Semin. p. 1-13.

Lambe, William T., and Robert V. Whitman.
1969. **Soil mechanics.** John Wiley and Sons, New York. 553 p.

Taylor, Donald W.
1952. **A direct shear test with drainage control.** Am. Soc. Test Mater. Spec. Tech. Publ. No. 13. 73 p.

U.S. Department of the Navy.
1971. **Soil mechanics, foundations, and earth structures.** NAVFAC DM-7. 302 p.

☆U.S. GOVERNMENT PRINTING OFFICE: 1978—703-112/15

Headquarters of the Northeastern Forest Experiment Station are in Broomall, Pa. Field laboratories and research units are maintained at:

- Beltsville, Maryland.
- Berea, Kentucky, in cooperation with Berea College.
- Burlington, Vermont, in cooperation with the University of Vermont.
- Delaware, Ohio.
- Durham, New Hampshire, in cooperation with the University of New Hampshire.
- Hamden, Connecticut, in cooperation with Yale University.
- Kingston, Pennsylvania.
- Morgantown, West Virginia, in cooperation with West Virginia University, Morgantown.
- Orono, Maine, in cooperation with the University of Maine, Orono.
- Parsons, West Virginia.
- Pennington, New Jersey.
- Princeton, West Virginia.
- Syracuse, New York, in cooperation with the State University of New York College of Environmental Sciences and Forestry at Syracuse University, Syracuse.
- Warren, Pennsylvania.