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Physical Property Data on Coarse Anthracite Waste

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UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm/sec	centimeter per second	in/min	inch per minute
° C	degree Celsius	lb	pound
ft	foot	lb/ft^3	pound per cubic foot
ft/yr	foot per year	min	minute
g	gram	mm	millimeter
gal	gallon	pct	percent
hr	hour	psi	pound per square inch
in	inch	yd^3	cubic yard

PHYSICAL PROPERTY DATA ON COARSE ANTHRACITE WASTE

By Bill M. Stewart[1] and L. A. Atkins[2]

ABSTRACT

Since 1974, a large amount of data has been developed concerning the physical properties and stability characteristics of waste generated by the mining and preparation of bituminous coal. However, very little information has been developed on the properties and characteristics of anthracite waste. During this Bureau of Mines research project, coarse anthracite breaker refuse from five sites in eastern Pennsylvania was sampled and the physical properties, which indicate stability characteristics, were determined in the laboratory.

Coarse anthracite breaker refuse is quite similar to coarse bituminous refuse in chemical and mineralogical composition. However, the physical properties of the anthracite waste materials tested are different from those of coarse bituminous refuse. For the coarse anthracite breaker refuse tested, the average maximum laboratory density is 113.2 lb/ft^3, the average angle of internal friction (direct shear) and average cohesion are 30.2° and 2.6 psi, respectively, and the average permeability (four sites) is 1.24×10^{-2} cm/sec. Stability analyses were conducted on six theoretical anthracite waste embankments. These analyses show the effects on minimum safety factors of geometry, phreatic surface level, and physical properties.

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INTRODUCTION

A survey conducted by the Bureau of Mines in 1966 (7)[3] showed that in the eastern Pennsylvania anthracite fields, there were over 800 refuse embankments which contained over 910 million yd^3 of material and covered a total area of 12,000 acres. About 7 billion tons of recoverable anthracite (by current mining methods) remain in Pennsylvania (8). One major coal company is currently conducting a 2-year feasibility study on surface-mining anthracite in Schuylkill County. If this operation proves feasible, the mine could produce 4 to 4.5 million tons of coal per year, greatly increasing the amount of waste produced.

Currently, over 70 pct of the anthracite culm banks in Pennsylvania are located within 2 miles of major population centers. Because of this, a culm bank failure could have a high potential for loss of life, injury, and extensive property damage. Without knowledge of the physical properties and strength characteristics of the waste material, geometry of the piles, and location of the phreatic surface, it is impossible to determine safety factors. Literature searches at the beginning of this research produced very few data on physical properties and strength characteristics of anthracite refuse. The purpose of this research is to provide mine inspectors and operators with an initial data base from which to conduct stability analyses of the culm banks.

The laboratory physical properties developed should not be taken as representative of the entire eastern Pennsylvania anthracite region. Only 5 sites of over 800 were sampled, and none of the sites sampled were in the Northern Field, which contains over 40 pct of the anthracite waste embankments. Although stability analyses were not conducted on the sampled sites, they were conducted on theoretical anthracite culm banks using the analytical laboratory physical properties developed from the samples collected.

SAMPLE COLLECTION

Approximately 2 tons of sample were collected at each of the five sites visited. Sites A and B are in the Eastern Middle Field, site C is in the Western Middle Field, and sites D and E are in the Southern Anthracite Field of eastern Pennsylvania. No samples were collected in the Northern Field. Figure 1 shows the approximate locations of the sites sampled.

At each location, the samples were hand-shoveled into 55-gal drums, which were then sealed. After all the samples were collected, they were shipped by truck to the Bureau's Spokane (Wash.) Research Center. At all sites except site A, the samples were collected at intervals along the embankment crest. This was done to get a more representative sample then would have been obtained if the samples were collected at one location on the embankment. Site A material was collected from a fresh pile of coarse waste near the strip mine. Access to the embankment crest at this site was not possible. The age of the refuse sampled varied considerably, ranging from fresh refuse at site A to about 20-year-old refuse at site D. All of the

[3] Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

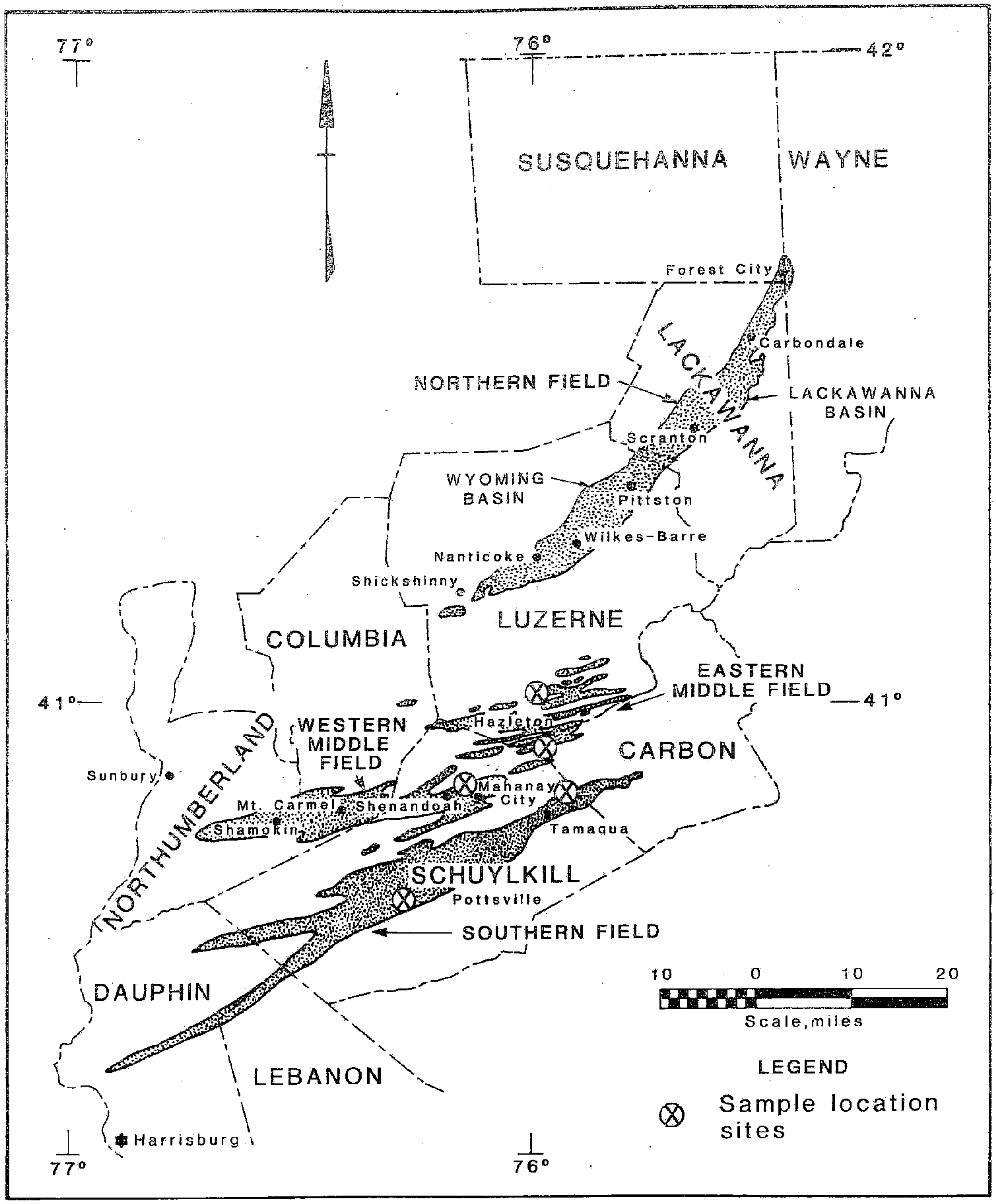


FIGURE 1. - General location of waste embankment sites sampled for physical property tests.

samples were believed to be coarse processed breaker refuse; but at some locations, unprocessed mine refuse could have been mixed with the breaker refuse. One observation made during sampling was that the larger refuse particles (+4 in) were intact. This is unusual with most shales associated with bituminous coal and would indicate that the anthracite waste shales are more resistant than the bituminous shales to weathering and slaking.

Small airtight-plastic-bag samples were collected at each sampling location. These samples were taken about 6 in below the surface and were used to determine the in-place moisture content.

TEST PROCEDURES

At the Spokane Research Center, each of the 55-gal-drum samples was weighed. Then the samples were dried from 24 to 48 hr, reweighed, and screened. The long drying periods were required so the material could be dry-screened. The samples requiring 48 hr to dry were saturated and had free-standing water on top when the lids of the drums were removed. The percent by weight of material passing various-sized screens was determined so that as-received grain-size-distribution curves could be developed for each site sampled. The material for the shear and permeability tests was prepared by hand-mixing the correct proportions of each size (according to the as-received grain size) so that the samples could be placed in the test cylinder at 95 pct of maximum laboratory dry density. Samples were also prepared and sent to the Bureau's Albany (Oreg.) Research Center for ultimate and proximate analyses. Fifty-pound samples from each site were crushed, split, ground, and rolled for these tests.

The laboratory tests at the Spokane Research Center were performed using the following procedures:

1. Grain-size distribution for the plus 200-mesh material (U.S. Standard sieve size) was determined according to American Society for Testing and Materials (1) (ASTM) standards. The grain-size distribution of the minus 200-mesh fraction was determined using a particle-size analyzer. This analyzer operates on the principle of Stoke's law, utilizing X-ray absorption (fig. 2).

2. The specific gravity of the plus 4-mesh material and of the minus 4-mesh material was determined according to ASTM standards (2).

3. Maximum and minimum densities and optimum moisture contents were determined according to ASTM standards (3, 5).

4. Direct shear tests were also conducted according to ASTM standards (4). The sample was not submerged prior to consolidation (fig. 3).

5. Permeability and settlement tests were conducted according to U.S. Bureau of Reclamation Earth Manual designation E-14 (fig. 4).

RESULTS OF PHYSICAL PROPERTY TESTS

GRAIN-SIZE DISTRIBUTION AND MATERIAL DESCRIPTION

To determine the grain-size distribution, each sample, after thorough drying, was separated on a shaker (fig. 5) in U.S. Standard sieve sizes of plus 3 in (77 mm), 1-1/2 in (38 mm), 3/4 in (19.5 mm), 3/8 in (9.6 mm), No. 4 sieve (4.9 mm), and minus No. 4 sieve. The minus No. 4 material was separated in sizes of plus No. 10 sieve (2.0 mm), No. 16 sieve (1.2 mm), No. 30 sieve (0.50 mm), No. 50 sieve (0.31 mm), No. 100 sieve (0.16 mm), No. 200 sieve (0.08 mm), and minus No. 200 sieve. The minus No. 200 sieve material was separated using a particle-size analyzer into clay and silt size. Figures 6, 7, and 8 show the minus 3-in grain-size curves of the samples after they arrived at the Spokane Research Center.

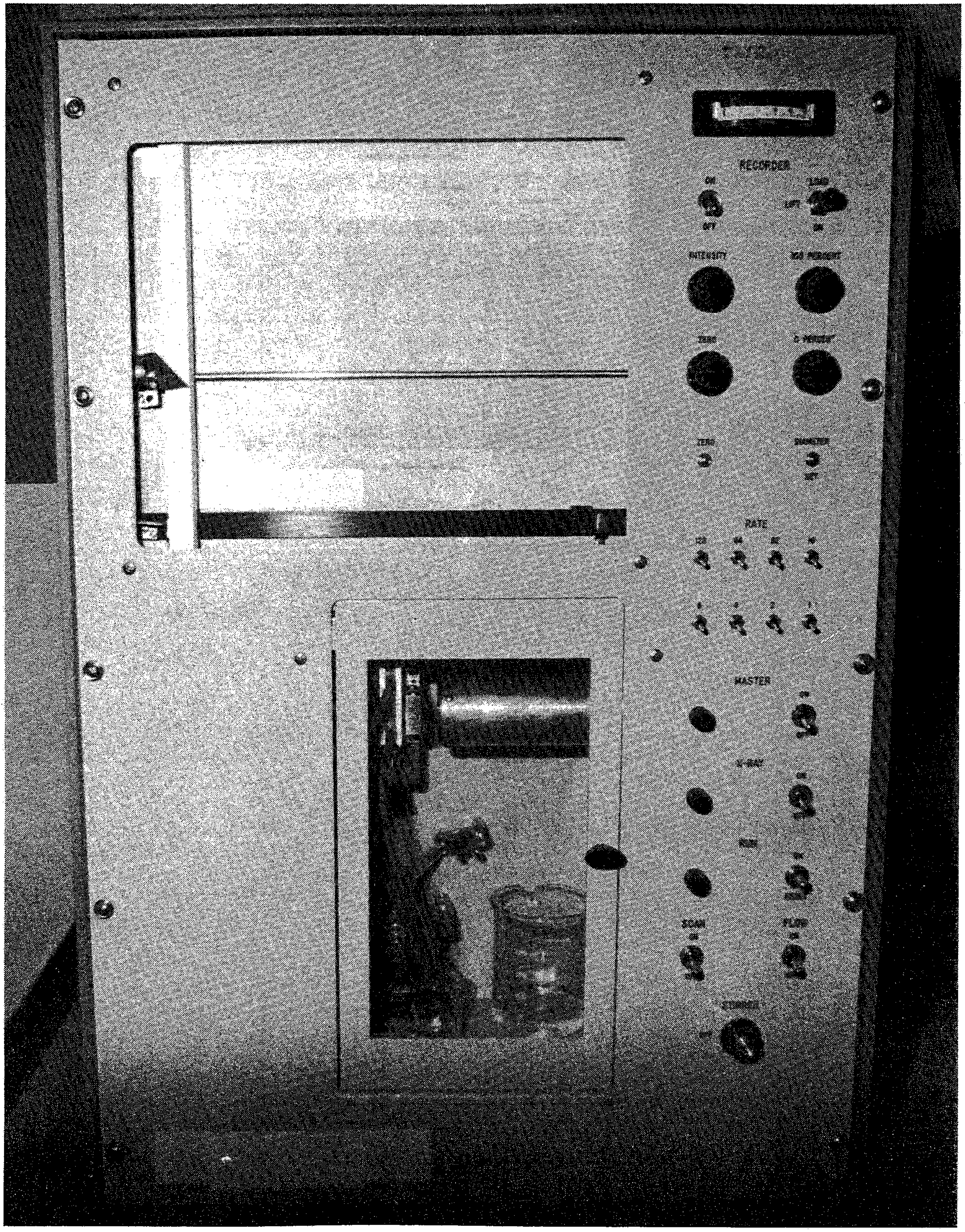


FIGURE 2. - Particle-size analyzer for determining distribution of minus 200-mesh material.

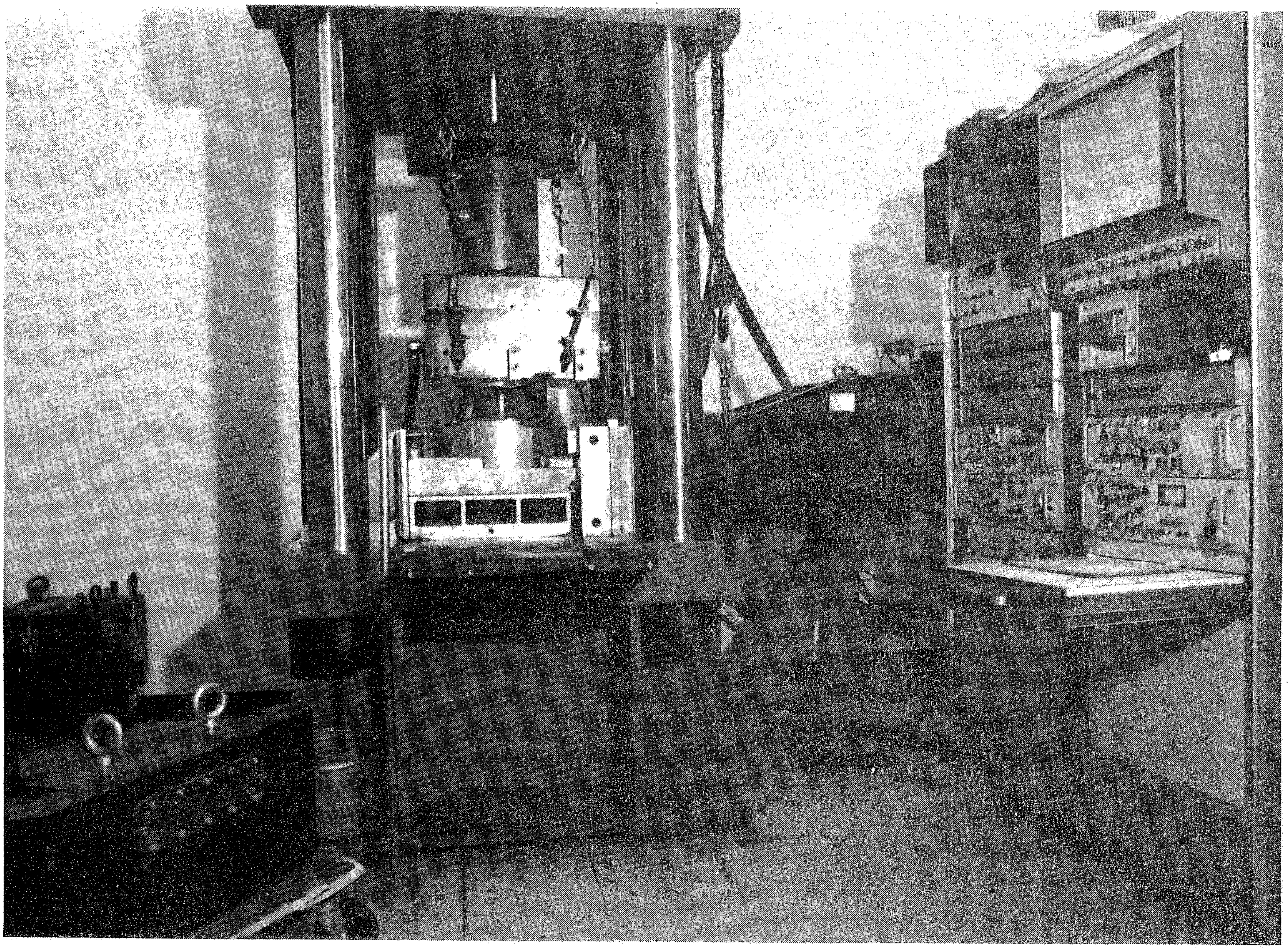


FIGURE 3. - Direct shear testing machine, readout and control panel.

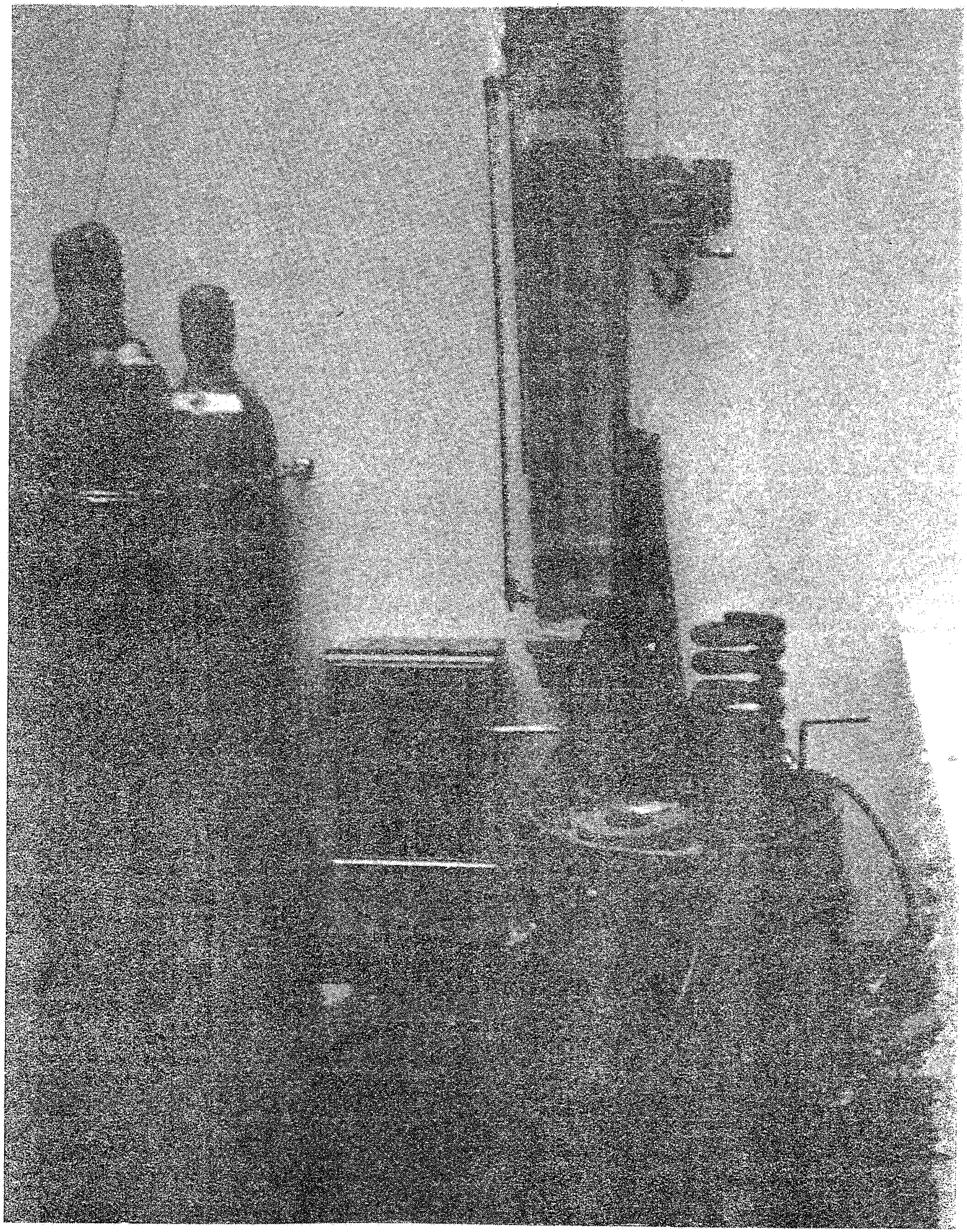


FIGURE 4. - Permeability test equipment.

FIGURE 5. - Shaker for plus 200-mesh grain-size distribution.

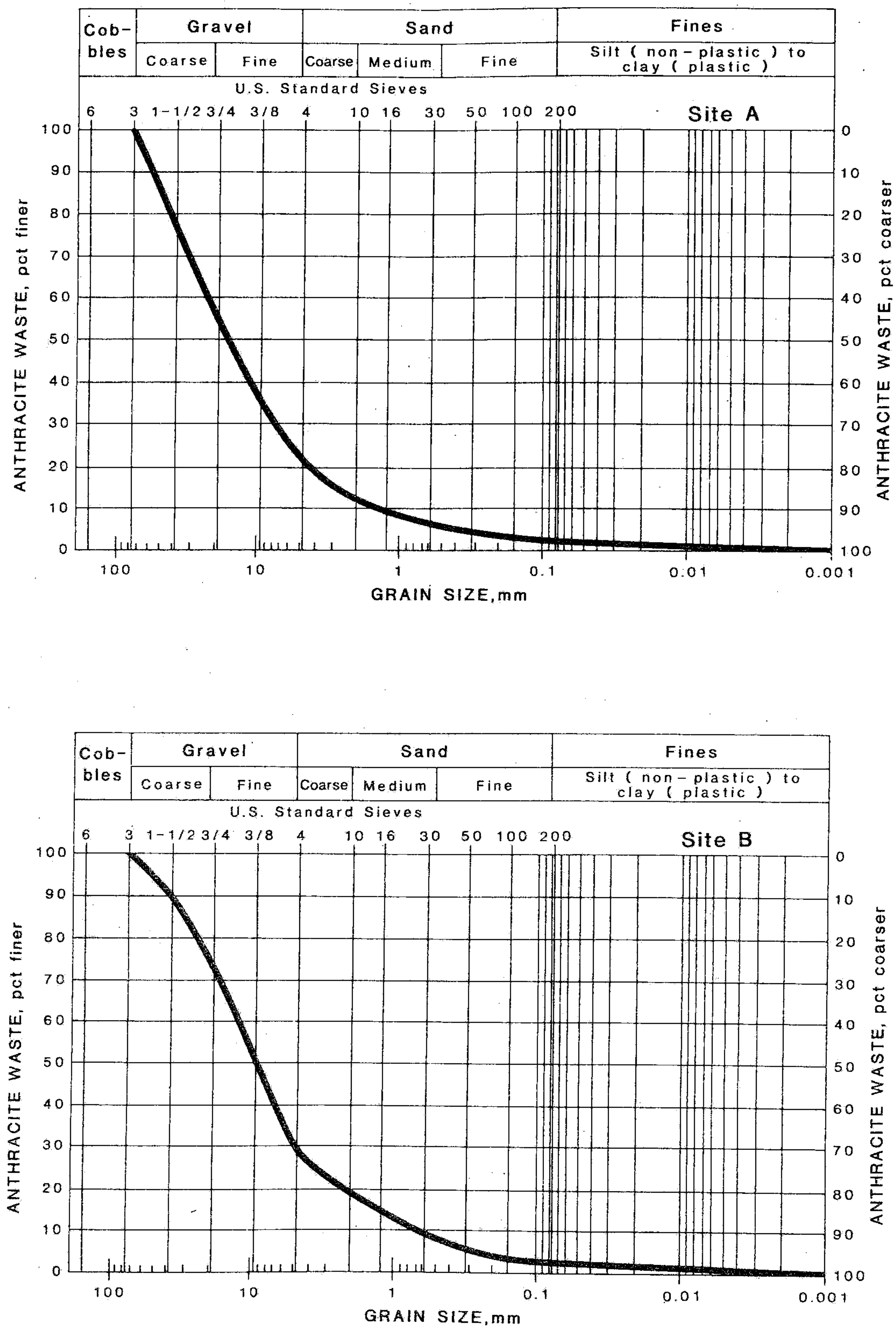
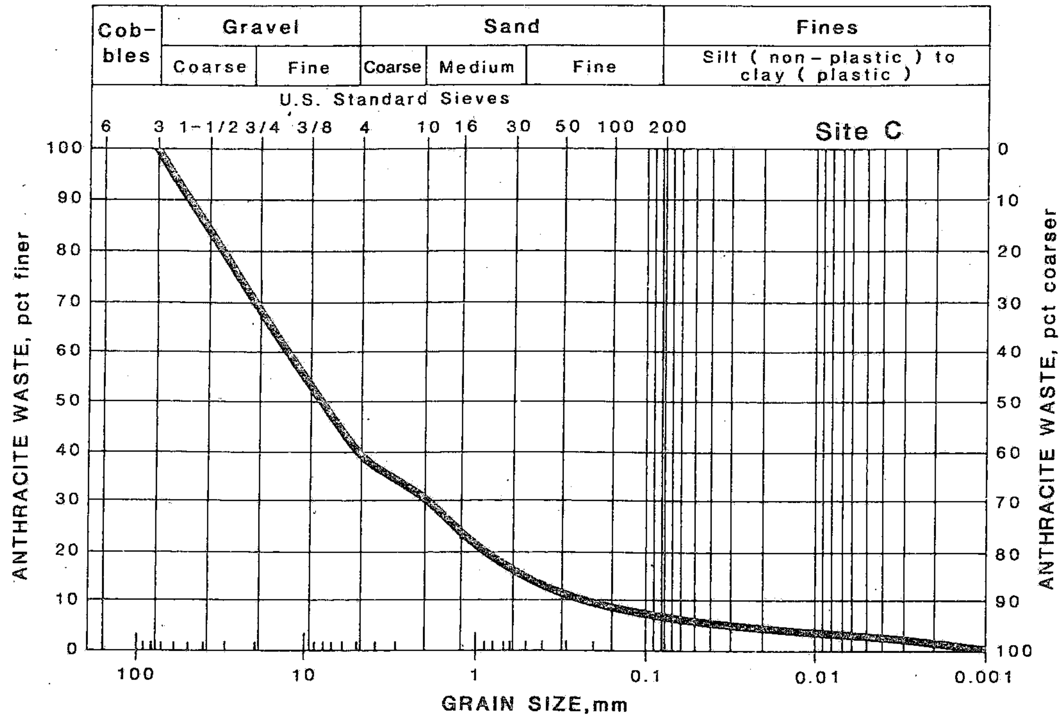


FIGURE 6. - Grain-size distribution of samples from sites A and B (Eastern Middle Field).



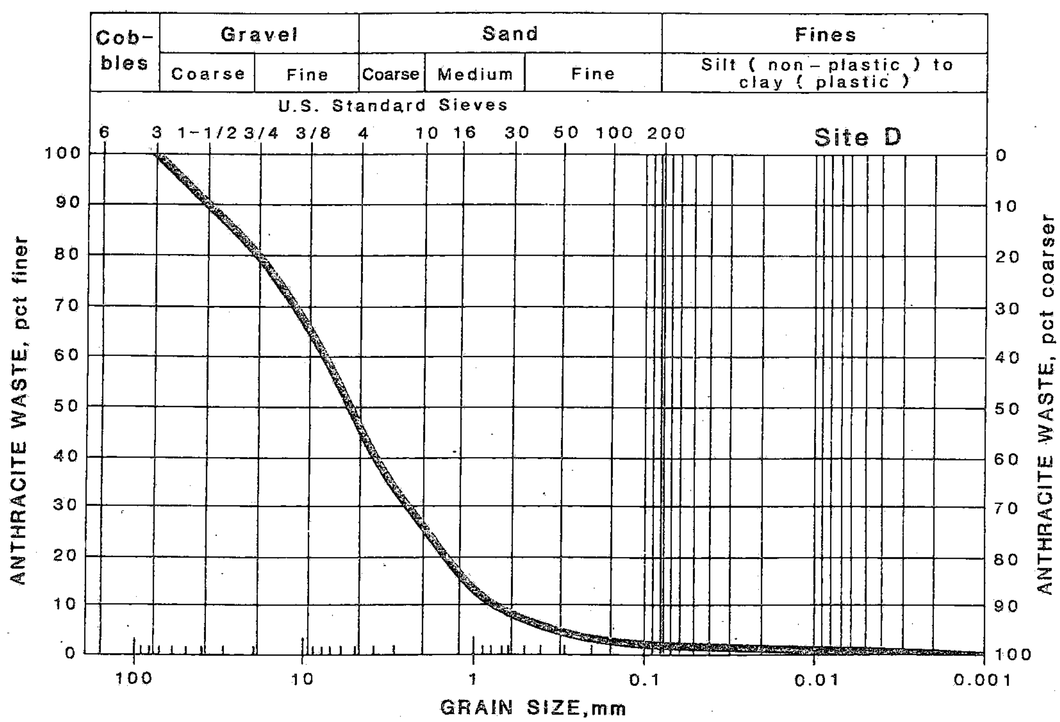


FIGURE 7. - Grain-size distribution of samples from site C (Western Middle Field) and site D (Southern Field).

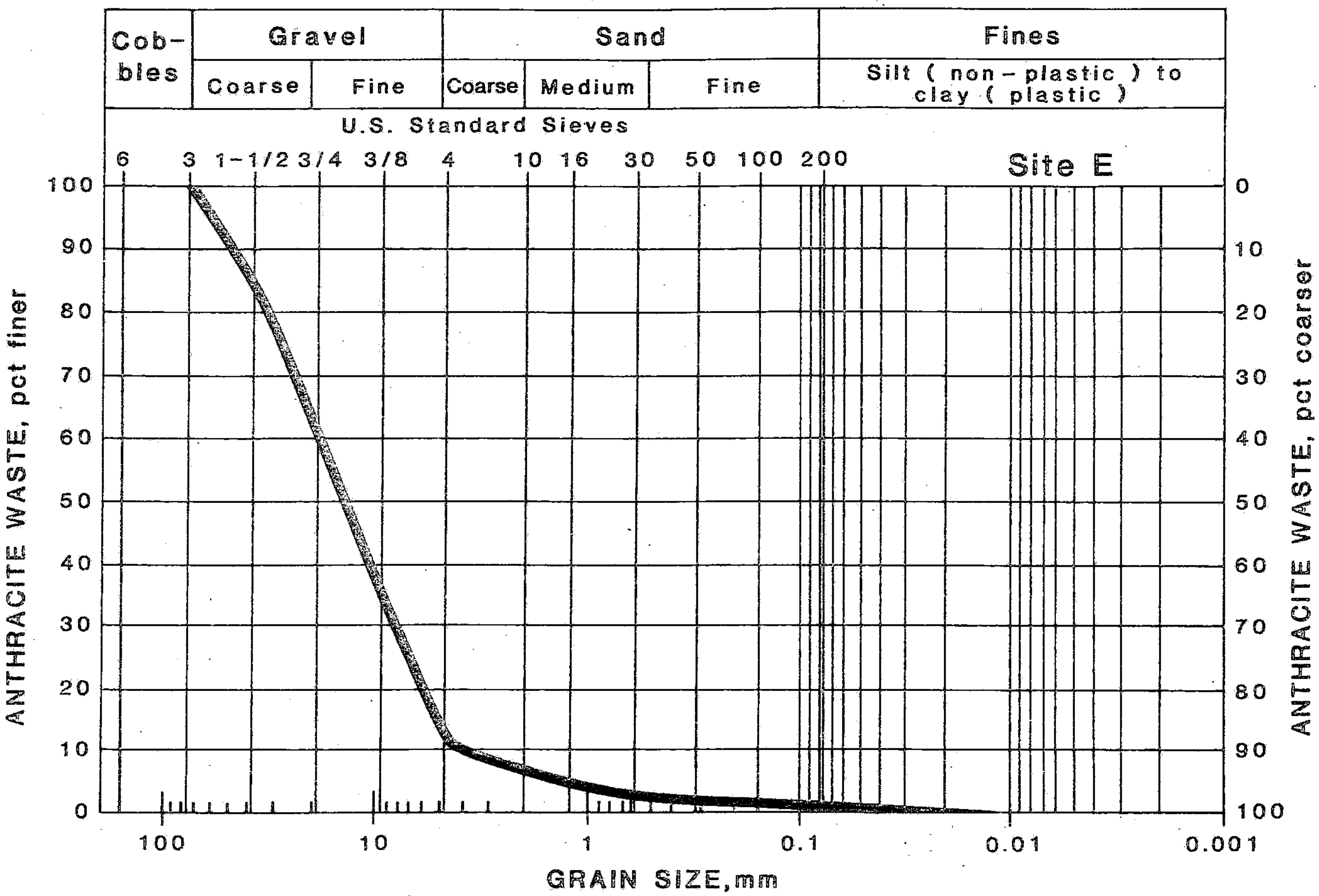


FIGURE 8. - Grain-size distribution of samples from site E (Southern Field).

From the grain-size curves, the effective size, the coefficient of uniformity, and the coefficient of curvature were determined. Table 1 shows a general description of each of the samples. Based on the grain-size distribution curves, the anthracite samples are classified as poorly graded or well graded gravels with few or no fines. The small percentage of fines in the samples was surprising. W. A. Wahler and Associates (11) reported that the average amount of minus 200-mesh material for 58 samples of bituminous waste in West Virginia was 13 pct. This is twice as much as found in any of the anthracite waste samples. The amount of fines present in a coal waste sample plays a key role in its physical properties (9-10). For this reason, determining gradation is an important first step in physical property analysis.

TABLE 1. - General description of as-received samples

Site	Effective size (D_{10}), mm	Coefficient of uniformity	Coefficient of curvature	Specific gravity	Soil classification[1]
A...	1.30	17.7	1.98	2.43	GW
B...	.79	17.7	2.30	2.41	GW
C...	.27	51.8	.86	2.24	GP-GM
D...	.73	11.6	.85	2.26	GP
E...	4.30	4.40	.95	2.43	GP

[1]GP--Poorly graded gravels, gravel-sand mixtures, little or no fines.
GM--Silty gravels, poorly graded gravel-sand-clay mixtures.
GW--Well-graded gravels, gravel-sand mixtures, little or no fines.

LABORATORY DENSITY

Density control is essential for the construction of stable waste embankments. Density is required input for the calculation of safety factors. For new coal waste embankments, maximum densities of the coal waste construction material are determined in the laboratory, and some percentage of this maximum is maintained throughout construction (density control). Many old coal waste embankments had no density control during construction and, therefore, no records of density were made. Density input for stability calculations of these types of embankments would have to come from an engineering judgment based on a composite of in-place densities taken in the field and the minimum and maximum densities determined in the laboratory. The effects of density on safety factors are shown in the "Stability Analyses" section.

The maximum laboratory densities for the anthracite waste samples tested were determined using the vibratory compaction method. Both impact and vibratory compaction methods were conducted on mine C material to determine which method gave the maximum density. For this material, the laboratory dry density for the impact method was 113.0 lb/ft^3 at 9.4 pct optimum moisture content, and for the vibration method it was 114.9 lb/ft^3 (wet method). Because of these results, the vibration method was used on the remaining samples. The small difference in the results would indicate that mine C material could be compacted to a high degree using vibration or impact methods. The small percent by weight of soil particles (less than 8 pct in all samples) passing a No. 200 sieve (figs. 6-8) would indicate that the material is free-draining with little or no cohesion and that compaction by vibration would produce maximum densities. Table 2 shows the maximum laboratory dry densities (wet and dry vibration method) and the minimum densities.

TABLE 2. - Density of anthracite breaker refuse, lb/ft^3

Site	Minimum laboratory dry density	Maximum laboratory dry density	
		Dry method	Wet method
A......	91.5	116.4	118.4
B......	90.0	112.7	113.7
C......	91.7	110.8	114.9
D......	86.8	105.7	103.8
E......	86.5	107.9	113.2

SHEAR STRENGTH

Consolidated drained shear strength was determined using the direct shear method. The sample sizes were 14 in (diameter) by 7 in (depth). The samples at field moisture content were compacted in the direct shear box at 95 pct of maximum laboratory dry density. Normal loads of 25, 50, and 100 psi were used. For all tests, the rate of shear wa 0.03 in/min. Due to the high permeability of the samples, zero pore pressure was assumed.

Table 3 shows the direct shear test results. Figures A-1 through A-5 in the appendix represent the tabulated results in graphical form (stress-strain curves) of the direct shear tests. Figure A-6 shows the strength envelope for each sample test series.

The average angle of internal friction and average cohesion for the five anthracite samples tested are 30.2° and 2.6 psi, respectively. As a comparison, table 4 shows drained direct shear results of composite bituminous coal waste samples from seven sites in West Virginia (6). For these samples, the average friction angle and cohesion are 32.8° and 4.3 psi, respectively. This comparison shows a somewhat weaker shear strength for anthracite waste.

TABLE 3. - Direct shear test results

Site	Placement moisture, pct	Placement density, lb/ft^3	Initial void ratio	Initial saturation, pct	Phi angle, deg	Cohesion, psi
A...	5.5	112.5	0.351	30.1	32.2	3.7
B...	6.6	108.0	.396	40.2	29.8	1.0
C...	7.5	109.2	.283	59.4	31.5	2.9
D...	5.1	100.4	.408	28.3	29.0	1.4
E...	4.0	107.5	.373	25.3	28.3	3.9

TABLE 4. - Direct shear results of bituminous coal waste samples from seven sites in West Virginia (6)

Sample[1]	Test conditions	Direct shear drained (minus 3/4-in fraction)					
		Placement moisture, pct	Placement density, lb/ft^3	Consolidated density, lb/ft^3	Degree of saturation, pct	Phi angle, deg	Cohesion, psi
1-J-13...	Average field conditions.	6.1	85.7	88.9	34.1	35	0.8
1-J-13...	95 pct of lab maximum.	6.1	91.4	93.8	46.8	33	2.3
1-K-8....	Average field conditions.	4.0	100.1	103.2	22.6	35	3.5
1-L-10...	.....do......	5.5	86.9	87.3	26.2	33	1.6
1-L-10...	95 pct of lab maximum.	5.5	97.0	99.5	40.7	30	6.6
1-M-10...	Average field conditions.	8.1	96.5	98.6	55.1	32	6.3
1-N-10...	.....do......	7.2	84.9	87.2	37.1	34	3.2
1-O-3....	.....do......	9.1	76.4	83.1	35.2	33	1.5
1-O-3....	95 pct of lab maximum.	9.1	83.4	86.0	48.0	31	3.7
1-P-4....	Average field conditions.	9.3	90.0	94.1	48.8	32	4.5

[1]Composite samples; numbers are those used in reference 6.

As mentioned in the introduction, the friction angle and cohesion (or shear strength) are physical property input data for stability analyses and calculation of safety factors. Because of this, it is important that these properties are derived as accurately as possible and that the samples from which the properties are derived truly represent the embankment being analyzed. The effects of shear strength on safety factors for a theoretical embankment are shown in the "Stability Analyses" section of this report.

PERMEABILITY AND SETTLEMENT

The permeability of the samples was determined using the constant head method according to U.S. Bureau of Reclamation Earth Manual Designation E-14. The samples were placed in the permeability test chamber at 95 pct of maximum laboratory dry density. The samples were compacted in three layers, 3 in thick. Each layer was scarified prior to adding the next layer. The samples were 19 in in diameter by 9 in deep and were tested at 100-pct saturation. The temperature of the

TABLE 5. - Permeability and settlement at 50-psi load

Site	Placement density, lb/ft^3	Consolidated dry density, lb/ft^3	Settlement, pct	Permeability, cm/sec
A......	112.5	117.4	4.2	1.11×10^{-2}
B......	108.0	111.2	2.9	1.15×10^{-2}
C......	109.2	111.6	2.2	2.76×10^{-6}
D......	100.4	103.0	2.5	1.21×10^{-2}
E......	107.5	112.7	4.6	1.49×10^{-2}

water was constant for all tests. After the material was placed in the permeability test chamber, a 50-psi normal load was applied and periodic settlement measurements were made. After settlement stopped, the percent settlement and consolidated dry density were determined. The permeability was then determined at the consolidated dry density. Permeability readings were taken several times a day until the permeability rate became nearly constant. Table 5 shows the results of the permeability-settlement tests.

The permeability of the samples from each site is nearly the same except for site C. In soils engineering work involving water-retaining structures, usually materials having permeability rates greater than 100 ft/yr (1×10^{-4} cm/sec) are classed as pervious; soils having permeabilities rates between 1 and 100 ft/yr (1×10^{-6} and 1×10^{-4} cm/sec) are classed as semipervious; and soils having permeability rates of less than 1 ft/yr (1×10^{-6} cm/sec) are classed as impervious. Thus, the anthracite breaker refuse from sites A, B, D, and E can be classed as pervious, and the refuse from site C as semipervious to impervious. The grain-size distribution curve (fig. 7) for site C material shows a poorly graded material; however, this material contained silt mixtures, whereas the other materials showed few or no fines. The minus 200-mesh material for site C material is around 6 pct finer by weight. The other four samples contain only 1 to 3 pct minus 200-mesh material. Also, table 3 shows an initial void ratio for site C material much lower than for the other four materials. These factors explain the low permeability for site C material. As a comparison, table 6 shows permeability results of bituminous coal waste (same composite samples as in the "Shear Strength" section) (6). This comparison shows that the anthracite waste tested is more pervious and free-draining than the bituminous waste tested. This also is important for embankment stability because the phreatic surface will remain low in a free-draining embankment. The effect of phreatic surface height on safety factors is shown in the stability analyses section. These analyses indicate the necessity of phreatic surface location throughout the life of embankments, especially those that impound mine waste sludge or are used for water storage.

TABLE 6. - Permeability results of bituminous coal waste samples at 55-psi load (6)

Permeability, cm/sec	Density, lb/ft^3	
	Placement dry	Consolidated
2.63×10^{-4}	90.6	92.3
2.61×10^{-4}	103.3	104.9
3.32×10^{-4}	92.2	95.8
9.80×10^{-7}	100.5	104.4
3.28×10^{-5}	88.6	90.9
5.98×10^{-5}	79.2	83.5
7.82×10^{-7}	97.3	103.3

BREAKAGE

The gradation curves in figures 9 and 10 show the effects of compaction and normal load application during the direct shear tests on particle breakage. Samples from sites B and D were used for the breakage tests. The curves show that the material from these sites did not break down to any great extent. The curves also show that breakage was due primarily

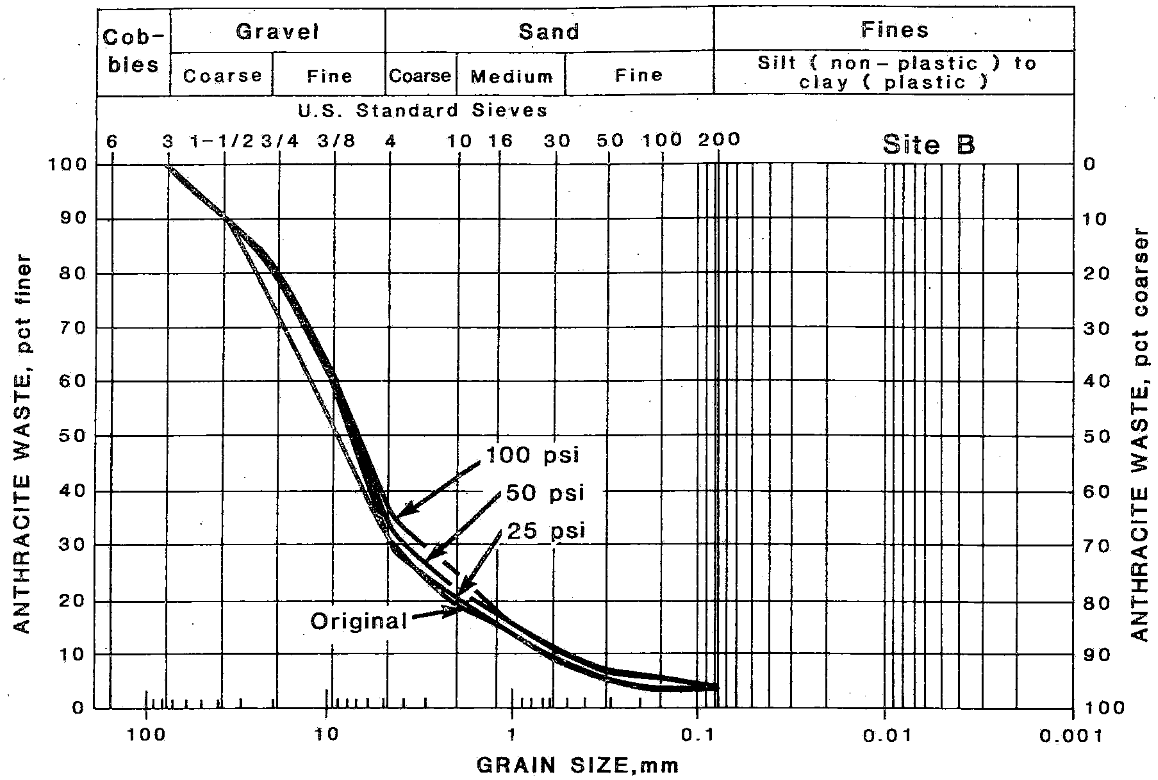


FIGURE 9. - Breakdown of material from site B due to compaction prior to direct shear tests and normal loading during direct shear.

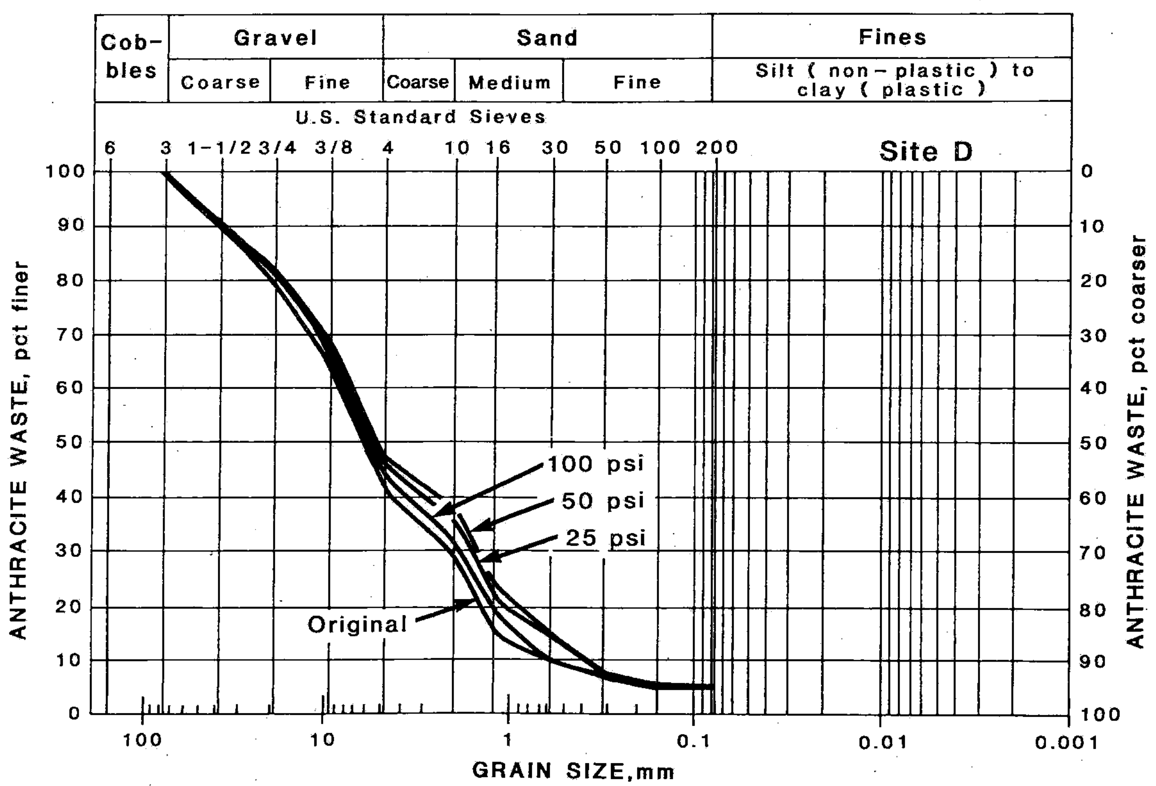


FIGURE 10. - Breakdown of material from site D due to compaction.

to the initial compaction of the samples rather than to the applied normal loads. This is especially evident on the site D material. The normal load applied at 100 psi shows less particle breakage than the 25- and 50-psi loads. In this case, the initial compaction effort on the 50- and 25-psi-loaded material was a little greater than that on the 100-psi-loaded material, resulting in a higher particle breakage.

CHEMICAL, MINERAL, AND ELEMENT IDENTIFICATION

Representative 1,000-g samples of each of the anthracite wastes collected were sent to the Albany Research Center for chemical, mineral, and element analyses. To obtain representative samples for those tests, the material collected at each site was dumped from the drums (after drying) and hand-mixed with scoop shovels. After mixing, 50-lb samples were crushed to minus 3/8-in size and split twice. Approximately 12-1/2 lb of minus 3/8-in samples were ground to minus 100-mesh size and split once. Approximately 6 lb of samples were rolled on paper to achieve thorough mixing. A flat sampling knife was used to obtain 1,000-g samples from the rolled material. This procedure was repeated for each of the five samples. These tests were conducted to determine the physical makeup of the anthracite refuse and to determine the dominant characteristics of the material. Potentially useful elements within the coal waste could also be detected. X-ray diffraction was used to determine the major, minor, and trace minerals; chemical tests indicated the compound percentage of the refuse ash, and spectrographic tests identified the elements present in the ash. Tables 7, 8, and 9 show the results. Table 9 also compares the average chemical composition of anthracite waste ash with that of bituminous coal waste ash; the compositions are similar except for the CaO and K_2O contents. The principal constituents are silica, alumina, and iron oxides.

TABLE 7. - X-ray diffraction analysis of anthracite refuse[1]

Site	Alpha quartz (SiO_2)	Illite and/or muscovite[2]	Kaolinite	Hematite (Fe_2O_3)	Plagioclase type
As-received:					
A	M(22)	M(15)	T(8)	T(4)	NT
B	M(23)	M(12)	M(11)	ND	NT
C	M(24)	M(9)	T(7)	T(2)	NT
D	M(14)	M(10)	M(22)	ND	NT
E	M(16)	M(10)	M(16)	T(2)	NT
650° C ash:					
A	M(22)	M(14)	NT	M(10)	T(10)
B	M(23)	M(13)	NT	T(2)	T(10)
C	M(26)	M(10)	NT	T(7)	T(10)
D	M(14)	T(10)	NT	M(11)	T(10)
E	M(16)	M(11)	NT	T(9)	T(10)
1,000° C ash:					
A	M(20)	T(7)	NT	M(14)	T(10)
B	M(23)	T(7)	NT	M(12)	T(10)
C	M(27)	T(5)	NT	M(12)	T(5)
D	M(16)	T(5)	NT	M(18)	T(5)
E	M(16)	T(4)	NT	M(12)	T(10)

M Minor phase (10 to 30 pct). T Trace phase (<10 pct).
ND Not detected. NT Not tested.

[1]Numbers in parentheses are estimated weight percent based on peak height.

[2]Illite and muscovite are isostructural and chemically similar with wide composition ranges. Therefore, no attempt was made to differentiate the 2 minerals.

TABLE 8. - Spectrographic analyses of anthracite waste ash

Site	Ag	Al	Cu	Fe	Ga	Mg	Mu	Na	Ni	Si	Ti	V
A......................	ND	A	E	B	D+	B	D+	C+	D	A+	C+	D+
B......................	ND	A	E	B	D+	B	D+	C+	D	A+	C+	D+
C......................	ND	A	E+	B	D+	B	D+	C+	D	A+	C+	D+
D......................	ND	A	E	B+	D+	B	D+	C+	D	A+	C+	D+
E......................	E+	A	E	B	D+	B	D+	C+	D	A+	C+	D+

A+ = 10 to 100 pct. C+ = 0.1 to 1 pct. E+ = 0.001 to 0.01 pct.
A = 3 to 30 pct. C = 0.03 to 0.3 pct. E = 0.0003 to 0.003 pct.
B+ = 1 to 10 pct. D+ = 0.01 to 0.1 pct. ND Not detected.
B = 0.3 to 3 pct. D = 0.003 to 0.03 pct.

Other elements checked for but not detected include As, B, Ba, Bi, Ca, Cb, Cd, Co, Cr, Ge, Hf, Li, Mo, P, Pb, Pd, P+, Sb, Sn, Se, Ta, W, Zn, Zr, and Y.

TABLE 9. - Chemical composition of anthracite waste ash, percent

Site	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	Na_2O	SiO_2	TiO_2
A....................	19.5	0.008	4.99	2.58	0.85	0.43	55.2	1.69
B....................	22.3	.03	4.56	2.46	.76	.35	60.3	1.66
C....................	20.0	.10	5.49	2.28	1.25	.39	61.0	1.85
D....................	21.9	.25	11.9	2.04	.73	.31	55.6	1.61
E....................	22.5	1.13	7.44	2.46	1.43	.49	58.6	1.61
Av. anthracite......	21.20	.30	6.90	2.40	1.00	.40	58.10	1.70
Av. bituminous coal (12)...............	22.60	2.20	7.20	4.00	1.30	.40	55.20	1.20

STABILITY ANALYSES

Using the simplified Bishop technique, stability analyses were performed on a theoretical anthracite waste embankment. The purpose of the stability analyses is to show how the safety factor is affected by changes to the embankment. The variables include geometry (downstream slope), physical properties (density, phi angle, cohesion), and location of the phreatic surface. The average physical property data of the five anthracite waste sites sampled were used in embankment analysis 1 (table 10). The most dramatic effects on the safety factor are

TABLE 10. - Safety factor comparison

Embankment analysis	Slope angle, deg	Embankment density, lb/ft^3	Tan ϕ	Cohesion, psi	Phreatic surface	Minimum safety factor (simplified Bishop)
1...........	27	107.5	0.58	2.6	Low (exits at toe).	1.500
2...........	27	90.0	.58	1.3	.....do............	1.420
3...........	27	90.0	.53	1.3	.....do............	1.309
4...........	45	107.5	.58	2.6	.....do............	.748
5...........	27	107.5	.58	2.6	High (exits at one-half embankment height).	.904
6...........	34	90.0	.53	1.3	Low (exits at toe).	.997

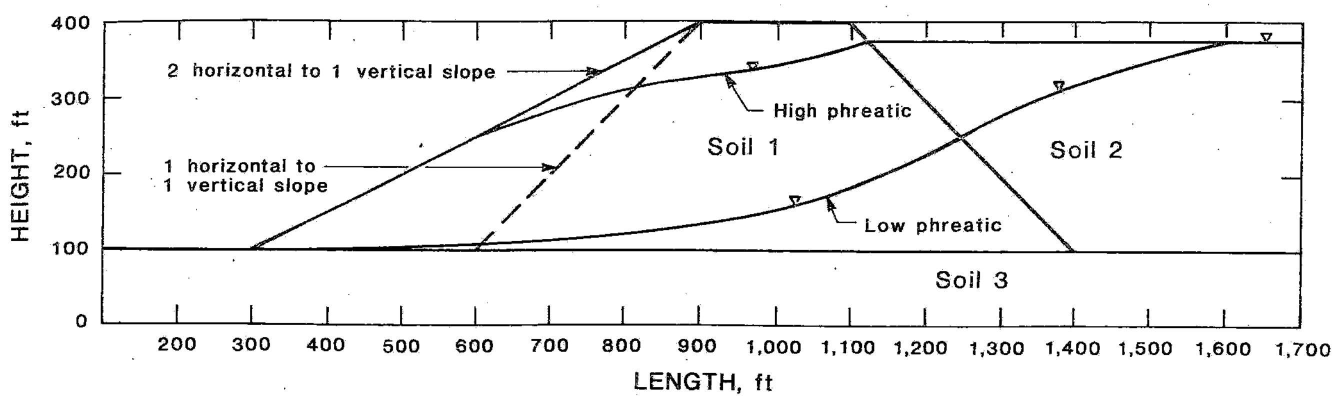


FIGURE 11. - Cross section of theoretical anthracite waste embankment used for stability analysis.

seen in embankment analyses 4 and 5. The safety factor in analysis 4 indicates the theoretical embankment would fail if the downstream slope was increased from 27° to 45°. The safety factor determined in analysis 5 also indicates a failure in the embankment if the phreatic surface rises to the level shown in figure 11 and exits the downstream slope at a distance of one-half the embankment height. Embankment analyses 2 and 3 show the effects of physical properties on the safety factor. By lowering the density, tan ϕ and cohesion (analysis 3), the safety factor reduces from 1.5 to 1.3. Although this is not as dramatic a reduction as seen in analyses 4 and 5, the minimum safety factor falls below the 1.5 safety factor required by law for new embankments (CFR, Title 30, Section 77.215, Ch. 7). By combining reductions in physical properties with an increase in slope angle, a very dramatic reduction in minimum safety factor results (embankment analysis 6).

These analyses show the effects on safety factors of embankment geometry, embankment material physical properties, and phreatic surface location. For most coal waste piles, density can be improved by mechanical compaction. Whether compaction by the vibratory or the impact method is best can be determined by standard laboratory tests. Whatever the method of compaction, the predetermined density to meet the minimum safety factor for the embankment design has to be maintained throughout the construction period. This is true for new structures as well as additions to old structures. As can be seen in embankment analyses 2 and 3 (table 10), accurate determination of the shear strength is important. A 2° reduction of the angle of internal friction lowered the safety factor from 1.42 to 1.31. Trained and experienced personnel in triaxial, direct, or in situ shear strength testing are needed to acquire accurate shear strength data. Regular and accurate monitoring of the phreatic surface is essential. The phreatic surface should be kept as low as possible.

CONCLUSIONS

The data developed in this report are based on samples collected from five sites in the anthracite fields of eastern Pennsylvania. Because of the limited number of sites sampled, the results should not be taken as representing the entire Pennsylvania anthracite mining district. For instance, samples were not collected in the Northern Field. Because of the separation of this field from the other three, it is possible that the physical properties of the waste from the Northern Field could be somewhat different.

The most common characteristic of the samples tested was the lack of fines. All the samples can be classified as poorly graded or well-graded gravels with few or no fines. The samples contained about half as much minus 200-mesh material as is normally found in bituminous coal waste. The ability of the larger particles to resist erosion and slaking also contributed to the small amount of fines.

The vibratory table method resulted in higher maximum laboratory densities than the standard impact method. Because of the free-draining nature of the material, density determined by the wet procedure was superior to that by the dry procedure in most cases. The average maximum laboratory dry density of the five anthracite breaker refuse samples is about 14 lb/ft^3 higher than the average composite density of seven bituminous coal refuse sites in West Virginia. Average specific gravity is also higher.

Even though the maximum laboratory densities are higher for anthracite waste than for bituminous waste, the internal friction angles are about the same or a little lower. This is probably a result of material gradation. The lack of fines in the anthracite waste would cause high initial void ratios and lower strength. The applied normal loads during direct shear testing had very little effect on material breakdown. Compaction of the material prior to testing caused some breakdown. None of the samples slaked or disintegrated when saturated.

Because of the lack of fines, the material from four sites had high permeability, averaging 1.25×10^{-2} cm/sec (12,933 ft/yr). High-permeability material will aid the overall stability of the embankments at these sites because the phreatic surface should stay at a relatively low level. Adequate drainage provisions would be necessary to control the high flow rates. Environmental concerns downstream would be high due to the large flow rate of low-quality effluent. The permeability of site C material was four orders of magnitude lower than that of the other material. Even though the material was poorly graded, the minus 200 U.S. Standard sieve size was two to three times greater, resulting in the lower permeability. Settlement of the material was measured prior to the permeability tests. The average settlement for the five samples subjected to a 50-psi normal load was 3.3 pct. This reduced the thickness an average of 0.3 in and increased the placement dry density an average of 3.7 lb/ft^3.

The major constituents of the waste ash are silica (SiO_2), alumina (Al_2O_3), and iron oxides (Fe_2O_3). The percentages of these constituents are almost identical to those in western bituminous waste and slightly lower than those in eastern bituminous waste. Calcium oxide (CaO) and potassium oxide (K_2O) are higher in bituminous waste ash than in anthracite waste ash.

Density, strength, and permeability properties are essential for proper design and stability analyses of mine waste embankments. Any new developments or operational changes such as change in mining equipment, mining method, modernization of preparation plants, increase in embankment heights, etc., can change the physical properties of the waste or the structural integrity of the embankment. Any such activity would require new physical property determination and stability analyses. Frequent physical inspections, current physical property data and stability analyses, and current phreatic surface data are necessary for mine waste embankment stability.

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APPENDIX.--DIRECT SHEAR TEST DATA AND CURVES

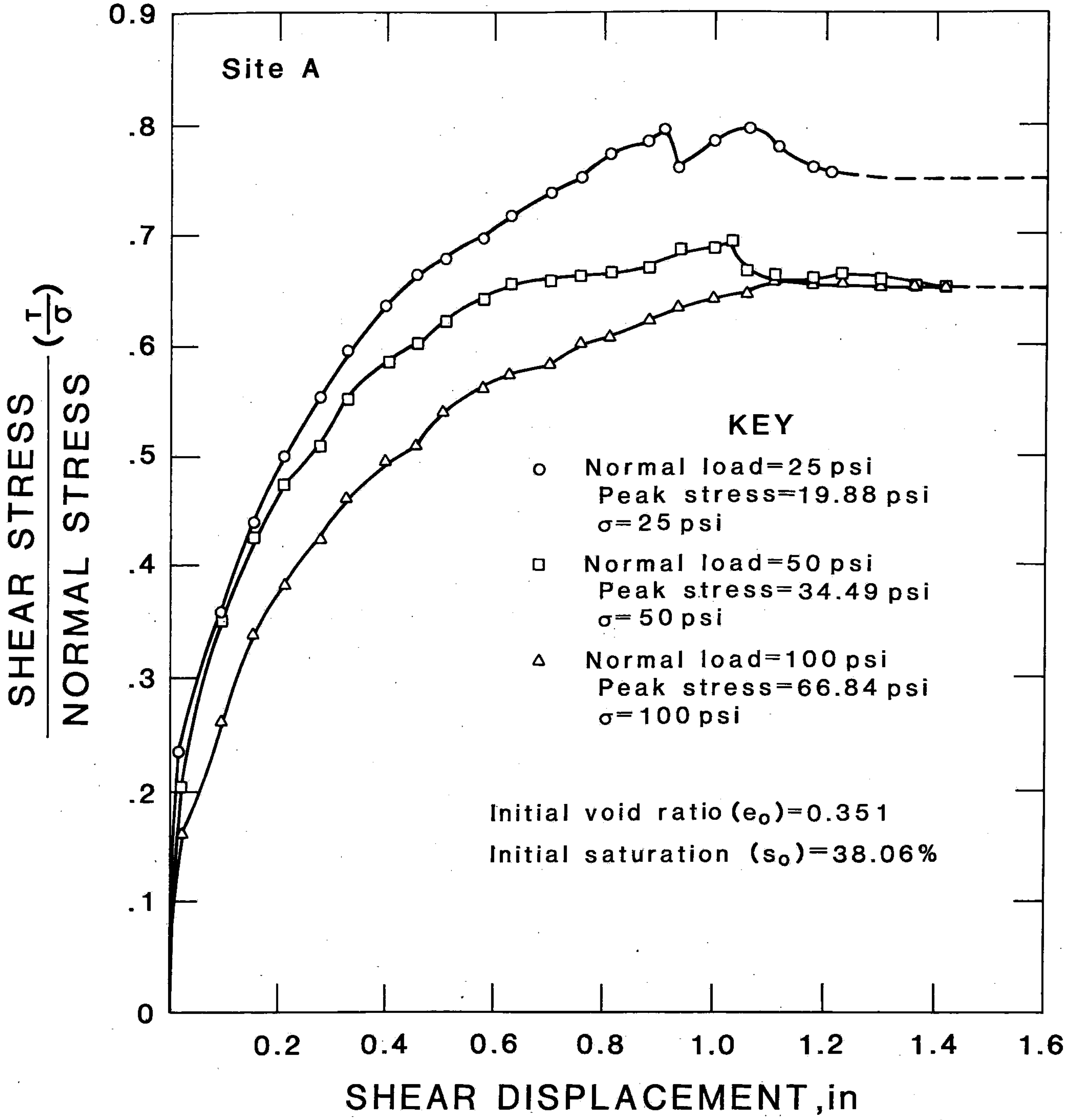

FIGURE A-1. - Normal displacement curves from direct shear tests of site A material.

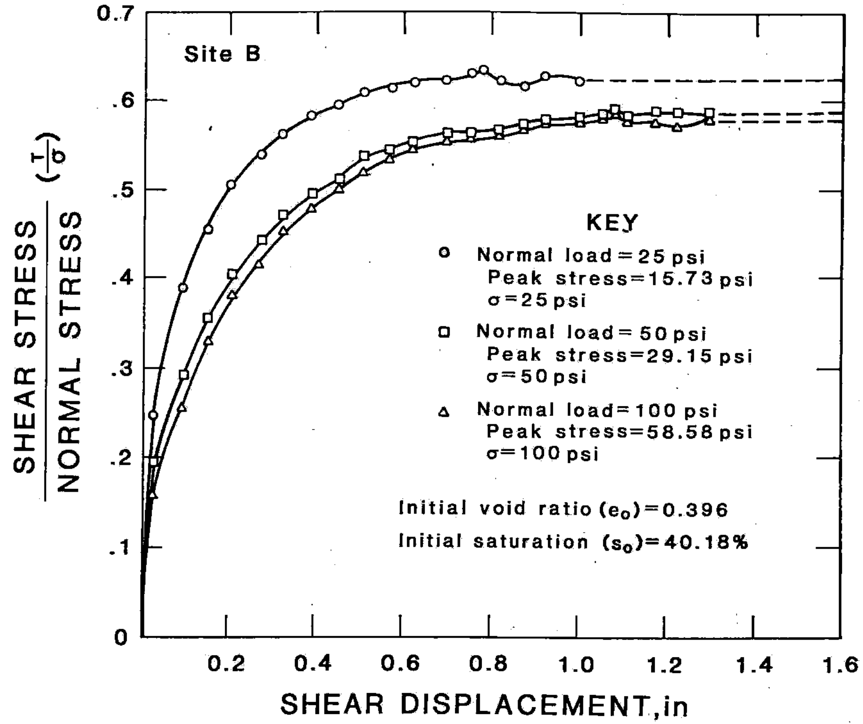

FIGURE A-2. - Normal displacement curves from direct shear tests of site B material.

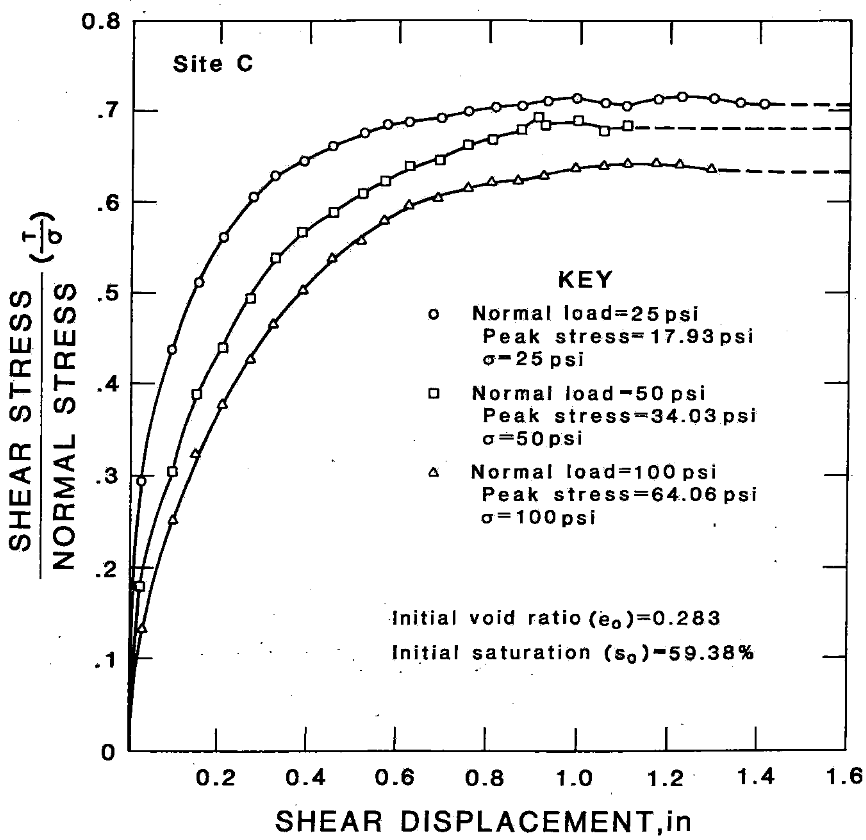

FIGURE A-3. - Normal displacement curves from direct shear tests of site C material.

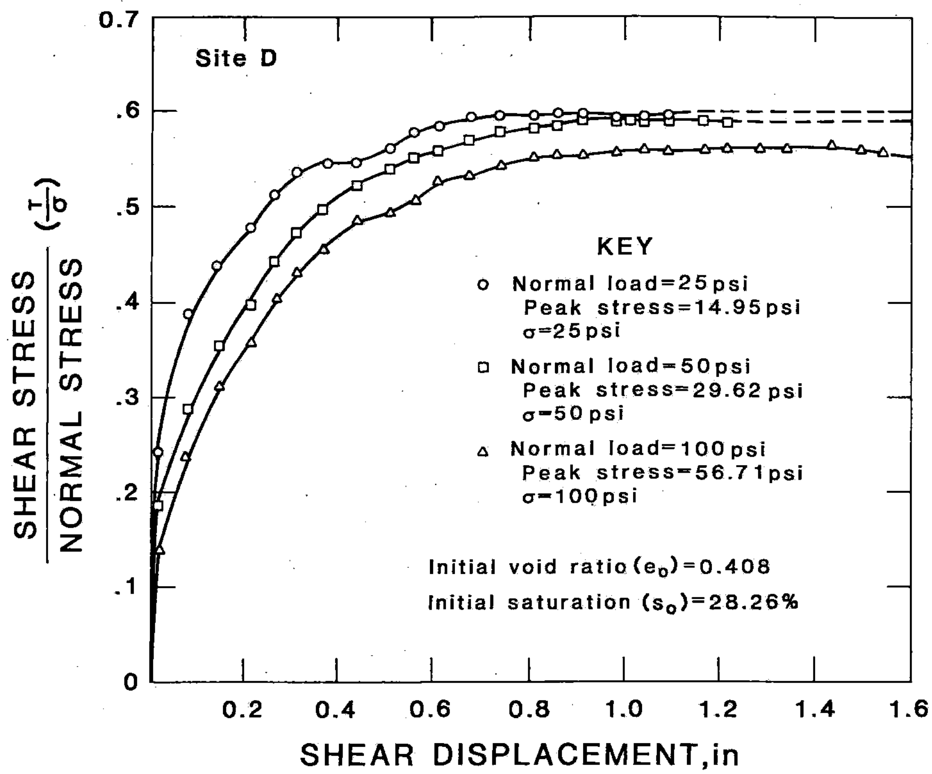

FIGURE A-4. - Normal displacement curves from direct shear tests of site D material.

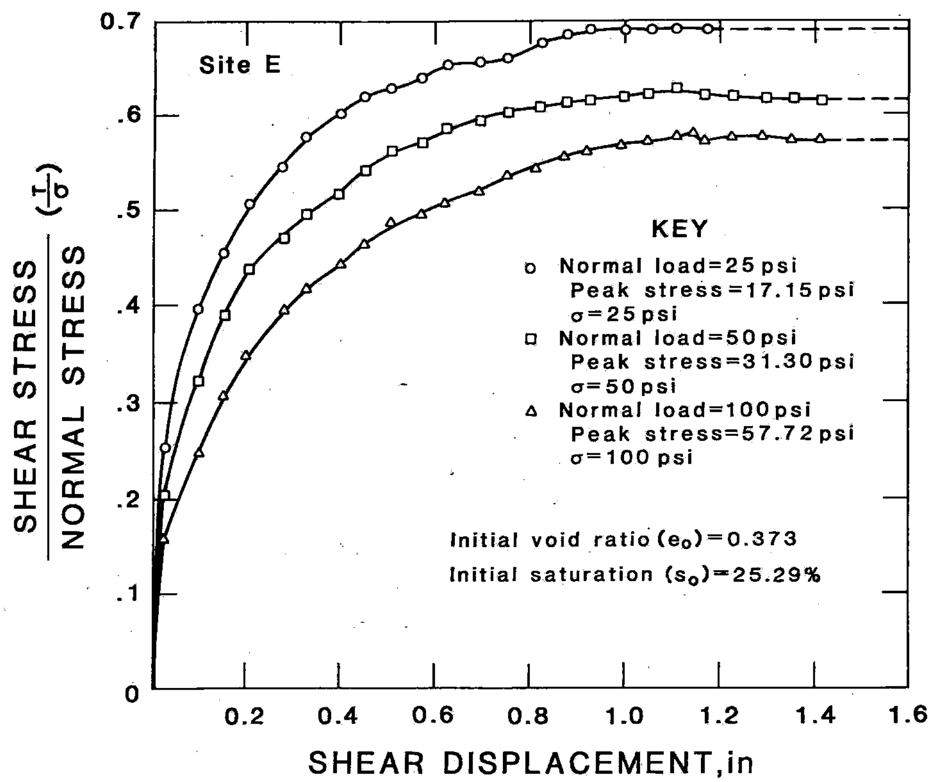

FIGURE A-5. - Normal displacement curves from direct shear tests of site E material.

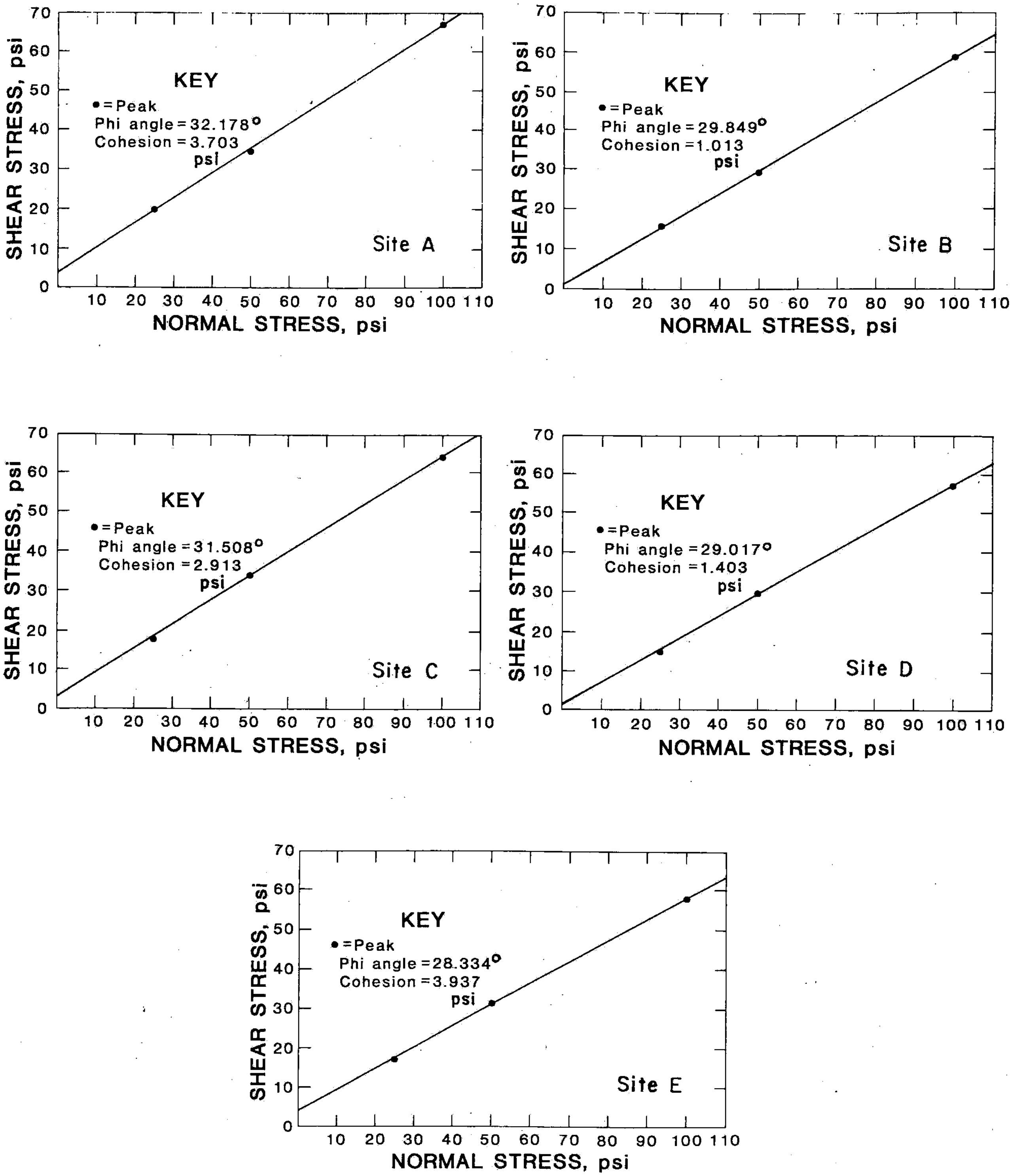

FIGURE A-6. - Plots of shear stress versus normal stress for site A through site E material.

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