Standard Test Method for Particle Size Analysis of Natural and Man-Made Riprap Materials[1]

This standard is issued under the fixed designation D 5519; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the particle size and mass analysis of natural and man-made riprap and related materials, including filter stone or coarse bedding materials.

1.2 This test method is applicable for graded riprap stone, both naturally occurring and quarried. It is applicable for sizes 3 in. (75 mm) and above, with the upper size limited only by equipment available for handling and weighing of the individual particles. This test method is also applicable for evaluation, sizing, and mass determinations of man-made riprap materials, such as recycled broken concrete.

1.3 Three alternate procedures are provided. The procedure used shall be as indicated in the specification for the material being tested. If no procedure is specified, the choice should be selected and confirmed by the testing agency. The procedures and referenced sections are:

1.3.1 *Test Method A: Size-Mass Grading*—Grading of the material based on both the size and mass. See 9.2.

1.3.2 *Test Method B: Size-Range Grading*—Determination of the grading of the material based on the sizes of the individual particles. See 9.3.

1.3.3 *Test Method C: Mass-Range Grading*—Determination of the grading of the material based on the mass of the individual particles. See 9.4.

1.4 During the measurements using the methods in accordance with 1.3.1, 1.3.2, or 1.3.3, other attributes, such as the amount of slab pieces, can be determined during testing.

1.5 The values stated in inch-pound units are to be regarded as the standard. The metric equivalents of inch-pound units given in parentheses may be approximate.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific precautionary statements are given in Section 7.

2. Referenced Documents

2.1 *ASTM Standards:*

C 136 Test Method for Sieve Analysis of Fine and Coarse Aggregates[2]

D 422 Test Method for Particle-Size Analysis of Soils[3]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[3]

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction[3]

D 4992 Practice for Evaluation of Rock to Be Used for Erosion Control[3]

D 5240 Test Method for Testing Rock Slabs to Evaluate Soundness of Riprap by Use of Sodium Sulfate or Magnesium Sulfate[3]

D 5312 Test Method for Evaluation of Durability of Rock for Erosion Control Under Freezing and Thawing Conditions[3]

E 11 Specification for Wire Cloth and Sieves for Testing Purposes[2]

3. Terminology

3.1 *Definitions:*

3.1.1 Terminology used within this test method is in accordance with Terminology D 653 with the addition of the following:

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *bedding (riprap)*—a layer of gravel, crushed stone, or filter materials placed on soil and under riprap to prevent soil migration up through the riprap, and to prevent undermining of the riprap due to erosion of the soil.

3.2.2 *slab pieces*—pieces of riprap that exhibit dimensional ratios of the thickness to width or width to length, or both, in excess of a specified ratio. The specified ratios typically range from 1:4 to 1:3 or less.

4. Summary of Test Method

4.1 The following three test methods for evaluating particle size distribution are available.

4.1.1 *Test Method A: Size-Mass Grading*—A sample of the material is obtained, individual particles are measured, and the particles are grouped into size ranges desired. The total mass of

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.17 on Rock for Erosion Control.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.08.

particles in the desired size range is determined. Particle size distribution percentages are then determined by calculation.

4.1.2 *Test Method B: Size Range Grading*—A sample of the material is obtained, individual particles are measured, counted, grouped into size ranges desired, and the distribution by size range is determined. The distribution in a size range, by mass, retained or passing, can be estimated.

4.1.3 *Test Method C: Mass-Range Grading*—A sample of the material is obtained, the mass of individual particles is measured, counted, masses are summed into mass ranges desired, and the distribution by mass ranges is determined.

5. Significance and Use

5.1 Riprap is commonly used to prevent erosion of underlying materials due to the effects of rain runoff, wind, flowing water, or wave action. The particle size distribution and mass of particles are two of the more important physical characteristics of riprap, whether quarried or from naturally occurring deposits.

5.2 The grading, particle mass, and other characteristics are important to ensure that riprap and the underlying bedding stone and filter materials will perform as designed to prevent erosion. Particle size and shape are key to having a uniform and interlocked riprap layer that will resist wind, wave, and water action. Poorly graded materials will result in either less than desired performance or the need to place additional riprap thickness.

5.3 This test method can be used to determine the particle size distribution of a sample of riprap or related materials, such as bedding, gabion, or riprap stone. It can be used during evaluation of a potential source or later as a means of product acceptance.

5.4 If a complete gradation in terms of size and mass is required, it will be necessary to perform testing in accordance with Test Method A. Mass and size can be related if the specific gravity of the rock is known and the shapes generated during production do not vary significantly. To obtain a complete gradation in terms of both mass and size, the unknown parameter may be estimated by calculation assuming that the clear square opening size is that of a particle midway between the size of sphere or cube, without significant amounts of slab-type pieces. Fig. 1 can be used to estimate either the size or mass of a rock piece.

5.5 Of the three test methods available, Test Method A is considered to provide the most quantitative description of the sample because both particle sizes and masses are determined. Test Method A employs a methodology similar to standard soil and aggregate particle size analysis tests (see Test Methods D 422 and C 136). Test Method B can be used for periodic product checks of particle sizes to ensure distribution meets specifications. Test Method C can be used if size can be inferred from a consistent source, and abnormal shapes or characteristics of the rock are not of concern.

5.6 Calculation needs for Test Methods B and C depend on the performance requirements specified for a particular project need. Requirements may be expressed in terms of percentage passing or retained for range of mass or size, or both. Test Method B determines the number of particles by size while Test Method C is by mass.

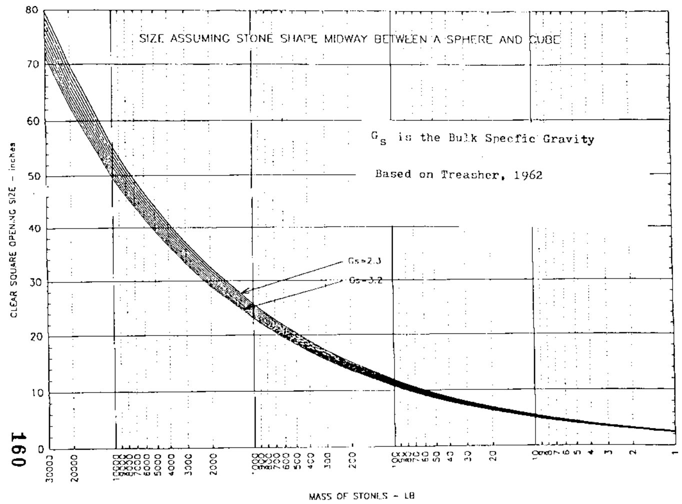


FIG. 1 Size Assuming Stone Shape Midway Between a Sphere and a Cube

5.7 Other characteristics of interest, such as average individual particle mass, presence of bedding planes of weakness, angularity, or amount of slab material may be determined during the performance of this test method.

5.8 The accuracy of this test method is limited by the representativeness of the sample tested. Interpretation of test results must consider the representativeness of the sample.

5.9 For large sizes of riprap, large sample sizes are required. Performance of this test method is labor and equipment intensive and therefore costly. The application of this test method should include considerations of the costs and time involved.

NOTE 1—The agency performing this test method can be evaluated in accordance with Practice D 3740. Not withstanding statements on precision and bias contained in this test method: The precision of this test method is dependent on the competence of the personnel performing it and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing. Users of this test method are cautioned that compliance with Practice D 3740 does not in itself ensure reliable testing. Reliable testing depends on many factors; Practice D 3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Scales*, of adequate capacity to determine the mass of the sorted riprap pieces either individually or in whole. The scale will be accurate to 1 % of the indicated mass. Calibrated or certified commercial truck or quarry scales of adequate capacity are typically used. For individual particle measurements using Test Method B, hoist line load cells have been used successfully.

6.2 *Sieves or Templates*, meeting the requirements of Specification E 11 for sizes up to 5 in. (125 mm). For sizes above 5 in., single-opening templates may be fabricated for the required sizes. Templates may be fabricated from steel bar or other sufficiently rigid materials in the sizes required. For templates openings from 5 in. to 16 in. (125 to 400 mm), the openings will be within ±2 % of the size, for templates greater than 16 in., the openings will be within ±0.25 in. (6.35 mm). Sieves and templates should be checked on a regular basis to verify squareness, straightness, and conformance to opening tolerances. Hand grips or handles should be considered for ease of use. For larger sizes, it has been found useful to fabricate templates in the form of a C-shaped caliper representing the sieve opening and the diagonal of the sieve opening (see Fig. 2).

6.3 *Transport Vehicle*, capable of conveying the individual or groups of the individual sorted riprap pieces from the sampling point to the test area, and from the test area to the weighing station. If truck scales are used, the transport vehicle should be tared prior to and after determination of the masses.

6.4 *Handling Equipment*, such as forklifts, loaders, or like equipment for sampling, transporting, assisting in the sorting, loading for transport, weighing, and other tasks involved in the physical performance of the test.

6.5 *Tape Measures* for determining particle size dimensions to estimate mass or determine slab pieces.

6.6 *Test Area*, sufficiently large to allow the placement of the test sample, areas or bins to place the sorted materials, and adequate to allow trucks, loaders, and other required equipment to operate safely. The test area should have a smooth surface, preferably of concrete, to provide a suitable work surface and prevent loss of the fines.

6.7 *Proportional Calipers*, fabricated in a sufficient size or sizes for use in determining if pieces meet or exceed dimensional ratios to be considered slab pieces (see Fig. 2).

6.8 *Miscellaneous Equipment*, such as spray paints to mark pieces, rock hammers, cameras for photo documentation, sample bags, tags or signs, data-recording forms, heavy work gloves, safety goggles or glasses, respirators or dust masks, and steel-toed boots or caps, as required for the work.

7. Hazards

7.1 Performance of this test method includes the moving, lifting, measurement, and transfer of large pieces of rock. This presents the potential for personnel injury from crushing, dropped or rolling of the riprap pieces. Whenever possible, the sample should be spread to a single layer depth to reduce personnel hazard from rolling or falling pieces.

7.2 Personnel performing this test method will be in the vicinity of working heavy equipment and precautions should be taken to prevent injury from equipment.

7.3 Working with and around the pieces may subject personnel to dust, flying particles, falling pieces, and excessive noise. Personnel should be adequately equipped and trained in the use of personal protective equipment.

8. Sampling

8.1 The precision and representativeness of this test method is directly related to the sampling process. The sampling should be carefully planned and executed to achieve optimum representativeness. All parties should be involved in the planning process. The sampling plan should be documented and included as a part of the final report.

8.2 The mass of the total test specimen should be large enough to ensure a representative gradation and should be such that it provides test results to the desired level of accuracy. One analogy is to consider a test specimen size of such size that the addition or loss of the largest expected piece will not change the results by more than a specified percentage.[4] If the particle mass is not known from experience, the particle mass may be estimated using Fig. 1, with an assumed representative specific gravity, or calculated using an assumed specific gravity and volume of the largest expected piece.

NOTE 2—Example: For a test specimen size to achieve a 1 % accuracy, assume that the largest individual piece mass is expected to be 150 lb (68 kg). For this piece to represent less than 1 %, the sample mass would be 15 000-lb (6 800-kg) minimum. For this piece to represent less than 5 % accuracy, the sample size would be 3000-lb (1360-kg) minimum.

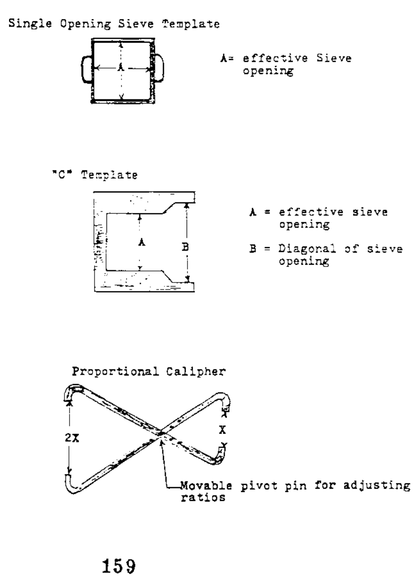
8.3 Take an adequate amount of sample to ensure that the minimum test specimen mass is available, however sampling will not be to a predetermined exact mass. Composite samples will be allowed only when included in the sample plan.

8.4 Sampling from the source material will be in accordance with the sampling plan with the emphasis on obtaining a sample representative of the whole in respect to mass, size, and shape.

8.5 Sample handling should be minimized to avoid unnecessary degradation and breakage. For materials that have been submerged, allow the sample to freely drain. Moisture content of riprap samples is considered inconsequential and the sample will be tested and reported as-found.

8.6 Other characteristics, such as soundness by Test Method D 5240, freeze-thaw resistance by Test Method D 5312 are normally determined prior to testing for size and mass. If these tests have not been performed previously, or if confirmation of the results is desirable, the sampling for these tests will be included in the sampling plan.

8.7 Photographs of the sampling process and related activities should be included in the report.



NOTE 1—The following figure illustrate typical apparatus that have been fabricated for use in this test method.

FIG. 2 Single-Opening Sieve Template

[4] Howard, A. K., and Horz, R. C., "Minimum Test Specimen for Gradation Analysis," *Geotechnical Testing Journal*, Vol 11, No. 3, September 1988, pp. 213–217.

8.8 Select the selection of sieve or template sizes for size or mass range groupings, or both, in accordance with project needs but should not be less than four sieve sizes or mass range groupings.

8.9 It may be desirable to retain the sample after testing to provide a visual comparison of a known gradation for quality-control purposes at a later date.

9. Procedure

9.1 Determine the total mass or volume of the sample delivered to the test site for all methods. Mass can be determined by truck scale prior to delivery to the test site.

9.2 *Test Method A: Size-Mass Grading*:

9.2.1 Move the sample to the test location. For samples that contain large pieces (greater than 12 in. (300 mm) in size), spread the sample in a thin layer.

9.2.2 Place each individual piece on the sieve or template to determine the sizes that the piece will pass and be retained on. Alternately, the template may be placed over the piece to determine the piece sizes. Either place the pieces into separate piles depending on size, or mark the individual pieces using paint or other means. For individual pieces over 36 in. (900 mm) in minimum dimension, determine the size by two or more individuals using a tape measure instead of a sieve or template. When a tape measure is employed, the measurements should determine the square sieve or template dimensions that the piece will pass through and be retained on.

NOTE 3—For samples containing large size pieces, it has been found convenient to mark the pieces for size using a color code, rather than sorting and moving them into separate piles. This eliminates the need to move the piece until the mass determination is made.

NOTE 4—A preliminary sorting by size can often be accomplished visually with only periodic checking with the template. If there is question concerning the size, the sieve or template will be used.

9.2.3 Determine the mass for each sorted piece size, including the fines passing the smallest required sieve (the sieve pan material). This may be accomplished by individual piece weighing at the test location, loading individual or numbers of pieces within a size in a transport vehicle for delivery to a weigh station, or by any other means that will result in the total mass for each sieve size.

9.2.4 If required, perform secondary sorts and counts of the number of pieces, the number of pieces exhibiting angularity (number of fractured faces), and the number of slab-like shapes for each of the sorted sizes.

9.2.5 Take photographs to document shape, color, or any unusual or unique properties of the material under test and include in the report.

9.2.6 Calculate the percentages in accordance with Section 10 for Test Method A.

9.3 *Test Method B: Size-Range Grading*:

9.3.1 Move the sample to the test location. For samples that contain large pieces (greater than 12 in. (300 mm) in size), the sample should be spread in a thin layer.

9.3.2 Place the particle piece on the sieve or template to determine the sieve sizes that the particles will pass and be retained on. Alternately, the template may be placed over the particle to determine the particle sizes. Either sort the pieces into separate piles, or mark the individual pieces using paint or other means. For individual pieces over 36 in. (900 mm) in minimum dimension, determine the size by two or more individuals using a tape measure instead of a sieve or template. When a tape measure is employed, the measurements should determine the square sieves or template dimensions that the piece will pass through and be retained on.

NOTE 5—For samples containing large pieces, it has been found convenient to mark the pieces for size using a color code, rather than sorting and moving them into separate piles.

9.3.3 If required, perform secondary sorts and counts of the number of pieces, the number of pieces exhibiting angularity (number of fractured faces), and the number of slab-like shapes for each of the sorted sizes.

NOTE 6—Slab pieces are those whose minimum to maximum dimensions (thickness to width, or width to length) ratios exceed a specified value, such as 1:4. Slab pieces are often considered detrimental in riprap due to their propensity to break during placement, "raft" with wave action, or to align and slip in use.

9.3.4 Take photographs to document shape, color, and any unusual or unique properties of the material under test and include in the report.

9.3.5 Count the number of particles falling into each size range within the gradation. If the project specifications are by mass, obtain the estimated size distributions by knowing the specific gravity of the rock and assuming a shape midway between a cube and a sphere. Use Fig. 1 to estimate mass from clear square opening equivalent size.

9.3.6 Calculate the percentages in accordance with Section 10 for Test Method B.

9.4 *Test Method C: Mass-Range Grading*:

9.4.1 Move the sample to the test location. For samples that contain large pieces (greater than 12 in. (300 mm) in size), spread the sample in a thin layer.

9.4.2 Determine the mass of each piece by placing the particle on a scale or by use of a hoist-type load cell. Determine the mass of each particle down to the minimum particle mass of importance. Determine the mass of material finer than the smallest mass of importance by comparing the initial sample mass minus the final cumulative mass of the individual particles measured. Count the number of particles and the cumulative mass of particles falling into the mass ranges of concern as testing proceeds and mark the individual pieces as to mass group. For individual pieces larger than hoist load-cell capacity, determine the mass by using large platform or truck scales.

9.4.3 If required, perform secondary sorts and counts of the number of pieces, the number of pieces exhibiting angularity (number of fractured faces), and the number of slab-like shapes.

9.4.4 Take photographs to document shape, color, and any unusual or unique properties of the material under test and include in the report.

9.4.5 Calculate the percentages in accordance with Section 10 for Test Method C.

10. Calculation

10.1 Calculation needs for Test Methods B and C depend on the performance requirements specified for a particular project need. Requirements may be expressed in terms of percentage passing or retained for range of mass or size, or both. Test Method B determines the number of particles by size while Test Method C is by mass.

10.2 *Test Method A—Size-Mass Percentage Grading*:

10.2.1 Determine the mass of each separate sieve size and the cumulative total mass, including the fines, of the test sample.

10.2.2 Calculate the percentage, P_r, retained on each sieve size by the following equation:

$$P_r = I/T \times 100 \quad (1)$$

where:
I = total mass of the material retained on a specific sieve size, and
T = total mass of the sample tested.

10.2.3 Calculate the percentage passing for each sieve size by subtracting the percentage retained from 100 for the largest sieve size, and then subtracting from that each successive sieve size. Plot the results on a graph showing the percentage of mass retained for each sieve size.

10.3 *Test Method B—Size-Range Grading*:

10.3.1 Determine the number of particles retained on each separate sieve and the total number of particles retained in accordance with 9.3.

10.3.2 Calculate the percentage, P_s, retained on each sieve by the following equation:

$$P_s = N/T_n \times 100 \quad (2)$$

where:
N = number of particles within a size range (passing a specific sieve and retained on a specific sieve), and
T_n = total number of particles.

10.3.3 Calculate the percentage passing for each sieve size by subtracting the percentage retained from 100 for the largest sieve size, and then subtracting that from each successive sieve size. Plot results on a graph showing the percentages retained or passing for each size range.

10.4 *Test Method C—Mass-Range Grading*:

10.4.1 Determine the number of particles in each mass range and the total mass, including the fines, of the test specimen in accordance with 9.4.

10.4.2 Calculate the percentage of each mass range, P_m, by the following equation:

$$P_m = M/M_t \times 100 \quad (3)$$

where:
M = number of particles within a mass range, and
M_t = total number of particles.

10.4.3 Calculate the percentages for each size range by subtracting the percentage from 100 for the largest range, and then subtracting that from each successive percentage. Plot the results on a graph showing the percentages for each mass range.

11. Report

11.1 Prepare a report including the following for each test performed:

11.1.1 Date test was performed,

11.1.2 Sample identification, source, and source location, including when appropriate, the elevation and coordinates of the sample source,

11.1.3 Test location at which the test was performed,

11.1.4 Location, capacity, accuracy, and last calibration of the scales used to determine the mass,

11.1.5 A copy of the sampling plan used to obtain the test sample, including the calculations of the required sample size, and assumed specific gravities,

11.1.6 Narrative of the actual method for performing the test,

11.1.7 Results of the test, including the specification acceptance limits (if provided), particle counts with accompanying masses or sizes determined, or both. Report cumulative masses or numbers of particles retained on or passing the size or mass ranges of concern. Report any other information obtained, such as the average piece mass on each sieve and the number of pieces retained on each sieve (Test Method A), mass of material not measured (Test Method C). Indicate any values that were determined by calculation,

11.1.8 A graph of the results. When project specifications have been provided, the specification ranges should also be plotted on the graph. Fig. 3 provides an example of a typical graph used for reporting results,

11.1.9 Report the largest particle mass or size encountered, the initial mass of the sample, and the resulting estimated accuracy of the sample representativeness (see 8.2).

11.1.10 Other test information obtained during the test, such as the number of slab pieces per sieve size, angularity, and the like,

11.1.11 Names of the individuals performing the test,

11.1.12 Any other test samples taken and the purpose, such as freeze-thaw, durability, hardness, and the like,

11.1.13 Specifications provided, including the sieve sizes, acceptance percentages, or other acceptance criteria,

11.1.14 Photographs or other illustrative information that may be relevant in evaluating the materials under test, and

11.1.15 Calibration data and frequency on the test sieves, templates, or calipers.

12. Precision and Bias

12.1 The precision of this test method has not been determined. Limited data are being evaluated to determine the precision of this test method. Subcommittee D18.17 is seeking pertinent data from users of this test method.

12.2 The procedure defined in this test method has no bias because the values of riprap particle size can be defined only in terms of a test method.

12.3 Variation in the results of this test method is a consequence of the variation in the materials sampled and tested and variation in the application of the test method.

13. Keywords

13.1 armor stone; filter bedding stone; filter material; gradation; riprap; slab

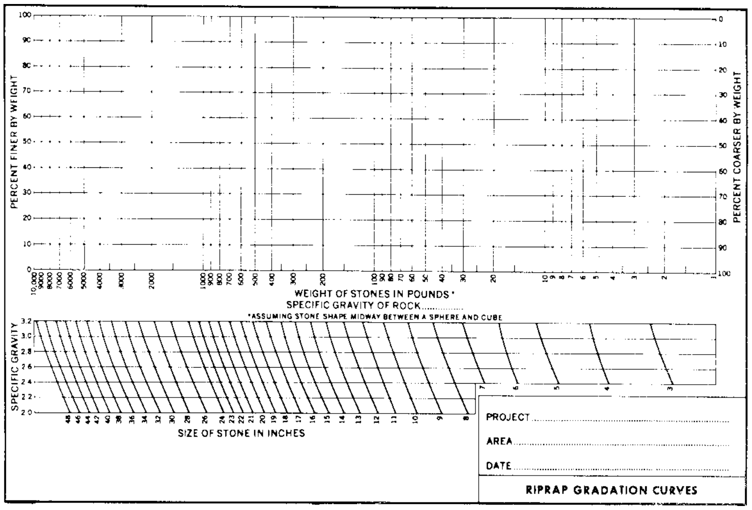


FIG. 3 Typical Grading Graph