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MINIMUM TEST SPECIMEN MASS FOR GRADATION ANALYSIS

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16. ABSTRACT

Minimum test specimen masses for determining the gradation of soil are recommended. Specimen masses currently recommended in various test standards (ASTM, AASHTO, etc.) vary considerably; records or explanations are unknown how specimen masses were selected. Gradation analysis of a soil is typically reported to the nearest 1 percentage point. Minimum test specimen mass for gradation analysis is shown to be 100 times the mass of the maximum particle size present in the soil to be tested.

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UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

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INTRODUCTION

This report presents recommended minimum test specimen masses for performing a gradation analysis of soil based on the maximum particle size present and it documents the rationale for the recommendations.

Selecting the specimen size to be used for determining the gradation of a soil is difficult and confusing because of conflicting and inconsistent values found in various testing standards. Determining the distribution of the different particle sizes present in a soil sample is one of the most basic tests performed on soils or on concrete aggregate. However, as shown in table 1, the recommended size of the specimen to be tested can vary by more than 1,000 percent. Table 1 gives the recommended specimen size as stated in various standards (ASTM, AASHTO, etc.) that currently exist and are being used worldwide.

The minimum specimen masses recommended in this report are listed at the bottom of table 1.

Table 1. – Comparison of specimen size for gradation testing.

Reference	Minimum specimen mass, in kilograms, based on maximum particle size in inches									
	No. 4 sieve (4.75 mm)	⅜ (9.5 mm)	½ (12.5 mm)	¾ (19.0 mm)	1 (25.0 mm)	1½ (37.5 mm)	2 (50 mm)	3 (75 mm)	5 (125 mm)	6 (150 mm)
ASTM C 136-84a [1][1]	0.5	1	2	5	10	15	20	60	300	500
ASTM C 117-84 [2]	0.5	1	--	2.5	--	5				
ASTM D 422-63 [3]	--	0.5	--	1	2	3	4	5		
ASTM D 1140-54 [4]	0.5	--	--	1.5	2	2.5				
ASTM D 2487-85 [5]	0.1	0.2		1.0		8.0		60.0		
AASHTO T 27-84 [6]	--	1	2	5	10	15	20	60	300	500
AASHTO T 11-85 [7]	0.5	1	--	2.5	--	5				
AASHTO T 88-86 [8]	--	0.5	--	--	2	--	4	5		
Corps of Engineers app. V, [9]	0.2	--	1	--	2	--	4	6		
BS 1377:1975 [10]	--	≈0.5	≈1.0	≈2.0	≈5	15	35			
USBR E-6 [11]	0.5	1.0		1.5		2.5	Larger than 1½ "sufficient amount to make a representative sample"			
Recommended values	0.05	0.25		1.1		10		70	310	

[1]Numbers in brackets refer to entries in the bibliography.

The minimum specimen masses recommended in this report were used in developing the Bureau of Reclamation procedure USBR 5325-86, *Performing Gradation Analysis of Gravel Size Fraction of Soils*. The concepts and information presented here have been submitted to ASTM (American Society for Testing and Materials) for possible incorporation into ASTM standards. A paper containing a similar presentation (coauthored by Ray Horz of the U.S. Army Corps of Engineers, Waterway Experiment Station who participated in development of the concepts) is to be submitted to the ASTM *Geotechnical Testing Journal.*

SUMMARY

The following minimum test specimen masses are recommended for performing a gradation analysis:

Maximum particle size		Recommended minimum test specimen mass	
inch	mm	kg	lbm
No. 4 sieve	4.75	0.05	0.1
⅜	9.5	0.25	0.5
¾	19.0	1.1	2.5
1½	37.5	10	20
3	75	70	150
5	125	310	680
8	200	1300	2800
12	300	4300	9400

APPLICATION

The most important steps in determining the gradation analysis of a soil are:

1. Obtaining a representative sample
2. Reducing the sample to test specimen size
3. Using proper testing procedures and equipment

This report addresses only the test specimen size. Because steps 1, 2 and 3 can have a much larger effect on results than proper test specimen size, it is assumed that all the steps have been performed perfectly. Other simplistic assumptions must also be made so that the discussion can be based on an ideal soil. Thus, variations in size of particles captured between two adjacent size sieves and in particle shape, angularity, and specific gravity are considered not to affect the test results.

Consequently, the concepts presented here must be regarded only as providing a purposeful, systematic method of specifying a minimum test specimen mass – for inclusion in gradation analysis testing standards – to promote uniformity and consistency.

BASIS FOR SELECTING MINIMUM TEST SPECIMEN SIZE

The minimum test specimen size, expressed here as the mass required, depends upon the accuracy required from the gradation test and how the data are to be reported.

Most organizations report the percent passing or percent retained on a certain sieve size to the nearest 1 percentage point – although values reported to 0.1 percentage point are not uncommon. This discussion is based upon reporting gradation percentages to the nearest 1 percentage point.

The term "accuracy" refers to "the closeness of agreement between an observed value and an accepted reference value." A gradation test specimen is usually a portion of a larger sample of soil. If the gradation percentages of the entire sample are used as the accepted reference value, then the accuracy becomes the difference in gradation percentages between the original soil sample and the specimen (portion) of the sample used for the gradation test.

Minimum specimen sizes recommended here are based upon whether the absence or the presence of one particle of the maximum particle size present (in the soil) will affect the accuracy of the test by ±1.0 percentage point. This criterion requires that the minimum specimen mass be at least 100 times the mass of the one maximum size particle.

Presence or Absence of One Particle

For gradation testing, the premise for setting the minimum specimen size is based upon the absence or the presence of one particle of the maximum size particle in the soil being tested.

To illustrate, visualize a soil sample being quartered or split to obtain a specimen for gradation analysis. The last split before obtaining the specimen for testing contains one 1½-inch particle (would pass a U.S.A. Standard series 1½-inch sieve but not a ¾-inch sieve) and all remaining particles pass the ¾-inch sieve. Assume the mass, of that one 1½-inch particle, is 80 grams.

Assuming a perfect split of the remaining particles; one portion, specimen A, contains 80 grams more mass than the other portion, specimen B, because of the presence of the one 1½-inch particle.

If specimen B has a mass of 8000 grams (assume minimum specimen size of 100 times the mass of the maximum size particle), then specimen A will have a mass of 8080 grams. If a gradation test is performed on both specimens, specimen A will have 0.990 percent [(80/8080) × 100] retained on the ¾-inch sieve – recorded on the data form as 1.0 percent – and reported as 1 percent; specimen B would indicate 0 percent retained on the ¾-inch sieve. Thus, if the specimen mass is 100 times the mass of the maximum particle size, the difference of one particle will make a difference in the test result of 1.0 percentage point.

Now, assume that regardless of the number of particles retained on the ¾-inch sieve, there will be a difference of only one particle between specimens A and B, again assuming perfect splitting. If the minimum specimen mass is at least 100 times the mass of the maximum particle size, then that one particle will not affect the results by more than 1.0 percentage point. For example, if 80 particles (mass of 80 grams each) were retained on the ¾-inch sieve for specimen B and 81 particles for specimen A, the percent retained would be [(6400/8000) × 100] = 80.0 for specimen B and [(6480/8080) × 100] = 80.2 for specimen A, both reported as 80 percent. However, if specimen B had 79.4 percent retained and specimen A had 79.6 percent (difference of 0.2 percentage point), the reported results would have been rounded to 79 and 80 percent, respectively; the difference would be 1 percentage point.

However, if the specimen size were less than 100 times the mass of the maximum particle, so that the difference between the two specimens was 1.1 percentage points, the difference could be 2 percentage points in the reported value. For example, if one-half of a split sample had 20.5 percent retained and the other half had 19.4 percent (difference of 1.1), the reported values would have been 21 and 19, respectively.

Increasing the specimen size to more than 100 times the maximum particle mass would not increase the accuracy of the test because of the effects of rounding numbers (discussion presented later).

Mass of Maximum Particle Size

If the mass of the minimum specimen for gradation testing is to be 100 times the mass of the maximum particle size, several assumptions must be made to establish the mass of the maximum size particle.

Maximum particle size relates to the smallest sieve opening the particle would pass. For example, a maximum particle size of 1½ inches means that the particle would pass a 1½-inch sieve but not a 1¼-inch sieve or, in terms of sieves used for most soil mechanics work, it would pass a 1½-inch sieve but not a ¾-inch sieve.

The first assumption is that the particle is a perfect sphere that barely passes the 1½-inch sieve opening. The mass of that particle would be:

$$(\pi D^3/6) \times \text{specific gravity} \times \text{density of water}$$

where *D* is the particle diameter.

To be conservative, the specific gravity is assumed to be 2.75, which represents a high value for most soils.

The value selected for the particle diameter becomes the most critical assumption because the diameter is cubed as shown above.

For the next assumption, it must be decided what diameter of a spherical particle would barely pass a 1½-inch sieve opening. ASTM E 11 gives the nominal dimensions and permissible variations for openings for standard test sieves (U.S.A. Standard series) [12]. Several possible values from this standard could be used.

The sieve opening is given (ASTM E 11) in millimeters as the "standard sieve designation" and in inches as the "alternative sieve designation." In most cases, the relationship between the two uses 25 millimeters = 1 inch. For example, the 1½-inch sieve has a designated opening of 37.5 millimeters and the 3-inch sieve is 75 millimeters.

The average opening is allowed a "permissible variation . . . from the standard sieve designation." For example, the 1½-inch sieve has an allowable variation of ±1.1 millimeter or a range of 36.4

to 38.6 millimeters for the average opening. The upper limit of this range will be referred to here as the "maximum average opening."

Also, there is a value shown in ASTM E 11 as "maximum opening size for not more than 5 percent of openings." For the 1½-inch sieve, this value is 39.1 millimeters. This value is referred to here as the "5-percent maximum opening."

The last value noted here is for the "maximum individual opening" (ASTM E 11). For the 1½-inch sieve, this is 39.5 millimeters.

Depending on which opening dimension is used, the diameter of a 1½-inch particle that barely passes a 1-½-inch sieve could range from 36.4 to 39.5 millimeters. For larger particle sizes, selecting the appropriate particle diameter (designated, maximum average, or maximum individual opening) can have a significant effect on the minimum test specimen mass as shown in table 2.

For soil having a maximum particle size of "1½ inch," the minimum specimen mass could range from 16.7 to 19.6 lbm (pounds mass). A nominal value of 20 lbm could easily be recommended for a test standard and the extra amount of soil would not generally be a practical problem. However, for a soil containing a maximum particle size of 3 inches, the minimum mass ranges from 134 to 155 lbm and the difference of 21 lbm becomes a practical concern.

Minimum Specimen Mass

It is suggested that the "maximum average opening" value be used since it is the permissible average opening. It is not likely that a sieve having either the "5-percent maximum opening" or a "maximum individual opening" would allow all particles of corresponding size in a test specimen to pass.

Table 2. – Minimum test specimen mass.

Sieve designation	Minimum test specimen mass, lbm		
	Designated opening	Maximum average opening	Maximum individual opening
No. 4 (4.75 mm)	0.034	0.037	0.043
1½ in (37.5 mm)	16.74	18.26	19.56
3 in (75 mm)	133.92	146.05	154.73

Using the "maximum average opening," the recommended minimum specimen masses for gradation testing are shown in table 3. The recommended masses are nominal values based on exact calculated numbers (the nominal values do not have explicit conversion between kg and lbm). The exact calculated values are summarized from table 4 which shows a more complete development of the precise masses required.

For practical reasons, the recommended minimum test specimen masses corresponding to the maximum particle sizes of the No. 4 sieve and ⅜ inch are larger than those indicated in the exact calculated values in table 3. The mass of one particle of No. 4 maximum size approaches the accuracy of the typical balance or scale used. For smaller sand sizes, the amount retained on certain sieves may be smaller than the accuracy of the balance. It is possible for sand sizes to stick in sieve openings and not be recoverable. For these reasons, the minimum test specimen mass for soil having a maximum particle size of the No. 4 sieve should be 50 grams (or 0.1 lbm) and for a maximum particle size of ⅜ inch should be 250 grams (or 0.5 lbm).

Effect of Rounding

Regardless of the specimen size for gradation testing, the laboratory operating procedure (particularly the rounding policy) can make a difference in the reported gradation percentages of ±1 percentage point.

Table 3. – Recommended minimum test specimen mass for gradation analysis.

Maximum particle size		Minimum test specimen mass[1]			
		Exact calculated value		Recommended nominal value	
inch	mm	kg	lbm	kg	lbm
No. 4 sieve	4.75	0.017	0.037	0.05 (50 g)	0.1
⅜	9.5	0.136	0.299	0.25 (250 g)	0.5
¾	19.0	1.084	2.39	1.1	2.5
1½	37.5	8.28	18.26	10	20
3	75	66.25	146.1	70	150
5	125	307.0	676.7	310	680
8	200	1259	2775	1300	2800
12	300	4248	9366	4300	9400

[1] Mass required to obtain ±1.0 percentage point accuracy. For other accuracies, divide value shown by accuracy required; i.e., for ±3 percentage point, divide by 3.

Table 4. – Minimum test specimen mass based on ASTM E 11 sieve openings.

Sieve designation[1]		Permissible	Maximum average	Maximum spherical particle		Mass of maximum size particle times 100	
Standard mm	Alternative inch	variation[1, 2] mm	opening mm	Volume [3]cm[3]	Mass [4]g	kg	[5]lbm
4.75	No. 4	±0.15	4.90	0.0616	0.169	0.0169	0.0373
9.5	⅜	±0.30	9.80	0.4928	1.355	0.1355	0.299
12.5	½	±0.39	12.89	1.1214	3.084	0.3084	0.680
19.0	¾	±0.6	19.6	3.9425	10.842	1.0842	2.39
25.0	1	±0.8	25.8	8.992	24.728	2.473	5.45
37.5	1½	±1.1	38.6	30.113	82.811	8.281	18.26
50	2	±1.5	51.5	71.519	196.68	19.668	43.36
75	3	±2.2	77.2	240.91	662.50	66.25	146.06
125	5	±3.7	128.7	1116.2	3069.5	306.95	676.7
[6]150	6		[7]154.5	1931.0	5310.3	531.03	1170.7
[6]200	8		[7]206	4577.2	12587.3	1258.73	2775
[6]300	12		[7]309	15448	42482	4248.2	9366
[6]450	18		[7]463.5	52137	143377	14338	31609

[1]From ASTM E 11-81.
[2]Permissible variation of average opening from the standard sieve designation.
[3]Using maximum average opening as diameter.
[4]Assumed 2.75 specific gravity.
[5]1 kg = 2.2046 lbm.
[6]Not listed in E 11, average opening calculated using 1 inch = 25 millimeters.
[7]Based in 1.03 times average opening.

A typical procedure for a laboratory is to record the calculated gradation percentages on the data form (or work sheet) to the nearest 0.1 percent. Subsequently, these values are rounded to the nearest 1 percent for reporting in tables, figures, reports, etc.

When a calculator or computer shows that the percent passing is 9.499999, the person entering the values on the data sheet would have rounded the value and recorded 9.5 percent. Then, for later reporting to the nearest 1 percent, someone using the data sheet would round the 9.5 to 10 percent. If the calculated value is rounded, this would be true no matter how many digits are recorded on the data forms. For example, the 9.499999 would have been rounded and recorded to 9.50, 9.500, 9.500, etc.

If the value to be recorded on the data form were to the nearest 1 percent—not the nearest 0.1 percent—then, the value recorded would have been 9 percent (9.499999 to the nearest 1 percent would be 9). If the number were the result of a computer or calculator value that was rounded by the computer or calculator to the nearest 1 percent as the last step, it also would result in a value of 9 percent.

The policy for rounding can be significant. One rounding method requires any number ending in 5 be rounded up to the next number, e.g., 82.5 becomes 83. This method is used by calculators and computers when instructed to round numbers. Another method requires that any number ending in 5 is rounded to the nearest even number (ASTM E 380, E 29) so that 82.5 would be rounded to 82 [13 and 14].

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