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5.18. *Engineering Characteristics of Soil Groups.*—(a) *General.*—Although there is no substitute for thorough testing to determine the important engineering properties of a particular soil, approximate values for typical soils of each USCS group can be given as a result of statistical analysis of available data (table 5-1). The attempt to put soils data into quantitative form involves the risk of (1) the data not being representative, and (2) using the values in design without adequate safety factors. In the early stages of planning, when different borrow areas and design sections are being studied, these averaged values of soil properties can be taken as useful qualitative guides. Because the values pertain to the soil groups, proper soil classification becomes of vital importance. Verification of field identification by laboratory gradation and Atterberg limits tests for design must be made on representative samples of each soil group encountered.

Table 5-1 is a summary of values obtained from more than 1,500 soil tests performed between 1960 and 1982 in the engineering laboratories of the Bureau of Reclamation in Denver, Colorado. The data, which were obtained from reports for which laboratory soil classifications were available, are arranged according to the USCS groups. The soils are from the 17 Western States in which the Bureau operates. Although the sampling area of the soils tested is limited, it is believed that the USCS is relatively insensitive to geographical distribution. The procedure for determining which of the many submitted samples should be tested was conducive to obtaining a representative range of values because samples were selected from the coarsest, the finest, and the average soil from each source.

For each soil property listed, the average, the standard deviation, the number of tests performed, the minimum test value, and the maximum test value are listed in table 5-1. Because all laboratory tests, except large-sized permeability tests, were made on compacted specimens of the minus No. 4 fraction of the soil, data on average values for the gravels were not available for most properties. The averages shown are subject to uncertainties that may arise from sampling fluctuations, and tend to vary widely from the true averages when the number of tests is small.

The values for laboratory maximum dry unit weight, optimum moisture content, specific gravity, and maximum and minimum index unit weight were obtained by tests described in section 5.49. The MH and CH soil groups have no upper boundary of liquid limits in the classification; therefore, it is necessary to give the range of those soils included in the table. The maximum liquid limits for the MH and the CH soils tested were 82 and 86 percent, respectively. Soils with higher liquid limits than these have inferior engineering properties.

(b) *Shear Strength.*—Two shear strength parameters are given for the soil groups under the headings c' and ϕ'. The values of c' and ϕ' are the vertical intercept and the angle of the envelope, respectively, of the Mohr strength envelope on an effective stress basis. (The Mohr plot is shown on fig. 5-13). The Mohr strength envelope is obtained by testing several specimens of compacted soil in a triaxial shear apparatus in which pore-fluid pressures developed during the test are measured.

The effective stresses are obtained by subtracting the measured pore-fluid pressures in the specimen from the stresses applied by the apparatus. The data used in compiling the values in table 5-1 are taken from UU (unconsolidated-undrained) and CU (consolidated-undrained) triaxial shear tests with pore-fluid pressure measurements and from CD (consolidated-drained) triaxial shear tests.

These values for shear strength are applicable for use in Coulomb's equation:

$$s = c' + (\sigma - \mu) \tan \phi' \qquad (1)$$

where:

s = shear strength,
u = pore-fluid pressure,
σ = applied normal stress,
ϕ' = effective angle of internal friction, and
c' = effective cohesion.

A discussion of the significance of pore-fluid pressure in the laboratory tests is beyond the scope of this text. The application of pore-pressure measurements to the shear strength of cohesive soils is discussed in [7]. The effective-stress principle, which takes the pore-fluid pressures into account, was used in arriving at recommended slopes given in chapter 6.

(c) *Permeability.*—The voids in the soil mass provide passages through which water can move. Such passages vary in size, and the paths of flow are tortuous and interconnected. If, however, a sufficiently large number of paths of flow are considered as acting together, an average rate of flow for

Table 5-1.—Average engineering properties of compacted soils. From the Western United States. Last updated October 6, 1982.

USCS soil type	Specific gravity: No. 4 minus	Specific gravity: No. 4 plus	Compaction, Laboratory: Maximum unit weight, lb/ft³	Compaction, Laboratory: Optimum moisture content, %	Compaction, Index unit weight: Max., lb/ft³	Compaction, Index unit weight: Min., lb/ft³	Shear strength, Avg. placement: Unit weight, lb/ft³	Shear strength, Avg. placement: Moisture content, %	Shear strength, Effective stress: c' lb/in²	Shear strength, Effective stress: ϕ', degrees	Values listed
	2.69	2.58	124.2	11.4	133.6	108.8	—	—	—	—	Average of all values
	0.02	0.08	3.2	1.2	10.4	10.2	—	—	—	—	Standard deviation
GW	2.65	2.39	119.1	9.9	113.0	88.5	—	—	—	—	Minimum value
	2.75	2.67	127.5	13.3	145.6	132.9	—	—	—	—	Maximum value
	16	9	5		16		0				Total number of tests
	2.68	2.57	121.7	11.2	137.2	112.5	127.5	6.5	5.9	41.4	Average of all values
	0.03	0.07	5.9	2.2	6.3	8.3	7.2	1.2	—	2.5	Standard deviation
GP	2.61	2.42	104.9	9.1	118.3	85.9	117.4	5.3	5.9	38.0	Minimum value
	2.76	2.65	127.7	17.7	148.8	123.7	133.9	8.0	5.9	43.7	Maximum value
	35	12	15		34		3				Total number of tests
	2.73	2.43	113.3	15.8	132.0	108.0	125.9	10.3	13.4	34.0	Average of all values
	0.07	0.18	11.5	5.8	3.1	0.2	0.9	1.2	3.7	2.6	Standard deviation
GM	2.65	2.19	87.0	5.8	128.9	107.8	125.0	9.1	9.7	31.4	Minimum value
	2.92	2.92	133.0	29.5	135.1	108.1	126.9	11.5	17.0	36.5	Maximum value
	34	17	36		2		2				Total number of tests
	2.73	2.57	116.6	13.9	—	—	111.1	15.9	10.2	27.5	Average of all values
	0.08	0.21	7.8	3.8	—	—	10.4	1.6	1.5	7.2	Standard deviation
GC	2.67	2.38	96.0	6.0	—	—	96.8	11.2	5.0	17.7	Minimum value
	3.11	2.94	129.0	23.6	—	—	120.9	22.2	16.0	35.0	Maximum value
	34	6	37		0		3				Total number of tests
	2.67	2.57	126.1	9.1	125.0	99.5	—	—	—	—	Average of all values
	0.03	0.03	6.0	1.7	6.0	7.1	—	—	—	—	Standard deviation
SW	2.61	2.51	118.1	7.4	116.7	87.4	—	—	—	—	Minimum value
	2.72	2.59	135.0	11.2	137.8	109.8	—	—	—	—	Maximum value
	13	2	1		12		0				Total number of tests
	2.65	2.62	115.6	10.8	115.1	93.4	103.4	5.4	5.5	37.4	Average of all values
	0.03	0.10	9.7	2.0	7.2	8.8	14.6	—	3.0	2.0	Standard deviation
SP	2.60	2.52	106.5	7.8	105.9	78.2	88.8	5.4	2.5	35.4	Minimum value
	2.77	2.75	134.8	13.4	137.3	122.4	118.1	5.4	8.4	39.4	Maximum value
	36	3	7		39		2				Total number of tests
	2.68	2.18	116.6	12.5	110.1	84.9	112.0	12.7	6.6	33.6	Average of all values
	0.06	0.11	8.9	3.4	8.7	7.9	11.1	5.4	5.6	5.7	Standard deviation
SM	2.51	2.24	92.9	6.8	88.5	61.6	91.1	1.6	0.2	23.3	Minimum value
	3.11	2.63	132.6	25.5	122.9	97.1	132.5	25.0	21.2	45.0	Maximum value
	149	9	123		21		17				Total number of tests
	2.69	2.17	118.9	12.4	—	—	115.6	14.2	5.0	33.9	Average of all values
	0.04	0.18	5.9	2.3	—	—	14.1	5.7	2.5	2.9	Standard deviation
SC	2.56	2.17	104.3	6.7	—	—	91.1	7.5	0.7	28.4	Minimum value
	2.81	2.59	131.7	18.2	—	—	131.8	22.7	8.5	38.3	Maximum value
	88	4	73		0		10				Total number of tests
	2.69	—	103.3	19.7	—	—	98.9	22.1	3.6	34.0	Average of all values
	0.09	—	10.4	5.7	—	—	11.5	8.9	4.3	3.1	Standard deviation
ML	2.52	—	81.6	10.6	—	—	80.7	11.1	0.1	25.2	Minimum value
	3.10	—	126.0	34.6	—	—	119.3	40.3	11.9	37.7	Maximum value
	65	0	39		0		14				Total number of tests
	2.71	2.59	109.3	16.7	—	—	106.5	17.7	10.3	25.1	Average of all values
	0.05	0.13	5.5	2.9	—	—	7.8	5.1	7.6	7.0	Standard deviation
CL	2.56	2.42	90.0	6.4	—	—	85.6	11.6	0.9	8.0	Minimum value
	2.87	2.75	121.4	29.2	—	—	118.7	35.0	23.8	33.8	Maximum value
	270	3	221		0		31				Total number of tests
	2.79	—	85.1	33.6	—	—	—	—	—	—	Average of all values
	0.25	—	2.3	1.6	—	—	—	—	—	—	Standard deviation
MH	2.47	—	82.9	31.5	—	—	—	—	—	—	Minimum value
	3.50	—	89.0	35.5	—	—	—	—	—	—	Maximum value
	10	0	5		0		0				Total number of tests

Table 5-1.—Average engineering properties of compacted soils. From the Western United States. Last updated October 6, 1982. —Continued.

USCS soil type	Specific gravity		Compaction: Laboratory		Index unit weight		Shear strength: Avg. placement		Effective stress		Values listed
	No. 4 minus	No. 4 plus	Maximum unit weight, lb/ft³	Optimum moisture content, %	Max., lb/ft³	Min., lb/ft³	Unit weight, lb/ft³	Moisture content, %	c' lb/in²	ϕ', degrees	
	2.73	—	95.3	25.0	—	—	93.6	25.7	11.5	16.8	Average of all values
	0.06	—	6.6	5.4	—	—	8.1	5.7	7.4	7.2	Standard deviation
CH	2.51	—	82.3	16.6	—	—	79.3	17.9	1.5	4.0	Minimum value
	2.89	—	107.3	41.8	—	—	104.9	35.3	21.5	27.5	Maximum value
	74	0	36		0			12			Total number of tests

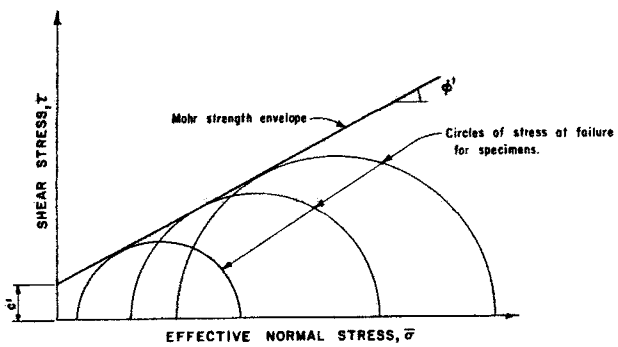

Figure 5-13.—Shear strength of compacted soils. 288–D–2474.

the soil mass can be determined under controlled conditions that will represent a property of the soil.

In 1856, H. Darcy showed experimentally that the rate of flow of water, q, through a soil specimen of cross-sectional area A was directly proportional to the imposed hydraulic gradient ($i = \Delta h/L$) or $q = kiA$. The coefficient of proportionality, k, has been called "Darcy's coefficient of permeability," "coefficient of permeability" (also referred to as hydraulic conductivity) or "permeability." Permeability is the soil property that indicates the ease with which water will flow through the soil. The use of k in estimating flow through soils is discussed in section 6.9(b). Many units of measurement are commonly used for expressing the coefficient of permeability. The units used on figure 5-14 are feet per year (or cubic feet per square foot per year at unit gradient). One foot per year is virtually equal to 10^{-6} cm/s.

Permeability in some soils is very sensitive to small changes in unit weight, water content, or gradation. Because of the possible wide variation in permeability, the numerical value of k should be considered only as an order of magnitude. It is customary in the Bureau of Reclamation to describe soils with permeabilities less than 1 ft/yr as impervious; those with permeabilities between 1 and 100 ft/yr as semipervious; and soils with permeabilities greater than 100 ft/yr as pervious. These values, however, are not absolute for the design of dams. Successful structures have been built whose various zones were constructed of soils with permeabilities not within these respective ranges.