NIOSH

RI 9651

REPORT OF INVESTIGATIONS/1999

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U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
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December 1999

International Standard Serial Number
ISSN 1066-5552

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm	centimeter	mm	millimeter
deg	degree	m/s	meter per second
g	gram	m/s^2	meter per second squared
kg	kilogram	m^2/s	square meter per second
kg/m^3	kilogram per cubic meter	pct	percent
km	kilometer	V	volt
L	liter	°	degree
m	meter	°C	degree Celcius
min	minute		

MATERIAL PROPERTIES AFFECTING THE STABILITY OF A 50-YEAR-OLD ROCK DUMP IN AN ACTIVE MINE

By D.R. Tesarik[1] and R.W. McKibbin[2]

ABSTRACT

Material properties affecting slope stability were measured in a large 50-year-old, partially consolidated rock dump located in an active open-pit mine. Field tests included single-ring infiltration and density. In addition, a nuclear depth-moisture gauge was used to measure water content in six stainless-steel-cased drillholes on the crest and an upper bench of the rock dump. Precipitation, evaporation, wind speed and direction, and temperature data were collected at a weather station installed on the dump's crest. Laboratory tests included particle-size distribution, specific gravity, Atterberg limits, and water content. By measuring material properties of a rock dump presumed to be stable, the safety of miners working on or at the toe of old rock dumps constructed of similar material and located in a similar climate can be assessed.

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INTRODUCTION

Mine waste dumps are generally located as close to an active mining site as possible to limit transportation costs. Therefore, expansion of open-pit mines or the discovery of economically minable resources near old rock dumps may require partial excavation of a dump, as occurred in this mine.

Because haulage roads are sometimes constructed below dumps, slope stability is of prime importance for the safety of equipment operators. Factors leading to the instability of dumps, particularly old ones, include unusually large precipitation events, gravity sorting of the material during construction, increased unit weight resulting from soil wetting, increase in slope angle caused by excavation or erosion, and loss of material strength caused by weathering. These factors can lead to dump failures that range from inconsequential slumps to catastrophic slides traveling great distances (Dunn and others, 1980) (figure 1).

The slope stability problem can be compounded if the material in the old dump has become weaker with time or if new material has been added. Between 1990 and 1996, MSHA databanks show that 136 haulage vehicles overturned while dumping because material at the top of the dump collapsed (Fesak and others, 1996). Slope failure accounted for more accidents than all other subcategories in the category of "surface powered haulage."

Knowledge of slope stability in this case study was made even more important because the number of miners working beneath the old dump slopes was greater than if the dump had been located away from active mining. Although slope stability studies may have been conducted prior to dump construction, it was possible that the dump may not have had the same material properties as it had 50 years ago.

Researchers have investigated various aspects of mine rock dump stability (table 1), yet until recently, a broad-based research program did not exist. To address this problem, the British Columbia Mine Dump Committee (BCMDC), comprised of representatives from the Canadian mineral industry; the Canada Centre for Mineral and Energy Technology (CANMET); the British Columbia Ministry of Environment, Lands, and Parks; and the Ministry of Energy, Mines, and Petroleum Resources (MEMPR), was formed in 1990. Under the auspices of this committee, many topics were addressed, including rock dump monitoring, failure runout, rock dump design, evaluation of failures, and instability mechanisms.

In the western United States, the U. S. Forest Service (USFS) conducted workshops with mining industry representatives, university researchers, and personnel from other government agencies to identify rock dump research needs and report on recent research accomplishments. From surveys conducted at these meetings, an evaluation of ongoing USFS research, information obtained from USFS permits for new rock dumps, and concerns expressed by mining industry engineers, Spokane Research Laboratory (SRL) researchers determined that the stability of old rock dumps in the western United States should be investigated. The objective of this work was to obtain information on the physical characteristics of rock dumps over 50 years old and arrange this information so that it could be used by mine operators and land managers to compare the characteristics of their own dumps. Such a comparison might allow them to assess the stability of aging rock dumps and make better decisions about designing new rock dumps based on specific characteristics, such as rock type, climate, or waste rock disposal methods.

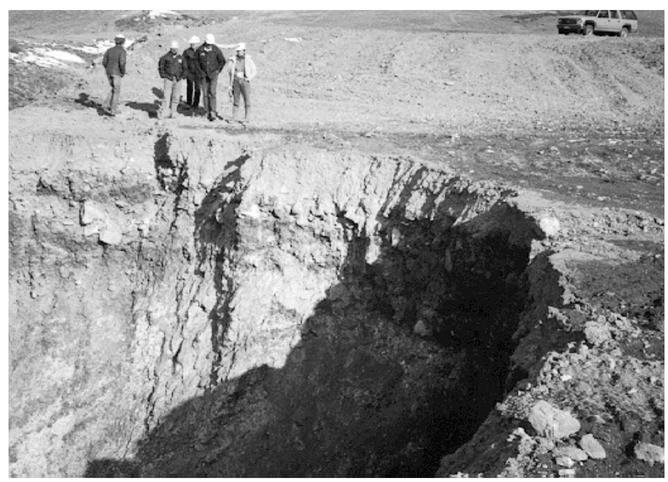

Figure 1.—Rock dump failure caused by water runoff.

SITE DESCRIPTION

This research study was conducted at a large, partially consolidated rock dump constructed of overburden from an open-pit mine. This dump, constructed prior to 1950, is composed primarily of highly fractured quartzite waste rock discarded from railroad trains into a mountain valley. The angle of repose is approximately 37°. Railroad tracks are not present on 1901 U.S. Geological Survey (USGS) maps of the area, but are indicated on a 1950 map. Between 1978 and 1983, the pit was expanded, and the dump was excavated up to 122 m horizontally (figure 2). During this expansion, a series of

Table 1.—Investigations of rock dump stability

Topic	Investigator	Date
Design of overburden piles	Piteau Assoc. (BCMDC)	1991
Rock dump monitoring	Klohn Leonoff (BCMDC)	1991
	HBT AGRA	1992
Failure runout	Golder Assoc. (BCMDC)	1992, 1994, 1995
Rock dump design	Piteau Assoc. (BCMDC)	1991
Evaluation of failures	Broughton (BCMDC)	1992
Instability mechanisms	Dawson and others (BCMDC)	1992
Liquefaction flowslides	CANMET	1994
	Dawson and others (BCMDC)	1998
Rock durability	Olivier	1976, 1979
	Vandre	1993
	Welsh	1988
	Vallejo and Robinson	1992
Particle-size distribution	Mariachi and others	1972
	Kemeny	1993
	Vukovic and Soro	1992
Material strength	Leps	1970
	Mariachi and others	1972
	Williams and Walker	1985
Hydrology	Leps	1973

benches with near-vertical, 15-m-high highwalls were constructed. These benches provided access to the interior part of the dump for physical property measurements that otherwise would not have been possible to obtain. Because of natural cementation and consolidation over time, minimal sloughing was observed at the toe of the dump highwalls.

Measurements of in situ density, infiltration rate, and water content were taken at the rock dump, and measurements of particle-size distribution, Atterberg limits, and specific gravity were obtained from rock samples from the dump. A weather station was installed on the crest of the dump to collect information on wind velocity and direction, temperature, and evaporation; however, precipitation data were not compiled because of an equipment design error. Instead, precipitation data were acquired from the weather station at the mine office approximately 3 km away and 445 m lower in elevation.

Figure 2.—Rock dump with 15-m-high vertical benches.

FIELD-DETERMINED MATERIAL PROPERTIES

Twelve pits designed to measure in situ density were excavated on benches with elevations ranging from 2,176 to 2,362 m (figure 3). These pits were located near the crest, the middle, and the toe of the rock dump to account for variations in the physical properties of the waste material resulting from gravity sorting as it was discarded. Procedures described in American Society for Testing and Materials (ASTM) standard D 5030-89, “Density of Soil and Rock in Place by the Water Replacement Method in a Test Pit,” were used. Based on guidelines presented in the ASTM standard for an estimated maximum particle diameter of 15 cm (figure 4), researchers from the Spokane Research Laboratory (SRL) constructed a 91-cm-diam aluminum test frame. An attempt was made to line the density pits with 0.25-mm-thick natural latex rubber sheeting. Although the latex sheeting conformed to hole geometry quite well, angular rocks ripped the material (figures 5 and 6), and 4-mil polyethylene sheeting was used instead. All material from the density pits was sealed in 19-L plastic buckets for transport to the soils laboratory at SRL.

Specific weight values ranged from 1,924 to 2,345 kg/m^3 (table 2). The average value was 2,156 kg/m^3, and the standard deviation was 120 kg/m^3. Density calculations were also made

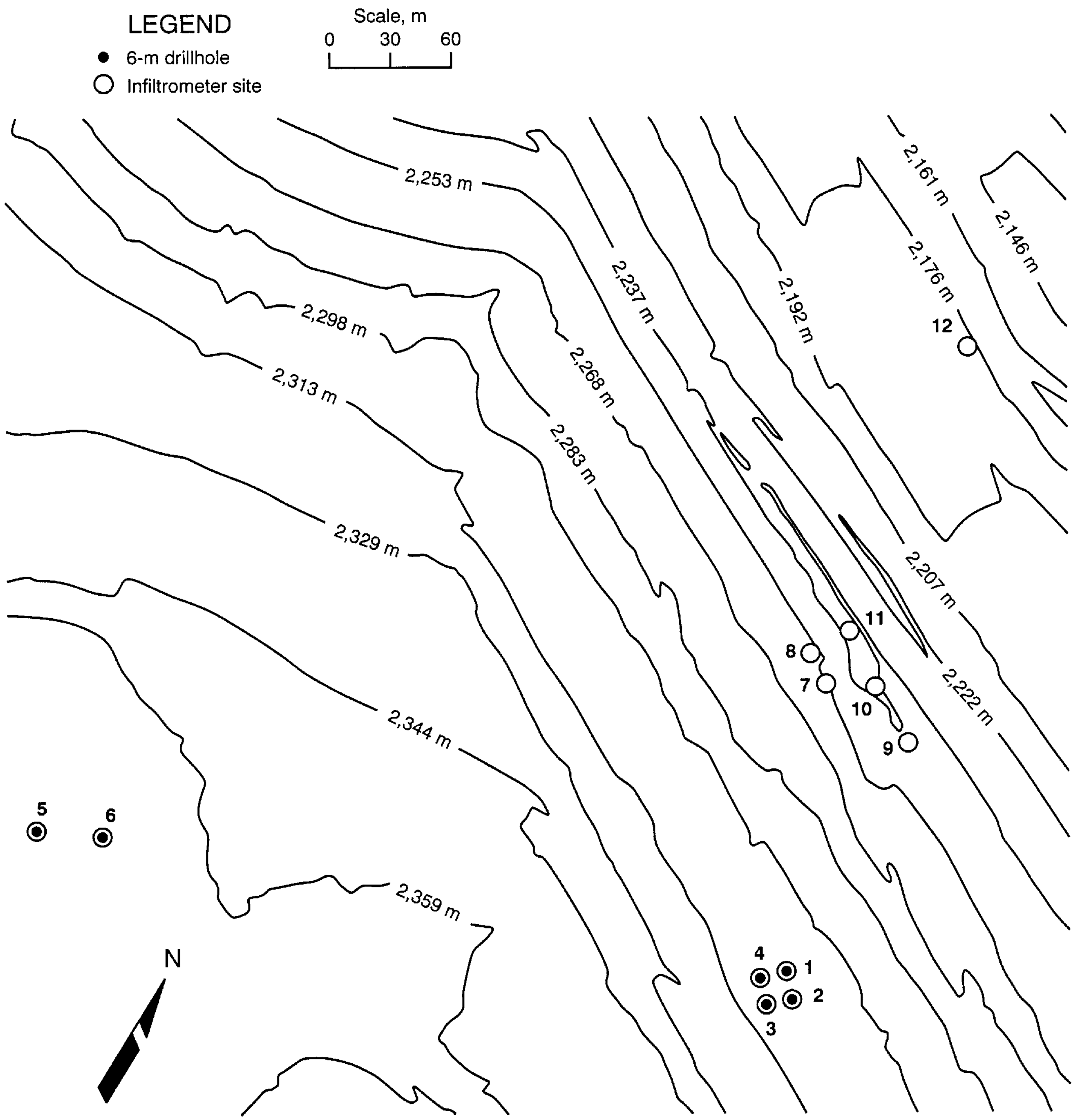

Figure 3.—Drillhole and infiltrometer sites.

for a control fraction consisting of minus 3.8-cm material. This size of material was chosen because it was to be used for direct shear tests in a 35.6-cm-diam cylindrical mold.

Density and water content were recorded at each site using a Troxler 3400-B nuclear surface-moisture density gauge.[1] The density measurements were taken with a cesium-137 source mounted 5 cm from the end of a source rod. The source rod was inserted into a vertical drill hole punched into the soil with a drill rod and hammered to depths from 5 to 31 cm. Water content measurements were taken with an americium-241 source rod near the center of the 37- by 23-cm gauge base. Detectors for attenuated radiation from these nuclear sources are located near the edge of the gauge base.

[1]Mention of specific products or manufacturers does not imply endorsement by the National Institute for Occupational Safety and Health.

Figure 4.—Frame for in situ density tests.

Figure 5.—Density frame covered with natural latex rubber sheeting.

Figure 6.—Density pit lined with polyethylene sheeting and filled with water.

Average density readings from the gauge were approximately 117 kg/m^3, or 5 pct, lower than density readings obtained using the water replacement method. A linear regression analysis on these two sets of data, minus the readings from sites 2 and 3, yielded a correlation coefficient of 0.88 and the following linear equation.

$$Y = 1.13X - 148.4, \tag{1}$$

where Y = density, kg/m^3 using the water replacement method

and X = density, kg/m^3 using a nuclear surface-moisture density gauge.

Table 2.—Density, water content, and void ratio

Site	Specific weight, kg/m^3		Water content determined by oven method, pct		Water content determined by nuclear density gauge, pct	Void ratio
	Entire sample	Control fraction	Entire sample	Control fraction		
1	2045	1930	3.44	3.83	5.1	0.37
2	2058	1937	6.24	6.75	8.8	0.39
3	2243	1977	4.32	5.03	8.9	0.37
4	2184	NA	5.41	5.64	8.6	0.29
5	2184	2102	3.08	3.36	5.4	0.30
6	2316	2292	4.57	4.90	5.2	0.22
7	2167	2020	2.24	2.56	4.2	0.38
8	2345	2293	3.34	3.70	7.0	0.20
9	2054	1969	4.58	5.02	4.5	0.38
10	2153	2108	5.36	5.61	6.1	0.35
11	2203	2147	5.10	5.67	7.2	0.30
12	1924	1920	9.10	9.79	9.4	0.53

NA. Not applicable.

Sites 2 and 3 were not included in the analysis because they appeared to be outliers. The correlation coefficient when these sites were included was 0.19.

Infiltration tests were performed at the bottom of each density pit (figure 7) except at site 12, where the test was conducted approximately 10 m northwest of the pit. These tests were conducted according to ASTM standard D 3385-88, except that only one infiltrometer ring was used, and changes in water volume were recorded at time intervals as small as 1 min. A mixture of powdered bentonite and water was packed around the outside of the infiltrometer ring to prevent water from seeping under the ring. Water volume flow into the ring was measured using 3.8-L gradations on a plastic tube plumbed into a 208-L steel barrel. Infiltration rates for sites 7 and 11 (table 3) could not be determined because water flow into the rock dump was the same as unrestricted water flow through the supply hose from the steel barrel. The minimum infiltration rate at these two sites was $1.47E^{-3}$ m/s.

Figure 7.—Infiltrometer.

Table 3.—Results of infiltration tests

Site	Infiltration rate, m/s	Test duration, min
1	2.94E-4	275
2	4.98E-7	1005
3	6.55E-5	413
4	1.54E-5	234
5	2.19E-5	297
6	4.53E-6	252
7	(1)	NA
8	5.82E-5	107
9	1.17E-4	235
10	2.12E-5	1403
11	(1)	NA
12	5.34E-6	1168

NA. Not applicable.

(1) Infiltration rate exceeded $1.47E^{-3}$ m/s.

HYDRAULIC CONDUCTIVITY PREDICTED FROM PARTICLE-SIZE DISTRIBUTION

The 10 most often applied empirical formulas for determining hydraulic conductivity from particle-size distribution are reduced to the following generalized formula by Vukovic and Soro (1992).

$$K = \frac{g}{\nu} C \, \phi(n) \, d \qquad (2)$$

where K = hydraulic conductivity, m/s,

g = acceleration due to gravity at 9.81 m/s^2

< = kinematic coefficient of viscosity, m^2/s,

C = dimensionless parameter,

N(n) = empirical function of porosity,

and d_e = effective grain diameter, m.

Specific values for C and d_e, expressions for N(n), and valid particle-size ranges for each of the 10 formulas represented by equation 2 are supplied by Vukovic and Soro (1992). Although these formulas were derived from experiments performed with sand-sized particles, researchers attempted to apply them to the entire range of particle-size distributions found at the 12 study sites (table 4), as well as the particle-size distributions for material passing U.S. Standard No. 4 mesh (4.75 mm) (table 5).

A linear regression analysis was used to compare these results with infiltration rates (table 6). For these sets of data, the highest correlation coefficients were calculated using the entire particle-size distribution curve and formulas reported by Hazen, Slichter, Terzaghi, Beyer, and Sauerbrei (Vukovic and Soro 1992).

Table 4.—Hydraulic conductivity predicted from particle-size distributions, entire sample, meters per second (adapted from Vokovic and Soro 1992)

Author	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Hazen	0.220E-3	0.229E-5	0.407E-4	0.130E-5	0.649E-4	0.146E-4
Slichter	0.525E-4	0.522E-6	0.773E-5	0.248E-6	0.126E-4	0.339E-5
Terzaghi	0.863E-4	0.841E-6	0.968E-5	0.296E-6	0.176E-4	0.282E-5
Beyer	0.744E-4	NA[1]	0.206E-4	0.321E-6	0.390E-4	0.292E-4
Sauerbrei	0.420E-2	0.758E-5	0.266E-3	0.304E-5	0.310E-4	0.824E-5
Kruegerr	0.377E-5	0.691E-6	0.219E-5	0.551E-6	0.540E-4	0.143E-4
Kozeny	0.726E-6	0.517E-6	0.137E-5	0.922E-7	0.458E-4	0.644E-5
Zunker	0.843E-6	0.404E-6	0.124E-5	0.132E-6	0.365E-4	0.693E-5
Zamarinu	0.215E-5	0.586E-6	0.154E-5	0.266E-6	0.440E-4	0.796E-5
USBR	0.271E-1	0.168E-4	0.733E-2	0.167E-4	0.102E-3	0.718E-4
	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12
Hazen	0.391E-3	0.771E-5	0.151E-3	0.184E-6	0.143E-5	0.422E-5
Slichter	0.825E-4	0.182E-5	0.352E-4	0.384E-7	0.282E-6	0.118E-5
Terzaghi	0.127E-3	0.149E-5	0.573E-4	0.589E-7	0.403E-6	0.201E-5
Beyer	0.178E-3	0.649E-5	0.441E-4	NA[1]	NA[1]	0.119E-5
Sauerbrei	0.768E-2	0.203E-4	0.599E-2	0.957E-5	0.265E-4	0.225E-5
Kruegerr	0.105E-5	0.423E-6	0.717E-5	0.217E-6	0.750E-6	0.382E-5
Kozeny	0.161E-6	0.312E-7	0.476E-5	0.108E-6	0.652E-6	0.349E-5
Zunker	0.209E-6	0.590E-7	0.385E-5	0.989E-7	0.511E-6	0.243E-5
Zaamarinu	0.538E-6	0.136E-6	0.591E-5	0.158E-6	0.623E-6	0.355E-5
USBR	0.903E-1	0.112E-2	0.671E-1	0.555E-4	0.282E-3	0.105E-5

[1]Beyer's equation produced a negative number.

Table 5.—Hydraulic conductivity predicted from particle-size distributions, sand fraction, meters per second (adapted from Vokovic and Soro 1992)

Author	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Hazen	0.873E-5	0.234E-7	0.914E-7	0.789E-7	0.123E-4	0.406E-5
Slichter	0.208E-5	0.531E-8	0.174E-7	0.151E-7	0.239E-5	0.946E-6
Terzaghi	0.342E-5	0.856E-8	0.218E-7	0.179E-7	0.334E-5	0.786E-6
Beyer	0.653E-5	0.121E-7	0.877E-7	0.857E-7	0.227E-4	0.216E-4
Sauerbrei	0.483E-5	0.331E-7	0.196E-6	0.138E-6	0.815E-5	0.251E-5
Kruegerr	0.229E-6	0.981E-7	0.163E-6	0.147E-6	0.122E-4	0.358E-5
Kozeny	0.449E-7	0.733E-7	0.101E-6	0.245E-7	0.103E-4	0.161E-5
Zunker	0.519E-7	0.574E-7	0.918E-7	0.351E-7	0.820E-5	0.173E-5
Zamarinu	0.132E-6	0.832E-7	0.114E-6	0.709E-7	0.989E-5	0.199E-5
USBR	0.490E-5	0.370E-7	0.610E-6	0.496E-6	0.237E-4	0.161E-4
	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12
Hazen	0.375E-8	0.285E-7	0.310E-6	0.641E-8	0.127E-7	0.243E-5
Slichter	0.791E-9	0.675E-8	0.721E-7	0.134E-8	0.250E-8	0.676E-6
Terzaghi	0.122E-8	0.552E-8	0.117E-6	0.206E-8	0.357E-8	0.115E-5
Beyer	NA[1]	0.522E-7	0.188E-6	NA[1]	0.390E-8	0.167E-5
Sauerbrei	0.926E-6	0.434E-6	0.945E-6	0.554E-8	0.758E-8	0.151E-5
Kruegerr	0.473E-7	0.446E-7	0.328E-6	0.406E-7	0.850E-7	0.163E-5
Kozeny	0.735E-8	0.329E-8	0.220E-6	0.205E-7	0.739E-7	0.150E-5
Zunker	0.953E-8	0.623E-8	0.177E-6	0.187E-7	0.579E-7	0.104E-5
Zamarinu	0.244E-7	0.144E-7	0.272E-6	0.297E-7	0.706E-7	0.151E-5
USBR	0.176E-5	0.241E-5	0.103E-5	0.622E-8	0.919E-8	0.612E-6

[1]Beyer's equation produced a negative number.

Table 6.—Correlation coefficients for calculated hydraulic conductivity and measured infiltration rates (adapted from Vokovic and Soro 1992)

Author	Entire curve	Curve from minus No. 4 mesh
Hazen	0.92	0.35
Slichter	0.93	0.42
Terzaghi	0.93	0.51
Beyer	0.81	0.12
Sauerbrei	0.75	0.29
Kruegerr	0.14	0.23
Kozeny	0.17	0.21
Zunker	0.17	0.22
Zamarinu	0.14	0.22
USBR	0.58	0.10

DOWNHOLE WATER CONTENT MEASUREMENTS

Measurements of the water content in rock dumps were taken using a Troxler 4300 nuclear depth-moisture gauge. This gauge was calibrated for use in stainless steel casings according to the procedures recommended by the manufacturer. That is, the gauge was inserted into a section of stainless steel pipe sealed at one end, and then readings were taken in a barrel of water.

Six 6.1-m-long holes were drilled vertically into the rock dump, two on the 2362-m elevation and four on the 2310-m elevation, using schedule 40, 5-cm nominal diameter, stainless steel, flush-coupled drill rods and three-wing carbide insert bits with pin threads. A short stainless steel adapter sub was fabricated for the bits. The bit, sub, and rod had nearly identical outside diameters to minimize the annulus between the drill string and the borehole wall. A small annulus was desirable because the drill string was left in the hole to serve as a hole casing for subsequent water content readings. The holes were advanced using only enough water to suppress dust and disturb as little of the rock dump material as possible. The annulus was filled with screened drill cuttings and then capped with a cement and sand mixture. Water content readings were taken approximately 10 weeks after the holes were capped to allow the drill water to equilibrate. Both the calibration and water content measurements were performed by a contractor with a Utah state license to use nuclear devices.

Downhole water content readings were recorded at 0.3-m intervals approximately every week for 4 weeks after the casings were installed and then after significant precipitation events (figure 8). The readings ranged from 2.6 pct at a depth of 0.3 m at site 5 on September 16 and 23, 1994, to 11.5 pct at a depth of 3.7 m at site 6 on June 5, 1995. Changes in water content ranged from 0 to 4.2 pct (figure 9). The largest increase occurred at site 1 at a depth of 2.4 m on June 5, 1995, following a period of rainfall (May 22 to June 4) when rainfall totaled 8.4 cm. In general, changes in water content decreased with depth up to 1.5 m below the dump surface and remained relatively constant from 1.5 to 5.8 m.

The maximum degree of saturation was 81.6 pct at a depth of 0.3 m. This amount was recorded at site 4 on February 7, 1995 (table 7). Values for depths greater than 0.3 m could not be calculated because void ratios were not available.

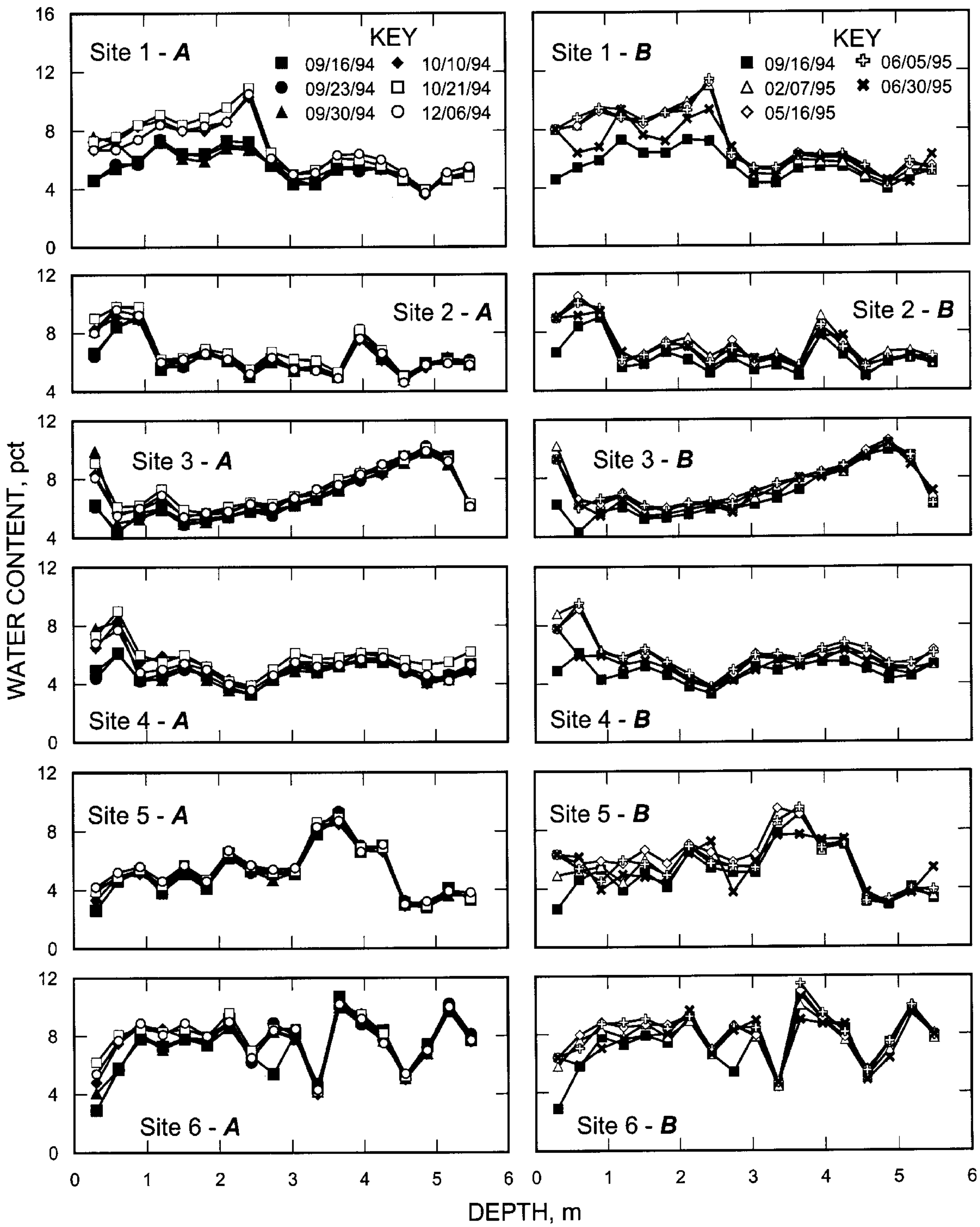

Figure 8.—Water content versus depth. ***A*, September 16 through December 6, 1994; *B*, February 7 through June 30, 1995.**

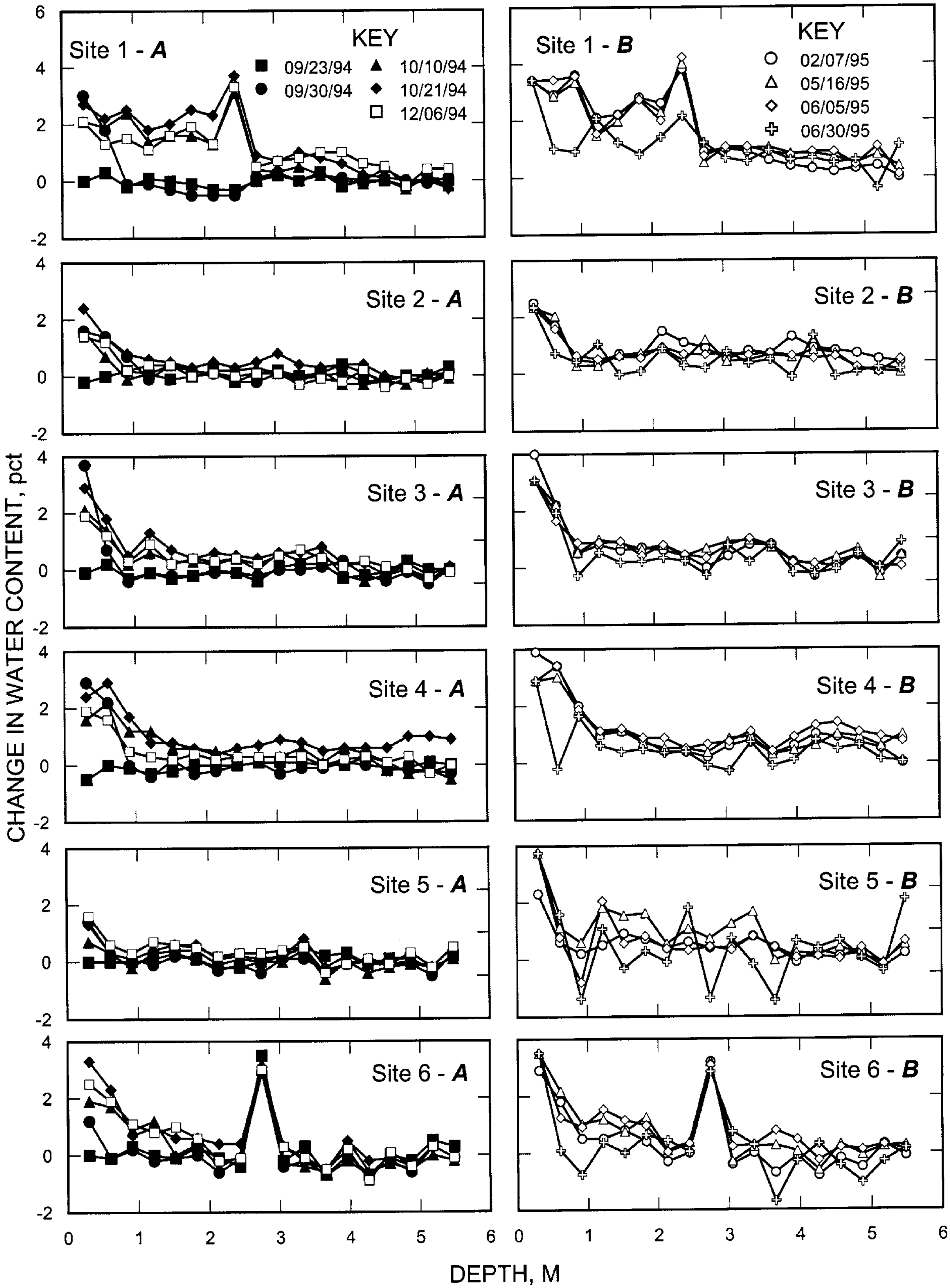

Figure 9.—Change in water content versus depth since September 16, 1994. *A*, September 16 through December 6, 1994; *B*, February 7 through June 30, 1995.

Table 7.—Degree of saturation at 0.3 m, percent

Site	Sep. 16	Sep. 23	Sep. 30	Oct. 10	Oct. 21	Dec. 6	Feb. 7	May 17	June 5	June 30
1	33.6	33.6	55.5	48.9	53.3	48.9	58.4	58.5	58.5	58.5
2	45.6	44.3	56.7	56.7	62.2	55.3	62.9	61.8	61.8	61.8
3	45.3	44.6	72.3	60.6	66.5	59.2	74.5	67.9	67.9	67.9
4	45.4	40.8	72.3	60.2	67.7	63.0	81.6	72.2	72.2	72.2
5	23.6	23.6	36.3	29.9	35.3	38.1	44.4	57.5	57.5	57.5
6	35.8	35.8	50.5	59.2	76.4	66.6	71.5	79.0	79.0	79.0

LABORATORY-DETERMINED MATERIAL PROPERTIES

Water content of the rock dump material was determined by using the oven drying method described in ASTM standard D 2216-90. All material collected at each site was weighed before and after it was dried in an oven. Water contents ranged from 2.2 to 9.1 pct, with an average of 4.7 pct and a standard deviation of 1.8 pct (table 2). The average value obtained with the nuclear surface-moisture density gauge was 6.7. Except at site 9, water contents obtained from the density gauge were larger than contents obtained by drying the material. The correlation coefficient for the data collected using these two methods was 0.67.

After drying, all material was screened over nested meshes with opening sizes of 76.20, 38.10, 19.05, 9.53, and 4.75 mm (U.S. Standard No. 4) to determine particle-size distribution (ASTM standard C 136-93). The minus 4.75-mm fraction was split repeatedly using a Jones splitter until a sample weighing approximately 0.5 kg was obtained. Particle-size distribution in this material was determined using the procedures specified in ASTM standard D 422. That is, approximately 300 g of the minus 4.75-mm fraction was washed over a 0.075-mm opening mesh (U.S. Standard No. 200). The material remaining on the 200 mesh was dried in an oven and screened through a nested set of sieves with openings of 2.00 (No. 10), 1.18 (No. 16), 0.60 (No. 30), 0.30 (No. 50), 0.15 (No. 100), and 0.075 (No. 200) mm. At 11 sites, over 90 pct of the material passed the 76.2-mm mesh (figures 10 through 21). The diameter of the largest rock fragment was 25 cm, but the average diameter of material retained on the 76.2-mm mesh was only 15 cm.

A Sedigraph 2000 particle-size analyzer was used to determine the particle-size distribution of the minus No. 140 mesh (0.106-mm) material. Approximately 25 g of soil was mixed with a solution of 99.9-pct water and 0.1-pct dispersing agent for analysis.

Following procedures described in ASTM standard D 4318-84, the liquid and plastic limits of the soil were determined. These results, along with the coefficients of uniformity and concavity, plastic index, Unified soil classification, and a specific gravity of minus No. 140 mesh (0.106-mm) material, are shown in table 8.

Table 8.—Soil classification data

Site	[1]C_u	[2]C_c	Liquid limit, pct	Plastic limit, pct	Plastic index, pct	Flow index, pct	Unified soil classification	SG[3]
1	107	9.9	21.0	18.3	2.7	-7.1	GP-GC	2.71
2	700	2.3	24.0	16.0	8.0	-10.7	GC	2.69
3	167	15.0	23.2	19.4	3.8	-10.6	GP-GC	2.71
4	335	1.2	20.2	17.9	2.3	-9.2	SC	2.66
5	105	0.1	NA	NA	NA	NA	GP	2.71
6	95	0.2	18.9	NA	NA	-2.1	GP	2.70
7	100	11.1	22.0	17.4	4.6	-8.3	GP-GC	2.73
8	230	14.4	22.2	16.2	6.0	-5.2	GP-GC	2.73
9	177	24.2	25.3	20.8	4.5	-7.3	GP-GC	2.70
10	1030	11.7	23.9	18.2	5.7	-7.6	GC	2.70
11	955	15.1	25.5	18.3	7.2	-5.4	GC	2.76
12	135	0.2	30.9	25.5	5.4	-9.1	SM	2.73

[1]Coefficient of uniformity. [2]Coefficient of concavity. [3]Specific gravity. NA. Not applicable.

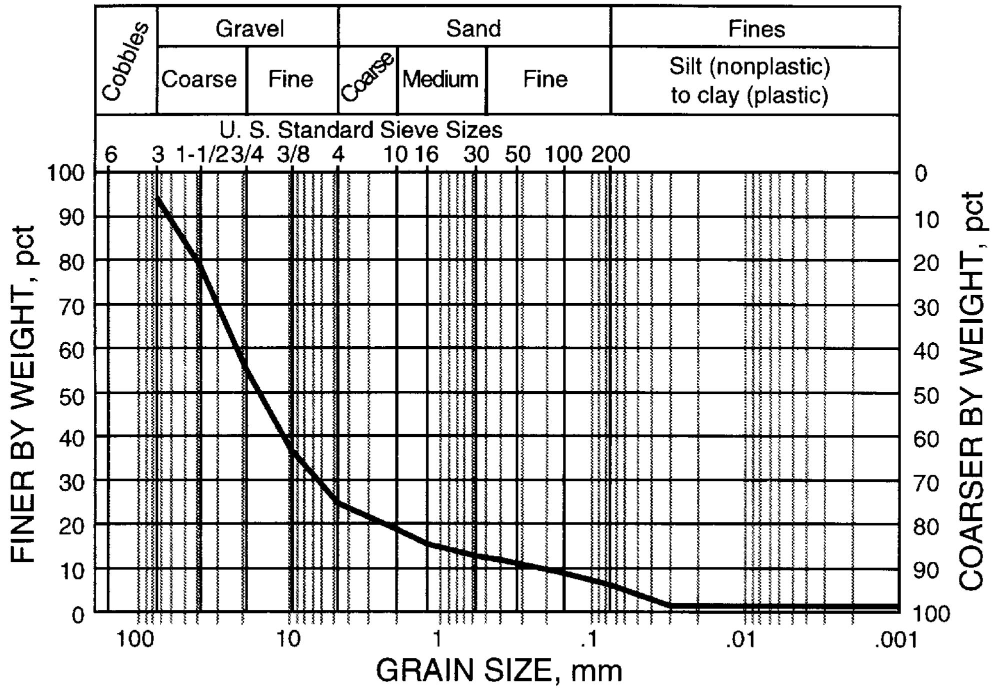

Figure 10.—Particle-size distribution curve for site 1.

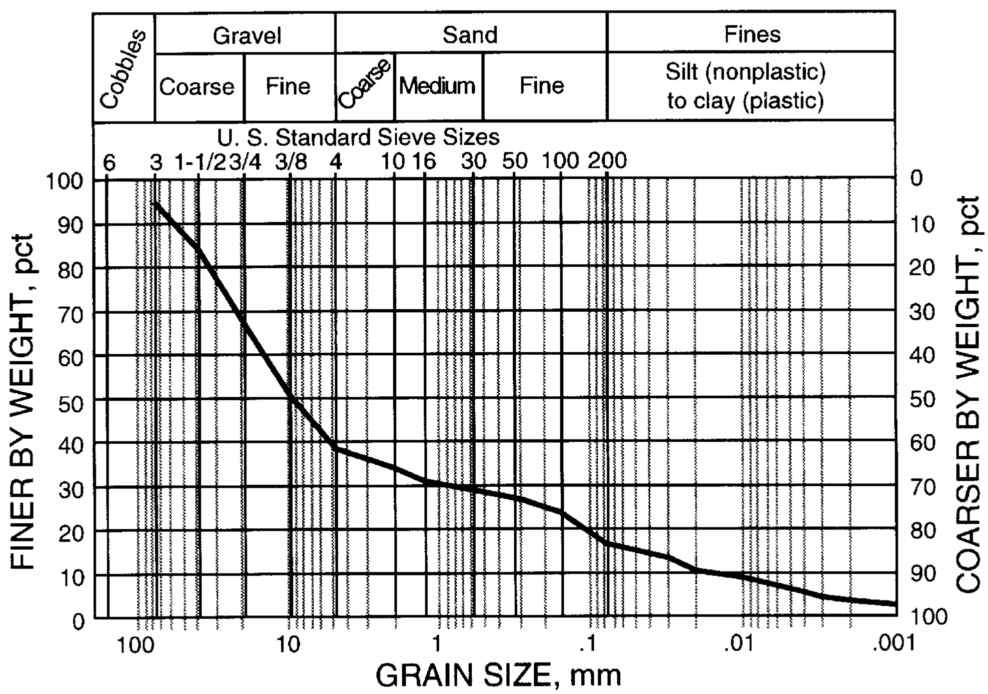

Figure 11.—Particle-size distribution curve for site 2.

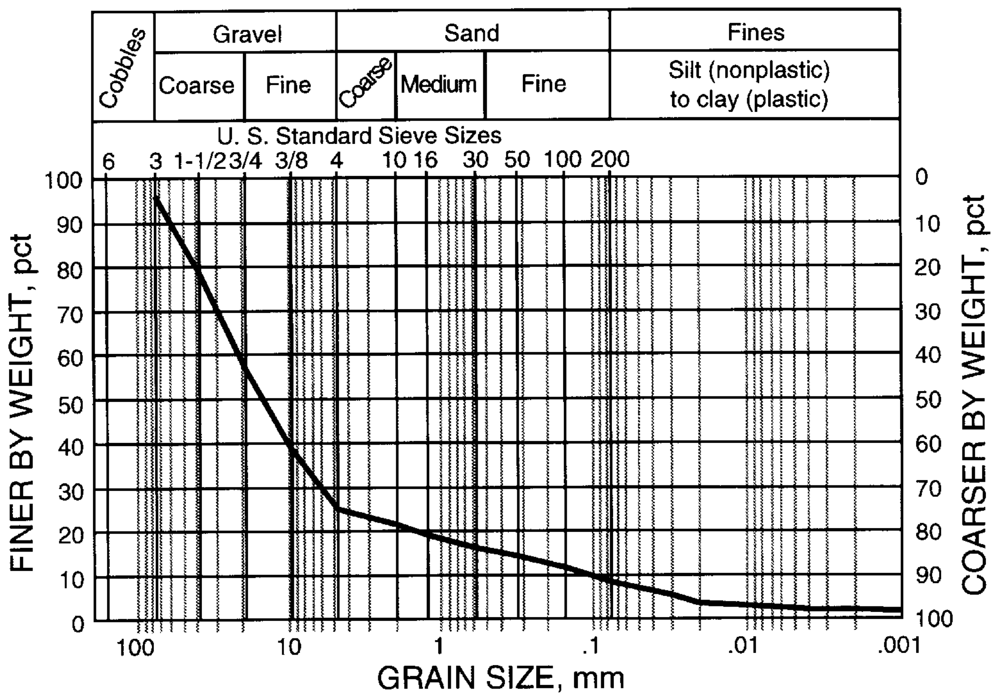

Figure 12.—Particle-size distribution curve for site 3.

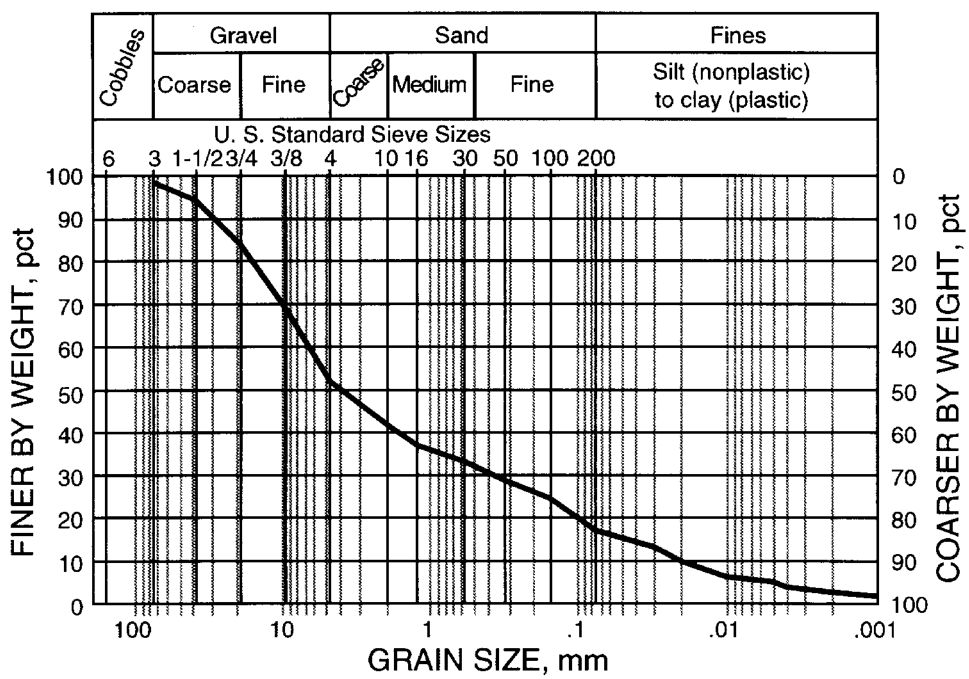

Figure 13.—Particle-size distribution curve for site 4.

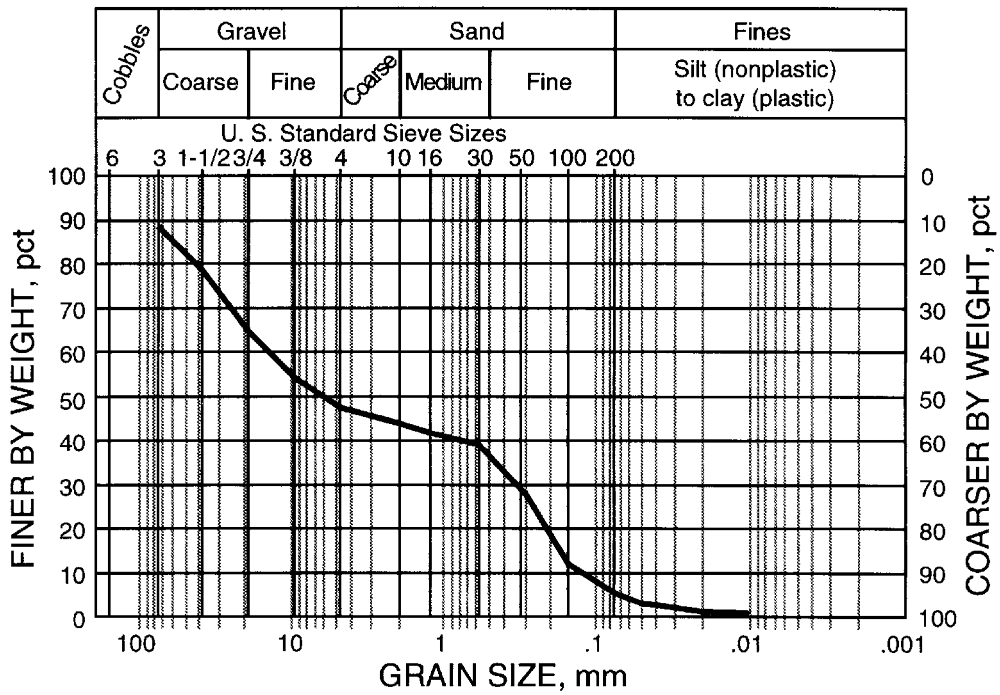

Figure 14.—Particle-size distribution curve for site 5.

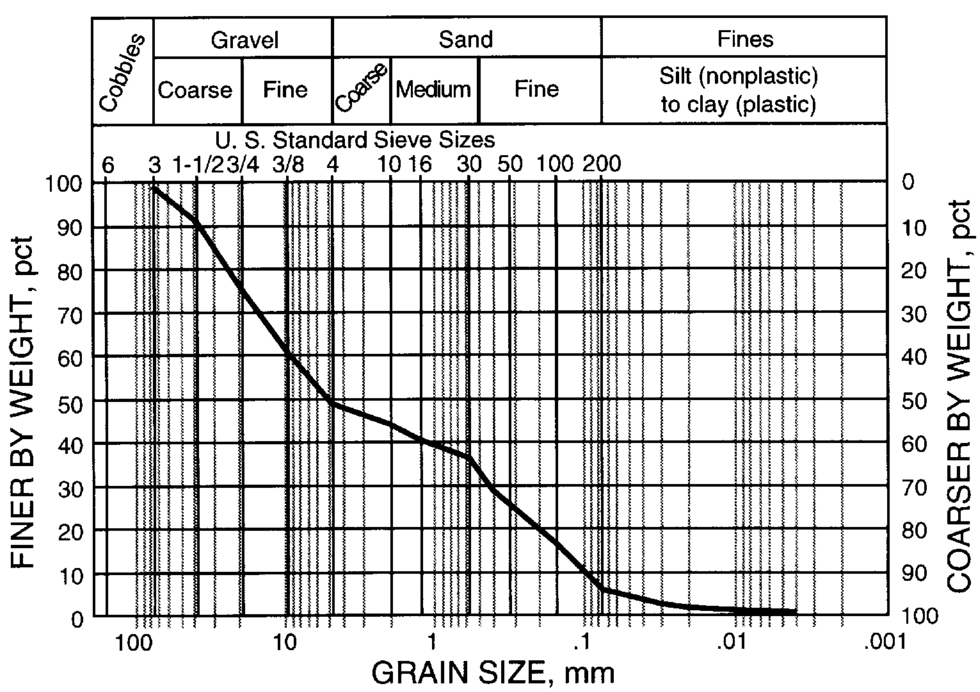

Figure 15.—Particle-size distribution curve for site 6.

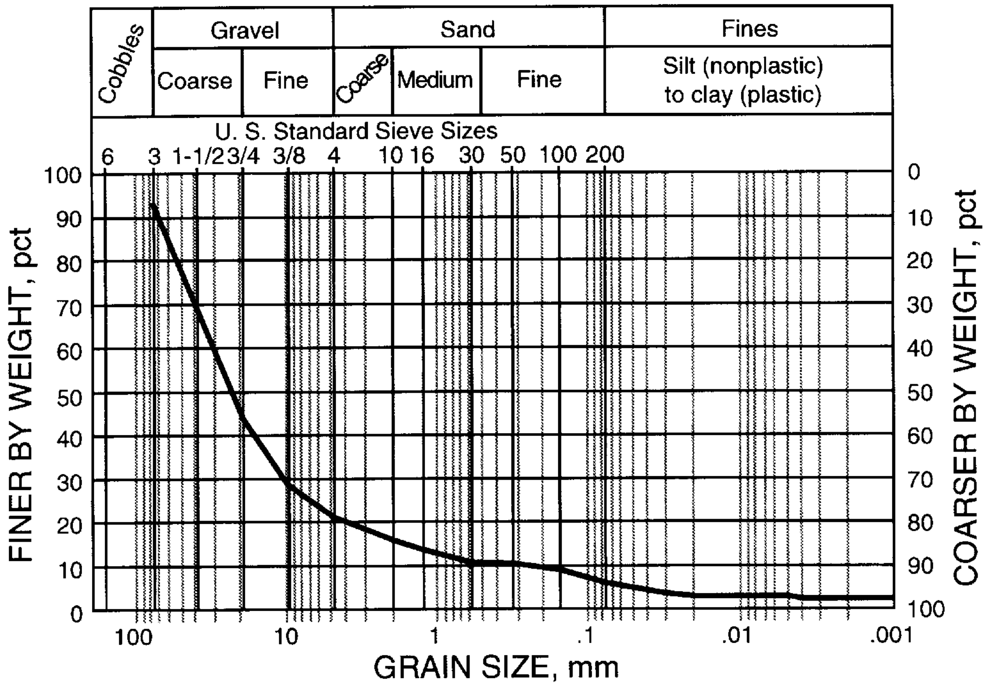

Figure 16.—Particle-size distribution curve for site 7.

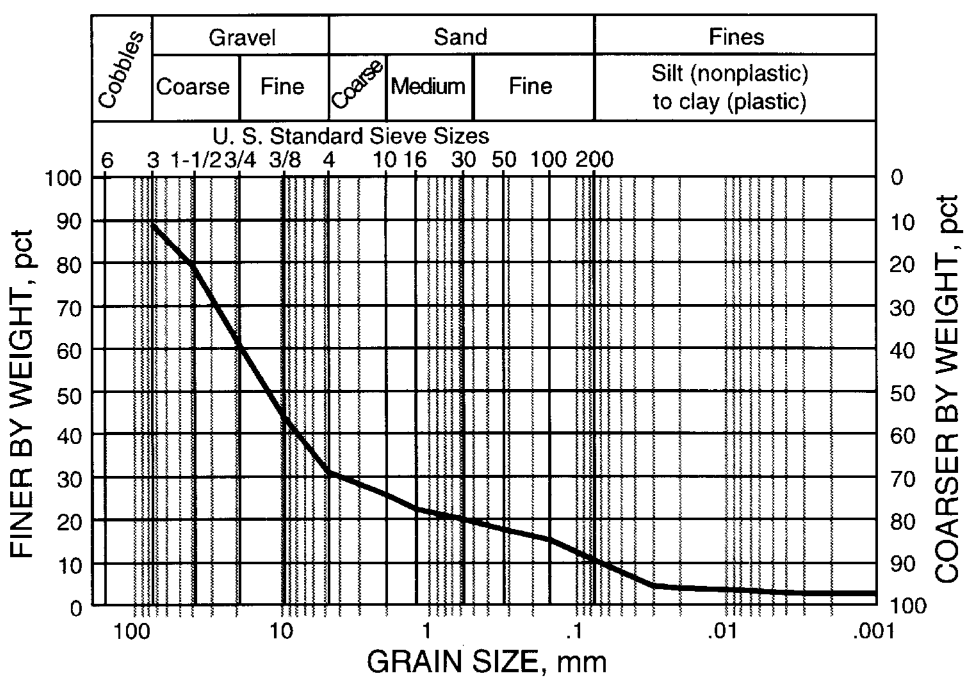

Figure 17.—Particle-size distribution curve for site 8.

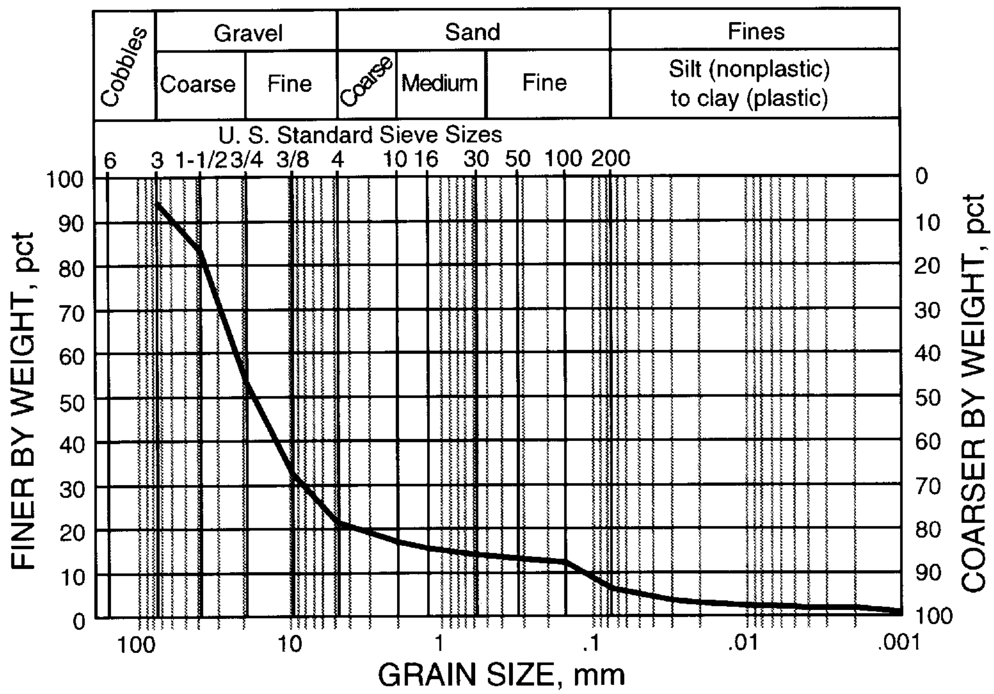

Figure 18.—Particle-size distribution curve for site 9.

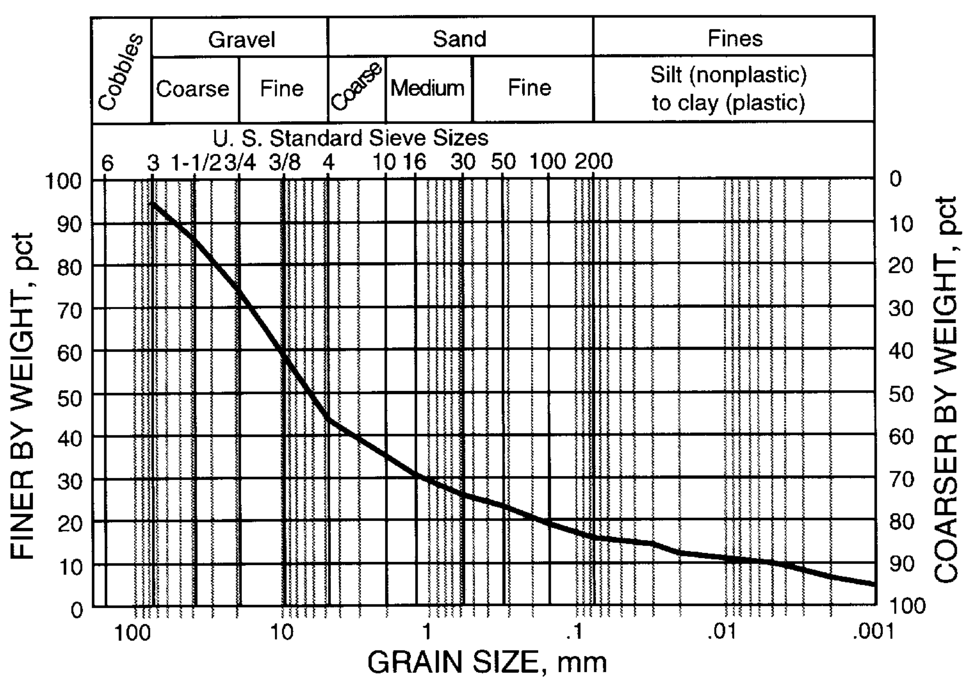

Figure 19.—Particle-size distribution curve for site 10.

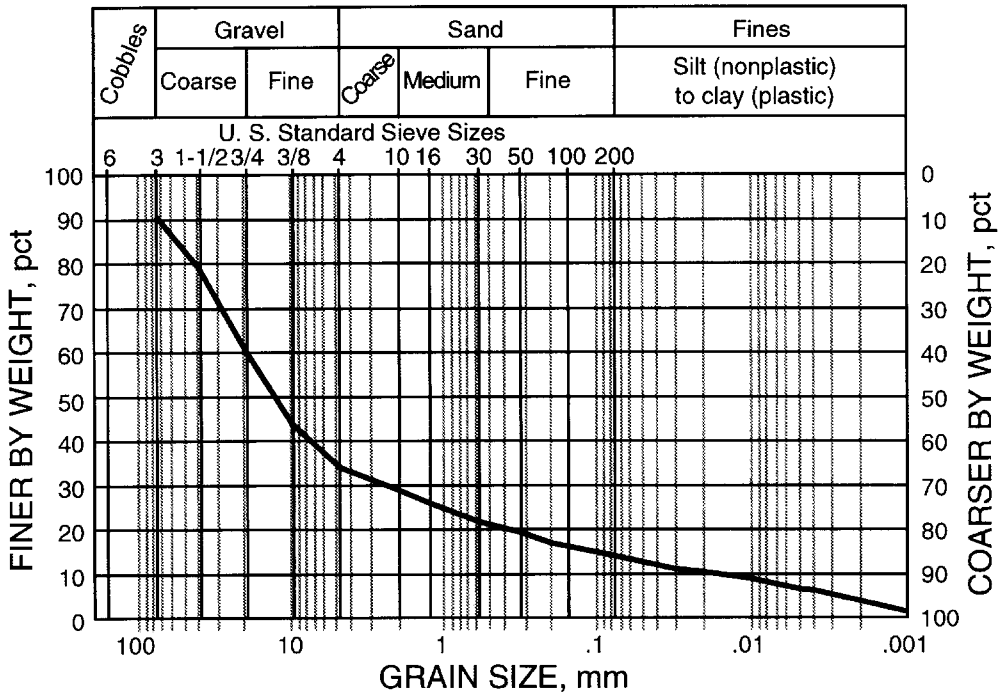

Figure 20.—Particle-size distribution curve for site 11.

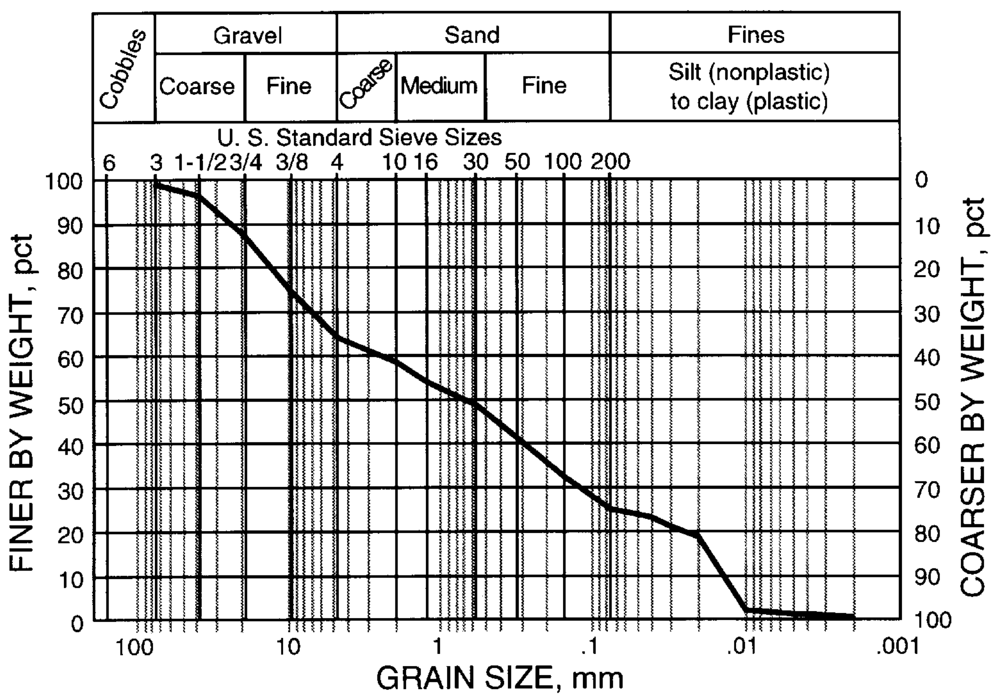

Figure 21.—Particle-size distribution curve for site 12.

PARTICLE-SIZE ANALYSIS USING IMAGE PROCESSING

Because mechanical sorting of large samples can be time consuming, a digital image processing program (Kemeny, 1993) was used to produce particle-size distribution curves from site 7 material. This program incorporates algorithms into the National Institute of Health's program "Image." It delineates individual particles in the images, applies statistical procedures that account for overlapping particles and two-dimensional aspects of the images, and produces a single particle-size distribution curve from multiple images of the same physical sample.

Two samples from site 7 were used to compare particle-size distribution curves obtained from mechanical and digital image processing. One sample contained 23 kg of minus 38-mm material, and the other contained only the material from the first sample retained on a 4.75-mm mesh. The material was spread out on a flat surface and videotaped with a high-resolution camera. Selected images from this tape were then imported to a computer disk for processing.

Two different types of light sources were used to illuminate the minus 38-mm sample: overhead fluorescent lighting and a blue artificial light that compensated for daylight film. For each type of light source, five images taken with different zoom lens settings on the camera were processed by the computer program. Although the shape of the distribution curves produced by the computer program followed the trend of the curve from the mechanical sort, both methods indicated a higher percentage of coarse material (figure 22). This discrepancy most likely occurred because the fines were too

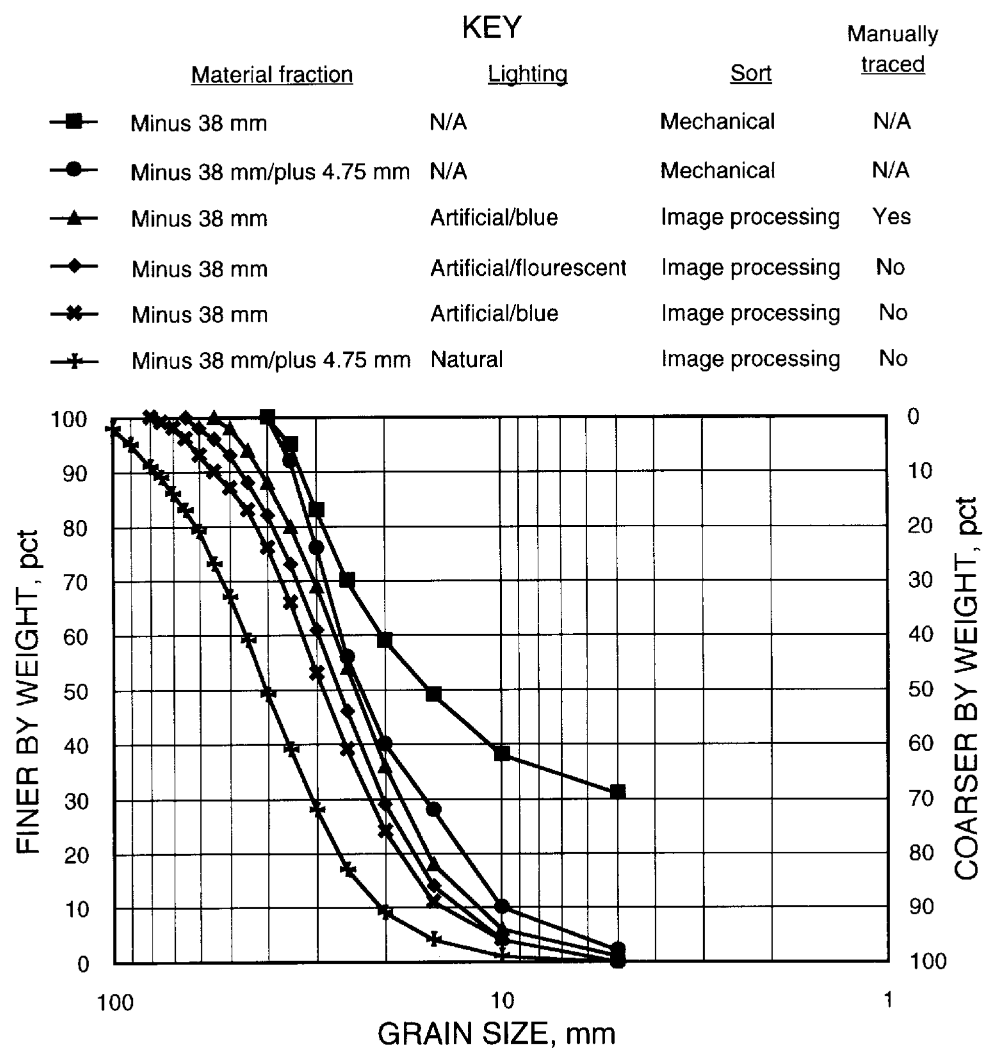

Figure 22.—Particle-size distribution curves produced from mechanical and digital image processing sorts.

small to be delineated and "blackened" in the image (Kemeny, 1993). Adjustments in the particle-size distribution curve can be made by estimating the percentage of the black area of the image that represents fines instead of shadows or objects placed in the image for scale. Manually tracing individual particles on the digital image using a computer mouse increased the accuracy of the curve produced from photo images, but the percentage of coarse particles predicted by the computer program was still too high. Similar results were obtained when the material used in these tests was screened with a 4.75-mm mesh and video-imaged under natural light. The image-processing program has been improved recently, and computer-generated particle-size distributions were compared to the results of on-site mechanical sorting (Girdner and others, 1996).

WEATHER STATION

An automated weather station was erected on the 2362-m elevation of the rock dump to record air temperature, wind velocity and direction, evaporation rate, and precipitation. This information was collected to help interpret soil water content recorded in the six holes, as well as to provide a baseline for rock slope stability studies.

An air temperature probe with a solar radiation shield; an R. M. Young Co. vane anemometer; a Campbell Scientific measurement and control module with a data storage unit; a 12-V power supply; and a solar panel were mounted on a 3-m-high tower. The control module, data storage module, and power supply were enclosed in a weatherproof container.

The collection of data started on July 14, 1994. Anemometer data indicate that maximum wind velocities are lower in August and September than during the rest of the year. Average maximum wind velocities of 9.8, 26.5, and 10.0 m/s were recorded between July 14 and October 9, 1994; October 10, 1994, and July 26, 1995; and July 27 and September 10, 1995, respectively. Gusts of 61.6 m/s were recorded on March 10 and 21, 1995, and gusts of 73.2 m/s were recorded on June 5, 1995. Maximum wind velocity directions generally had azimuths of 150° to 300°, indicating that the wind rarely blew from the northeast (figure 23). Temperature data were consistent with seasonal temperature cycles (figure 24), with a maximum recorded on August 5, 1994 (29 °C), and a minimum on December 31, 1994 (-19 °C).

A raised platform was constructed adjacent to the tower for a Novalynx evaporation pan and all-season precipitation gauge. Data from these two instruments were also collected by the Campbell Scientific datalogger on the tower. Data collection started on August 30, 1994; however, a design error in the precipitation gauge resulted in erroneous values. A replacement sensor was installed in late July 1995, but observed rainfall was not always recorded, resulting in insufficient data for calculating evaporation. Readings from the rain gauge installed near the mine office at an elevation of 1917 m indicated that significant precipitation events occurred in the period between March through July 1995 (figure 25).

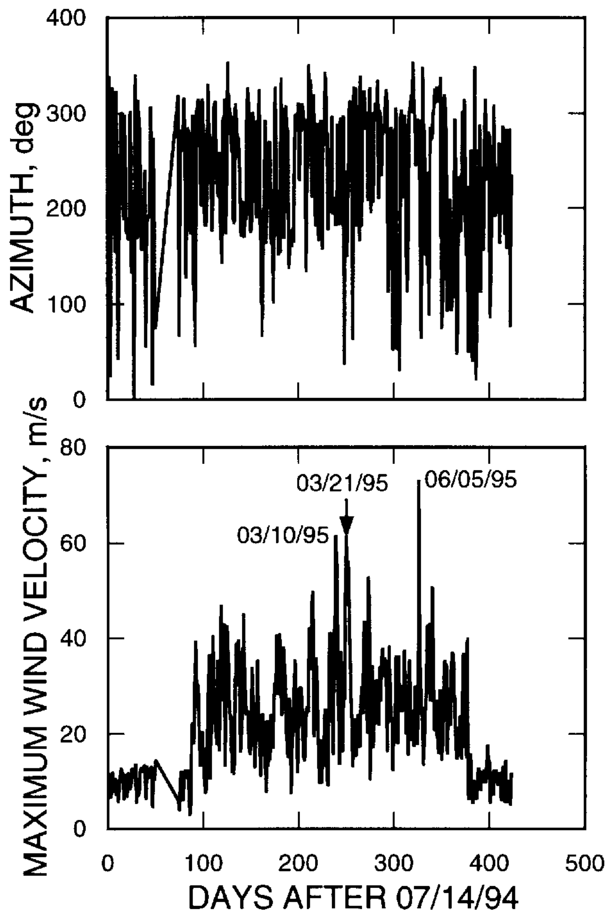

Figure 23.—Maximum wind velocity and azimuth versus time.

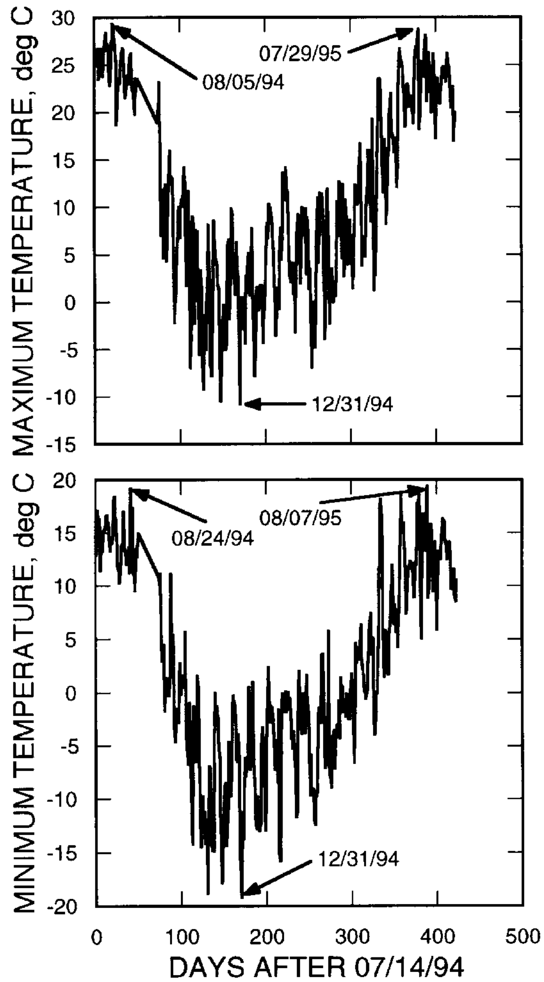

Figure 24.—Minimum and maximum temperature versus time.

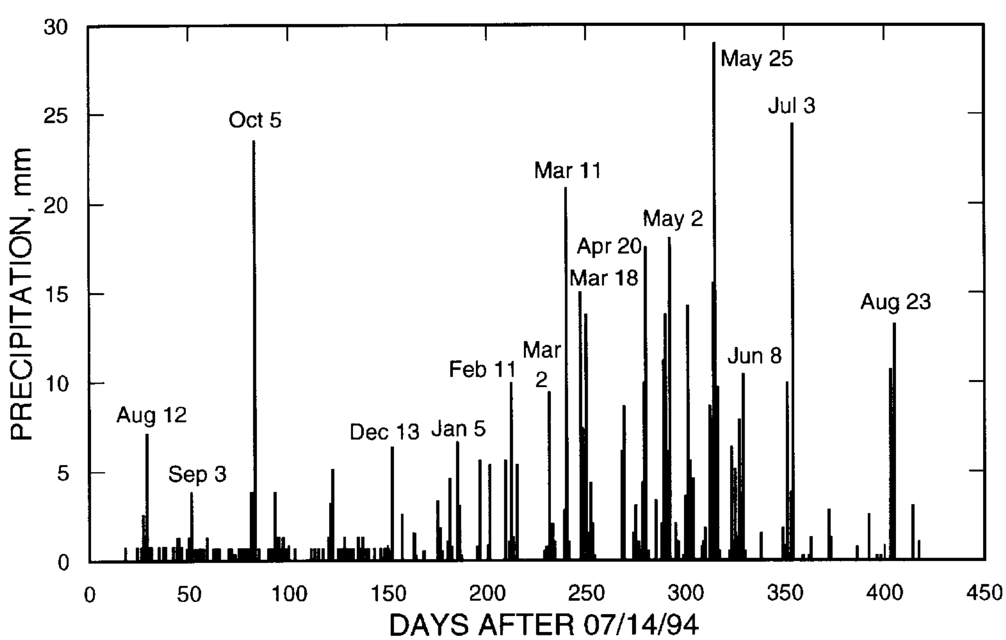

Figure 25.—Precipitation versus time.

SUMMARY AND CONCLUSIONS

Material properties of a rock dump constructed of mine overburden at least 50 years ago were measured using field and laboratory techniques. Field measurements included in situ density, surface water content, single-ring infiltrometer, and downhole water content. Instruments installed at a weather station near the dump's crest collected wind, temperature, precipitation, and evaporation data. The rationale for conducting this work was to correlate the performance of an old rock dump with its material properties. This information could be used to evaluate the stability of other old rock dumps.

Soil water content measurements were taken with a Campbell Pacific nuclear depth-moisture gauge in 6.1-m-deep, vertical, stainless-steel-cased holes. These measurements indicated that water content decreased with depth up to 1.5 m below the dump's surface and remained relatively constant from 1.5 to 5.8 m. Despite numerous daily precipitation events in which rainfall exceeded 15 mm, the maximum degree of saturation at a depth of 0.3 m in the rock dump was 82 pct. The condition of a partially saturated surface, a relatively constant water content in the dump's interior, and the self-cementing nature of the dump material may be the reasons why the dump has remained stable for over 50 years.

Researchers determined that a nuclear surface-moisture density gauge could be used to measure surface density provided that the gauge was calibrated with measurements obtained by the water replacement method. However, the average water content of the dump material measured by the gauge exceeded values obtained from oven drying by 40 pct, and correlation coefficient of data obtained from these two measurement techniques was only 0.67.

This work was intended to identify those physical properties and climatic conditions common to old, stable rock dumps. Similar investigations at failed rock dumps could identify differences in material properties between stable and unstable dumps that are critical to slope stability. With this knowledge, safer working practices could be developed. Future research could also include direct shear tests to determine material strength, slope stability analyses to calculate factors of safety, and investigations of the physical processes associated with natural cementation observed at this site.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the mine management and engineering staff involved in this project for suggestions in the experimental design, access to the research area, construction and maintenance of the weather station, contracting with the drilling company to drill and case the access holes for water content measurements, and providing the water truck for the infiltration and in situ density tests. Bill M. Stewart and Ronald R. Backer, mining engineers at the Spokane Research Laboratory, provided assistance with the field tests. Terrance J. McMahon, mining engineer, SRL, retired, assisted with the laboratory tests; Bruce C. Vandre, geotechnical engineer, USFS, retired, helped to identify research opportunities; and John M. Kemeny, associate professor, Dept. of Mining and Geological Engineering, University of Arizona, provided the digital image processing software and assistance in its use.

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December 1999