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Physical Property Data on Fine Coal Refuse

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PHYSICAL PROPERTY DATA ON FINE COAL REFUSE

by

R. A. Busch,[1] R. R. Backer,[2] L. A. Atkins,[3] and C. D. Kealy[2]

ABSTRACT

Sludge ponds of fine coal, fine soil, and water created behind large piles of coarse coal waste can present hazardous conditions; this is a Bureau of Mines report of the subsurface physical property data developed on the fine coal waste materials that make up the core areas of two typical coal waste impoundments. These data will help define more completely the engineering properties of this problem area of the structures.

Additional calorific, chemical, and mineralogical data were obtained on the coal waste materials to determine possible uses or development of byproducts. The possibility of extracting alumina from coal ash was also investigated.

INTRODUCTION

Since the early 1960's, the coal industry has been under constant pressure by environmental legislation to clean up liquid discharge into streams. Consequently, rather large sludge ponds have developed which consist of fine coal, fine soil, and water. These ponds are generally formed behind large piles of coarse coal waste and in conjunction therewith formulate the often-criticized coal waste impoundments. As a sequel to Bureau of Mines RI 7964 (1),[4] this report deals primarily with the physical and chemical properties of the fine coal wastes in the pond.

The previous report was most concerned with the coarse material and contained only a minimum of sludge information from a few surface samples. To obtain more information on coal sludge, especially at various depths, a sampling program was carried out on two typical waste piles. Four holes were drilled and sampled at 5-foot intervals. These samples were carefully extracted from the drill holes and shipped back to the laboratory in a manner

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[1] Civil engineer.
[2] Mining engineer.
[3] Engineering technician.
[4] Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

that would minimize disturbance. Laboratory tests were performed on these samples to provide data that could be used to evaluate problems involving drainage, liquefaction, strength, and stability. In addition, these samples, plus coarse refuse and red dog from previous sampling, were subjected to a typical coal analysis which could provide information as to the possible use of the waste products as a fuel or as a source for marketable byproducts.

SITE SELECTION

The sites chosen for sampling were selected on the basis of availability as well as being considered representative. They were inactive at the time of sampling, which allowed access by the sampling crew with light equipment (fig. 1). Heavy drilling equipment could not be used because the deposit was saturated and the support capability was poor. Consequently, drilling and sampling were carried out by hand methods (fig. 2).

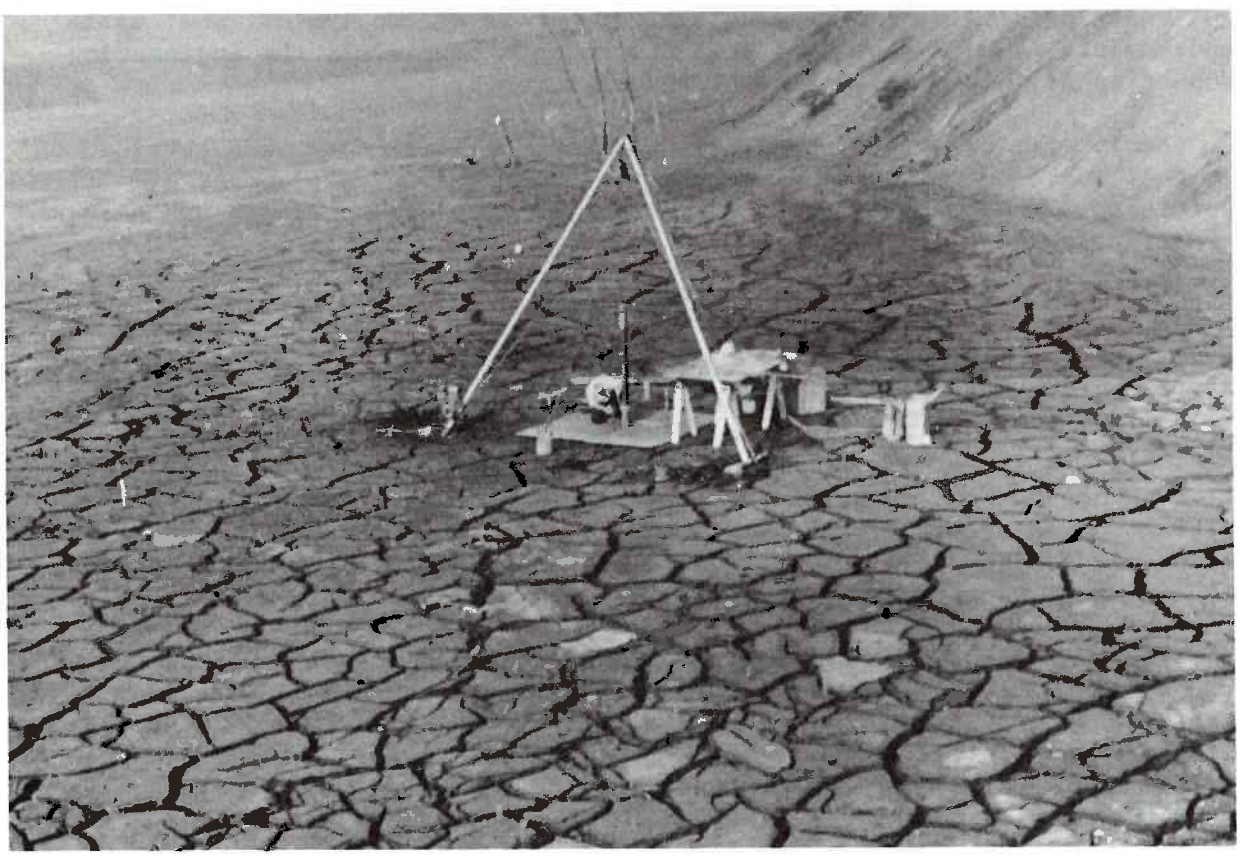

FIGURE 1. - Tripod setup on sludge zone at WDH-1.

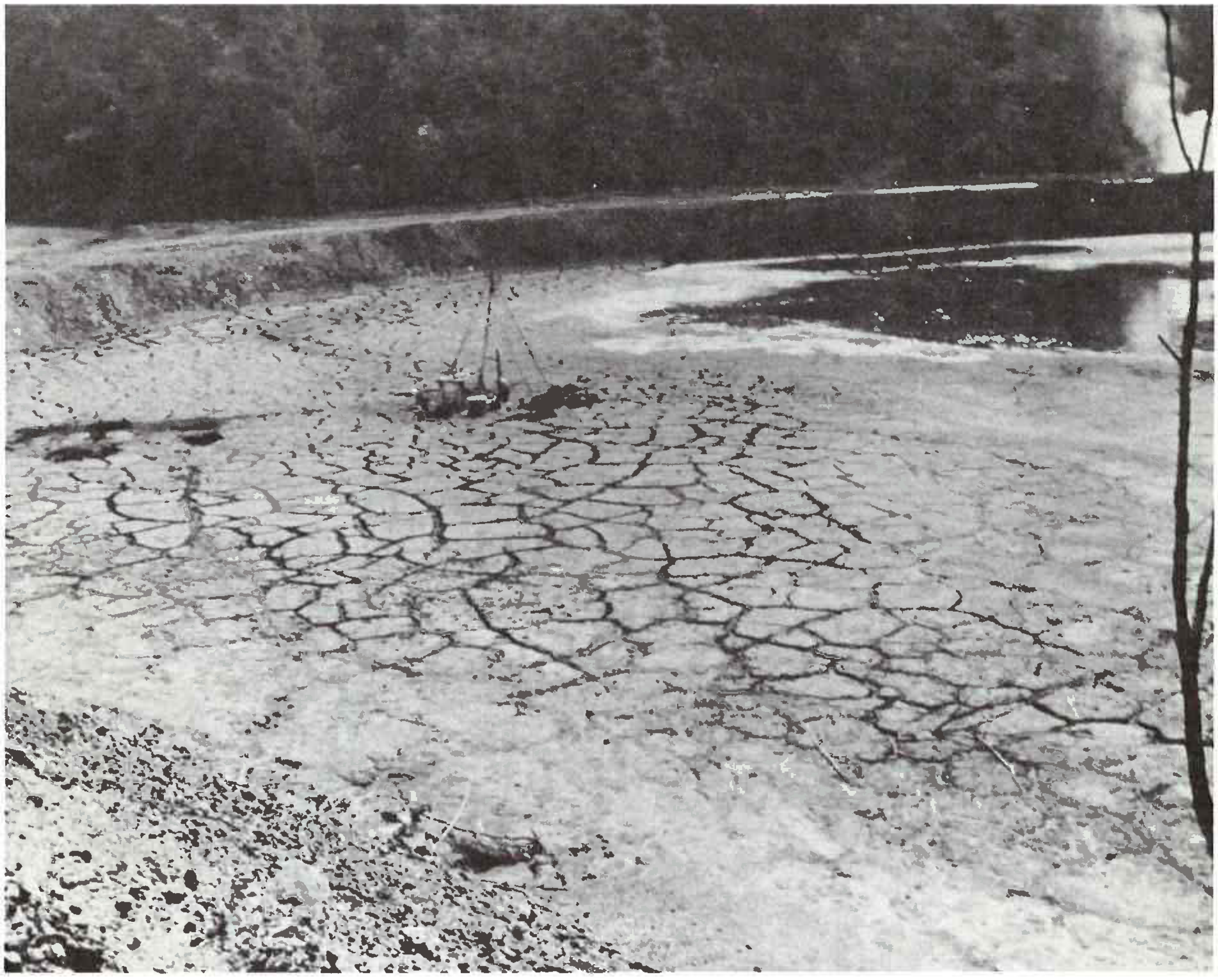

FIGURE 2. - Sampling setup on WDH-2 (note WDH-1 at left of photo).

The difficulty of obtaining the samples and the limitations on time and funds narrowed the fieldwork down to two holes per site. It was decided to concentrate the sampling in what was considered the most hazardous materials--the saturated fine sludge farthest from the discharge line (figs. 3-4). It should be noted, however, that the history of the discharge location was not available so there may be discrepancies in the uniformity of the sludge with varying depths in any one hole.

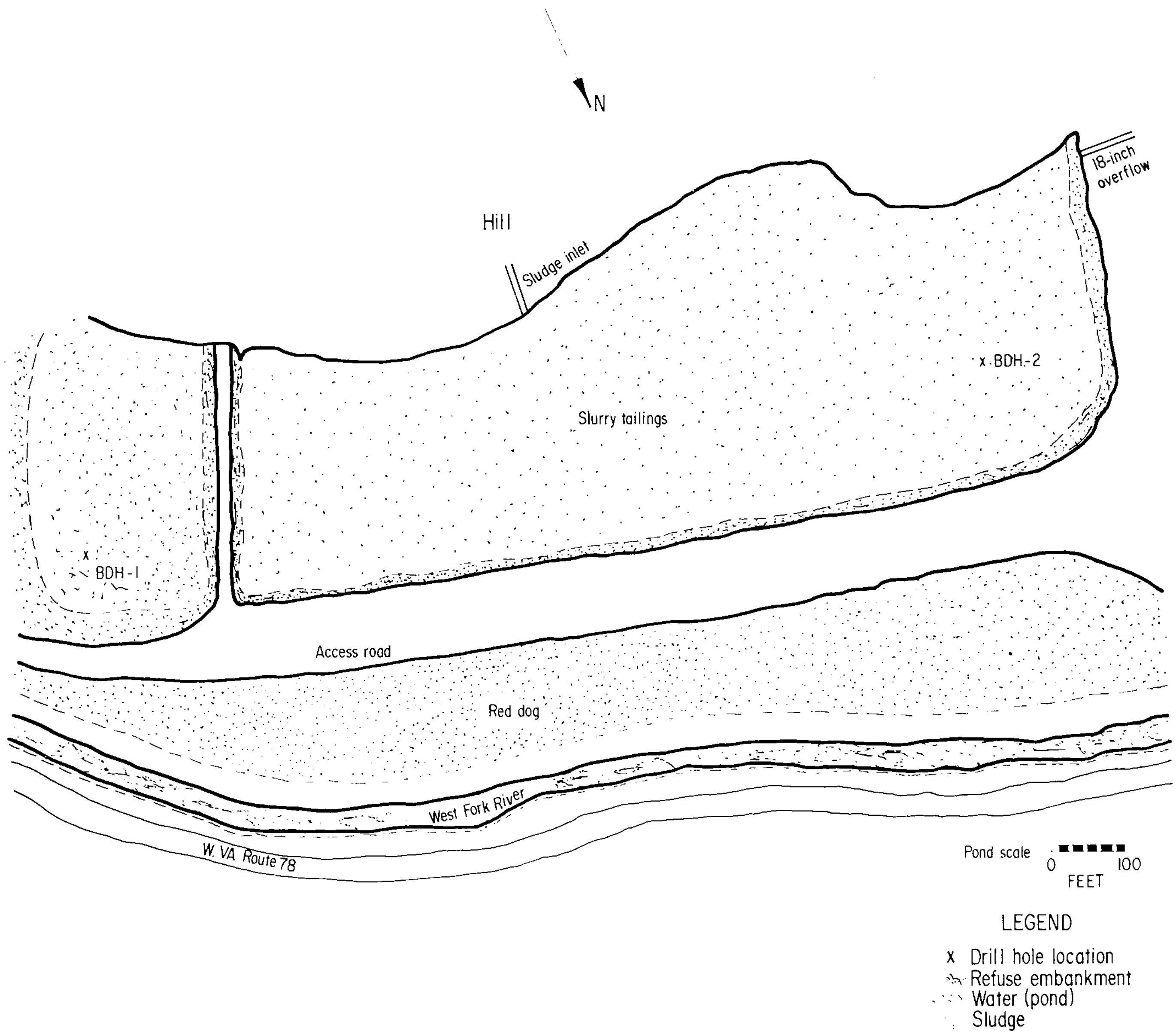

FIGURE 3. - Site and location of BDH-1 and BDH-2.

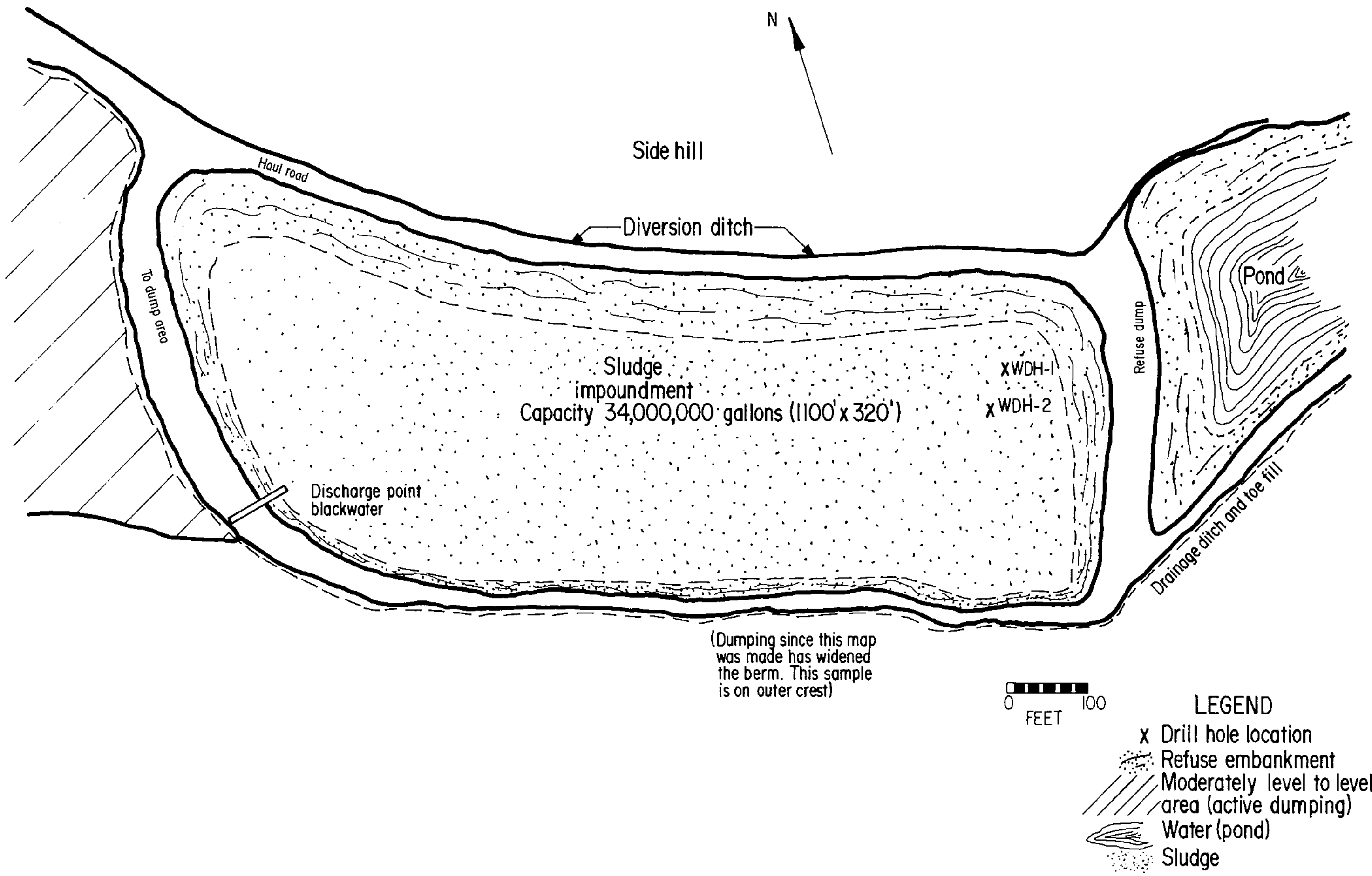

FIGURE 4. - Site and location of WDH-1 and WDH-2.

METHOD OF DRILLING AND SAMPLING

The holes were drilled by hand auger. Because of the tendency of the saturated material to flow into the hole, it was necessary to case the hole immediately. The casing was 5-foot-long sections of 4-inch diameter pipe. Figure 5 shows how the coupling was slipped over this pipe at connections and welded. The casing was driven ahead of the augered hole by a weight suspended from a tripod and raised by a cathead mounted on one leg of the tripod. After a length of casing was driven, the hole was drilled by hand auger. At 5-foot intervals, the hole was sampled by pushing a thin-walled sampler into the sludge ahead of the casing and retrieving the sample. To break the suction at the bottom of the thin-walled tube and prevent the sample from being sucked out, an air line was attached to the outside of the tube and air was pumped into the area at the bottom of the tube as the tube was being extracted. This method of driving casing, drilling, and sampling was performed until it became impractical to continue.

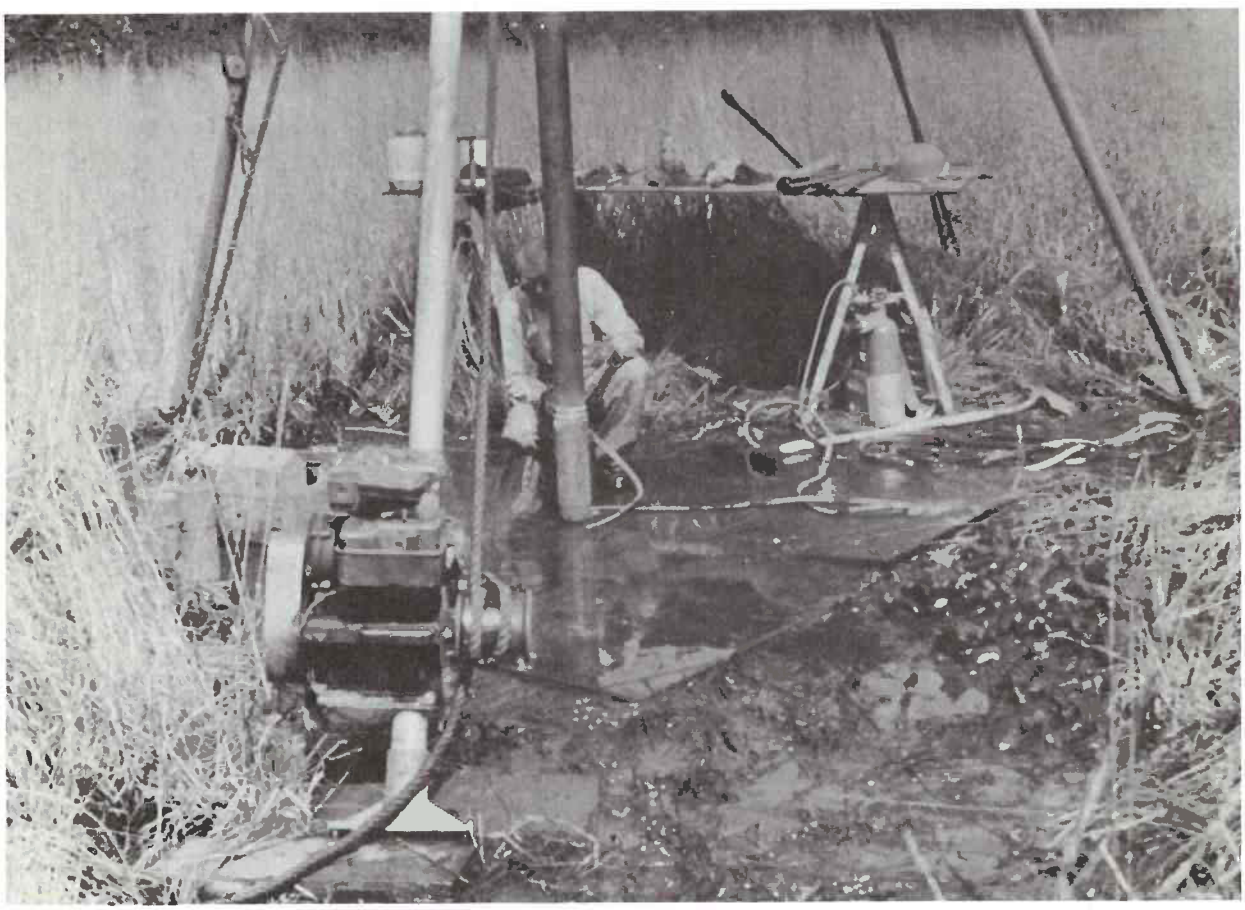

FIGURE 5. - Brazing casing sections prior to driving.

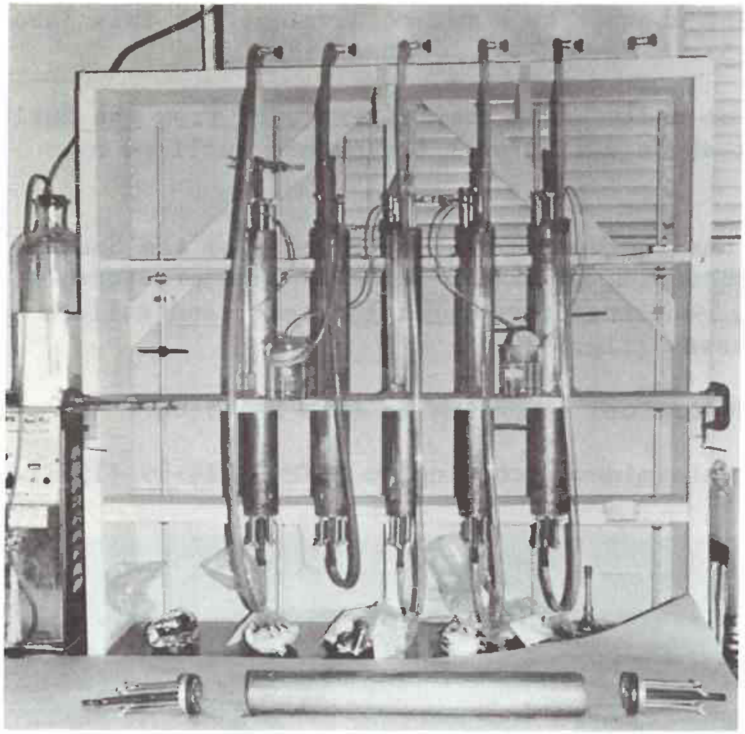

FIGURE 6. - Constant head permeability setup.

FIGURE 7. - Sedigraph 5000 for determining minus 200-mesh particle size.

PROCEDURES

The laboratory tests were performed in the Bureau of Mines Spokane Mining Research Center (SMRC) laboratory using the following procedures:

1. Permeability of the undisturbed Shelby[5] tube samples was determined by a SMRC-developed method using a constant head (fig. 6).

2. Grain-size distribution was performed according to ASTM Standard D-422-63, part II. The minus 200-mesh portion was tested with a Sedigraph 5000[5] particle size analyzer. The Sedigraph operates on the principle of Stokes' law, utilizing X-ray absorption (fig. 7).

3. Specific gravity was determined according to ASTM Standard D-854-58, part II.

4. Maximum density and optimum moisture content were determined according to ASTM D-698-70. Minimum density was determined according to ASTM D-2049-69.

5. The one-dimensional compression tests were

[5]Reference to specific makes or models of equipment is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

performed in a SMRC-designed test chamber by a method developed in this laboratory by Nicholson and Busch (5).

6. The direct shear test on undisturbed samples extruded from the Shelby tubes was performed on a direct shear device with the method outlined by Lambe (3) (fig. 8).

7. The triaxial shear on undisturbed samples extruded from the Shelby tubes was performed primarily according to ASTM D-2850-70. The pressure of the pore fluid was continuously monitored throughout the test, and failure was determined using effective stresses (fig. 9).

8. The liquid limit was determined according to ASTM D-423-66.

9. The plastic limit was determined according to ASTM D-424-59 (1971).

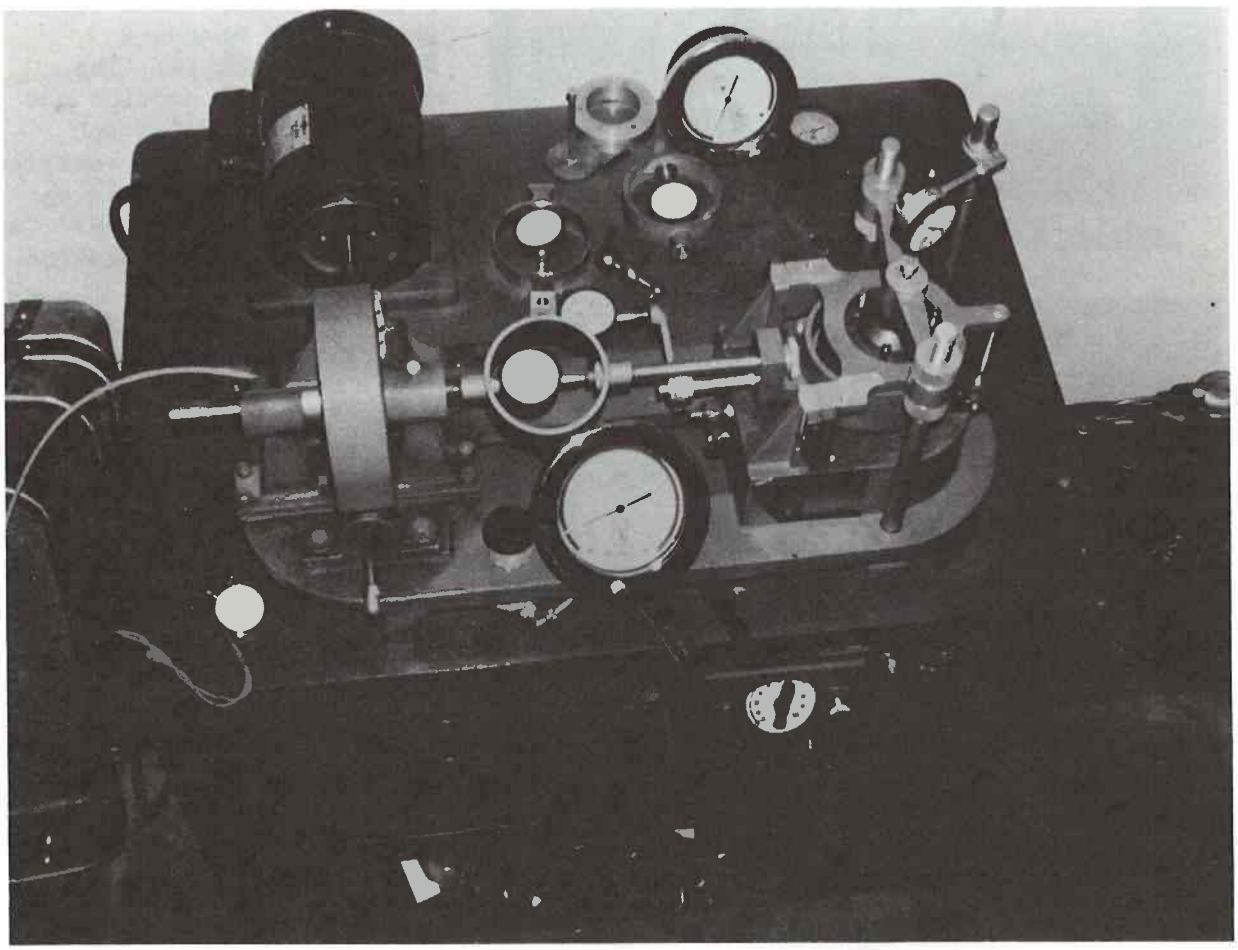

FIGURE 8. - Direct shear device.

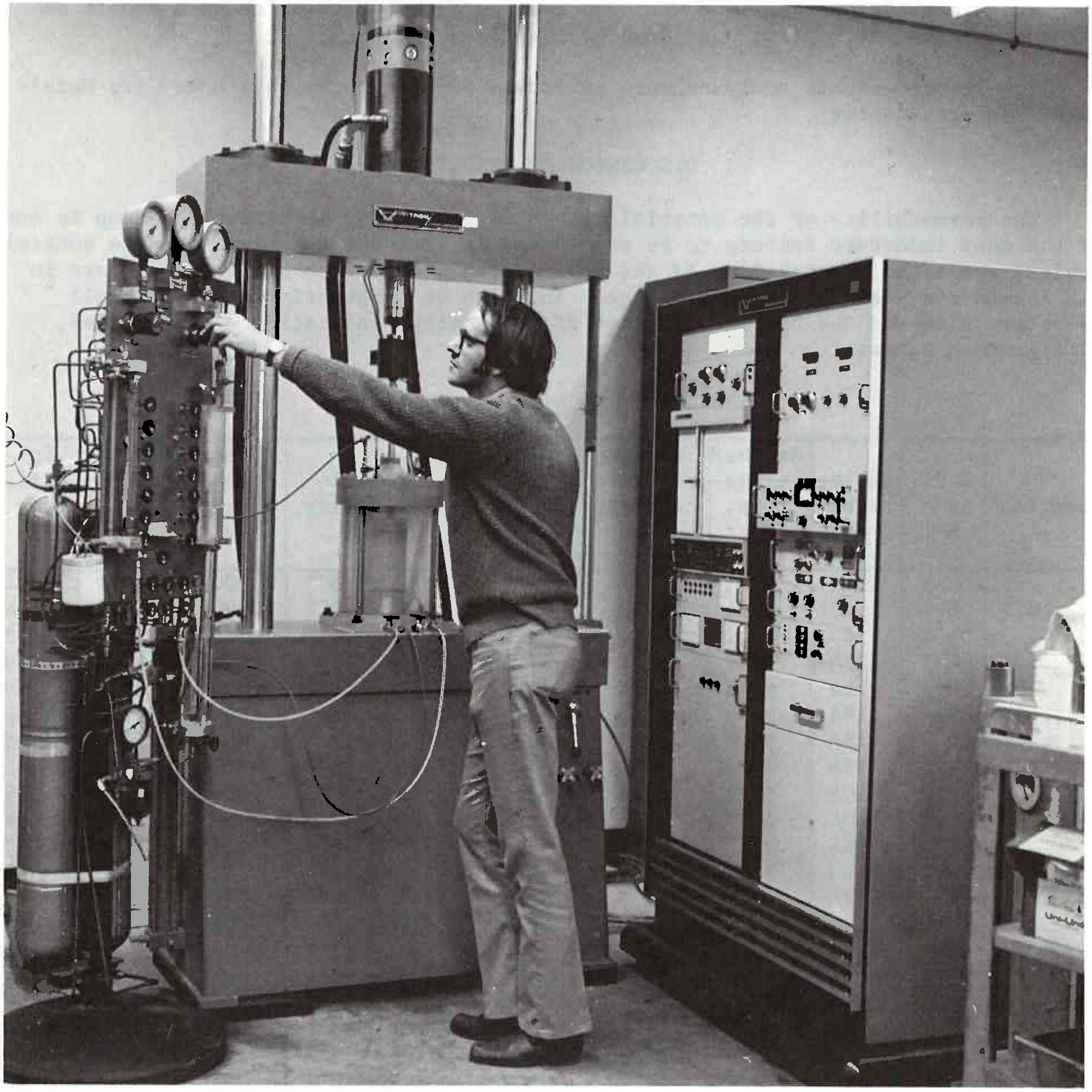

FIGURE 9. - Triaxial shear testing apparatus.

The following tests were performed by others:

1. Ultimate and proximate coal analyses and chemical composition of ash were determined according to Bulletin 638 (7). The ultimate and proximate coal analyses were performed by the Pittsburgh Energy Research Center. The chemical composition of ash was determined by the Aluminum Co. of America (Alcoa) Laboratories.

2. Mineralogical analysis was done through X-ray diffraction on a sample of pulverized material. Tests were done by the Alcoa Laboratories.

3. Spectrographic analyses were performed on ash by the Salt Lake City Metallurgy Research Center.

DISCUSSION OF RESULTS

The permeability of the material within an embankment or mine waste dump is one of the most important factors to be considered in drainage and water seepage control. Table 1 shows the permeability of the undisturbed Shelby tube samples which are in the low-to-very-low permeability range. This can be substantiated by the small effective size and the high coefficient of uniformity, indicating a well-graded, fine-grained material.

TABLE 1. - In situ properties

Location[1]	Drill hole No.	Shelby tube No.	Assumed elevation, feet	Inplace moisture content, percent	Inplace dry density, lb/ft^3	Vertical permeability, cm/sec	Effective size, mm[2]	Coefficient of uniformity	Specific gravity
W........	DH-1	14A	99.1	63.2	48.1	5.77×10^{-5}	0.00062	10.97	1.54
W........	DH-1	7	94.4	51.0	55.6	5.31×10^{-6}	.00049	14.90	1.64
W........	DH-1	8	89.1	57.1	53.9	1.38×10^{-6}	.00042	13.57	1.68
W........	DH-1	13A	84.1	56.2	49.1	2.21×10^{-6}	.00062	14.19	1.59
W........	DH-1	15A	69.1	54.4	54.0	2.00×10^{-6}	.0006	11.00	1.59
W........	DH-1	16A	64.3	50.3	53.2	2.18×10^{-6}	.00062	10.64	1.52
W........	DH-2	18A	99.0	62.5	48.2	8.76×10^{-6}	.00056	11.61	1.66
W........	DH-2	17A	94.1	47.4	55.0	7.76×10^{-7}	.00076	14.47	1.45
W........	DH-2	19A	89.1	59.0	53.8	1.40×10^{-6}	.0006	14.17	1.65
W........	DH-2	20A	84.1	51.7	53.0	2.28×10^{-6}	.001	20.00	1.52
W........	DH-2	5A	79.1	49.9	51.6	4.67×10^{-6}	.001	11.00	1.47
W........	DH-2	6A	74.1	51.1	53.1	5.59×10^{-6}	.0014	11.43	1.58
W........	DH-2	7A	69.1	51.9	52.8	2.42×10^{-6}	.0011	12.73	1.53
W........	DH-2	8A	64.1	52.3	46.8	2.48×10^{-6}	.001	12.00	1.59
W........	DH-2	9A	59.1	54.5	53.2	2.90×10^{-6}	.00105	11.90	1.54
B........	DH-1	1	99.0	45.6	46.4	2.97×10^{-4}	.0016	40.62	1.48
B........	DH-1	2	95.1	44.3	47.2	2.49×10^{-5}	.0026	57.69	1.50
B........	DH-1	3	90.1	48.9	47.8	6.53×10^{-6}	.004	45.00	1.46
B........	DH-1	4	75.1	24.2	61.0	2.06×10^{-4}	.04	8.50	1.85
B........	DH-1	5	70.1	21.3	56.8	3.05×10^{-4}	.069	8.55	1.56
B........	DH-1	6	65.1	25.8	55.8	8.86×10^{-4}	.088	6.14	1.64
B[3].......	DH-2	3A	99.2	63.0	55.3	3.75×10^{-3}	.0004	10.50	2.07
B........	DH-2	10A	94.1	62.2	51.0	9.18×10^{-7}	.00086	7.32	1.74
B........	DH-2	11A	89.1	64.0	54.2	7.51×10^{-7}	.00035	8.71	1.84
B........	DH-2	12A	84.2	59.6	50.9	1.76×10^{-6}	.00045	7.11	1.84
B........	DH-2	A	79.1	57.7	51.1	1.38×10^{-6}	.0006	7.50	1.69
B........	DH-2	1A	74.2	60.1	52.5	1.86×10^{-6}	.00083	7.23	1.70
B........	DH-2	2A	69.2	57.7	52.8	4.12×10^{-6}	.00041	9.02	1.66

[1] Surface elevation at all drill holes was assumed at 100 feet.
[2] The size at which 10 percent is finer.
[3] Shelby tube 3A contained a large amount of vertical roots and holes.

The range of the grain-size distribution curves (fig. 10) for each drill hole shows a relatively well-graded material, quite similar within each drill hole, with the exception of BDH-1. BDH-1 was not homogeneous in respect to size distribution and showed a much larger particle size in the deeper samples. This indicates that the discharge line was probably in a different location at some earlier date and not as shown on figure 1.

Specific gravity values shown in table 1 are relatively uniform for each site location. The low values of specific gravity indicate high coal content. The specific gravity of pure coal is in the range of 1.25 to 1.70 (6).

The importance of shear strength data dictated a rather extensive shear test program. Two types of shear tests were performed on undisturbed Shelby tube samples: drained direct shear and unconsolidated triaxial shear. Results of the direct shear are shown in table 2. They indicate that there is some degree of strength and cohesion. However, these tests were allowed to drain and were run slowly enough to prevent pore pressure buildup. The angle of internal friction, ϕ, was determined by using peak stresses.

TABLE 2. - Shelby tube shear data

Site No.	Drill hole No.	Shelby tube No.	Mean elevation, feet	Drained direct shear, in situ conditions					
				Moisture content, percent	Placement density, pcf	Consolidation density, pcf	Degree of saturation, percent	ϕ, degrees	Cohesion, psi
W....	DH-1	14A	99.1	58.4	53.0	62.5	100.0	32	0.9
W....	DH-1	8	89.1	50.2	58.4	66.0	100.0	29	4.7
W....	DH-1	16A	64.2	49.7	56.5	62.9	100.0	32	4.0
W....	DH-2	18A	99.0	66.0	54.4	66.0	100.0	26	3.0
W....	DH-2	17A	94.1	61.6	54.2	65.0	100.0	28	2.2
W....	DH-2	9A	59.1	47.9	57.0	62.5	100.0	32	2.9
B....	DH-1	2	95.1	55.8	47.4	50.8	87.7	35	.4
B....	DH-1	3	90.1	53.4	52.4	57.8	99.5	34	1.8
B....	DH-1	4	75.1	21.8	63.7	69.0	66.8	35	1.3
B....	DH-2	3A	99.2	59.9	61.9	74.9	100.0	20	5.4
B....	DH-2	11A	89.1	65.8	56.4	69.1	100.0	25	2.0
B....	DH-2	2A	69.2	63.7	52.7	57.2	100.0	34	1.2

The undrained, unconsolidated triaxial shear tests show no shear strength or cohesion. This can be attributed to the high degree of saturation which allowed the pore fluid pressure, μ, to attain the same pressure as the confining liquid or lateral pressure, σ_3. By using the effective maximum stress ratio for failure, the results are zero.

PARTICLE SIZE DISTRIBUTION

SAMPLE IDENTIFICATION **BDH-1**

DATE **5-13-74**

BY **LAA**

Preparation **0.3% Calgon solution**

Maximum Size: 3,900 micrometers

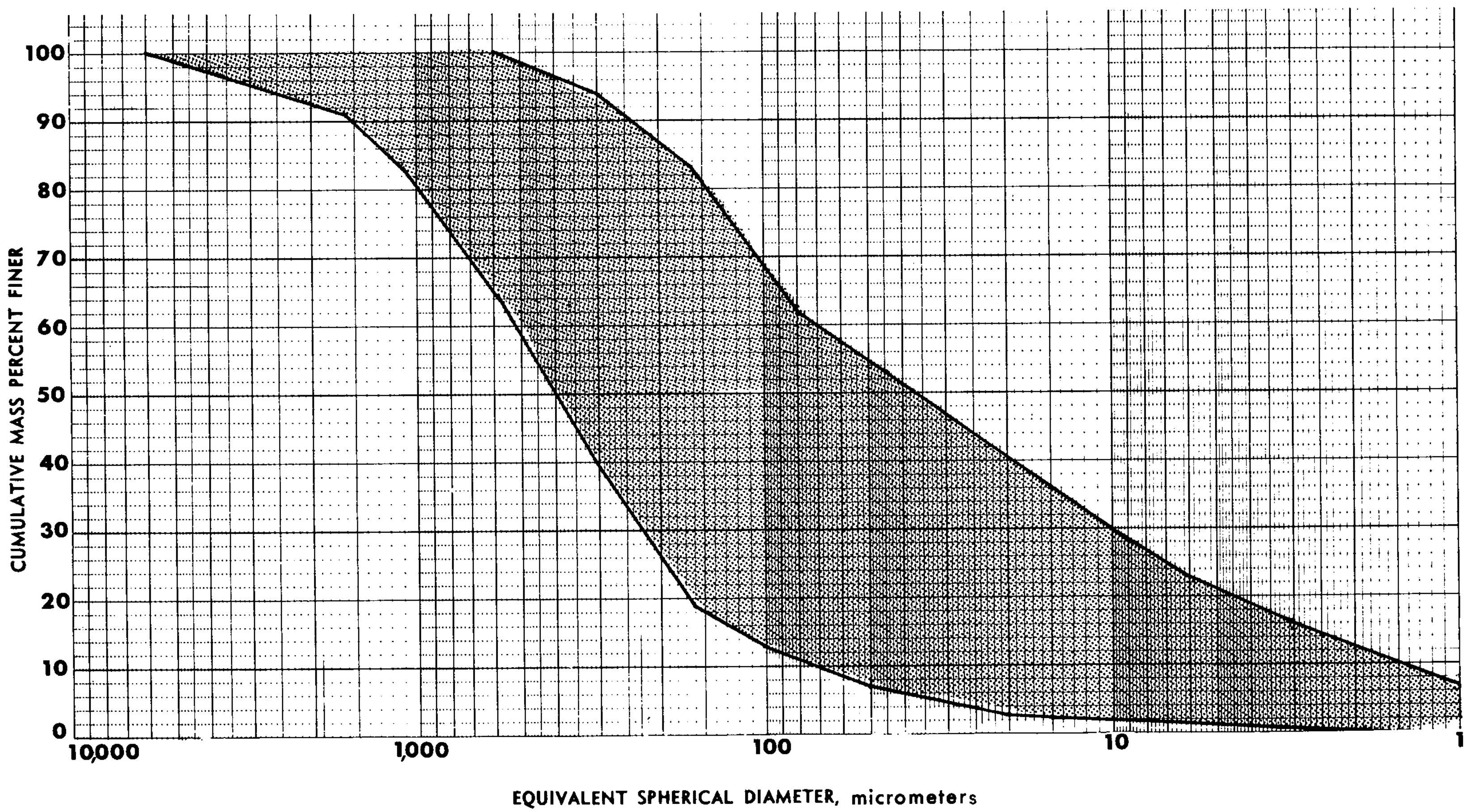

FIGURE 10. - Particle size ranges for drill hole samples.

PARTICLE SIZE DISTRIBUTION

SAMPLE IDENTIFICATION BDH-2

DATE 5-13-74

BY LAA

Preparation 0.3% Calgon solution

Maximum Size: 310 micrometers

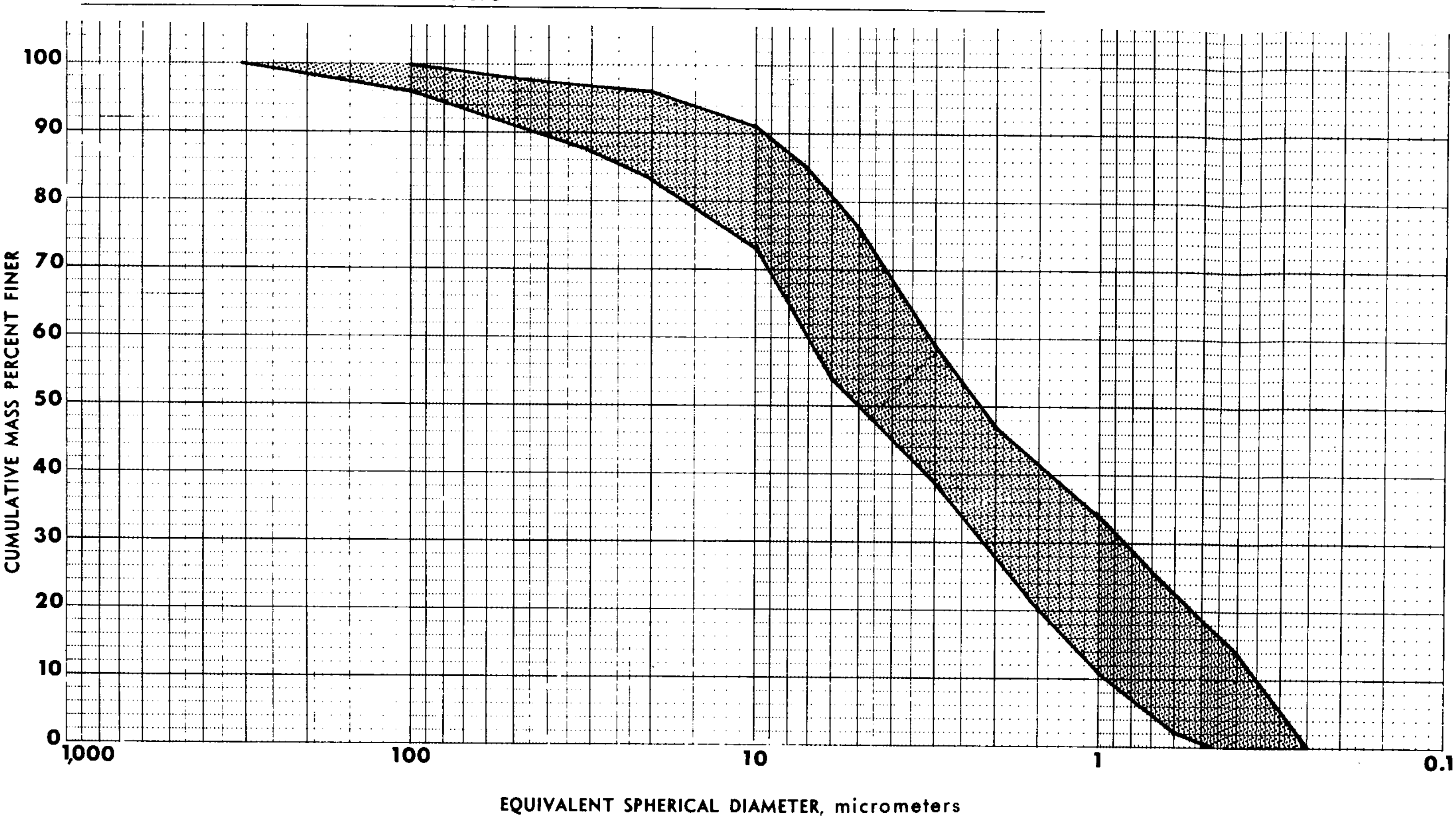

FIGURE 10. - Particle size ranges for drill hole samples.–Continued

PARTICLE SIZE DISTRIBUTION

SAMPLE IDENTIFICATION **WDH-1**

DATE **5-13-74**

BY **LAA**

Preparation **0.3%Calgon solution**

Maximum Size 590 micrometers

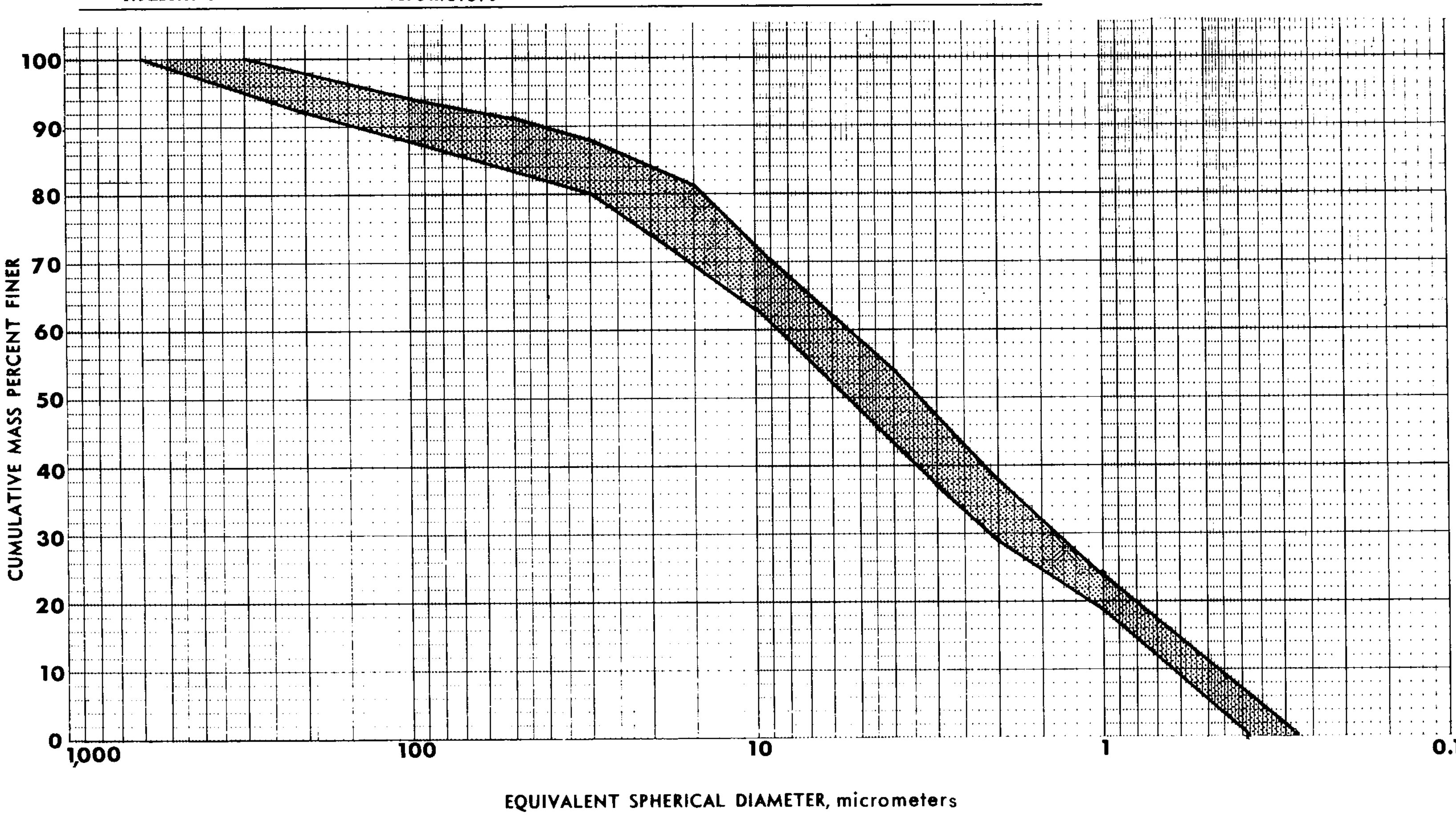

FIGURE 10. - Particle size ranges for drill hole samples.—Continued

PARTICLE SIZE DISTRIBUTION

SAMPLE IDENTIFICATION WDH-2

DATE 5-13-74

BY LAA

Preparation 0.3%Calgon solution

Maximum Size: 420 micrometers

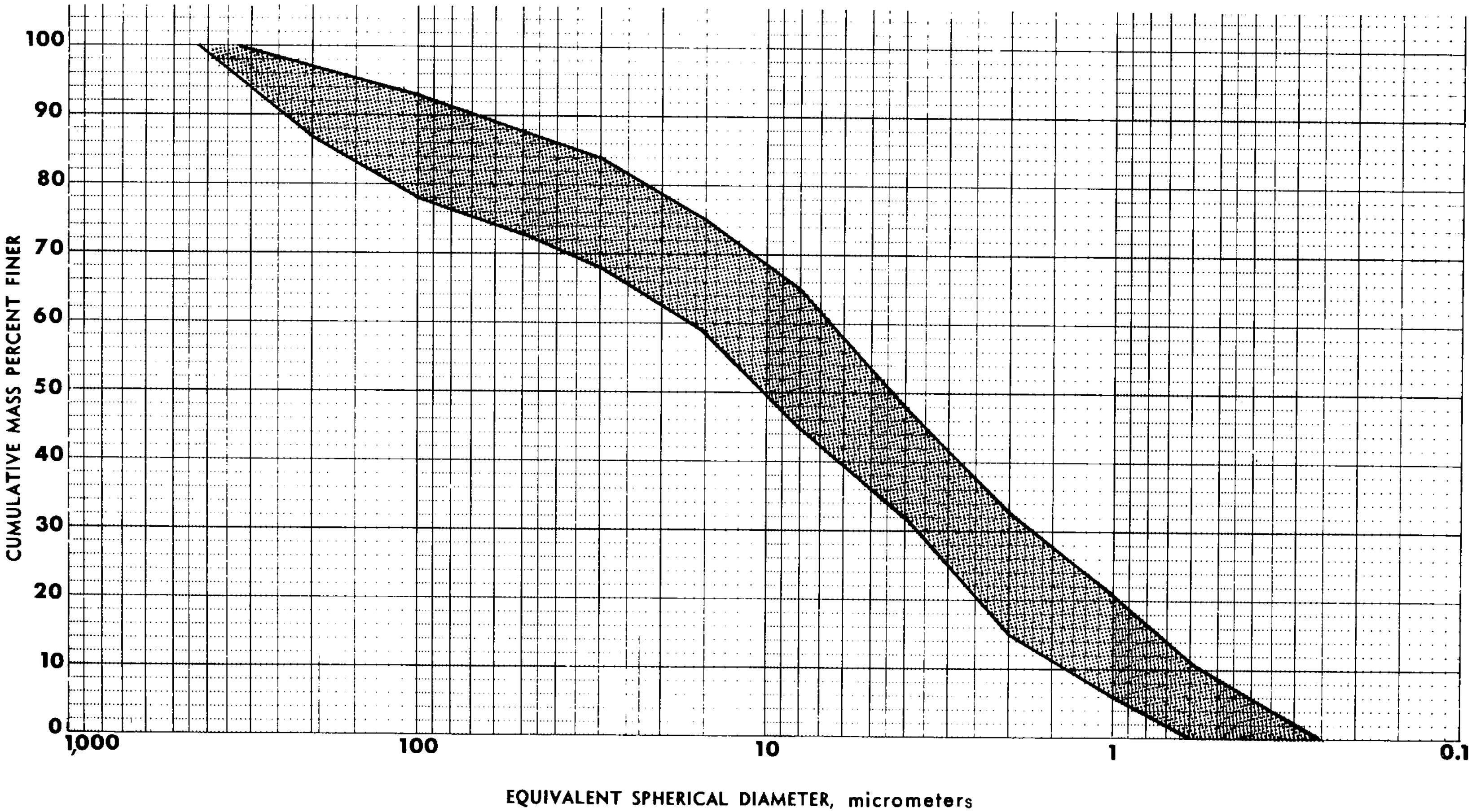

FIGURE 10. - Particle size ranges for drill hole samples.–Continued

$$S_s = \frac{\text{major effective stress}}{\text{minor effective stress}} = \frac{\sigma_1 + \sigma_3 - \mu}{\sigma_3 - \mu}, \tag{1}$$

where σ_1 = the major principal stress,

σ_3 = the minor principal stress,

and μ = the pore fluid pressure.

The presence of water does not affect the angle of internal friction of a soil, but as these test results indicate, it can dramatically affect the shear strength of the soil. The value of shear strength that should be used in analysis can vary considerably, depending on whether a slow "creep" type of failure or a sudden "quick" condition exists. The slow permeability rates in coal sludge would indicate the possibility of pore water pressures and reduced strength.

One-dimensional compression tests were performed on four composited samples (one for each drill hole). After the previous tests were performed, all Shelby tubes from each drill hole were composited and water was mixed with each to attain the average in situ water content. The sample was then placed in the test chamber near the average inplace density. The test results yielded earth pressure at rest values, K_o, approaching 1.0 (table 3). The test chamber was not completely sealed, allowing some water to drain during the test; this may account for the results that show a K_o value less than 1. However, the pore water pressure monitored during the test shows the reading to be the same as the vertical applied stress. These test results also indicate either no shear strength and the material being in a quick condition or zero effective stress. The Poisson's ratio and Young's modulus can be obtained from this test (table 3).

The maximum and minimum densities shown in table 3 are average numbers for the two drill holes. Although it is not considered practical to compact the entire sludge deposit, it is worth noting that the average field densities for the two holes are less than 80 percent of maximum. Using the Proctor density as the maximum and the usual minimum laboratory density as a base, the relative density of the most dense field sample is only 54 percent, which puts it in the critical range of potential liquefaction. Any sudden reduction in void ratio due to a shock or shifting of the pond could easily set up a "quick" condition resulting in zero shear strength.

As noted in table 1, some of the field densities observed are lower than the laboratory minimum density. This is probably due to the excessive water in the sludge deposit which separates the soil particles and increases the void ratio. The laboratory minimum tests are performed on dry material.

TABLE 3. - Composite samples

Site No.	Drill hole No.	Proctor Density Determination: Maximum density, pcf	Proctor Density Determination: Optimum moisture content, percent	Minimum density, pcf	Grain Size: Effective size, D_{10}	Grain Size: Coefficient of uniformity	Specific gravity	One-Dimensional Compression Tests: Dry density, pcf	Water content, percent	Percent of natural dry density	Vertical applied stress[1] psi	Constrained modulus,[2] psi	Earth pressure at rest[3]	Poisson's ratio[4]	Young's modulus,[5] psi	Atterberg Limits: Liquid limit	Atterberg Limits: Plasticity index
W	DH-1	66.4	27.8	44.8	.00048	11.67	1.61	53.0	55.4	101.3	0	0.0	0	0	0.0	41.7	8.7
								54.5		104.2	25	898.2	1.00	.500	.0		
								55.6		106.3	50	1,066.1	1.00	.500	.0		
								56.8		108.6	75	1,131.8	1.00	.500	.0		
								58.1		111.1	100	1,167.3	.992	.498	13.1		
W	DH-2	-	-	-	.00078	10.26	1.60	49.9	53.4	96.1	0	.0	0	0	.0	38.0	2.7
								53.6		103.3	25	353.0	.96	.490	21.0		
								55.3		106.6	50	493.9	.98	.495	14.8		
								57.0		109.8	75	580.2	.973	.493	23.1		
								59.4		114.4	100	606.6	.937	.484	56.2		
B	DH-1	70.4	18.0	50.0	.006	58.33	1.58	61.5	35.0	117.1	0	.0	0	0	.0	34.3	0
								64.0		121.9	25	678.7	1.00	.5	.0		
								64.4		122.7	50	1,183.9	1.00	.5	.0		
								64.6		123.0	75	1,621.0	.997	.499	8.1		
								65.0		123.8	100	1,960.8	.990	.497	29.4		
B	DH-2	-	-	-	.000349	9.17	1.87	51.1	60.6	97.3	0	.0	0	0	.0	51.1	13.1
								53.4		101.7	25	566.0	.980	.495	16.9		
								54.1		103.0	50	863.6	.990	.497	12.9		
								54.9		104.6	80	1,115.8	.994	.498	10.4		
								55.0		104.8	100	1,357.5	.990	.497	20.3		

1 σ_v = vertical applied stress.
2 M = constrained modulus = σ_v/vertical deformation $(\epsilon\nu)$.
3 K_o = earth pressure at rest = lateral horizontal stress $(\sigma_h)/\sigma_v$.
4 ν = Poisson's ratio = $K_o/(1+K_o)$.
5 E = Young's modulus = $M(1-\nu-2\nu^2)/(1-\nu)$.

Dashes indicate test was not run.

Because of the apparent substantial percentages of coal in the waste materials, regular coal proximate and ultimate analyses were performed, and the results are tabulated in table 4. The ash, volatile matter, and fixed carbon percentages obtained by the proximate analysis define the amount of combustible material in the refuse, while the calorific value defines the rank of the coal. The ultimate analysis describes the elemental composition of the coal portion and the percent ash.

TABLE 4. - Standard coal analyses

	Sample			
	BDH-1[1]	WDH-1[1]	Average red dog[2]	Average coarse[3]
Proximate analysis:				
In situ moisture...........percent..	35.0	55.4	7.1	7.4
Moisture free:				
Volatile matter............do.....	22.1	22.1	6.8	15.8
Fixed carbon...............do.....	52.4	45.6	3.4	29.0
Ash........................do.....	25.5	32.3	89.8	55.2
Heat content..............Btu/lb..	10,690.0	9,600.0	597.0	5,944.0
Moisture and ash free:				
Volatile matter..........percent..	29.7	32.6	70.0	36.6
Fixed carbon...............do.....	70.3	67.4	30.0	63.4
Heat content..............Btu/lb..	14,340.0	14,180.0	4,856.0	13,102.0
Ultimate analysis, percent:				
Moisture free:				
Hydrogen..........................	3.6	3.3	.5	2.2
Carbon............................	62.3	56.1	4.7	35.2
Nitrogen..........................	1.0	.8	.1	.6
Oxygen............................	6.8	7.0	3.4	5.7
Sulfur............................	.8	.5	1.5	1.1
Ash...............................	25.5	32.3	89.8	55.2
Moisture and ash free:				
Hydrogen..........................	4.9	4.8	5.1	5.1
Carbon............................	83.6	82.8	58.4	77.7
Nitrogen..........................	1.3	1.2	.9	1.3
Oxygen............................	9.2	10.5	25.6	13.3
Sulfur............................	1.0	.7	10.0	2.6

[1]Composite of sludge from drill hole.
[2]Composite of burned coarse coal waste from prior sampling program.
[3]Composite of coarse coal waste from prior sampling program.

A chemical analysis was run on the ash left after burning the refuse. By studying the composition of the ash, any significant high percentages of compounds can be easily identified. This analysis was made to determine if there are any useful recoverable elements in such an abundant source of "raw material." Table 5 lists the composition of the various samples.

TABLE 5. - Chemical composition of ash

Sample	SiO_2	Fe_2O_3	TiO_2	Al_2O_3	CaO	Na_2O	SO_3	K_2O	MgO	Lost on fusion
BDH-1............	56.8	7.9	1.2	25.2	1.4	0.2	1.2	3.7	1.3	0.6
WDH-1............	53.2	5.4	1.0	26.6	3.2	.5	2.8	4.3	1.9	.6
Average red dog..	60.9	8.1	1.3	22.9	.6	.3	.7	3.7	1.0	.3
Average coarse...	59.2	7.2	1.2	22.6	2.2	.4	1.8	4.0	1.3	.8

X-ray diffraction of the refuse identifies major, minor, and trace minerals. These data point out the dominant characteristics of the refuse material and are listed in table 6.

TABLE 6. - X-ray diffraction analysis of coal refuse

Sample	Quartz	Illite	Kaolinite	Calcite	Feldspar	Gypsum	Hetalite	Mullite	Cristobalite
BDH-1[1]...........	M	m	m	-	-	-	-	-	-
WDH-1[1]...........	M	t	m	t	t	-	-	-	-
Average red dog[2].	M	-	-	-	-	m	m	m	t
Average coarse[3]..	M	m	m	t	t	-	-	-	-

M = major mineral, m = minor mineral, t = trace mineral, - = undetected.
[1]Composite of sludge from drill hole.
[2]Composite of burned coarse coal waste from prior sampling program.
[3]Composite of coarse coal waste from prior sampling program.

In addition to X-ray diffraction, the ash was also examined by spectrographic analysis to identify the elements present. These data, listed in table 7, can be correlated with the results of the chemical analysis and X-ray diffraction of the ash.

TABLE 7. - Spectrographic analysis of coal ash

Site	Ag	Al	Be	Ca	Co	Cr	Cu	Fe	Ga	K	Mg	Mn	Na	Ni	Pb	Sc	Si	Ti	V	Y	Zr
BDH-1[1]........	F	A	F	C	E	E	E	B	E	B	B	D	C	D	D	E	A	C	D	E	E
WDH-1[1]........	-	A	F	B	E	E	E	B	E	B	B	D	C	D	D	E	A	C	D	E	E

[1]Composite of sludge from drill hole.
NOTE.--A = Probably >10 percent.
B = Probably 1-10 percent.
C = Probably 0.1-1 percent.
D = Probably 0.01-0.1 percent.
E = Probably 0.001-0.01 percent.
F = Probably 0.0001-0.001 percent.
\- = Undetected.

CONCLUSIONS AND RECOMMENDATIONS

The physical properties and field conditions of coal sludge combine to make deposits of this material unstable. The extremely fine size of the material plus the rather well graded grain sizes make the permeability very slow.

Consequently, the material acts as a barrier, impounding water, and if saturated, it is extremely difficult to drain. This characteristic of coal sludge allows waste piles to become dangerous. It is generally accepted that if a fine-grained saturated sand has a relative density less than 60 percent, it may liquefy when subjected to sudden shock or reorientation of particles. Since most sludge is transported as a slurry from spigots, deposits occur which could be on the verge of liquefaction. The slow settling characteristics of the low-specific-gravity particles are conducive to loose or honeycombed structures of high void ratio with high degree of saturation.

The shear strength of sludge as determined by drained direct shear was very similar to the coarse coal waste, as could be expected. The results of saturated undrained triaxial shear tests indicate that in this condition, which may be more representative of field conditions, the sludge has very little strength. It is quite apparent that if a sudden failure due to a slide or shock were to occur, the sludge would not contribute anything to the resisting forces.

Coal sludge comprises approximately 25 to 30 percent ash when dried, but still yields about 10,000 Btu per pound, which places it in the subbituminous coal range. Since this material is a prime liability in waste embankments, utilization as a fuel would solve a hazard problem. Even if it were a marginal product, elimination of legal disposal problems may make utilization economically feasible. Some companies are currently reclaiming coal from sludge ponds by minidredge machines. Recovery is about 40 tons of coal per hour.

The objection to high-ash coal is based upon fouling problems, erosion, decreased heat conduction, and corrosion of furnaces.[6] New developments in furnace design have resulted in units that can handle 30-percent ash material with little trouble, and projections are that furnaces will soon take coals approaching 50 percent ash.

The ash itself could very well be a valuable byproduct with its high alumina content. It has been reported that in Britain, 1 ton of alumina was obtained from 10 to 12 tons of ash.[7] [8] A comparison of bauxite, the principal alumina ore, and coal waste ash follows:

	Bauxite (percent)	Coal waste ash (approx. percent)
Al_2O_3....	50 to 60	25
SiO_2.....	2 to 20	60
Fe_2O_3....	1 to 25	7
TiO_2.....	1 to 3	([1])
Other....	([1])	

[1]Not determined.

[6]Reference 4, pp. 820-891.
[7]Reference 4, p. 1098.
[8]Coal ash produced from burning U.S. coal waste average about the same percent Al_2O_3 as ash from British coal and, therefore, should contain the same amount of alumina.

Coal Age magazine has quoted Alcoa as privately estimating that alumina from coal wastes could be produced on a commercial scale cheaper than the delivered cost of alumina produced from high-grade bauxite from outside the United States (2). It was also stated that current technology makes this recovery "matter of fact."

It appears that refuse materials could possibly be used as a supply of heat for the production of alumina, and the ash from this burning would be a source of feed ore for alumina. Once the alumina was extracted, the new material would be high in SiO_2 and would very likely be a suitable construction material.

REFERENCES

1. Busch, R. A., R. R. Backer, and L. A. Atkins. Physical Property Data on Coal Waste Embankment Materials. BuMines RI 7964, 1974, 142 pp.

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3. Lambe, W. T. Soil Testing for Engineers. John Wiley & Sons, Inc., New York, 1967, p. 88.

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5. Nicholson, D. E., and R. A. Busch. Earth Pressure at Rest and One-Dimensional Compression in Mine Hydraulic Backfills. BuMines RI 7198, 1968, 40 pp.

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7. U.S. Bureau of Mines. Methods of Analyzing and Testing Coal and Coke. BuMines Bull. 638, 1967, 82 pp.

APPENDIX.--DIRECT SHEAR COMPUTER PROGRAM AND EXAMPLE DATA OUTPUT

TEST NO.	DATE TESTED	TESTED BY
WDH1-ST14A-DS-1	12-10-73	L ATKINS

CROSS SECT. AREA = 4.910 IN.　　DRY WT. = .149 LBS.　　DRY DENSITY = 52.390 LBS./CU.FT.

SAMPLE THICKNESS = 1.000 IN.　　WET WT. = .229 LBS.　　WET DENSITY = 80.523 LBS./CU.FT.

SAMPLE VOLUME = .0028 CU.FT.　　SPEC. GRAV. = 1.540　　MOISTURE CONTENT = 53.700 PER CENT

INITIAL CONSOLIDATION = .123 IN.　　PROVING RING NO. 54　　CONSOLIDATED DRY DENSITY = 59.737 LBS./CU.FT.

INITIAL POROSITY = 45.506 PER CENT　　CAPACITY = 100 LBS.

INITIAL VOID RATIO = .835　　APPLIED LOAD = 73.650 LBS.　　INITIAL SATURATION = 100.00 PER CENT

INITIAL MOISTURE CONTENT = 57.20 PERCENT

TOT. TIME (MIN/SEC)	SHEAR DIAL (IN.)	SHEAR DISP. (IN.)	NORM. DIAL (IN.)	NORM. DISP. (IN.)	PROV. RING DIAL (IN.)	STRESS FOR. (LBS.)	STRESS FOR. /LOAD RATIO	SHEAR FORCE (LBS/SQ IN)	VOID RATIO	POROSITY (PER CENT)
00/00	.100	0	.380	.123	0	2.0601	.0280	.4196	.6093	37.8627
	.110	.010	.378	-0.002	.0053	9.8558	.1338	2.0176	.6057	37.7207
	.120	.010	.376	-0.002	.0114	18.8721	.2562	3.8832	.6020	37.5780
	.130	.010	.374	-0.002	.0140	22.7378	.3087	4.7028	.5983	37.4347
	.140	.010	.372	-0.002	.0161	25.8729	.3513	5.3790	.5947	37.2907
	.150	.010	.370	-0.002	.0178	28.4202	.3859	5.9394	.5910	37.1460
	.160	.010	.368	-0.002	.0190	30.2238	.4104	6.3496	.5873	37.0007
	.170	.010	.366	-0.002	.0202	32.0324	.4349	6.7650	.5836	36.8547
	.180	.010	.365	-0.001	.0216	34.1490	.4637	7.2503	.5818	36.7814
	.190	.010	.363	-0.002	.0226	35.6654	.4843	7.6126	.5781	36.6344
	.200	.010	.362	-0.001	.0233	36.7292	.4987	7.8817	.5763	36.5607
	.210	.010	.360	-0.002	.0242	38.1000	.5173	8.2200	.5726	36.4126
	.220	.010	.359	-0.001	.0250	39.3213	.5339	8.5294	.5708	36.3383
	.230	.010	.358	-0.001	.0256	40.2391	.5464	8.7761	.5690	36.2639
	.240	.010	.356	-0.002	.0260	40.8519	.5547	8.9585	.5653	36.1144
	.250	.010	.355	-0.001	.0268	42.0796	.5713	9.2785	.5635	36.0394
	.260	.010	.353	-0.002	.0271	42.5408	.5776	9.4321	.5598	35.8889
	.270	.010	.352	-0.001	.0277	43.4644	.5901	9.6905	.5580	35.8134
	.280	.010	.351	-0.001	.0279	43.7726	.5943	9.8138	.5561	35.7377
	.290	.010	.350	-0.001	.0284	44.5441	.6048	10.0429	.5543	35.6619
	.300	.010	.349	-0.001	.0287	45.0075	.6111	10.2047	.5525	35.5858
	.310	.010	.348	-0.001	.0288	45.1621	.6132	10.2979	.5506	35.5096
	.320	.010	.347	-0.001	.0291	45.6262	.6195	10.4632	.5488	35.4332
	.330	.010	.346	-0.001	.0292	45.7810	.6216	10.5590	.5469	35.3566
	.340	.010	.346	0	.0296	46.4006	.6300	10.7637	.5469	35.3566
	.350	.010	.345	-0.001	.0296	46.4006	.6300	10.8262	.5451	35.2798
	.360	.010	.345	0	.0296	46.4006	.6300	10.8894	.5451	35.2798
	.370	.010	.344	-0.001	.0300	47.0211	.6384	11.0998	.5433	35.2029
	.380	.010	.344	0	.0304	47.6424	.6469	11.3128	.5433	35.2029
	.390	.010	.343	-0.001	.0306	47.9534	.6511	11.4542	.5414	35.1257
	.400	.010	.343	0	.0310	48.5759	.6596	11.6721	.5414	35.1257
	.410	.010	.342	-0.001	.0314	49.1993	.6680	11.8928	.5396	35.0484
	.420	.010	.342	0	.0312	48.8875	.6638	11.8887	.5396	35.0484
19/51	.430	.010	.342	0	.0309	48.4202	.6574	11.8465	.5396	35.0484

PEAK STRESS = 10.0202 PSI　　PEAK SATURATION =100.00 PERCENT

ULTIMATE STRESS = 9.8616 PSI (ELIMINATED FROM GRAPH)

TEST NO.	DATE TESTED	TESTED BY
WOH1-ST14A-DS-2	12-10-73	L ATKINS

CROSS SECT. AREA = 4.910 IN. DRY WT. = .147 LBS. DRY DENSITY = 51.634 LBS./CU.FT.

SAMPLE THICKNESS = 1.000 IN. WET WT. = .223 LBS. WET DENSITY = 78.587 LBS./CU.FT.

SAMPLE VOLUME = .0028 CU.FT. SPEC. GRAV. = 1.540 MOISTURE CONTENT = 52.200 PER CENT

INITIAL CONSOLIDATION = .158 IN. PROVING RING NO. 267 CONSOLIDATED DRY DENSITY = 61.323 LBS./CU.FT.

INITIAL POROSITY = 46.291 PER CENT CAPACITY = 500 LBS.

INITIAL VOID RATIO = .862 APPLIED LOAD = 147.300 LBS. INITIAL SATURATION = 100.00 PER CENT

INITIAL MOISTURE CONTENT = 62.70 PERCENT

TOT. TIME (MIN/SEC)	SHEAR DIAL (IN.)	SHEAR DISP. (IN.)	NORM. DIAL (IN.)	NORM. DISP. (IN.)	PROV. RING DIAL (IN.)	STRESS FOR. (LBS.)	STRESS FOR./LOAD RATIO	SHEAR FORCE (LBS/SQ IN)	VOID RATIO	POROSITY (PER CENT)
00/00	.100	0	.475	.158	0	0	0	0	.5677	36.2131
	.110	.010	.474	-0.001	.0018	16.2180	.1101	3.3200	.5659	36.1372
	.120	.010	.472	-0.002	.0034	30.6340	.2080	6.3033	.5621	35.9850
	.130	.010	.470	-0.002	.0046	41.4460	.2814	8.5721	.5584	35.8320
	.140	.010	.467	-0.003	.0055	49.5550	.3364	10.3025	.5528	35.6012
	.150	.010	.465	-0.002	.0059	53.1590	.3609	11.1095	.5491	35.4464
	.160	.010	.464	-0.001	.0064	57.6640	.3915	12.1143	.5472	35.3687
	.170	.010	.462	-0.002	.0069	62.1690	.4221	13.1297	.5435	35.2128
	.180	.010	.460	-0.002	.0073	65.7730	.4465	13.9645	.5398	35.0561
	.190	.010	.459	-0.001	.0076	68.4760	.4649	14.6159	.5379	34.9775
	.200	.010	.458	-0.001	.0080	72.0800	.4893	15.4677	.5361	34.8987
	.210	.010	.457	-0.001	.0083	74.7830	.5077	16.1342	.5342	34.8197
	.220	.010	.455	-0.002	.0086	77.4860	.5260	16.8080	.5305	34.6611
	.230	.010	.454	-0.001	.0088	79.2880	.5383	17.2925	.5286	34.5815
	.240	.010	.453	-0.001	.0091	81.9910	.5566	17.9799	.5268	34.5017
	.250	.010	.452	-0.001	.0092	82.8920	.5627	18.2776	.5249	34.4217
	.260	.010	.451	-0.001	.0095	85.5950	.5811	18.9780	.5230	34.3416
	.270	.010	.451	0	.0097	87.3970	.5933	19.4853	.5230	34.3416
	.280	.010	.450	-0.001	.0099	89.1990	.6056	19.9983	.5212	34.2612
	.290	.010	.449	-0.001	.0100	90.1000	.6117	20.3139	.5193	34.1806
	.300	.010	.448	-0.001	.0102	91.9020	.6239	20.8372	.5174	34.0999
	.310	.010	.448	0	.0102	91.9020	.6239	20.9556	.5174	34.0999
	.320	.010	.448	0	.0104	93.7040	.6361	21.4886	.5174	34.0999
	.330	.010	.447	-0.001	.0104	93.7040	.6361	21.6120	.5156	34.0189
	.340	.010	.447	0	.0105	94.6050	.6423	21.9458	.5156	34.0189
	.350	.010	.446	-0.001	.0107	96.4070	.6545	22.4937	.5137	33.9378
	.360	.010	.446	0	.0108	97.3080	.6606	22.8364	.5137	33.9378
	.370	.010	.446	0	.0108	97.3080	.6606	22.9704	.5137	33.9378
	.380	.010	.445	-0.001	.0108	97.3080	.6606	23.1060	.5119	33.8564
	.390	.010	.445	0	.0108	97.3080	.6606	23.2431	.5119	33.8564
	.400	.010	.445	0	.0109	98.2090	.6667	23.5982	.5119	33.8564
	.410	.010	.444	-0.001	.0109	98.2090	.6667	23.7398	.5100	33.7749
	.420	.010	.444	0	.0109	98.2090	.6667	23.8830	.5100	33.7749
	.430	.010	.444	0	.0108	97.3080	.6606	23.8074	.5100	33.7749
	.440	.010	.444	0	.0106	95.5060	.6484	23.5091	.5100	33.7749
21/48	.450	.010	.444	0	.0105	94.6050	.6423	23.4301	.5100	33.7749

PEAK STRESS = 20.0018 PSI PEAK SATURATION =100.00 PERCENT

ULTIMATE STRESS = 19.2678 PSI (ELIMINATED FROM GRAPH)

TEST NO. WDH1-ST14A-DS-3 | DATE TESTED 12-10-73 | TESTED BY L ATKINS

CROSS SECT. AREA = 4.910 IN. | DRY WT. = .156 LBS. | DRY DENSITY = 55.064 LBS./CU.FT.

SAMPLE THICKNESS = 1.000 IN. | WET WT. = .224 LBS. | WET DENSITY = 78.742 LBS./CU.FT.

SAMPLE VOLUME = .0028 CU.FT. | SPEC. GRAV. = 1.540 | MOISTURE CONTENT = 43.000 PER CENT

INITIAL CONSOLIDATION = .173 IN. | PROVING RING NO. 267 | CONSOLIDATED DRY DENSITY = 66.583 LBS./CU.FT.

INITIAL POROSITY = 42.723 PER CENT | CAPACITY = 500 LBS.

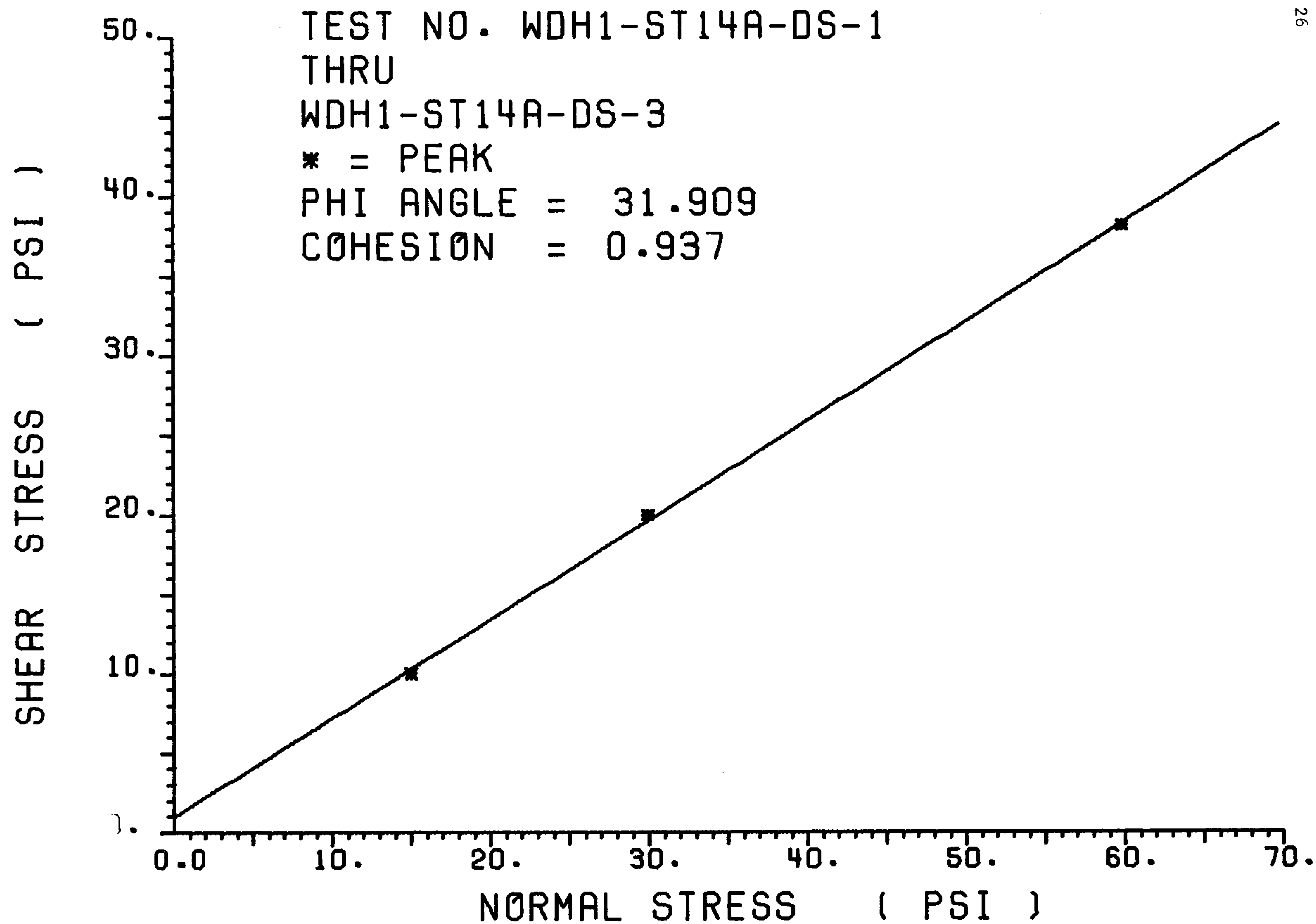
INITIAL VOID RATIO = .746 | APPLIED LOAD = 294.600 LBS. | INITIAL SATURATION = 100.00 PER CENT

INITIAL MOISTURE CONTENT = 55.30 PERCENT

TOT. TIME (MIN/SEC)	SHEAR DIAL (IN.)	SHEAR DISP. (IN.)	NORM. DIAL (IN.)	NORM. DISP. (IN.)	PROV. RING DIAL (IN.)	STRESS FOR. (LBS.)	STRESS FOR./LOAD RATIO	SHEAR FORCE (LBS/SQ IN)	VOID RATIO	POROSITY (PER CENT)
00/00	.100	0	.593	.173	0	0	0	0	.4439	30.7417
	.110	.010	.593	0	.0029	26.1290	.0887	5.3488	.4439	30.7417
	.120	.010	.592	-0.001	.0045	40.5450	.1376	8.3426	.4421	30.6579
	.130	.010	.590	-0.002	.0063	56.7630	.1927	11.7400	.4386	30.4896
	.140	.010	.587	-0.003	.0081	72.9810	.2477	15.1728	.4334	30.2356
	.150	.010	.584	-0.003	.0101	91.0010	.3089	19.0180	.4282	29.9797
	.160	.010	.582	-0.002	.0114	102.7140	.3487	21.5786	.4247	29.8081
	.170	.010	.580	-0.002	.0126	113.5260	.3854	23.9759	.4212	29.6356
	.180	.010	.578	-0.002	.0137	123.4370	.4190	26.2074	.4177	29.4623
	.190	.010	.576	-0.002	.0144	129.7440	.4404	27.6934	.4142	29.2881
	.200	.010	.574	-0.002	.0152	136.9520	.4649	29.3886	.4107	29.1131
	.210	.010	.572	-0.002	.0159	143.2590	.4863	30.9077	.4072	28.9372
	.220	.010	.571	-0.001	.0164	147.7640	.5016	32.0524	.4055	28.8489
	.230	.010	.569	-0.002	.0168	151.3680	.5138	33.0130	.4020	28.6717
	.240	.010	.568	-0.001	.0175	157.6750	.5352	34.5768	.4002	28.5828
	.250	.010	.566	-0.002	.0179	161.2790	.5475	35.5618	.3967	28.4042
	.260	.010	.565	-0.001	.0182	163.9820	.5566	36.3579	.3950	28.3146
	.270	.010	.563	-0.002	.0186	167.5860	.5689	37.3636	.3915	28.1347
	.280	.010	.562	-0.001	.0190	171.1900	.5811	38.3806	.3897	28.0445
	.290	.010	.562	0	.0193	173.8930	.5903	39.2057	.3897	28.0445
	.300	.010	.561	-0.001	.0196	176.5960	.5994	40.0402	.3880	27.9540
	.310	.010	.560	-0.001	.0199	179.2990	.6086	40.8840	.3863	27.8632
	.320	.010	.559	-0.001	.0200	180.2000	.6117	41.3242	.3845	27.7722
	.330	.010	.558	-0.001	.0200	180.2000	.6117	41.5616	.3828	27.6811
	.340	.010	.558	0	.0200	180.2000	.6117	41.8015	.3828	27.6811
	.350	.010	.557	-0.001	.0201	181.1010	.6147	42.2545	.3810	27.5896
	.360	.010	.556	-0.001	.0202	182.0020	.6178	42.7125	.3793	27.4980
	.370	.010	.556	0	.0204	183.8040	.6239	43.3886	.3793	27.4980
	.380	.010	.555	-0.001	.0206	185.6060	.6300	44.0725	.3775	27.4061
	.390	.010	.555	0	.0206	185.6060	.6300	44.3340	.3775	27.4061
	.400	.010	.554	-0.001	.0206	185.6060	.6300	44.5985	.3758	27.3140
	.410	.010	.554	0	.0208	187.4080	.6361	45.3017	.3758	27.3140
	.420	.010	.553	-0.001	.0208	187.4080	.6361	45.5749	.3740	27.2216
	.430	.010	.553	0	.0208	187.4080	.6361	45.8513	.3740	27.2216
	.440	.010	.552	-0.001	.0206	185.6060	.6300	45.6874	.3723	27.1290
	.450	.010	.552	0	.0206	185.6060	.6300	45.9676	.3723	27.1290
21/12	.460	.010	.552	0	.0205	184.7050	.6270	46.0266	.3723	27.1290

PEAK STRESS = 38.1686 PSI | PEAK SATURATION =100.00 PERCENT

ULTIMATE STRESS = 37.6181 PSI (ELIMINATED FROM GRAPH)


TEST NO. WDH1-ST14A-DS-1
THRU
WDH1-ST14A-DS-3
* = PEAK
PHI ANGLE = 31.909
COHESION = 0.937
SHEAR STRESS (PSI)
NORMAL STRESS (PSI)
50.
40.
30.
20.
10.
0.0
10.
20.
30.
40.
50.
60.
70.

```
      PROGRAM DIRSHEAR
C
C
      COMMON PEEK(25),PLOAD(25),ULT(25),ULOAD(25),TNUM(2),TNUMF(2),
     1 TEST(3),KNTP,KNTU
C
      DIMENSION A(11,75), TESTER1(5), TESTER2(5), TIME(75)
C
      INTEGER TESTER1, TESTER2, TEST
C
      REAL MOIST, MOISTURE, NORMINIT, MOISTA
C
C
C                KNTU= NUMBER OF DATA SETS USING ULTIMATE FOR PLOTTING.
C                KNTP= NUMBER OF DATA SETS USING PEAK FOR PLOTTING.
C                  N = NUMBER OF POINTS IN EACH SET
C
C                TEST(1)=
C                         1 - PLOT ENTIRE GRAPH
C                         0 - PLOT AXIS AND POINTS ONLY
C                TEST(2)=
C                         1 - DROP PEAK VALUE
C                         0 - KEEP PEAK VALUE
C                TEST(3)=
C                         1 - DROP ULTIMATE VALUE
C                         0 - KEEP ULTIMATE VALUE
C
    2 CONTINUE
      KNTU = 0
      KNTP=0
      NJUMP = 0
C
C                 READ HEADING AND INITIAL NORMAL DIAL READING
C
    1 READ(60,600) TEST,TNUM,DATE,TESTER1,TESTER2,RINGN,MCAP
      IF (EOFCKF(60) .EQ. 1) GO TO 999                                   M-081974
      READ(60,602) MOIST,WETWT,THICK,AREA,PSI,GRAV, MOISTA
C
C                SAVE FIRST TEST NUMBER FOR PLOT LABEL.
C
      IF ( NJUMP .EQ. 1 ) GO TO 4
      TNUMF(1) = TNUM(1)
      TNUMF(2) = TNUM(2)
      NJUMP = 1
C
    4 READ(60,604) A(1,1), A(1,2), NORMINIT
      N=0
    5 N=N+1
C
C                READ DATA
C
      READ(60,604) TIME(N), A(2,N), A(4,N), A(6,N), ITRIG
      IF ( ITRIG .EQ. 4H      ) GO TO 5
C
```

```
C               CHECK FOR INITIAL CONSOLIDATION
C
      CONSOL = 0.0
      IF ( NORMINIT .EQ. 0.0 ) GO TO 10
      CONSOL = NORMINIT-A(4,1)
C
C               CALCULATE INITIAL VALUES
C
   10 ACCUM = 0.0
      APPLOAD = AREA * PSI
      RADIUS=SQRT(AREA/3.14159)
      ARIA = CONTACT(ACCUM,RADIUS)
      SAMVOL = AREA * THICK / 1728.
      WETWT = WETWT * .0022
      DENWET = WETWT/ SAMVOL
      DENDRY=DENWET/(1 +MOIST)
      DRYWT = DENDRY * SAMVOL
      CONDEN = DRYWT / ( (THICK - CONSOL) * AREA)
      CONDEN = CONDEN * 1728.
      MOISTURE = MOIST*100
      VOLCC = SAMVOL * 1728.* 16.387064
      VS = DRYWT * 453.6 / GRAV
      VOID=(VOLCC-VS)/VS
      POR = VOID/ (1. + VOID) * 100.
      NCAP=1000
      IF ( MCAP .EQ. 4H500 ) NCAP = 500
      IF ( MCAP .EQ. 4H100 ) NCAP = 100
      IF ( MCAP .EQ. 4H2500 ) NCAP = 2500
      SATURATE = ( (MOISTA * GRAV)/ VOID ) * 100.
      IF ( SATURATE .GT. 100. ) SATURATE = 100.
      MOISTA = MOISTA * 100.
      IF ( MOISTA .EQ. 0.0 ) SATURATE = 0.0
C
C               WRITE HEADING
C
      WRITE(61'700) TNUM'DATE'TESTER1'TESTER2
      WRITE(61,702) AREA,DRYWT,DENDRY
      WRITE(61,704) THICK,WETWT,DENWET
      WRITE(61,706) SAMVOL,GRAV,MOISTURE
      WRITE(61,708) CONSOL,RINGN, CONDEN
      WRITE (61, 710) POR, MCAP
      WRITE (61,712) VOID, APPLOAD, SATURATE
      WRITE(61,713) MOISTA
C
C               SET FIRST ROW OF OUTPUT IN TABLE
C
C               SUBTRACT INITIAL CONSOLIDATION TO GET ACTUAL THICKNESS AT TIME
C               OF DATA READINGS.
C
      THICK = THICK - CONSOL
      THICKA = THICK
      A(3,1)=0.0
      A(5,1)=CONSOL
      A(7,1)=STRESS(A(6,1),NCAP)
```

```
      A(8,1)=A(7,1)/APPLOAD
      A(9,1) = A(7,1)/ARIA
      A(10,1) = ( AREA * THICK * 16.387064 - VS)/ VS
      A(11,1) = A(10,1)/ (1. + A(10,1) ) * 100.
C
C              CALCULATE DATA IN TABLE
C
      DO 50 K = 2,N
      A(3,K) = A(2,K) - A(2,K-1)
      ACCUM = ACCUM + A(3,K)
      A(5,K) = A(4,K) - A(4,K-1)
      A(7,K) = STRESS(A(6,K), NCAP)
      A(8,K) = A(7,K) / APPLOAD
      ARIA = CONTACT (ACCUM, RADIUS )
      A(9,K) = A(7,K) / ARIA
      THICK = THICK + A(5,K)
      A(10,K) = ( AREA * THICK * 16.387064 - VS)/ VS
      A(11,K) = A(10,K) / (1. + A(10,K)) * 100.
   50 CONTINUE
C
C              WRITE OUT RESULTS IN TABLE FORM
C
      K1 = 1                                                            M-081974
      K2 = 30                                                           M-081974
   60 IF (K2 .GT. N) K2 = N                                             M-081974
      WRITE (61,714)
      WRITE (61,716)
      WRITE (61,718)
      WRITE(61,714)
      IAST = 1H*
      WRITE(61,720) (IAST, I = 1,131)
      WRITE (61,714)
C*****WRITE (61, 722) ( TIME(J), (A(I,J), I = 2,11), J = 1,N)
      WRITE (61,722) (TIME(J),(A(I,J),I=2,11),J=K1,K2)                  M-081974
      IF (K2 .EQ. N) GO TO 65                                           M-081974
      K1 = K2 + 1                                                       M-081974
      K2 = K1 + 49                                                      M-081974
      WRITE (61,701)                                                    M-081974
  701 FORMAT (1H1)                                                      M-081974
      GO TO 60                                                          M-081974
   65 CONTINUE                                                          M-081974
C
C          CALCULATE PEAK = STRESS/AREA -- AT HIGHEST STRESS FORCE/LOAD RATIO.
C
      MAX = 0
      PEAK = 0.0
      DO 75 J = 1, N
      IF( A(8,J) .LE. PEAK ) GO TO 75
      PEAK = A(8,J)
      MAX = J
   75 CONTINUE
      PEAK = A(7, MAX)
      NEND =  N - MAX
C
```

```
      PEAKSAT = ( (MOIST * GRAV) / A(10,MAX) ) * 100.
      IF ( PEAKSAT .GT. 100. ) PEAKSAT = 100.
C
C               CALCULATE ULTIMATE BASED ON PEAK TERM
C
      IF ( NEND ) 76,76,78
   76 ULTIMATE = PEAK
      GO TO 110
   78 GO TO (80,80,80,85), NEND
   80 ULTIMATE = A(7,N )
      GO TO 110
   85 LN = 0
      DO 90 J = 1,NEND
      M =  N - J
      IF ( A(7,M) / A(7,N ) .GT. .05) GO TO 95
   90 LN = LN + 1
   95 IF ( LN .EQ. 0 ) GO TO 80
      SUM = 0.0
      M = 0
      DO 100 J = M,LN
      NZ =  N - M
  100 SUM = SUM + A(7,NZ)
      ULTIMATE = SUM / (LN + 1)
C
C               DIVIDE PEAK AND ULTIMATE BY AREA AND SAVE FOR PLOTTING
C               ALSO SET LOAD EQUAL TO PSI READING AND SAVE FOR PLOTTING
C
  110 PK = PEAK / AREA
      IF ( TEST(2) .EQ. 1 ) GO TO 115
      KNTP = KNTP + 1
      PEEK(KNTP) = PK
      PLOAD(KNTP) = PSI
      WRITE(61,726) PK
      GO TO 120
  115 WRITE(61,724) PK
  120 WRITE(61,731) PEAKSAT
      UT = ULTIMATE / AREA
      IF ( TEST(3) .EQ. 1 ) GO TO 125
      KNTU = KNTU + 1
      ULT(KNTU) = UT
      ULOAD(KNTU) = PSI
      WRITE(61,730) UT
      GO TO 130
  125 WRITE(61,728) UT
C
  130 IF(ITRIG .EQ. 4HAA   ) GO TO 1
C
      CALL GRAPH
      GO TO 2                                                           M-081974
  999 CONTINUE                                                          M-081974
C
C               600 S  ARE INPUT FORMATS
C
  600 FORMAT(3I1, 3A8, 10A4, A7, 2X, A4)
```

```
  602 FORMAT (F9.0'6F10.0)
  604 FORMAT ( A5, 4X, 3F10.0, 39X, A2)
C
C            700 S  ARE OUTPUT FORMATS
C
  700 FORMAT (1H1*40X*8HTEST NO.*12X*11HDATE TESTED*11X*9HTESTED BY//39X
     1, 2A8,7X,A8,13X,5A4/83X,5A4//)
  702 FORMAT ( 9X, 19HCROSS SECT. AREA = ,F6.3, 4H IN., 12X,10HDRY WT. =
     1 ,F6*3,5H LBS*,14X,14HDRY DENSITY = ,F7*3,12H LBS*/CU*FT*/)
  704 FORMAT ( 9X, 19HSAMPLE THICKNESS = ,F6.3, 4H IN., 12X,10HWET WT. =
     1 ,F6.3, 5H LBS.,14X,14HWET DENSITY = ,F7.3,12H LBS./CU.FT./)
  706 FORMAT ( 9X, 19HSAMPLE  VOLUME    = , F6*4, 7H CU*FT*,9X,14HSPEC* G
     1RAV. = ,F6.3, 15X, 19HMOISTURE CONTENT = ,F7.3,9H PER CENT//)
  708 FORMAT ( 9X, 24HINITIAL CONSOLIDATION = ,F6.3, 4H IN., 23X, 17HPRO
     1VING RING NO* , A7, 9X, ≠CONSOLIDATED≠/,99X, ≠DRY DENSITY = ≠,F7*3
     ., ≠ LBS./CU.FT.≠/)
  710 FORMAT ( 9X, 24HINITIAL  POROSITY     = , F6.3, 9H PER CENT,18X,11
     1HCAPACITY = , A4,5H LBS.,/ 99X, ≠INITIAL≠ )
  712 FORMAT ( 9X, 24HINITIAL  VOID  RATIO  = ,F6.3, 27X,15HAPPLIED LOAD
     1 = , F8.3, 5H LBS., 5X, ≠SATURATION = ≠, F6.2, ≠ PER CENT≠ / )
  713 FORMAT (9X, ≠INITIAL MOISTURE CONTENT = ≠ F5*2, ≠ PERCENT≠//)
  714 FORMAT (2X,10(11X,1H*))
  716 FORMAT (3X,11HTOT. TIME *,12HSHEAR DIAL *,12HSHEAR DISP.*,12H NORM
     1* DIAL*, 12HNORM* DISP.*,12HPROV* RING *,12HSTRESS FOR.*,12HSTRESS
     2 FOR.*,12HSHEAR FORCE*,12H    VOID    *,11H  POROSITY )
  718 FORMAT(3X,11H(MIN/SEC) *12H   ( IN. )   *,12H   ( IN. )   *,12H   ( IN.
     1 )  *,12H   ( IN. )   *,12H DIAL (IN.)*,12H   ( LBS. ) *,12H/LOAD RAT
     2IO*,12H(LBS/SQ IN)*,12H   RATIO    *,11H (PER CENT))
  720 FORMAT (2X,131A1)
  722 FORMAT (4X, A5,5H    *, 4( 1X, F7*3, 4H    *), 2X,F6*4,4H    *,2X,
     1  F8.4, 2H *, 2X,F6.4,4H    *,1X,F8.4,3H   *,2X,F6.4,4H    *,2X,F8.4)
  724 FORMAT( //25X,14HPEAK STRESS = ,F8.4,4H PSI,    24H (ELIMINATED FRO
     1M GRAPH))
  726 FORMAT( //25X,14HPEAK STRESS = ,F8.4,4H PSI)
  728 FORMAT(21X,18HULTIMATE STRESS = ,F8.4,4H PSI,   24H (ELIMINATED FRO
     1M GRAPH))
  730 FORMAT(21X,18HULTIMATE STRESS = ,F8.4, 4H PSI)
  731 FORMAT (1H+, 80X, ≠PEAK SATURATION =≠, F6.2, ≠ PERCENT≠/)
      GO TO 2
  331 CONTINUE
C
      END
```

PROGRAM VARIABLES

00642	R	A	04316	R	GRAV	04305	I	MCAP	04434	R	PEAKSAT	04031	I	TESTER2
04330	R	ACCUM	04423	I	I	04265	R	MOIST	04450	R	PK	04310	R	THICK
04332	R	APPLOAD	04422	I	IAST	04273	R	MOISTA	04377	R	POR	04413	R	THICKA
04312	R	AREA	04322	I	ITRIG	04267	R	MOISTURF	04314	R	PSI	04036	R	TIME
04340	R	ARIA	04425	I	J	04320	I	N	04336	R	RADIUS	04436	R	ULTIMATE
04356	R	CONDEN	04415	I	K	04401	I	NCAP	04303	R	RINGN	04452	R	UT
04326	R	CONSOL	04416	I	K1	04433	I	NEND	04344	R	SAMVOL	04371	R	VOID
04301	R	DATE	04417	I	K2	04276	I	NJUMP	04410	R	SATURATF	04363	R	VOLCC
04352	R	DENDRY	04441	I	LN	04271	R	NORMINIT	04445	R	SUM	04367	R	VS
04350	R	DENWET	04442	I	M	04447	I	NZ	04024	I	TESTER1	04306	R	WETWT
04354	R	DRYWT	04430	I	MAX	04431	R	PEAK						

COMMON VARIABLES

00323	I	KNTP	00000	R	PEEK	00320	I	TEST	00314	R	TNUMF	00144	R	ULT

```
00324 I    KNTU          00062 R    PLOAD         00310 R    TNUM          00226 R    ULOAD

    STATEMENT NUMBERS

     1 04641          75 05640          110 06016          604 00014          710 00241          722 00503
     2 04630          76 05676          115 06047          700 00022          712 00271          724 00540
     4 04740          78 05701          120 06055          701 00000          713 00325          726 00561
     5 04755          80 05712          125 06114          702 00050          714 00342          728 00573
    10 05024          85 05716          130 06122          704 00105          716 00346          730 00614
    50 05446          90 05741          331 06135          706 00142          718 00423          731 00626
    60 05462          95 05753          600 00002          708 00177          720 00500          999 06133
    65 05613         100 05774          602 00010

    EXTERNAL REFERENCES

         CONTACT             EOFCKF             GRAPH             SQRT             STRESS

              FORTRAN DIAGNOSTIC RESULTS  FOR   DIRSHEAR

NULL STATEMENT NUMBERS
     331
  COMPILED LENGTHS OF DIRSHEAR - P   06152   C   00325   D   00000
```

```
MS FORTRAN  (4.2) / MSOS                             09/24/74            PAGE 001
      FUNCTION STRESS ( B,N)
      IF ( N .EQ. 500 ) GO TO 50
      IF (N .EQ. 100) GO TO 100
      IF ( N .EQ. 2500 ) GO TO 150
C
C     COMPUTATIONS FOR 1000-POUND RING
C
      STRESS = 5.368421 + 25562.348 * B
      RETURN
C
C     COMPUTATION FOR 500-POUND RING
C
C  50 STRESS = 8920.0 * B                 CHANGED TO FOLLOWING CARD ON 18 JAN 72
   50 STRESS = 9010.0 * B
      RETURN
C
C     COMPUTATION FOR 100-POUND RING
C
  100 STRESS = 26638.302*B**3 + 185.42126*B**2 + 1469.1632*B + 2.0601
      RETURN
C
C      COMPUTATION FOR 2500-POUND RING.                        6JUN72
C
  150 STRESS = 63000. * B
      RETURN
      END

 STATEMENT NUMBERS

  50 00060            100 00064            150 00105

 EXTERNAL REFERENCES

 SYSTEM EXTERNALS ONLY

                 FORTRAN DIAGNOSTIC RESULTS  FOR    STRESS

   COMPILED LENGTHS OF STRESS   - P   00147   C   00000   D   00000
NO ERRORS
```

```
MS FORTRAN  (4.2) / MSOS                                 09/24/74          PAGE 001

      FUNCTION CONTACT (D,R)
      SINTERM = 2 * R * R * ASIN( D/(2.*R) )
      SQTERM = D/2. * SQRT ( 4. * R * R - D * D )
      CONTACT = 3.14159 * R * R - ( SQTERM + SINTERM )
      RETURN
      END

   PROGRAM VARIABLES

 00004 R    SINTERM        00011 R    SQTERM

   EXTERNAL REFERENCES

        ASIN                      SQRT

              FORTRAN DIAGNOSTIC RESULTS  FOR    CONTACT

 COMPILED LENGTHS OF CONTACT   - P   00130   C   00000   D   00000
NO ERRORS

MS FORTRAN  (4.2) / MSOS                                 09/24/74          PAGE 001

      FUNCTION ASIN(X)
C.....THIS PROGRAM COMPUTES THE ARCSIN FUNCTION USING THE ALGORYTHEM
C.....ON PAGE 163 OF APPROXIMATIONS FOR DIGITAL COMPUTERS BY HASTINGS
C.....1955 PRINSTON UNIVERSITY PRESS.
      DIMENSION A(8)
      DATA(A=-.0012624911,.0066700901,-.0170881256,.0308918810,
     1      -.0501743046,.0889789874,-.2145988016,1.5707963050)
      ASIN = 0.0
      DO 25 J = 1, 8
      ASIN = ASIN * X + A(J)
   25 CONTINUE
      ASIN = 1.570796326     - SQRT(1-X) * ASIN
      RETURN
      END

   PROGRAM VARIABLES

 00002 R    A              00024 I    J

   STATEMENT NUMBERS

    25 00056

   EXTERNAL REFERENCES

        SQRT

              FORTRAN DIAGNOSTIC RESULTS  FOR    ASIN

 COMPILED LENGTHS OF ASIN      - P   00130   C   00000   D   00000
NO ERRORS
```

```
MS FORTRAN  (4.2) / MSOS                              09/24/74            PAGE 001
      SUBROUTINE GRAPH
C
C
      COMMON YP(25),YPL(25),YU(25),YUL(25),TNUM(2),TNUMF(2),TEST(3),
     1 KNTP,KNTU
C
      INTEGER TEST
C
      DIMENSION X(25),Y(25),IBUF(50),IWORD(6)
C
C
C                YP = PEAK STRESSES
C               YPL = CORRESPONDING LOADS
C              KNTP = NUMBER OF PEAKS TO PLOTTED
C                YU = ULTIMATE STRESSES
C               YUL = CORRESPONDING LOADS
C              KNTU = NUMBER OF ULTIMATES TO BE PLOTTED
C           TEST(1) =
C                    1 - DRAW ENTIRE PLOT.
C                    0 - PLOT AXIS AND POINTS ONLY.
C             KOUNT = 0 IMPLIES PEAKS
C             KOUNT = 1 IMPLIES ULTIMATES
C
C
C               GET X, Y MAXIMUM FOR PLOT
C
      KOUNT = 0
      MN = YPL(KNTP) / 10. + 1.
      XMAX = MN * 10
      YMAX = 0.0
      DO 10 K=1,KNTP
      IF(YP(K) .LE. YMAX) GO TO 10
      YMAX = YP(K)
   10 CONTINUE
      MN = YMAX / 10. + 1.
      YMAX = MN * 10
C
C               SCL = SCALE FACTOR -- INCHES/USERS UNIT
C
C*****YMAX=50.
C*****SCL = 9./ YMAX
      XSC = 12.86/XMAX                                                M-081974
      YSC = 9.0/YMAX                                                  M-081974
      IF ((YMAX*XSC) .GT. 9.0) GO TO 12                               M-081974
      SCL = XSC                                                       M-081974
      YMAX = 9.0/XSC + 0.5                                            M-081974
      MN = YMAX/10.0                                                  M-081974
      YMAX = MN*10                                                    M-081974
      GO TO 15                                                        M-081974
   12 SCL = YSC                                                       M-081974
      XMAX = 12.86/YSC + 0.5                                          M-081974
      MN = XMAX/10.0                                                  M-081974
      XMAX = MN*10                                                    M-081974
   15 CONTINUE                                                        M-081974
```

```
      CALL PLOTS ( IBUF,50, 7 )
      CALL PLOT(3.0,-12.0,-3)
      CALL PLOT(0.0,9.5,-3)
      CALL FACTOR(.70)
C
C                THRU 260 -- PLOTS Y AXIS AND NUMBERS IT.
C
      FPN = 0.0
      CALL NUMBER(0.0,.75,.21,FPN,270.,0)
      CALL PLOT(0.0,.14,3)
      CALL PLOT(0.0,0.0,2)
      MN = YMAX
      LTK = 0
      STEP = 0.0
      DO 260 K = 1,MN
      LTK = LTK + 1
      STEP = STEP + 1 * SCL
      CALL PLOT(STEP,0.0,2)
      IF ( LTK .EQ. 5) GO TO 250
      IF ( LTK .EQ. 10 ) GO TO 255
      CALL PLOT(STEP,.07,2)
      CALL PLOT(STEP,0.0,2)
      GO TO 260
  250 CONTINUE
      CALL PLOT(STEP,.14,2)
      CALL PLOT(STEP,0.0,2)
      GO TO 260
  255 FPN = FPN + 10.
      CALL NUMBER(STEP,.75,.21,FPN,270.,0)
      CALL PLOT(STEP,.14,3)
      CALL PLOT(STEP,0.0,2)
      LTK = 0
  260 CONTINUE
      FPN = 0.0
C
C                THRU 280 DRAWS X AXIS AND NUMBERS IT.
C
      CALL NUMBER(-.4,.21,.21,FPN,270.,1)
      CALL PLOT(0.0,.14,3)
      CALL PLOT(0.0,0.0,2)
      MN = XMAX
      LTK = 0
      STEP = 0.0
      DO 280 K = 1,MN
      LTK = LTK + 1
      STEP = STEP - 1 * SCL
      CALL PLOT(0.0,STEP,2)
      IF ( LTK .EQ. 5) GO TO 270
      IF ( LTK .EQ. 10) GO TO 275
      CALL PLOT(-.07,STEP,2)
      CALL PLOT(0.0,STEP,2)
      GO TO 280
  270 CONTINUE
      CALL PLOT(-.14,STEP,2)
```

```
      CALL PLOT(0.0,STEP,2)
      GO TO 280
  275 FPN = FPN + 10.
      BACK = STEP + .21
      CALL NUMBER(-.40,BACK,.21,FPN,270.,0)
      CALL PLOT(-.14,STEP,3)
      CALL PLOT(0.0,STEP,2)
      LTK=0
  280 CONTINUE
C
C               PUT DATA POINTS ON GRAPH
C
      ISYMBOL = 11
      DO 40 KK = 1, KNTP
      YPT = YP(KK) * SCL
      XPT = YPL(KK) * SCL
      XPT = XPT *(-1)
   40 CALL SYMBOL( YPT, XPT, .12, ISYMBOL,270., -1)
      IF ( TEST(1) .EQ. 1 ) GO TO 60
C  45 CALL PLOT (0.0, 0.0, 3)
   45 CONTINUE
      WRITE (59,810)
      PAUSE 1
      GO TO 420
   46 CONTINUE
      ISYMBOL = 2
      DO 50 KK = 1, KNTU
      XPT = YUL(KK) * SCL
      YPT = YU(KK) * SCL
   50 CALL SYMBOL(XPT,YPT,.12,ISYMBOL,0.0,-1)
C
C               TEST TO SEE IF REST OF GRAPH IS TO BE PLOTTED
C
      IF(TEST(1) .NE. 1) 55,206
   55 XPT = XMAX * SCL + 6.
      CALL PLOT (XPT,0.0,3)
      RETURN
C
C               LABEL Y AXIS
C
   60 ENCODE(23,800,IWORD)
C     CALL SYMBOL (-1.5,1.25,.28,IWORD,90.0,23)
      CALL SYMBOL (1.25,1.5,.28,IWORD,0.0,23)
C
C               LABEL X AXIS
C
      ENCODE (23,801,IWORD)
C     CALL SYMBOL (3.5,-.98,.28,IWORD,0.0,23)
      CALL SYMBOL (-.98,-3.5,.28,IWORD,270.,23)
C
C               SET LOADS AND STRESSES IN ARRAYS  X  AND  Y  FOR CURVE FITTING.
C
      DO 205 K=1,KNTP
      Y(K) = YP(K)
```

```
  205 X(K) = YPL(K)
      NPLTP = KNTP
      GO TO 209
  206 DO 207 K=1,KNTU
      Y(K) = YU(K)
  207 X(K) = YUL(K)
      NPLTP = KNTU
C
C             DETERMINE STRAIGHT LINE EQUATION THRU DATA PTS.
C
  209 XAVE = 0.0
      YAVE = 0.0
      DO 210 K = 1,NPLTP
      XAVE = XAVE + X(K)/NPLTP
  210 YAVE = YAVE + Y(K)/NPLTP
      XY = 0.0
      DENOM = 0.0
      DO 220 K = 1,NPLTP
      XY = XY + X(K) * Y(K)
  220 DENOM = DENOM + ( X(K) - XAVE )**2
C
C             A = Y INTERCEPT      B = SLOPE
C
      B = ( XY - NPLTP * XAVE * YAVE )/ DENOM
      A = YAVE - B * XAVE
C
C             THRU 290 -- PLOT STRAIGHT LINE EQUATION DETERMINED FOR PTS.
C
      MN = XMAX
      YPT = A * SCL
      CALL PLOT(YPT,0.0,3)
      XPT = 0.0
      DO 290 K = 1,MN
      XPT = XPT - 1 * SCL
      YPT = YPT + B * SCL
C*****IF ( YPT .GT. YMAX ) GO TO 295
      IF (YPT .GT. YMAX*SCL) GO TO 295                            M-081974
  290 CALL PLOT(YPT,XPT,2)
C
C             LABEL PHI ANGLE AND COHESION AND PUT ON RIGHT EDGE OF GRAPH
C
  295 XPT = XMAX * SCL + .5
      YPOINT = 9.0
      IF(KOUNT .EQ. 1) GO TO 415
      ENCODE(28,804,IWORD) TNUMF
      CALL SYMBOL(9.0,-1.5,.28,IWORD,270.,28)
      ENCODE(4,805,IWORD)
      CALL SYMBOL(8.5,-1.5,.28,IWORD,270.,4)
      ENCODE(19,806,IWORD) TNUM
      CALL SYMBOL(8.0,-1.5,.28,IWORD,270.,19)
      ENCODE(8,807,IWORD)
      CALL SYMBOL(7.5,-1.5,.28,IWORD,270.,8)
      GO TO 402
  415 YPOINT = YPOINT - 3.5
```

```
      CALL SYMBOL(XPT, YPOINT-4.0, .28, 2, 0.0, -1)
      ENCODE(11,808,IWORD)
      CALL SYMBOL(XPT+.28, YPOINT-4.0, .28, IWORD, 0.0, 11)
  402 ENCODE(13,802,IWORD)
      CALL SYMBOL(7.0,-1.5,.28,IWORD,270.,13)
      CALL WHERE (XD,YPT,FACT)
      ANG = ATAN (B) * 57.29577
      XD = XD + .15
      CALL NUMBER(7.0,-XD+2.14,.28,ANG,270.,3)
      ENCODE(12,803,IWORD)
      CALL SYMBOL(6.5,-1.5,.28,IWORD,270.,12)
      CALL WHERE (XD,YPT,FACT)
      XD = XD + .2
      CALL NUMBER(6.5,-XD+1.78,.28,A,270.,3)
C
C
      IF ( KOUNT .EQ. 1 ) GO TO 420
      KOUNT = 1
      GO TO 45
C
C             RUN PEN AHEAD 10 INCHES.
C
  420 XPT = YMAX * SCL + 5.
      CALL PLOT (XPT,0.0,-3)
C
C
      RETURN
C
C             FORMATS FOR PLOT LABELS.
C
  800 FORMAT (23HSHEAR  STRESS   ( PSI ))
  801 FORMAT(23HNORMAL STRESS   ( PSI ))
  802 FORMAT(13HPHI ANGLE =  )
  803 FORMAT(12HCOHESION  = )
  804 FORMAT(9HTEST NO. 2A8)
  805 FORMAT(4HTHRU)
  806 FORMAT(2A8)
  807 FORMAT(8H* = PEAK)
  808 FORMAT(11H = ULTIMATE)
  810 FORMAT (27H CHANGE INK ON PLOT TO  RED)
C
C
      END

 PROGRAM VARIABLES

00452 R  A        00223 I  IBUF     00376 I  LTK      00440 R  XAVE     00141 R  Y
00503 R  ANG      00410 I  ISYMBOL  00321 I  MN       00475 R  XD       00442 R  YAVE
00450 R  B        00305 I  IWORD    00437 I  NPLTP    00322 R  XMAX     00327 R  YMAX
00406 R  BACK     00331 I  K        00344 R  SCL      00415 R  XPT      00454 R  YPOINT
00446 R  DENOM    00412 I  KK       00377 R  STEP     00335 R  XSC      00413 R  YPT
00477 R  FACT     00313 I  KOUNT    00057 R  X        00444 R  XY       00341 R  YSC
00363 R  FPN

 COMMON VARIABLES

00323 I  KNTP     00320 I  TEST     00314 R  TNUMF    00062 R  YPL      00226 R  YUL
00324 I  KNTU     00310 R  TNUM     00000 R  YP       00144 R  YU

 STATEMENT NUMBERS
```

```
   10 00613          50 01400         209 01542         270 01222         415 02037         804 00030
   12 00672          55 01425         210 01556         275 01240         420 02226         805 00034
   15 00710          60 01437         220 01606         280 01276         800 00000         806 00036
   40 01325         205 01504         250 01042         290 01676         801 00007         807 00040
   45 01354         206 01521         255 01056         295 01712         802 00016         808 00043
   46 01364         207 01526         260 01105         402 02103         803 00023         810 00047

  EXTERNAL REFERENCES

        ATAN                NUMBER              PLOTS               SYMBOL              WHERE
        FACTOR              PLOT

            FORTRAN DIAGNOSTIC RESULTS  FOR    GRAPH

NULL STATEMENT NUMBERS
    46
 COMPILED LENGTHS OF GRAPH    - P   02267   C   00325   D   00000
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