

NOTICE

“AgTT Plus Certification” is comprised with the following listed FOP’s...

T-19 TTQP / UDOT

T-85 TTQP / UDOT

T-2 WAQTC

R-76 WAQTC

T-11 / T-27 WAQTC

T-335 WAQTC

T-176 WAQTC

BULK DENSITY (“UNIT WEIGHT”) AND VOIDS IN AGGREGATE FOP FOR AASHTO T 19

02

Scope

This FOP describes methods for determining bulk density and void content of aggregates not exceeding five inches in nominal maximum size. Aggregates are tested in a compacted state unless loose bulk density is required by the specifying agency. The procedure yields values based on aggregates in a dry condition.

A representative aggregate sample is placed in a calibrated measure and the mass determined. The bulk density is calculated by dividing the aggregate mass by the volume of the measure. Bulk density for this FOP is expressed as pounds per cubic foot (lb/ft³). Void content is expressed as a percentage and will require knowledge of the $G_{sb}(OD)$ (oven-dry bulk specific gravity) of the aggregate.

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Significance

Results of this test method are frequently used when materials are proportioned on a volume basis or where a minimum density is specified by the governing agency. The test is also useful in determining mass/volume relationships for purchase agreements.

Apparatus

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- **Balance:** Of sufficient capacity and readable to 0.1% of sample mass or better. Must meet the requirements of AASHTO M 231.
- **Tamping Rod:** A round steel rod of $\frac{5}{8}$ inch diameter, approximately 24 inches in length, with one end rounded to a hemispherical tip of the same diameter as the rod.

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- **Measure:** A cylindrical metal measure with the top and bottom parallel to each other. The height should be 80 to 150 percent of the diameter. The volume of the measure shall conform to the requirements of Table 1. The top rim shall be plane and smooth within 0.01 inch and the interior wall of the measure shall be smooth and seamless. The metal thickness of the measure shall conform to the requirements of Table 2.

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- **Shovel or Scoop:** Of convenient size and shape for filling the measure.
- **Calibration Equipment:** A piece of plate glass at least 1/4 inch thick, and at least 1 inch larger than the diameter of the measure.
- **Thermometer (for Calibration):** Range of 50 – 90° F, readable to 1° F.

Table 1 – Capacities of Measures

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Nominal Maximum Aggregate Size	Capacity of Measure *
1/2"	1/10 ft ³
1"	1/3 ft ³
1 1/2"	1/2 ft ³
3"	1 ft ³
4"	2.5 ft ³
5"	3.5 ft ³

* The actual volume of the measure shall be at least 95% of the nominal volume indicated in this table.

Table 2 – Requirements for Measures

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Capacity of Measure	Thickness of Metal		
	Bottom	Upper 1 1/2" of Wall *	Remainder of Wall
Less than 0.4 ft ³	0.20 in.	0.10 inch	0.10 inch
0.4 through 1.5 ft ³	0.20 in.	0.20 inch	0.12 inch
Over 1.5 through 2.8 ft ³	0.4 in.	0.25 inch	0.15 inch
Over 2.8 through 4.0 ft ³	0.5 in.	0.3 inch	0.20 inch

* The additional upper wall thickness may be achieved by attaching a reinforcing band at the top of the measure.



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Calibration of Measure

Measures shall be calibrated annually, or whenever there is a question of accuracy, according to the following steps:

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1. Determine mass to the nearest 0.1 lb (50 g). (This does not preclude making mass determinations of greater accuracy).
2. Determine the mass of the clean dry measure and glass plate.
3. Fill the measure with water at room temperature and cover with the glass plate in such a way as to eliminate air bubbles.
4. Leaving the glass plate in place, remove water from the exposed surfaces of the glass plate and measure and determine the mass of the measure, water and glass plate.
5. Subtract the mass of the empty measure and glass plate.
6. Remove the glass plate and determine the temperature of the water in the measure (nearest 1°F). Find the density of water corresponding to the measured temperature in Table 3, interpolating if needed.
7. Divide the mass of water in the measure by the density determined in the previous step. Express the volume of the measure to the nearest 0.001 ft³.

Table – 3 Density of Water

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Temperature (° F)	Density (lb/ft ³)
60	62.366
65	62.336
70	62.301
(73.4)	(62.274)
75	62.261
80	62.216
85	62.166

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Sampling

- Obtain the sample according to AASHTO T 2. Reduce to appropriate testing size according to AASHTO T 248.

Note 1: For this FOP, Nominal Maximum Size is one specification sieve size larger than the first sieve to cumulatively retain more than 10 percent.



Sample Preparation

- 16 • The test sample shall represent a volume approximately 125 to 200 percent of that required to fill the measure.
- The sample shall be handled in such a way as to prevent segregation.
- Dry the sample to constant mass in an oven regulated at 230 ±9°F according to the FOP for AASHTO T 255. Cool to room temperature prior to conducting the test.

Selection of Procedure

17 The shoveling procedure for loose bulk density shall only be permitted when the governing agency requires it. Otherwise, compaction of the aggregate in the measure shall be by rodding or jiggling depending on nominal maximum aggregate size.

Rodding: Compact the aggregate in the measure by rodding when the nominal maximum aggregate size is less than or equal to 1½ inch.

Jiggling: Compact the aggregate in the measure by jiggling for nominal maximum aggregate sizes larger than 1½ inch.

Procedure, General

- 19 • Record all masses to the nearest 0.1 lb (50 g). (This does not preclude mass determinations of greater accuracy).
- Determine the mass of the clean, empty measure.
- Select the appropriate procedure from the following.

Rodding Procedure

- 20 1. Fill the measure approximately 1/3 full and level the layer with the fingers. Compact the layer with 25 strokes of the tamping rod taking care to not forcibly strike the bottom of the measure.
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2. Fill the measure approximately 2/3 full and level that layer with the fingers. Compact the layer with 25 strokes of the tamping rod, penetrating to the underlying layer if possible.

Note 2: When rodding large or angular aggregate pieces it may not be possible to completely penetrate the layer being compacted. Vigorous effort used in rodding the material is considered sufficient to achieve the proper degree of compaction.



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3. Fill the measure to overflowing and rod again as in step 2 above. After rodding, level the surface with the fingers or with a straightedge such that slight projections above the top of the measure compensate for the depressions in the surface below the top of the measure.
4. Determine the mass of the measure and aggregate. Subtract the mass of the empty measure. Record mass in pounds.

Jigging Procedure



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1. Fill the measure in three approximately equal layers, compacting each layer by alternately lifting opposite sides of the measure approximately 2 inches and allowing it to fall in a manner that results in a sharp slapping blow. Each layer shall be compacted by applying 50 blows (25 per side).
2. When full, the measure shall be leveled with the fingers or a straightedge such that slight projections above the top of the measure compensate for the depressions in the surface below the top of the measure.
3. Determine the mass of the measure and aggregate. Subtract the mass of the empty measure. Record mass in pounds.

Shoveling Procedure

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1. Using a shovel or scoop, carefully fill the measure to overflowing. Do not allow aggregate particles to fall from a height more than 2 inches above the top of the measure. Do not allow vibration or any movement of the measure that will compact the aggregate beyond the loose state. Prevent segregation of the aggregate as the measure is filled.

- 31 2. When full, the measure shall be leveled with the fingers or a straightedge such that slight projections above the top of the measure compensate for the depressions in the surface below the top of the measure.
3. Determine the mass of the measure and aggregate. Subtract the mass of the empty measure. Record mass in pounds.

Calculations

32 Calculate values for bulk density and voids to the nearest 0.1, but round to the whole number for reporting.

33 **Bulk Density:** Calculate the bulk density for the rodding, jigging, or shoveling method according to the following formula:

$$M = \frac{(G - T)}{V}$$

where:

M = bulk density of aggregate (lb/ft³)

G = mass of aggregate plus measure (lb)

T = mass of measure (lb)

V = volume of measure (ft³)

34 **Void Content:** Calculate the percentage of voids according to the following formula:

$$\text{Voids, \%} = \frac{100((S \times W) - M)}{S \times W}$$

where:

M = bulk density of aggregate (lb/ft³)

S = dry bulk specific gravity, G_{sb}(OD), as determined by AASHTO T 84 or AASHTO T 85

W = density of water (62.3 lb/ft³)

Sample Worksheet for Test Method AASHTO T 19

Date: _____ Project: _____

Material: 1½ inch Nominal Maximum Size Coarse Aggregate

Source: _____ Tested By: _____

I – Calibration of Measure

Line	Description	Data Source or Formula	No. 1	No. 2	Average
A	Measure + Plate + Water (lb)	Balance	48.10	48.09	
B	Dry Measure + Plate (lb)	Balance	16.87	16.87	
C	Water (lb)	A – B	31.23	31.22	
D	Water Temperature (° F)	Thermometer	75	73	
E	Water Density (lb/ft ³)	Table No. 3	62.261	62.277	
F	Volume of Measure (ft ³)	C/E	0.5016	0.5013	0.501

II – Aggregate Bulk Density and Void Content

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Procedure Used: **RODDING** Jigging Shoveling

Line	Description	Data Source or Formula	No. 1	No. 2	Average
G	Measure + Aggregate (lb)	Balance	74.07	74.68	
H	Empty Measure (lb)	Balance	14.83	14.83	
J	Aggregate (lb)	G – H	59.24	59.85	
K	Volume of Measure (ft ³)	Avg. from “F”	0.501	0.501	
L	Aggregate Bulk Density (lb/ft ³)	J/K	118.2	119.5	118.8 *
M	Oven-Dry Bulk Specific Gravity, G _{sb} (OD)	T 84 or T 85			2.628
N	Density of Water	Constant			62.3 lb/ft ³
O	Voids, %	See Below			27.4 *

* Note: These values are calculated to the nearest 0.1 but must be rounded to the whole number for reporting purposes. 36

Voids in Aggregate

Formula:

$$\text{Voids, \%} = \frac{100((M \times N) - L)}{M \times N}$$

Example:

$$\frac{100((2.628 \times 62.3) - 118.8)}{2.628 \times 62.3} = 27.4, \text{ say } 27\%$$

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Report

- Report on standard agency forms
- Project description and location
- Material source and description, including nominal maximum size
- Method used: rodding, jiggling, or shoveling
- Bulk density by rodding, jiggling, or loose bulk density to the nearest 1 lb/ft³
- Void content of aggregate compacted by rodding, jiggling, or loose bulk density to the nearest 1 percent
- Procedure used (Rodding, Jiggling, or Shoveling)

Tips

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- Make sure the aggregate is dry
- Calibrate the volume of the measure at least annually or whenever there is a question of accuracy
- Use rodding or jiggling method based on nominal maximum aggregate size, unless the governing agency specifically calls for the shoveling method.
- Obtain $G_{sb}(OD)$ (oven-dry bulk specific gravity) according to AASHTO T 84 or AASHTO T 85 for void content calculation.
- Calculate values for bulk density and voids to the nearest 0.1 but round to the whole number for reporting.

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REVIEW QUESTIONS

1. According to this FOP, aggregate up to _____ in Nominal Maximum Size may be tested.
2. Summarize requirements for volume of the measure.
3. The _____ method should be used to fill the measure when nominal maximum size of aggregate is 1 inch.
4. What approximate volume of aggregate is used for conducting this test?
5. To what degree of accuracy is the volume of the measure determined?
6. When is the shoveling method allowed?
7. Given the following, the bulk density of the aggregate as reported is _____.

Mass of Measure and Aggregate: 36.24 lb.

Mass of Measure: 8.47 lb.

Volume of Measure: 0.248 ft³

Dry Bulk Specific Gravity (G_{sb}): 2.649

Density of Water: 62.3 lb/ft³

8. Given the data from question 7, the void content as reported is _____.

PERFORMANCE EXAM CHECKLIST

BULK DENSITY (“UNIT WEIGHT”) AND VOIDS IN AGGREGATE FOP FOR AASHTO T 19

Participant Name: _____ Exam Date: _____

Procedure

Calibration of Measure

- 1. All masses determined to 0.1% of sample mass or better? _____
- 2. Clean dry mass of measure and glass plate determined? _____
- 3. Measure filled with water at room temperature and glass plate placed to eliminate air bubbles? _____
- 4. Exterior of measure and glass plate dried and mass determined? _____
- 5. Mass of water determined? _____
- 6. Temperature of water measured and density of water determined? _____
- 7. Volume of measure correctly determined to 0.001 ft³? _____

Sample Preparation

- 1. Sample obtained by AASHTO T 2 and reduced by AASHTO T 248? _____
- 2. Aggregate dried to constant mass at 230 ±9° F? _____
- 3. Aggregate quantity 125 to 200 percent of that needed to fill measure? _____
- 4. Sample handled so as to avoid segregation? _____

Procedure

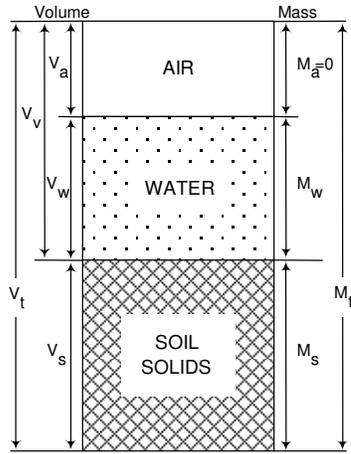
- 1. All masses determined to 0.1 lb or 50 g or better? _____
- 2. Mass of clean, empty measure determined? _____
- 3. Correct method of filling measure selected based on agency requirements and nominal maximum aggregate size? (1½ inch or less by rodding; greater than 1½ inch by jiggling; shoveling only when required by agency) _____
- 4. Rodding performed in 3 layers, leveling first two layers with fingers; 25 rods per layer but not forcibly striking bottom of measure on first layer; penetrating depth of layer if possible; third layer filled to overflowing? _____
- 5. Jiggling performed in 3 layers; 50 drops per layer (25 per opposite side); last layer filled to overflowing? _____

- 6. Shoveling performed by carefully filling in loose state; not dropping aggregate more than 2 inches; avoiding vibration or movement of measure? _____
- 7. For all procedures, final layer leveled with fingers or straightedge such that projections above top of measure compensate for depressions? _____
- 8. Mass of aggregate and measure determined properly? _____
- 9. Mass of aggregate determined by subtracting empty measure from total? _____
- 10. Bulk density correctly calculated? _____
- 11. Dry bulk specific gravity of aggregate obtained? _____
- 12. Void content correctly determined? _____

Comments: First attempt: (Pass/Fail) ____ Second attempt: (Pass/Fail) ____

Signature of Examiner _____.

**SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE
FOP FOR AASHTO T 85**



Phase diagram

01
02
03

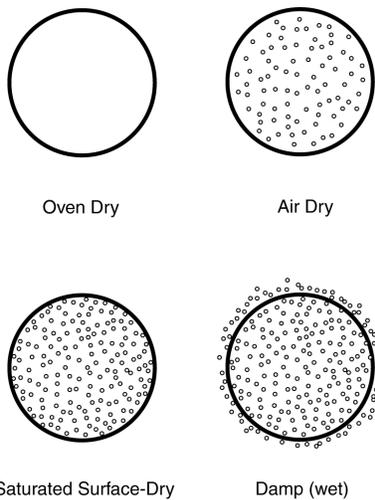
Significance

Bulk specific gravity is a characteristic used for calculating the volume occupied by the aggregate or various mixtures containing aggregate, including Portland Cement Concrete, bituminous mixes, and other materials that are proportioned or analyzed on an absolute volume basis. Specific gravity is the ratio of the mass of a material to the mass of an equal volume of water. Several categories of specific gravity are used relative to aggregate.

Bulk specific gravity (oven dry), G_{sb} , is used for computations when the aggregate is dry. Bulk specific gravity (saturated surface dry or SSD), $G_{sb SSD}$, is used if the aggregate is wet. Apparent specific gravity, G_{sa} , is based solely on the solid material making up the constituent particles and does not include the pore space within the particles that is accessible to water.

Absorption values are used to calculate the change in the mass of an aggregate due to water absorbed in the pore spaces within the constituent particles, compared to the dry condition, when it is deemed that the aggregate has been in contact with water long enough to satisfy most of the absorption potential. The laboratory standard for absorption is that obtained after submerging dry aggregate for between 15 to 19 hours in water. Aggregates mined from below the water table may have a higher absorption, when used, if not allowed to dry. Conversely, some aggregates, when used, may contain an amount of absorbed moisture less than the 15 hours soaked condition. For an aggregate that has been in contact with water and that has free moisture on the particle surfaces, the percentage of free moisture can be determined by deducting the absorption from the total moisture content.

The pores in lightweight aggregates may or may not become filled with water after immersion for 15 hours. In fact, many such aggregates can remain immersed in water for several days without satisfying most of the aggregates' absorption



Moisture conditions

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05
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potential. Therefore, this method is not intended for use with lightweight aggregate.

Scope

This procedure covers the determination of specific gravity and absorption of coarse aggregate in accordance with AASHTO T 85-14. Specific gravity may be expressed as bulk specific gravity (G_{sb}), bulk specific gravity - saturated surface dry (G_{sb} SSD), or apparent specific gravity (G_{sa}). G_{sb} and absorption are based on aggregate after soaking in water. This procedure is not intended for use with lightweight aggregates.

Terminology

Absorption – the increase in the mass of aggregate due to water being absorbed into the pores of the material, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry mass. The aggregate is considered “dry” when it has been maintained at a temperature of $110 \pm 5^\circ\text{C}$ ($230 \pm 9^\circ\text{F}$) for sufficient time to remove all uncombined water.

Saturated Surface Dry (SSD) – the condition of an aggregate particle when the permeable voids are filled with water, but no water is present on exposed surfaces.

Specific Gravity – the ratio of the mass, in air, of a volume of a material to the mass of the same volume of gas-free distilled water at a stated temperature.

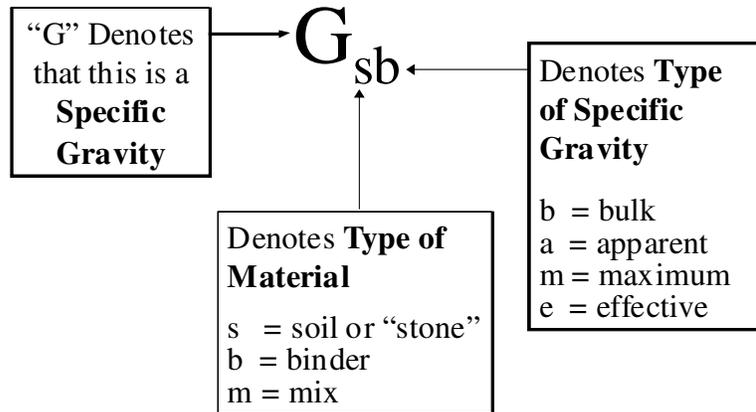
Apparent Specific Gravity (G_{sa}) – the ratio of the mass, in air, of a volume of the impermeable portion of aggregate to the mass of an equal volume of gas-free distilled water at a stated temperature.

Bulk Specific Gravity (G_{sb}) – the ratio of the mass, in air, of a volume of aggregate (including the permeable and impermeable voids in the particles, but not including the voids between particles) to the mass of an equal volume of gas-free distilled water at a stated temperature.

Bulk Specific Gravity (SSD) (G_{sb} SSD) – the ratio of the mass, in air, of a volume of aggregate,

including the mass of water within the voids filled to the extent achieved by submerging in water for 15 to 19 hours (but not including the voids between particles), to the mass of an equal volume of gas-free distilled water at a stated temperature.

Definition: (Specific Gravity Symbols)



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Sample Container

Apparatus

- Balance or scale: with a capacity of 5 kg, sensitive to 1 g, and meeting the requirements of AASHTO M 231.
- Sample container: a wire basket of 3.35 mm (No. 6) or smaller mesh, with a capacity of 4 to 7 L (1 to 2 gal) to contain aggregate with a nominal maximum size of 37.5 mm (1 1/2 in.) or smaller; or a larger basket for larger aggregates, or both.
- Water tank: watertight and large enough to completely immerse aggregate and basket, equipped with an overflow valve to keep water level constant.
- Suspension apparatus: wire used to suspend apparatus shall be of the smallest practical diameter.
- Sieves: 4.75 mm (No. 4) or other sizes as needed, conforming to AASHTO M 92.
- Large absorbent towel

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Sample Preparation

1. Obtain the sample in accordance with the FOP for AASHTO T 2 (see Note 1).
2. Mix the sample thoroughly and reduce to the approximate sample size required by Table 1 in accordance with the FOP for AASHTO T 248.
3. Reject all material passing the appropriate sieve by dry sieving.
4. Thoroughly wash sample to remove dust or other coatings from the surface and re-screen the washed dry sample over the appropriate sieve. Reject all material passing that sieve.
5. The sample shall meet or exceed the minimum mass given in Table 1.

Note 1: If this procedure is used only to determine the G_{sb} of oversized material for the FOP for AASHTO T 99 or T 180 and in the calculations for the FOP for AASHTO T 224, the material can be rejected over the appropriate sieve. For T 99 / T 180 Methods A and B, use the 4.75 mm (No.4) sieve; for T 99 / T 180 Methods C and D, use the 19 mm (3/4 in).

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Table 1

Nominal Maximum Size*, mm (in.)	Minimum Mass of Test Sample, g (lb)
12.5 (1/2) or less	2000 (4.4)
19.0 (3/4)	3000 (6.6)
25.0 (1)	4000 (8.8)
37.5 (1 1/2)	5000 (11)
50 (2)	8000 (18)
63 (2 1/2)	12,000 (26)
75 (3)	18,000 (40)

* One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained. Where large gaps in specification sieves exist, intermediate sieve(s) may be inserted to determine nominal maximum size.

Procedure

1. Dry the test sample to constant mass at a temperature of $110 \pm 5^{\circ}\text{C}$ ($230 \pm 9^{\circ}\text{F}$) and cool in air at room temperature for 1 to 3 hours.

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Note 2: Where the absorption and specific gravity values are to be used in proportioning concrete mixtures in which the aggregates will be in their naturally moist condition, the requirement for initial drying to constant mass may be eliminated and, if the surfaces of the particles in the sample have been kept continuously wet until test, the 15-hour soaking may also be eliminated.

2. Immerse the aggregate in water at room temperature for a period of 15 to 19 hours.

Note 3: When testing coarse aggregate of large nominal maximum size requiring large test samples, it may be more convenient to perform the test on two or more subsamples, and then combine values obtained.

3. Place the empty basket into the water bath and attach to the balance. Inspect the immersion tank to ensure the water level is at the overflow outlet height. Tare the balance with the empty basket attached in the water bath.

4. Remove the test sample from the water and roll it in a large absorbent cloth until all visible films of water are removed. Wipe the larger particles individually. If the test sample dries past the SSD condition, immerse in water for 30 min, and then resume the process of surface-drying.

Note 4: A moving stream of air may be used to assist in the drying operation, but take care to avoid evaporation of water from aggregate pores.

5. Determine the SSD mass of the sample, and record this and all subsequent masses to the nearest 0.1 g or 0.1 percent of the sample mass, whichever is greater. Designate this mass as "B".

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6. Immediately place the SSD test sample in the sample container and weigh it in water maintained at $23.0 \pm 1.7^{\circ}\text{C}$ ($73.4 \pm 3^{\circ}\text{F}$). Shake the container to release entrapped air before recording the weight. Re-inspect the immersion tank to ensure the water level is at the overflow outlet height. Designate this submerged weight as "C".



SSD Sample



Submerged container

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Note 5: The container should be immersed to a depth sufficient to cover both it and the test sample during mass determination. The wire suspending the container should be of the smallest practical size to minimize any possible effects of a variable immersed length.

7. Remove the sample from the basket. Ensure that all material has been removed and place in a container of known mass.
8. Dry the test sample to constant mass in accordance with the FOP for AASHTO T 255/T 265 (Aggregate section) and cool in air at room temperature for 1 to 3 hours. Designate this mass as "A".

Calculations

Perform calculations and determine values using the appropriate formula below. In these formulas, A = oven dry mass, B = SSD mass, and C = weight in water.

Bulk specific gravity (G_{sb}) 17

$$G_{sb} = \frac{A}{B - C}$$

Bulk specific gravity, SSD ($G_{sb} SSD$) 18

$$G_{sb}SSD = \frac{B}{B - C}$$

Apparent specific gravity (G_{sa}) 19

$$G_{sa} = \frac{A}{A - C}$$

Absorption 20

$$\text{Absorption} = \frac{B - A}{A} \times 100$$

Sample Calculations

Sample	A	B	C	B - C	A - C	B - A
1	2030.9	2044.9	1304.3	740.6	726.6	14.0
2	1820.0	1832.5	1168.1	664.4	651.9	12.5
3	2035.2	2049.4	1303.9	745.5	731.3	14.2

Sample	G_{sb}	$G_{sb} SSD$	G_{sa}	Absorption
1	2.742	2.761	2.795	0.7
2	2.739	2.758	2.792	0.7
3	2.730	2.749	2.783	0.7

These calculations demonstrate the relationship between G_{sb} , G_{sb} SSD, and G_{sa} . G_{sb} is always lowest, since the volume includes voids permeable to water. G_{sb} SSD is always intermediate. G_{sa} is always highest, since the volume does not include voids permeable to water. When running this test, check to make sure the values calculated make sense in relation to one another.

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Report

- Results on forms approved by the agency
- Specific gravities to 3 decimal places
- Absorption to 0.1 percent

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Tips!

- Shake the container and sample when weighing in water to release entrapped air.
- Compare G_{sb} , G_{sb} SSD, and G_{sa} to see if they make sense.

REVIEW QUESTIONS

1. What size sample is required for aggregate with a nominal maximum size of 25 mm (1 in.)?
2. When is soaking required? For how long must material be soaked?
3. When, in the process, are dry and SSD masses determined?

PERFORMANCE EXAM CHECKLIST

**SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE
FOP FOR AASHTO T 85**

Participant Name _____ Exam Date _____

Record the symbols “P” for passing or “F” for failing on each step of the checklist.

Procedure Element	Trial 1	Trial 2
1. Sample obtained by FOP for AASHTO T 2 and reduced by FOP for AASHTO T 248 or from FOP for AASHTO T 99 / T 180?	_____	_____
2. Screened on the appropriate size sieve?	_____	_____
3. Sample mass appropriate?	_____	_____
4. Particle surfaces clean?	_____	_____
5. Dried to constant mass 110 ±5°C (230 ±9°F) and cooled to room temperature?	_____	_____
6. Covered with water for 15 to 19 hours?	_____	_____
7. Basket placed into immersion tank and attached to balance?	_____	_____
8. Immersion tank inspected for proper water height?	_____	_____
9. Balance tared with basket in tank and temperature checked 23.0 ±1.7°C (73.4 ±3°F)?	_____	_____
10. Sample removed from water and rolled in cloth to remove visible films of water?	_____	_____
11. Larger particles wiped individually?	_____	_____
12. Evaporation avoided?	_____	_____
13. Sample mass determined to 0.1 g?	_____	_____
14. Sample immediately placed in basket, in immersion tank?	_____	_____
15. Entrapped air removed before weighing by shaking basket while immersed?	_____	_____
16. Immersion tank inspected for proper water height?	_____	_____
17. Immersed sample weight determined to 0.1 g?	_____	_____
18. All the sample removed from basket?	_____	_____
19. Sample dried to constant mass and cooled to room temperature?	_____	_____

OVER

Procedure Element

Trial 1 Trial 2

20. Sample mass determined to 0.1 g? _____

21. Proper formulas used in calculations? _____

Comments: First attempt: Pass____Fail____ Second attempt: Pass____Fail____

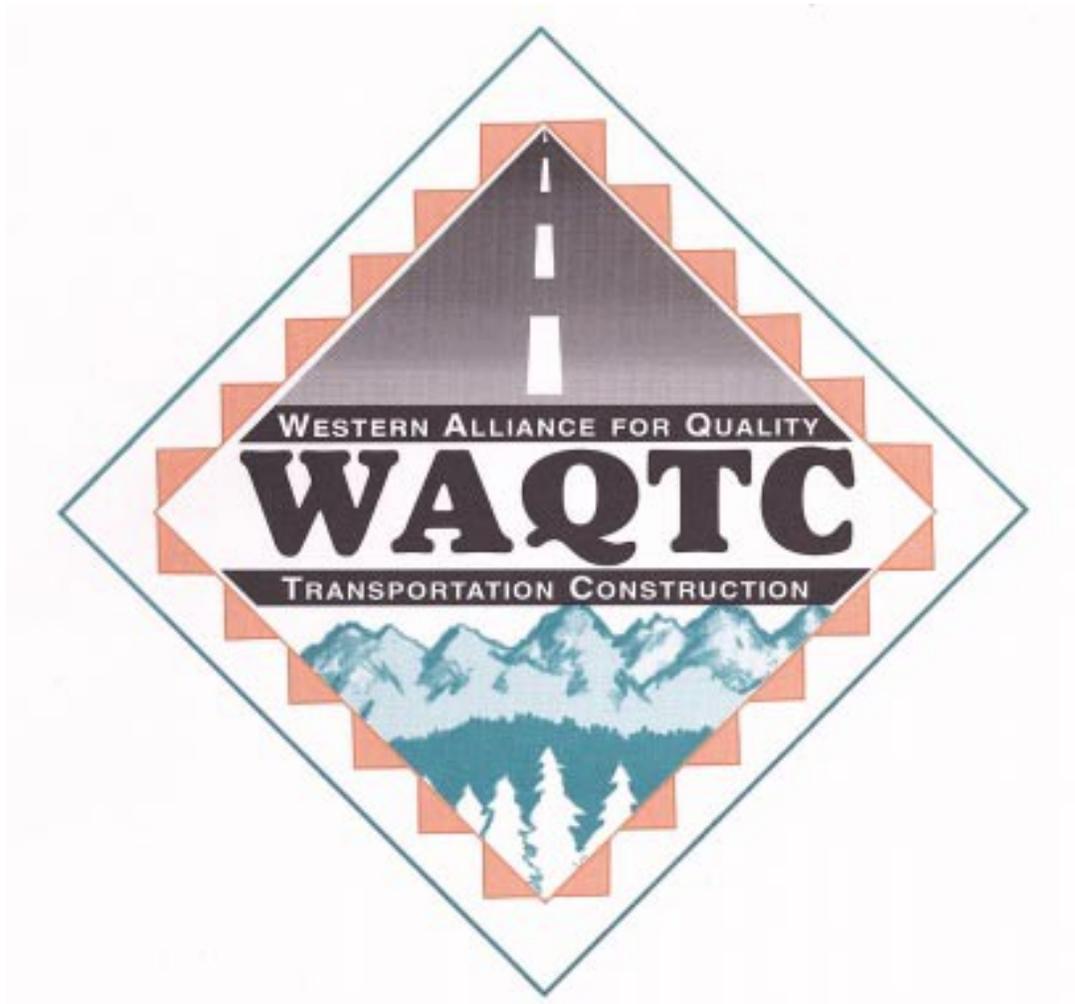
Examiner Signature _____ WAQTC #: _____

**Transportation Technician
Qualification Program**

AGGREGATE

Participant

Workbook



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PREFACE

This module is one of a set developed for the Western Alliance for Quality Transportation Construction (WAQTC). WAQTC is an alliance supported by the western state Transportation Departments, along with the Federal Highway Administration (FHWA) and the Western Federal Lands Highway Division (WFLHD) of FHWA. WAQTC's charter includes the following mission.

MISSION

Provide continuously improving quality in transportation construction.

Through our partnership, we will:

- Promote an atmosphere of trust, cooperation, and communication between government agencies and with the private sector.
- Assure personnel are qualified.
- Respond to the requirements of identified needs and new technologies that impact the products that we provide.

BACKGROUND

There are two significant driving forces behind the development of the WAQTC qualification program. One, there is a trend to the use of quality control/quality assurance (QC/QA) specifications. QC/QA specifications include qualification requirements for a contractor's QC personnel and will be requiring WAQTC qualified technicians. Two, Federal regulation on materials sampling and testing (23 CFR 637, *Quality Assurance Procedures for Construction*, published in June 1995) mandates that by June 29, 2000 all testing technicians whose results are used as part of the acceptance decision shall be qualified. In addition, the regulation allows the use of contractor test results to be used as part of the acceptance decision.

OBJECTIVES

WAQTC's objectives for its Transportation Technician Qualification Program include the following:

- To provide highly skilled, knowledgeable materials sampling and testing technicians.
- To promote uniformity and consistency in testing.
- To provide reciprocity for qualified testing technicians between states.
- To create a harmonious working atmosphere between public and private employees based upon trust, open communication, and equality of qualifications.

Training and qualification of transportation technicians is required for several reasons. It will increase the knowledge of laboratory, production, and field technicians – both industry and agency personnel – and increase the number of available, qualified testers. It will reduce problems associated with test result differences. Regional qualification eliminates the issue of reciprocity between states and allows qualified QC technicians to cross state lines without having the concern or need to be requalified by a different program.

The WAQTC Executive Board

FOREWORD

This module is one of six developed to satisfy the training requirements prescribed by Western Alliance for Quality Transportation Construction (WAQTC) for technicians involved in transportation projects. The six modules cover:

- Aggregate
- Concrete
- Asphalt I
- Asphalt II
- Embankment and Base
- In-place Density

The modules are based upon AASHTO test methods along with procedures developed by WAQTC. They are narrative in style, illustrated, and include step-by-step instruction. There are review questions at the end of each test procedure, which are intended to reinforce the participants' understanding and help participants prepare for the final written and performance exams. Performance exam check lists are also included. The appendixes include the corresponding AASHTO and WAQTC test methods.

It is the technician's responsibility to stay current as changes are made to this living document.

The comments and suggestions of every participant are essential to the continued success and high standards of the Transportation Technician Qualification Program. Please take the time to fill out the Course Evaluation Form as the course progresses and hand it in on the last day of class. If you need additional room to fully convey your thoughts, please use the back of the form.

The WAQTC Executive Board

GUIDANCE FOR COURSE EVALUATION FORM

The Course Evaluation Form on the following page is very important to the continuing improvement and success of this course. The form is included in each Participant Workbook. During the course introduction, the Instructor will call the participants' attention to the form, its content, and the importance of its thoughtful completion at the end of the course. Participants will be encouraged to keep notes, or write down comments as the class progresses, in order to provide the best possible evaluation. The Instructor will direct participants to write down comments at the end of each day and to make use of the back of the form if more room is needed for comments.

On the last day of the course, just before the written examination, the Instructor will again refer to the form and instruct participants that completion of the form after their last examination is a requirement before leaving. Should the course have more than one Instructor, participants should be directed to list them as A, B, etc., with the Instructor's name beside the letter, and direct their answers in the Instructor Evaluation portion of the form accordingly.

WESTERN ALLIANCE FOR QUALITY TRANSPORTATION CONSTRUCTION COURSE EVALUATION FORM

The WAQTC Transportation Technician Qualification Program would appreciate your thoughtful completion of all items on this evaluation form. Your comments and constructive suggestions will be an asset in our continuing efforts to improve our course content and presentations.

Course Title: _____

Location: _____

Dates: _____

Your Name (Optional): _____

Employer: _____

Instructor(s) _____

COURSE CONTENT

Will the course help you perform your job better and with more understanding? Yes Maybe No

Explain: _____

Was there an adequate balance between theory, instruction, and hands-on application? Yes Maybe No

Explain: _____

Did the course prepare you to confidently complete both examinations? Yes Maybe No

Explain: _____

What was the most beneficial aspect of the course? _____

What was the least beneficial aspect of the course? _____

GENERAL COMMENTS

General comments on the course, content, materials, presentation method, facility, registration process, etc. Include suggestions for additional Tips!

INSTRUCTOR EVALUATION

Were the objectives of the course, and the instructional and exam approach, clearly explained?	Yes	Maybe	No
--	-----	-------	----

Explain: _____

Was the information presented in a clear, understandable manner?	Yes	Maybe	No
--	-----	-------	----

Explain: _____

Did the instructors demonstrate a good knowledge of the subject?	Yes	Maybe	No
--	-----	-------	----

Explain: _____

Did the instructors create an atmosphere in which to ask questions and hold open discussion?	Yes	Maybe	No
--	-----	-------	----

Explain: _____

COURSE OBJECTIVES AND SCHEDULE

Learning Objectives

Instructional objectives for this course include:

- Being familiar with Quality Assurance (QA) concepts
- Developing a background in measurements and calculations
- Being knowledgeable in highway materials terminology
- Respecting safety issues
- Acquiring knowledge of random sampling techniques
- Understanding the basics of aggregate
- Becoming proficient in the following quality control test procedures:

FOP for AASHTO T 2

Sampling of Aggregates

FOP for AASHTO R 76

Reducing Field Samples of Aggregate to Testing Size

FOP for AASHTO T 255

Total Evaporable Moisture Content of Aggregate by Drying

FOP for AASHTO T 27

Sieve Analysis of Fine and Coarse Aggregates, and

AASHTO T 11

Materials Finer than 75 μm (No. 200) in Mineral Aggregates
by Washing

FOP for AASHTO T 335

Determining the Percentage of Fracture in Coarse Aggregate

FOP for AASHTO T 176

Plastic Fines in Graded Aggregate by Use of the Sand
Equivalent Test

The overall goals of this aggregate course are to understand the basics of aggregate and to be competent with specific quality control test procedures identified for the Transportation Technician Qualification Program of the Western Alliance for Quality Transportation Construction (WAQTC). Additional studies beyond this course will be required for those desiring greater in-depth knowledge of the theory behind the test procedures included herein.

Course Outline and Suggested Schedule**Day One**

0800	Welcome Introduction of Instructors Introduction and Expectations of Participants
0815	WAQTC Mission and TTQP Objectives Instructional Objectives for the Course Overview of the Course Course Evaluation Form
0830	Review of Quality Assurance Concepts
0845	Background in Measurements and Calculations
0945	Break
1000	Random Sampling
1030	Basics of Aggregate
1045	Sampling of Aggregates FOP for AASHTO T 2
1115	Reducing Field Samples of Aggregate to Testing Size FOP for AASHTO R 76
1145	Review Questions Questions and Answers
1200	Lunch
1315	Laboratory Practice Reducing Field Samples
1645	Evaluation End of Day

Day Two

0800	Questions from the Previous Day
0815	Total Evaporable Moisture Content of Aggregate by Drying FOP for AASHTO T 255

0845	Sieve Analysis of Fine and Coarse Aggregates FOP for AASHTO T 27 Materials Finer than 75 μm (No. 200) in Mineral Aggregate by Washing FOP for AASHTO T 11
0945	Break
1000	Continuation of Sieve Analysis and Washing
1030	Laboratory Practice Moisture Content Sieve Analysis and Washing
1130	Review Questions Questions and Answers
1200	Lunch
1315	Laboratory Practice Moisture Content (continued) Sieve Analysis and Washing (continued)
1645	Evaluation End of Day

Day Three

0800	Questions from Previous Day
0815	Determining the Percentage of Fracture in Coarse Aggregate FOP for AASHTO T 335
0845	Plastic Fines in Graded Aggregates and Soils by the Use of the Sand Equivalent Test FOP for AASHTO T 176
0915	Review Questions Questions and Answers
0945	Break
1000	Laboratory Practice Completion of Any Moisture Content Determinations Fracture

1200 Lunch

1315 Laboratory Practice
Sand Equivalent

1645 Evaluation
End of day

Day Four

0800 Start of Exams

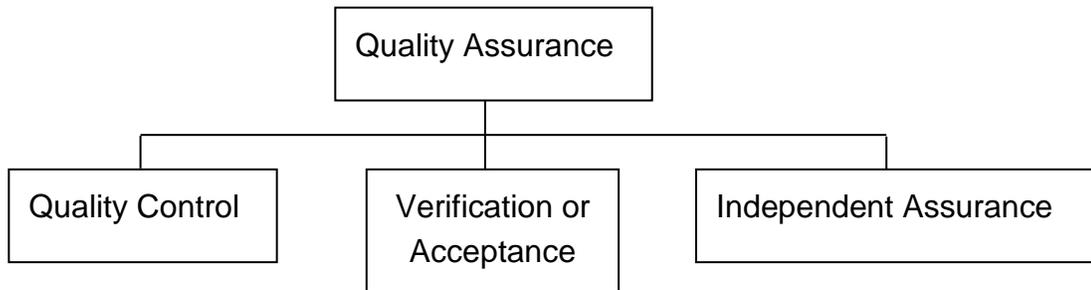
Participants will break into groups so that written and practical exams may be given concurrently.

Evaluation

QUALITY ASSURANCE CONCEPTS

The Federal Highway Administration (FHWA) has established requirements that each State Transportation Department (STD) must develop a Quality Assurance (QA) Program that is approved by the FHWA for projects on the National Highway System (NHS). In addition to complying with this requirement, implementing QA specifications in a construction program includes the benefit of improvement of overall quality of highway and bridge construction.

A QA Program may include three separate and distinct parts as illustrated below.



Quality Assurance (QA) are those planned and systematic actions necessary to provide confidence that a product or service will satisfy given requirements for quality.

Quality Control (QC) are those operational, process control techniques or activities that are performed or conducted to fulfill contract requirements for material and equipment quality. In some states, the constructor is responsible for providing QC sampling and testing, while in other states the STD handles QC. Where the constructor is responsible for QC tests, the results may be used for acceptance only if verified or accepted by additional tests performed by an independent group.

Verification/Acceptance consists of the sampling and testing performed to validate QC sampling and testing and, thus, the quality of the product. Verification/Acceptance samples are obtained and tests are performed independently from those involved with QC. Samples taken for QC tests may not be used for Verification/Acceptance testing.

Independent Assurance (IA) are those activities that are an unbiased and independent evaluation of all the sampling and testing procedures used in QC and Verification/Acceptance. IA may use a combination of laboratory certification, technician qualification or certification, proficiency samples, or split samples to assure that QC and Verification/Acceptance activities are valid. Agencies may qualify or certify laboratories and technicians, depending on the state in which the work is done.

BACKGROUND ON MEASUREMENTS AND CALCULATIONS

01

Introduction

This section provides a background in the mathematical rules and procedures used in making measurements and performing calculations. Topics include:

- Units: Metric vs. English
- Mass vs. Weight
- Balances and Scales
- Rounding
- Significant Figures
- Accuracy and Precision
- Tolerance

Also included is discussion of real-world applications in which the mathematical rules and procedures may not be followed.

02

Units: Metric vs. English

The bulk of this document uses dual units. Metric units are followed by Imperial, more commonly known as English, units in parentheses. For example: 25 mm (1 in.). Exams are presented in metric or English.

03

Depending on the situation, some conversions are exact, and some are approximate. One inch is exactly 25.4 mm. If a procedure calls for measuring to the closest 1/4 in., however, 5 mm is close enough. We do not have to say 6.35 mm. That is because 1/4 in. is half way between 1/8 in. and 3/8 in. – or half way between 3.2 and 9.5 mm. Additionally, the tape measure or rule used may have 5 mm marks, but may not have 1 mm marks and certainly will not be graduated in 6 mm increments.

04

In SI (Le Systeme International d’Unites), the basic unit of mass is the kilogram (kg) and the basic unit of force, which includes weight, is the Newton (N). Mass in this document is given in grams (g) or kg.

Basic units in SI include:

Length: meter, m
 Mass: kilogram, kg
 Time: second, s

Derived units in SI include:

Force: Newton, N

SI units

Metric

English

25 mm	1 in.
1 kg	2.2 lb
1000 kg/m ³	62.4 lb/ft ³
25 MPa	3600 lb/in. ²

Some approximate conversions

See the section below on “Mass vs. Weight” for further discussion of this topic.

Mass vs. Weight

05

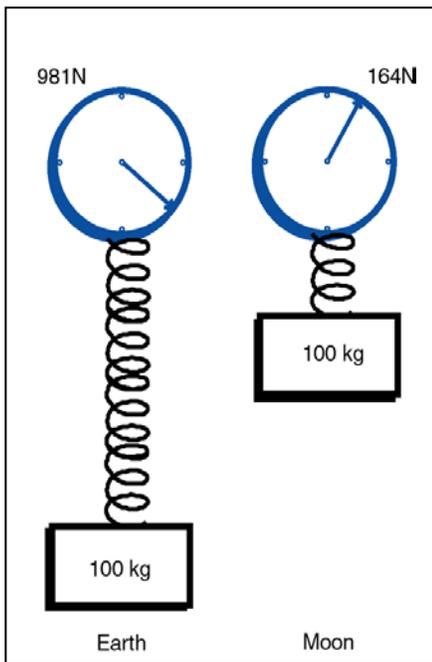
The terms mass, force, and weight are often confused. Mass, *m*, is a measure of an object’s material makeup, and has no direction. Force, *F*, is a measure of a push or pull, and has the direction of the push or pull. Force is equal to mass times acceleration, *a*.

06

$$F = ma$$

Weight, *W*, is a special kind of force, caused by gravitational acceleration. It is the force required to suspend or lift a mass against gravity. Weight is equal to mass times the acceleration due to gravity, *g*, and is directed toward the center of the earth.

$$W = mg$$



Comparison of mass and weight

07

In SI, the basic unit of mass is the kilogram (kg), the units of acceleration are meters per square second (m/s^2), and the unit of force is the Newton (N). Thus a person having a mass of 84 kg subject to the standard acceleration due to gravity, on earth, of $9.81 m/s^2$ would have a weight of:

08

$$W = (84.0 \text{ kg})(9.81 \text{ m/s}^2) = 824 \text{ kg}\cdot\text{m/s}^2 = 824 \text{ N}$$

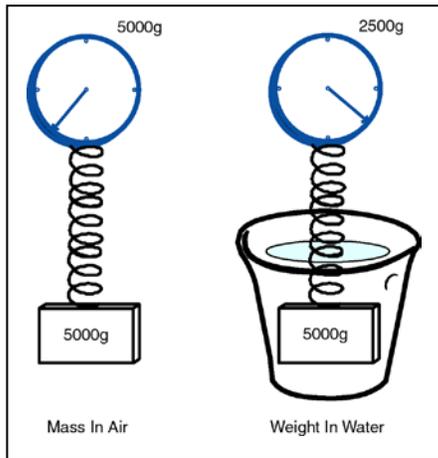
In the English system, mass can be measured in pounds-mass (lb_m), while acceleration is in feet per square second (ft/s^2), and force is in pounds-force (lb_f). A person weighing $185 lb_f$ on a scale has a mass of $185 lb_m$ when subjected to the earth’s standard gravitational pull. If this person were to go to the moon, where the acceleration due to gravity is about one-sixth of what it is on earth, the person’s weight would be about $31 lb_f$, while his or her mass would remain $185 lb_m$. Mass does not depend on location, but weight does.

While the acceleration due to gravity does vary with position on the earth (latitude and elevation), the variation is not significant except for extremely

precise work – the manufacture of electronic memory chips, for example.

As discussed above, there are two kinds of pounds, lb_m and lb_f . In laboratory measurements of mass, the gram or kilogram is the unit of choice. But, is this mass or force? Technically, it depends on the instrument used, but practically speaking, mass is the result of the measurement. When using a scale, force is being measured – either electronically by the stretching of strain gauges or mechanically by the stretching of a spring or other device. When using a balance, mass is being measured, because the mass of the object is being compared to a known mass built into the balance.

09



Submerged weight

10

11

12

In this document, mass, not weight, is used in test procedures except when determining “weight” in water. When an object is submerged in water (as is done in specific gravity tests), the term weight is used. Technically, what is being measured is the force the object exerts on the balance or scale while the object is submerged in water (or the submerged weight). This force is actually the weight of the object less the weight of the volume of water displaced.

In summary, whenever the common terms “weight” and “weighing” are used, the more appropriate terms “mass” and “determining mass” are usually implied, except in the case of weighing an object submerged in water.

Balances and Scales

Balances, technically used for mass determinations, and scales, used to weigh items, were discussed briefly above in the section on “Mass vs. Weight.” In field operating procedures, we usually do not differentiate between the two types of instruments. When using either one for a material or object in air, we are determining mass. For those procedures in which the material or object is suspended in water, we are determining weight in water.

13

AASHTO recognizes two general categories of instruments. Standard analytical balances are used

14

in laboratories. For most field operations, general purpose balances and scales are specified. Specifications for both categories are shown in Tables 1 and 2.

Table 1
Standard Analytical Balances

Class	Capacity	Readability and Sensitivity	Accuracy
A	200 g	0.0001 g	0.0002 g
B	200 g	0.001 g	0.002 g
C	1200 g	0.01 g	0.02 g

Table 2
General Purpose Balances and Scales

Class	Principal Sample Mass	Readability and Sensitivity	Accuracy
G2	2 kg or less	0.1 g	0.1 g or 0.1 percent
G5	2 kg to 5 kg	1 g	1 g or 0.1 percent
G20	5 kg to 20 kg	5 g	5 g or 0.1 percent
G100	Over 20 kg	20 g	20 g or 0.1 percent

15

Rounding

Numbers are commonly rounded up or down after measurement or calculation. For example, 53.67 would be rounded to 53.7 and 53.43 would be rounded to 53.4, if rounding were required. The first number was rounded up because 53.67 is closer to 53.7 than to 53.6. Likewise, the second number was rounded down because 53.43 is closer to 53.4 than to 53.5. The reasons for rounding are covered in the next section on “Significant Figures.”

If the number being rounded ends with a 5, two possibilities exist. In the more mathematically sound approach, numbers are rounded up or down depending on whether the number to the left of the 5 is odd or even. Thus, 102.25 would be rounded down to 102.2, while 102.35 would be rounded up to 102.4. This procedure avoids the bias that would exist if all numbers ending in 5 were rounded up or all numbers were rounded down. In some calculators, however, all rounding is up. This does result in some bias, or skewing of data, but the significance of the bias may or may not be significant to the calculations at hand.

Significant Figures

- General

16

A general purpose balance or scale, classified as G20 in AASHTO M 231, has a capacity of 20,000 g and an accuracy requirement of ±5 g. A mass of 18,285 g determined with such an instrument could actually range from 18,280 g to 18,290 g. Only four places in the measurement are significant. The fifth (last) place is not significant since it may change.

17

Mathematical rules exist for handling significant figures in different situations.

An example in Metric (**m**) or English(**ft**), when performing addition and subtraction, the number of significant figures in the sum or difference is determined by the least precise input. Consider the three situations shown below:

<u>Situation 1</u>	<u>Situation 2</u>	<u>Situation 3</u>
35.67	143.903	162
+ 423.938	- 23.6	+33.546
		- .022
= 459.61	= 120.3	= 196
not 459.608	not 120.303	not 195.524

Rules also exist for multiplication and division. These rules, and the rules for mixed operations involving addition, subtraction, multiplication, and/or division, are beyond the scope of these

materials. AASHTO covers this topic to a certain extent in the section called “Precision” or “Precision and Bias” included in many test methods, and the reader is directed to those sections if more detail is desired.

18

- Real World Limitations

While the mathematical rules of significant digits have been established, they are not always followed. For example, AASHTO Method of Test T 176, *Plastic Fines in Graded Aggregates and Soils by the Use of the Sand Equivalent Test*, prescribes a method for rounding and significant digits in conflict with the mathematical rules.

In this procedure, readings and calculated values are always rounded up. A clay reading of 7.94 would be rounded to 8.0 and a sand reading of 3.21 would be rounded to 3.3. The rounded numbers are then used to calculate the Sand Equivalent, which is the ratio of the two numbers multiplied by 100. In this case:

$$\frac{3.3}{8.0} \times 100 = 41.250 \dots$$

rounded to 41.3 and reported as 42

Not: $\frac{3.21}{7.94} \times 100 = 40.428 \dots$

rounded to 40.0 and reported as 40)

It is extremely important that engineers and technicians understand the rules of rounding and significant digits just as well as they know procedures called for in standard test methods.

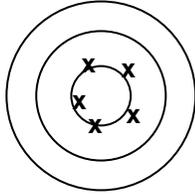
Accuracy and Precision

19

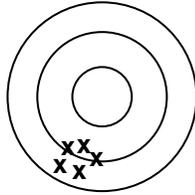
Although often used interchangeably, the terms accuracy and precision do not mean the same thing.

20

In an engineering sense, accuracy denotes nearness to the truth or some value accepted as the truth,



ACCURATE BUT NOT PRECISE,
SCATTERED



PRECISE BUT NOT ACCURATE,
BIASED

while precision relates to the degree of refinement or repeatability of a measurement.

Two bulls-eye targets are shown to the left. The upper one indicates hits that are scattered and, yet, are very close to the center. The lower one has a tight pattern, but all the shots are biased from the center. The upper one is more accurate, while the lower one is more precise. A biased, but precise, instrument can often be adjusted physically or mathematically to provide reliable single measurements. A scattered, but accurate, instrument can be used if enough measurements are made to provide a valid average.

Consider the measurement of the temperature of boiling water at standard atmospheric pressure by two thermometers. Five readings were taken with each, and the values were averaged.

Thermometer No. 1	Thermometer No. 2
101.2° 214.2°	100.6° 213.1°
101.1° 214.0°	99.2° 210.6°
101.2° 214.2°	98.9° 210.0°
101.1° 214.0°	101.0° 213.8°
101.2° 214.2°	100.3° 212.5°
AVG = 101.2° 214.2°	AVG = 100.0° 212°

No. 1 shows very little fluctuation, but is off the known boiling point (100°C or 212°F) by 1.2°C or 2.2°F. No. 2 has an average value equal to the known boiling point, but shows quite a bit of fluctuation. While it might be preferable to use neither thermometer, thermometer No. 1 could be employed if 1.2°C or 2.2°F were subtracted from each measurement. Thermometer No. 2 could be used if enough measurements were made to provide a valid average.

Engineering and scientific instruments should be calibrated and compared against reference standards periodically to assure that measurements are accurate. If such checks are not performed, the accuracy is uncertain, no matter what the precision. Calibration of an instrument removes fixed error, leaving only random error for concern.

Tolerance

26 Dimensions of constructed or manufactured objects,
including laboratory test equipment, cannot be
specified exactly. Some tolerance must be allowed.
Thus, procedures for including tolerance in
27 addition/subtraction and multiplication/division
operations must be understood.

- Addition and Subtraction

When adding or subtracting two numbers that individually have a tolerance, the tolerance of the sum or difference is equal to the sum of the individual tolerances.

An example in Metric (**m**) or English (**ft**), if the distance between two points is made up of two parts, one being 113.361 ± 0.006 and the other being 87.242 ± 0.005 then the tolerance of the sum (or the difference) is:

$$(0.006) + (0.005) = 0.011$$

and the sum would be 200.603 ± 0.011 .

- Multiplication and Division

28 To demonstrate the determination of tolerance again in either Metric (**m**) or English (**ft**) for the product of two numbers, consider determining the area of a rectangle having sides of 76.254 ± 0.009 and 34.972 ± 0.007 . The percentage variations of the two dimensions are:

$$\frac{0.009}{76.254} \times 100 = 0.01\% \quad \frac{0.007}{34.972} \times 100 = 0.02\%$$

The sum of the percentage variations is 0.03 percent – the variation that is employed in the area of the rectangle:

Area =
 $2666.8 \text{ (m}^2 \text{ or ft}^2) \pm 0.03 \text{ percent} = 2666.8 \pm 0.8$
 $\text{(m}^2 \text{ or ft}^2\text{)}.$

- Real World Applications

Tolerances are used whenever a product is manufactured. For example, the mold used for determining soil density in AASHTO T 99 has a diameter of 101.60 ± 0.41 mm (4.000 ± 0.016 in) and a height of 116.43 ± 0.13 mm (4.584 ± 0.005 in).

Using the smaller of each dimension results in a volume of:

$$(\pi/4) (101.19 \text{ mm})^2 (116.30 \text{ mm}) = 935,287 \text{ mm}^3 \text{ or } 0.000935 \text{ m}^3$$

$$(\pi/4) (3.984 \text{ in})^2 (4.579 \text{ in}) = 57.082 \text{ in}^3 \text{ or } 0.0330 \text{ ft}^3$$

Using the larger of each dimension results in a volume of:

$$(\pi/4) (102.01 \text{ mm})^2 (116.56 \text{ mm}) = 952,631 \text{ mm}^3 \text{ or } 0.000953 \text{ m}^3$$

$$(\pi/4) (4.016 \text{ in})^2 (4.589 \text{ in}) = 58.130 \text{ in}^3 \text{ or } 0.0336 \text{ ft}^3$$

The average value is 0.000944 m^3 (0.0333), and AASHTO T 99 specifies a volume of:

$$0.000943 \pm 0.000008 \text{ m}^3$$

or a range of

$$0.000935 \text{ to } 0.000951 \text{ m}^3$$

$$0.0333 \pm 0.0003 \text{ ft}^3$$

or a range of

$$0.0330 \text{ to } 0.0336 \text{ ft}^3$$

Because of the variation that can occur, some agencies periodically standardize molds, and make adjustments to calculated density based on those calculations.

Summary

30

Mathematics has certain rules and procedures for making measurements and performing calculations that are well established. So are standardized test procedures. Sometimes these agree, but occasionally, they do not. Engineers and technicians must be familiar with both, but must follow test procedures in order to obtain valid, comparable results.

TERMINOLOGY

Many of the terms listed below are defined differently by various agencies or organizations. The definitions of the American Association of State Highway and Transportation Officials (AASHTO) are the ones most commonly used in this document.

Absorbed water – Water drawn into a solid by absorption, and having physical properties similar to ordinary water.

Absorption – The increase in the mass of aggregate due to water being absorbed into the pores of the material, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry mass.

Acceptance – See verification.

Acceptance program – All factors that comprise the State Transportation Department's (STD) determination of the quality of the product as specified in the contract requirements. These factors include verification sampling, testing, and inspection and may include results of quality control sampling and testing.

Admixture – Material other than water, cement, and aggregates in Portland cement concrete (PCC).

Adsorbed water – Water attached to the surface of a solid by electrochemical forces, and having physical properties substantially different from ordinary water.

Aggregate – Hard granular material of mineral composition, including sand, gravel, slag or crushed stone, used in roadway base and in Portland cement concrete (PCC) and asphalt mixtures.

- **Coarse aggregate** – Aggregate retained on or above the No. 4 (4.75 mm) sieve.
- **Coarse-graded aggregate** – Aggregate having a predominance of coarse sizes.
- **Dense-graded aggregate** – Aggregate having a particle size distribution such that voids occupy a relatively small percentage of the total volume.
- **Fine aggregate** – Aggregate passing the No. 4 (4.75 mm) sieve.
- **Fine-graded aggregate** – Aggregate having a predominance of fine sizes.
- **Mineral filler** – A fine mineral product at least 70 percent of which passes a No. 200 (75 μ m) sieve.
- **Open-graded gap-graded aggregate** – Aggregate having a particle size distribution such that voids occupy a relatively large percentage of the total volume.
- **Well-Graded Aggregate** – Aggregate having an even distribution of particle sizes.

Aggregate storage bins – Bins that store aggregate for feeding material to the dryer in a hot mix asphalt (HMA) plant in substantially the same proportion as required in the finished mix.

Agitation – Provision of gentle motion in Portland cement concrete (PCC) sufficient to prevent segregation and loss of plasticity.

Air voids (V_a) – Total volume of the small air pockets between coated aggregate particles in asphalt mixtures; expressed as a percentage of the bulk volume of the compacted paving mixture.

Ambient temperature – Temperature of the surrounding air

Angular aggregate – Aggregate possessing well-defined edges at the intersection of roughly planar faces

Apparent specific gravity (G_{sa}) – The ratio of the mass, in air, of a volume of the impermeable portion of aggregate to the mass of an equal volume of water at a stated temperature.

Asphalt – A dark brown to black cementitious material in which the predominate constituents are bitumens occurring in nature or obtained through petroleum processing. Asphalt is a constituent of most crude petroleum.

Asphalt emulsion – A mixture of asphalt binder and water.

Asphalt binder – An asphalt specially prepared in quality and consistency for use in the manufacture of asphalt mixtures.

Asphalt mixtures – A controlled mix of aggregate and asphalt binder.

Automatic cycling control – A control system in which the opening and closing of the weigh hopper discharge gate, the bituminous discharge valve, and the pugmill discharge gate are actuated by means of automatic mechanical or electronic devices without manual control. The system includes preset timing of dry and wet mixing cycles.

Automatic dryer control – A control system that automatically maintains the temperature of aggregates discharged from the dryer.

Automatic proportioning control – A control system in which proportions of the aggregate and asphalt binder fractions are controlled by means of gates or valves that are opened and closed by means of automatic mechanical or electronic devices without manual control.

Bag (of cement) – 94 lb of Portland cement (Approximately 1 ft³ of bulk cement)

Base – A layer of selected material constructed on top of subgrade or subbase and below the paving on a roadway.

Bias – The offset or skewing of data or information away from its true or accurate position as the result of systematic error.

Binder – Asphalt binder or modified asphalt binder that binds the aggregate particles into a dense mass.

Boulders – Rock fragment, often rounded, with an average dimension larger than 300 mm (12 in.).

Bulk specific gravity – The ratio of the mass, in air, of a volume of aggregate (G_{sa}) or compacted HMA mix (G_{mb}) (including the permeable and impermeable voids in the particles, but not including the voids between particles) to the mass of an equal volume of water at a stated temperature.

Bulk specific gravity (SSD) – The ratio of the mass, in air, of a volume of aggregate ($G_{sa SSD}$) or compacted asphalt mixtures ($G_{mb SSD}$), including the mass of water within the voids (but not including the voids between particles), to the mass of an equal volume of water at a stated temperature. (See saturated surface dry.)

Cementitious Materials – cement and pozzolans used in concrete such as: Portland cement, fly ash, silica fume, and blast-furnace slag.

Clay – Fine-grained soil that exhibits plasticity over a range of water contents, and that exhibits considerable strength when dry, also, that portion of the soil finer than 2 μm .

Cobble – Rock fragment, often rounded, with an average dimension between 75 and 300 mm (3 and 12 in.).

Cohesionless soil – Soil with little or no strength when dry and unconfined or when submerged, such as sand

Cohesive soil – Soil with considerable strength when dry and that has significant cohesion when unconfined or submerged.

Compaction – Densification of a soil or asphalt mixtures by mechanical means.

Compaction curve (Proctor curve or moisture-density curve) – The curve showing the relationship between the dry unit weight or density and the water content of a soil for a given compactive effort.

Compaction test (moisture-density test) – Laboratory compaction procedure in which a soil of known water content is placed in a specified manner into a mold of given dimensions, subjected to a compactive effort of controlled magnitude, and the resulting density determined.

Compressibility – Property of a soil or rock relating to susceptibility to decrease in volume when subject to load.

Constant mass – The state at which a mass does not change more than a given percent, after additional drying for a defined time interval, at a required temperature.

Constructor – The builder of a project. The individual or entity responsible for performing and completing the construction of a project required by the contract documents. Often called a contractor, since this individual or entity contracts with the owner.

Cutback asphalt – Asphalt binder that has been modified by blending with a chemical solvent.

Crusher-run – The total unscreened product of a stone crusher.

Delivery tolerances – Permissible variations from the desired proportions of aggregate and asphalt binder delivered to the pugmill.

Density – The ratio of mass to volume of a substance. Usually expressed in lb/ft³ (kg/m³).

Design professional – The designer of a project. This individual or entity may provide services relating to the planning, design, and construction of a project, possibly including materials testing and construction inspection. Sometimes called a “contractor,” since this individual or entity contracts with the owner.

Dryer – An apparatus that dries aggregate and heats it to specified temperatures.

Dry mix time – The time interval between introduction of aggregate into the pugmill and the addition of asphalt binder.

Durability – The property of concrete that describes its ability to resist disintegration by weathering and traffic. Included under weathering are changes in the pavement and aggregate due to the action of water, including freezing and thawing.

Dust Proportion – DP (Dust to Effective (asphalt) Binder Ratio) – The percent passing the No. 200 sieve divided by the percent of effective asphalt binder.

Effective specific gravity (G_{se}) – The ratio of the mass in air of a unit volume of a permeable material (excluding voids permeable to asphalt binder) at a stated temperature to the mass in air (of equal density) of an equal volume of gas-free distilled water at a stated temperature.

Effective diameter (effective size) – D_{10} , particle diameter corresponding to 10 percent finer or passing.

Embankment – Controlled, compacted material between the subgrade and subbase or base in a roadway.

End-result specifications – Specifications that require the Constructor to take the entire responsibility for supplying a product or an item of construction. The Owner’s (the highway agency’s) responsibility is to either accept or reject the final product or to apply a price

adjustment that is commensurate with the degree of compliance with the specifications. Sometimes called performance specifications, although considered differently in highway work. (See performance specifications.)

Family of curves – a group of soil moisture-density relationships (curves) determined using AASHTO T 99 or T 180, which reveal certain similarities and trends characteristic of the soil type and source.

Field operating procedure (FOP) – Procedure used in field testing on a construction site or in a field laboratory. (Based on AASHTO or NAQTC test methods.)

Fineness modulus – A factor equal to the sum of the cumulative percentages of aggregate retained on certain sieves divided by 100; the sieves are 150, 75, 37.5, 19.0, 9.5, 4.75, 2.36, 1.18, 0.60, 0.30, and 0.15 mm. Used in the design of concrete mixes. The lower the fineness modulus, the more water/cement paste that is needed to coat the aggregate.

Fines – Portion of a soil or aggregate finer than a 75 μm (No. 200) sieve. Also silts and clays.

Fractured Face – An angular, rough, or broken surface of an aggregate particle created by crushing or by other means. A face is considered a “fractured face” whenever one-half or more of the projected area, when viewed normal to that face, is fractured with sharp and well defined edges. This excludes small nicks.

Fractured particle – A particle of aggregate having at least the minimum number of fractured faces specified.

Free water – Water on aggregate available for reaction with hydraulic cement. Mathematically, the difference between total moisture content and absorbed moisture content.

Glacial till – Material deposited by glaciation, usually composed of a wide range of particle sizes, which has not been subjected to the sorting action of water.

Gradation (grain-size distribution) – The proportions by mass of a soil or fragmented rock distributed by particle size.

Gradation analysis (grain size analysis or sieve analysis) – The process of determining grain-size distribution by separation of sieves with different size openings.

Hot aggregate storage bins – Bins that store heated and separated aggregate before final proportioning into the mixer.

Hot mix asphalt (HMA) – High quality, thoroughly controlled hot mixture of asphalt binder and well-graded, high quality aggregate.

Hot Mix Asphalt (HMA) batch plant – A manufacturing facility for producing hot mix asphalt (HMA) that proportions aggregate by weight and asphalt by weight or volume.

HMA continuous mix plant – A manufacturing facility for producing HMA that proportions aggregate and asphalt binder by a continuous volumetric proportioning system without specific batch intervals.

Hydraulic cement – Cement that sets and hardens by chemical reaction with water.

Independent assurance – Unbiased and independent evaluation of all the sampling and testing procedures, equipment, and technicians involved with Quality Control (QC) and Verification/Acceptance.

In situ – Rock or soil in its natural formation or deposit.

Liquid limit – Moisture content corresponding to the boundary between the liquid and plastic states.

Loam – A mixture of sand, silt or clay, or a combination thereof, with organic matter.

Lot – A quantity of material to be controlled. It may represent a specified mass, a specified number of truckloads, or a specified time period during production.

Manual proportioning control – A control system in which proportions of the aggregate and asphalt binder fractions are controlled by means of gates or valves that are opened and closed by manual means. The system may or may not include power assisted devices in the actuation of gate and valve opening and closing.

Materials and methods specifications – Also called prescriptive specifications. Specifications that direct the Constructor to use specified materials in definite proportions and specific types of equipment and methods to place the material.

Maximum size – One sieve larger than nominal maximum size.

Mesh – The square opening of a sieve.

Moisture content – The ratio, expressed as a percentage, of the mass of water in a material to the dry mass of the material.

Nominal maximum size – One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained. Where large gaps in specification sieves exist, intermediate sieve(s) may be inserted to determine nominal maximum size.

Note: The first sieve to normally retain more than 10 percent of the material usually is the second sieve in the stack but may be the third sieve.

Nuclear gauge – Instruments used to measure in-place density, moisture content, or asphalt binder content through the measurement of nuclear emissions.

Optimum moisture content (optimum water content) – The water content at which a soil can be compacted to a maximum dry density by a given compactive effort.

Organic soil – Soil with a high organic content.

Owner – The organization that conceives of and eventually operates and maintains a project. A State Transportation Departments (STD) is an Owner.

Paste – Mix of water and hydraulic cement that binds aggregate in Portland cement concrete (PCC).

Penetration – The consistency of a bituminous material, expressed as the distance in tenths of a millimeter (0.1 mm) that a standard needle vertically penetrates a sample of the material under specified conditions of loading, time, and temperature.

Percent of Absorbed (asphalt) Binder (P_{ba}) – The total percent of the asphalt binder that is absorbed into the aggregate, expressed as a percentage of the mass of aggregate rather than as a percentage of the total mass of the mixture. This portion of the asphalt binder content does not contribute to the performance of the mix.

Percent aggregate (stone) (P_s) – The percent aggregate (stone) content, expressed as a percentage of the total mass of the sample.

Percent of Effective (asphalt) Binder (P_{be}) – The total asphalt binder content of a paving mixture minus the portion of asphalt binder that is lost by absorption into the aggregate particles, expressed as a percentage of the mass of aggregate. It is the portion of the asphalt binder content that remains as a coating on the outside of the aggregate particles.

Percent compaction – The ratio of density of a soil, aggregate, or asphalt mixtures in the field to a maximum density determined by a standard compaction test, expressed as a percentage.

Performance specifications – Specifications that describe how the finished product should perform. For highways, performance is typically described in terms of changes over time in physical condition of the surface and its response to load, or in terms of the cumulative traffic required to bring the pavement to a condition defined as “failure.” Specifications containing warranty/guarantee clauses are a form of performance specifications.

Plant screens – Screens located between the dryer and hot aggregate storage bins that separate the heated aggregates by size.

Plastic limit – Moisture content corresponding to the boundary between the plastic and the semisolid states.

Plasticity – Property of a material to continue to deform indefinitely while sustaining a constant stress.

Plasticity index – Numerical difference between the liquid limit and the plastic limit and, thus, the range of water content over which the soil is plastic.

Portland cement – Hydraulic cement produced by pulverizing Portland cement clinker.

Portland cement concrete (PCC) – A controlled mix of aggregate, Portland cement, and water, and possibly other admixtures.

PCC batch plant – A manufacturing facility for producing Portland cement concrete.

Prescriptive specifications – See Materials and Methods specification.

Proficiency samples – Homogeneous samples that are distributed and tested by two or more laboratories. The test results are compared to assure that the laboratories are obtaining the same results.

Pugmill – A shaft mixer designed to mix aggregate and cement.

Quality assurance – Planned and systematic actions necessary to provide confidence that a product or service will satisfy given requirements for quality. The overall system for providing quality in a constructed project, including Quality Control (QC), Verification/Acceptance, and Independent Assurance (IA).

Quality assurance specifications – Also called QC/QA specifications. A combination of end-result (performance) specifications and materials and methods (prescriptive) specifications. The Constructor is responsible for quality control, and the Owner (highway agency) is responsible for acceptance of the product.

Quality control (QC) – Operational, process control techniques or activities that are performed or conducted to fulfill contract requirements for material or equipment quality.

Random sampling – Procedure for obtaining non-biased, representative samples.

Sand – Particles of rock passing the No. 4 (4.75 mm) sieve and retained on the No. 200 (75 μ m) sieve.

Saturated surface dry (SSD) – Condition of an aggregate particle, asphalt mixtures or Portland cement concrete (PCC) core, or other porous solid when the permeable voids are filled with water, but no water is present on exposed surfaces. (See bulk specific gravity.)

Segregation – The separation of aggregate by size resulting in a non-uniform material.

SHRP – The Strategic Highway Research Program (SHRP) established in 1987 as a five-year research program to improve the performance and durability of roads and to make those roads safe for both motorists and highway workers. SHRP research funds were partly used for the development of performance-based specifications to directly relate laboratory analysis with field performance.

Sieve – Laboratory apparatus consisting of wire mesh with square openings, usually in circular or rectangular frames.

Silt – Material passing the (75 μm) sieve that is non-plastic or very slightly plastic, and that exhibits little or no strength when dry and unconfined. Also, that portion of the soil finer than 75 μm and coarser than 2 μm .

Slump – Measurement related to the workability of concrete.

Soil – Sediments or unconsolidated accumulations of solid particles produced by the physical and chemical disintegration of rocks, and which may or may not contain organic matter.

Specific gravity – The ratio of the mass of a volume of a material to the mass of an equal volume of water at a stated temperature.

- **G_{mm}** – theoretical maximum specific gravity (Gravity_{mix max})
The ratio of the mass of a given volume of asphalt mixtures with no air voids to the mass of an equal volume of water, both at a stated temperature.
- **G_{mb}** – measured bulk specific gravity (Gravity_{mix bulk})
The ratio of the mass, in air, of a volume of compacted HMA mix (including the permeable and impermeable voids in the particles, but not including the voids between particles) to the mass of an equal volume of water at a stated temperature.
- **G_{sb}** – oven-dry bulk specific gravity of aggregate (Gravity_{stone bulk})
The ratio of the mass, in air, of a volume of aggregate (including the permeable and impermeable voids in the particles, but not including the voids between particles) to the mass of an equal volume of water at a stated temperature.
- **G_{sa}** – apparent specific gravity of aggregate (Gravity_{stone apparent})
The ratio of the mass, in air, of a volume of the impermeable portion of aggregate to the mass of an equal volume of water at a stated temperature.
- **G_{se}** – effective specific gravity of aggregate (Gravity_{stone effective})
The ratio of the mass in air of a unit volume of a permeable material (excluding voids permeable to asphalt binder) at a stated temperature to the mass in air (of equal density) of an equal volume of gas-free distilled water at a stated temperature.
- **G_b** – specific gravity of the binder (Gravity_{binder})
The ratio of the mass of a volume of asphalt binder to the mass of an equal volume of water at a stated temperature.

Spine – smooth line extending through the point of maximum density/optimum moisture content of a family of moisture-density curves.

Stability – The ability of an asphalt mixture to resist deformation from imposed loads. Stability is dependent upon internal friction, cohesion, temperature, and rate of loading.

Stratified random sampling – Procedure for obtaining non-biased, representative samples in which the established lot size is divided into equally-sized sublots.

Subbase – A layer of selected material constructed between the subgrade and the base course in a flexible HMA roadway, or between the subgrade and Portland cement concrete (PCC) pavement in a rigid PCC roadway.

Subgrade – Natural soil prepared and compacted to support a structure or roadway pavement.

Sublot – A segment of a lot chosen to represent the total lot.

Superpave™ – Superpave™ (Superior Performing Asphalt Pavement) is a trademark of the Strategic Highway Research Program (SHRP). Superpave™ is a product of the SHRP asphalt research. The Superpave™ system incorporates performance-based asphalt materials characterization with design environmental conditions to improve performance by controlling rutting, low temperature cracking and fatigue cracking. The three major components of Superpave™ are the asphalt binder specification, the mix design and analysis system, and a computer software system.

Theoretical maximum specific gravity (G_{mm}) – The ratio of the mass of a given volume of asphalt mixtures with no air voids to the mass of an equal volume of water, both at a stated temperature.

Topsoil – Surface soil, usually containing organic matter.

Uniformity coefficient – C_u , a value employed to quantify how uniform or well-graded an aggregate is: $C_u = D_{60}/D_{10}$. 60 percent of the aggregate, by mass, has a diameter smaller than D_{60} and 10 percent of the aggregate, by mass, has a diameter smaller than D_{10} .

Unit weight – The ratio of weight to volume of a substance. The term “density” is more commonly used.

µm – Micro millimeter (micron) Used as measurement for sieve size.

Vendor – Supplier of project-produced material that is other than the constructor.

Verification – Process of sampling and testing performed to validate Quality Control (QC) sampling and testing and, thus, the quality of the product. Sometimes called Acceptance.

Void in the mineral aggregate (VMA) – The volume of inter-granular void space between aggregate particles of compacted asphalt mixtures that includes air and asphalt binder; expressed as a percentage of the bulk volume of the compacted paving mixture.

Void filled with asphalt (VFA) – The portion of the void in the mineral aggregate (VMA) that contains asphalt binder; expressed as a percentage of the bulk volume of mix or the VMA.

Wet mixing period – The time interval between the beginning of application of asphalt binder and the opening of the mixer gate.

Zero air voids curve (saturation curve) – Curve showing the zero air voids density as a function of water content.

SAFETY

The procedures included in this manual may involve hazardous materials, operations, and equipment. The procedures do not address all of the safety issues associated with their use. It is the responsibility of the employer to assess workplace hazards and to determine whether personal protective equipment (PPE) must be used. PPE must meet applicable American National Standards Institute (ANSI) standards, and be properly used and maintained. The employer must establish appropriate safety and health practices, in compliance with applicable state and federal laws, for these procedures and associated job site hazards. Hazardous materials must be addressed in a Hazard Communication program, and Material Safety Data Sheets (MSDS) must be obtained and available to workers. Supervisors and employees should be aware of job site hazards, and comply with their employer's safety and health program. The following table identifies some areas that may affect individuals performing the procedures in this manual.

Body Part Affected	Potential Hazards	PPE/Procedures That May Be Appropriate
Head	Falling or fixed overhead objects; electrical shock	Hard hat or other protective helmet
Eyes and Face	Flying objects, radiation, molten metal, chemicals	Safety glasses, goggles, face shields; prescription or filter lenses
Ears	Noise	Ear plugs, ear muffs
Respiratory System	Inhalation of dusts, chemicals; O ₂ deficiency	Properly fit and used respiratory protection consistent with the hazard
Skin	Chemicals including cement; heat	Appropriate chemical or heat resistant gloves, long-sleeve shirts, coveralls
Mouth, digestive system	Ingestion of toxic materials	Disposable or washable gloves, coveralls; personal hygiene
Hands	Physical injury (pinch, cut, puncture), chemicals	Appropriate gloves for physical hazards and compatible with chemicals present
Feet	Falling, sharp objects; slippery surfaces, chemicals	Safety shoes or boots (steel toed, steel shank); traction soles; rubber boots – chemicals, wet conditions
Joints, muscles, tendons	Lifting, bending, twisting, repetitive motions	Proper training and procedures; procedure modifications
Body/Torso	Falls; Burial	Fall protection; trench sloping or shoring
Miscellaneous	Traffic	Visibility, awareness, communication; driver training, safety awareness
Whole body	Radiation	Radiation safety training

RANDOM SAMPLING OF CONSTRUCTION MATERIALS

01

Significance

Sampling and testing are two of the most important functions in quality control (QC). Data from the tests are the tools with which the quality of product is controlled. For this reason, great care must be used in following standardized sampling and testing procedures.

02

In controlling operations, it is necessary to obtain numerous samples at various points along the production line. Unless precautions are taken, sampling can occur in patterns that can create a bias to the data gathered. Sampling at the same time, say noon, each day may jeopardize the effectiveness of any quality program. This might occur, for example, because a material producer does certain operations, such as cleaning screens at an aggregate plant, late in the morning each day. To obtain a representative sample, a reliable system of random sampling must be employed.

Scope

The procedure presented here eliminates bias in sampling materials. Randomly selecting a set of numbers from a table or calculator will eliminate the possibility for bias. Random numbers are used to identify sampling times, locations, or points within a lot or subplot. This method does not cover how to sample, but rather how to determine sampling times, locations, or points.

03

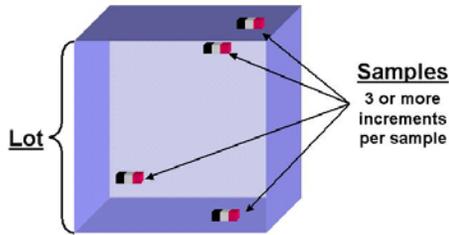
04

Sampling Concepts

A lot is the quantity of material evaluated by QC procedures. A lot is a preselected quantity that may represent hours of production, a quantity or number of loads of material, or an interval of time. A lot may be comprised of several portions that are called sublots or units. The number of sublots comprising a lot will be determined by the agency's specifications.

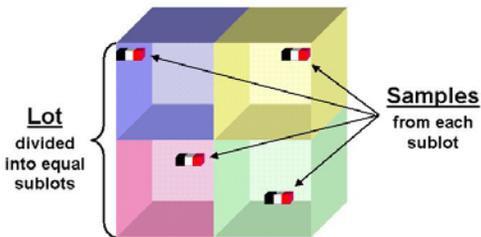
Straight Random Sampling

One or more sample locations may be selected, using the entire lot as a single unit



Stratified Random Sampling

The lot is divided into two or more equal sublots. Samples are taken from each subplot



05

Straight Random Sampling vs. Stratified

Random Sampling: Straight random sampling considers an entire lot as a single unit and determines each sample location based on the entire lot size. Stratified random sampling divides the lot into a specified number of sublots or units and then determines each sample location within a distinct subplot. Both methods result in random distribution of samples to be tested for compliance with the agency’s specification.

06

Agencies stipulate when to use straight random sampling or stratified random sampling. AASHTO T 2, Sampling of Aggregates, for example, specifies a straight random sampling procedure.

Picking Random Numbers from a Table

07

Table 1 contains pairs of numbers. The first number is the “pick” number and the second is the Random Number, “RN”. The table was generated with a spreadsheet and the cells (boxes at the intersection of rows and columns) containing the RNs actually contain the “random number function.” Every time the spreadsheet is opened or changed, all the RNs change.

1. Select a Pick number in a random method. The first two or last two digits in the next automobile license plate you see would be one way to select. Another would be to start a digital stop watch and stop it several seconds later, using the decimal part of the seconds as your Pick number.
2. Find the RN matching the Pick number.

Picking Random Numbers with a Calculator

08

09

Many calculators have a built-in random number function. To obtain a random number, key in the code or push the button(s) the calculator’s instructions call for. The display will show a number between 0.000 and 1.000 and this will be your random number.

TABLE 1
Random Numbers

Pick	RN								
01	0.998	21	0.758	41	0.398	61	0.895	81	0.222
02	0.656	22	0.552	42	0.603	62	0.442	82	0.390
03	0.539	23	0.702	43	0.150	63	0.821	83	0.468
04	0.458	24	0.217	44	0.001	64	0.187	84	0.335
05	0.407	25	0.000	45	0.521	65	0.260	85	0.727
06	0.062	26	0.781	46	0.462	66	0.815	86	0.708
07	0.370	27	0.317	47	0.553	67	0.154	87	0.161
08	0.410	28	0.896	48	0.591	68	0.007	88	0.893
09	0.923	29	0.848	49	0.797	69	0.759	89	0.255
10	0.499	30	0.045	50	0.638	70	0.925	90	0.604
11	0.392	31	0.692	51	0.006	71	0.131	91	0.880
12	0.271	32	0.530	52	0.526	72	0.702	92	0.656
13	0.816	33	0.796	53	0.147	73	0.146	93	0.711
14	0.969	34	0.100	54	0.042	74	0.355	94	0.377
15	0.188	35	0.902	55	0.609	75	0.292	95	0.287
16	0.185	36	0.674	56	0.579	76	0.854	96	0.461
17	0.809	37	0.509	57	0.887	77	0.240	97	0.703
18	0.105	38	0.013	58	0.495	78	0.851	98	0.866
19	0.715	39	0.497	59	0.039	79	0.678	99	0.616
20	0.380	40	0.587	60	0.812	80	0.122	00	0.759

Examples of Straight Random Sampling Procedures Using Random Numbers

10

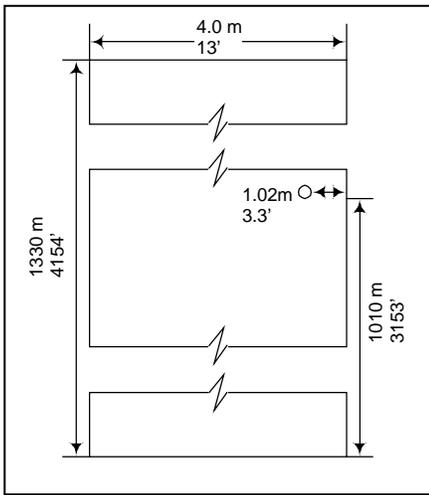
Sampling from a Belt or Flowing Stream:

Agencies specify the frequency of sampling in terms of time, volumes, or masses. The specification might call for one sample from every 1,000,000 kg(1000 t) or 1100 Tons(T) of aggregate. If the random number was 0.317, the sample would be taken at $(0.317)(1,000,000 \text{ kg}) = 317,000 \text{ kg}$ (317 t). Or $(.317) (1100 \text{ T}) = 349 \text{ T}$.

One sample per day might also be specified. If the day were 9 hours long and the random number 0.199, the sample would be taken at $(0.199) (9 \text{ hrs}) = 1.79 \text{ hr} = 1 \text{ hr}, 48 \text{ minutes}$ into the day. AASHTO T 2 permits this time to be rounded to the nearest 5 minutes.

11

Sampling from Haul Units: Based on the agency’s specifications – in terms of time, volume, or mass – determine the number of haul units that comprise a lot. Multiply the selected random



Sampling from a roadway

number(s) by the number of units to determine which unit(s) will be sampled.

For example, if 20 haul units comprise a lot and one sample is needed, pick one RN. If the RN were 0.773, then the sample would be taken from the $(0.773)(20) = 15.46$, or 16th haul unit.

Sampling from a Roadway with Previously Placed Material:

The agency's specified frequency of sampling – in time, volume, or mass – can be translated into a location on a job. For example, if a sample is to be taken every 800 m³ (1000yd³) and material is being placed 0.15 m (0.50 ft) thick and 4.0 m (13 ft) wide, then the lot is 1330 m (4154 ft) long. You would select two RNs in this case. To convert yd³ to ft³ multiply by 27.

The first RN would be multiplied by the length to determine where the sample would be taken along the project. The second would be multiplied by the width to determine where, widthwise, the sample would be taken. For example, a first RN of 0.759 would specify that the sample would be taken at $(0.759)(1330 \text{ m})$ or $(4154 \text{ ft}) = 1010 \text{ m}$ or 3153 ft from the beginning. A second RN of 0.255 would specify that the sample would be taken at $(0.255)(4.0 \text{ m})$ or $(13 \text{ ft}) = 1.02 \text{ m}$ or 3.3 ft from the right edge of the material. To avoid problems associated with taking samples too close to the edge, no sample is taken closer than 0.3 m (1 ft) to the edge. If the RN specifies a location closer than 0.3 m (1 ft), then 0.3 m (1 ft) is added to or subtracted from the distance calculated.

Sampling from a Stockpile: AASHTO T 2 recommends against sampling from stockpiles. However, some agencies use random procedures in determining sampling locations from a stockpile. Bear in mind that stockpiles are prone to segregation and that a sample obtained from a stockpile may not be representative. Refer to AASHTO T 2 for guidance on how to sample from a stockpile.

18

In-Place Density Testing: Agency specifications will indicate the frequency of tests. For example, one test per 500 m³ (650 yd³) might be required. If the material is being placed 0.15 m (0.50 ft) thick and 10.0 m (33 ft) wide, then the lot is 333 m (1090 ft) long. You would select two RNs in this case.

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The first RN would be multiplied by the length to determine where the sample would be taken along the project. The second would be multiplied by the width to determine where, widthwise, the sample would be taken. For example, a first RN of 0.387 would specify that the sample would be taken at (0.387)(333 m) or (1090 ft) = 129 m or (422 ft) from the beginning. A second RN of 0.558 would specify that the sample would be taken at (0.588)(10.0 m) or (33 ft) = 5.88 m or (19 ft) from the right edge of the material. To avoid problems associated with taking samples too close to the edge, no sample is taken closer than 0.3 m (1 ft) to the edge. If the RN specifies a location closer than 0.3 m (1 ft), then 0.3 m (1 ft) is added to or subtracted from the distance calculated.

AGGREGATE

WAQTC

RANDOM SAMPLING

BASICS OF AGGREGATE

Class	Type	Family
Igneous	Intrusive	Granite
	Extrusive	Basalt
Sedimentary	Calcareous	Limestone
	Siliceous	Sandstone
Metamorphic	Foliated	Slate
	Non-foliated	Marble

Rock class, type, family

Introduction

Properties of aggregate materials depend upon mineral constituents present in parent rock formations. Rock is grouped in three major classes:

- Igneous
- Sedimentary
- Metamorphic

Classes are divided into types, which are further divided into families.

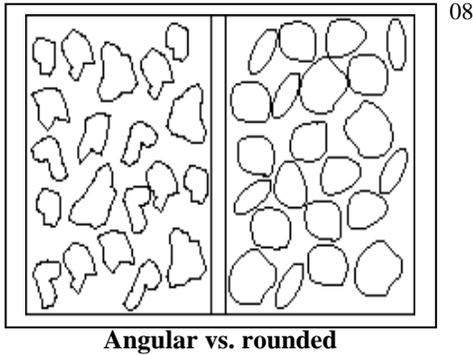
Geology

Igneous rocks are formed by solidification of molten rock. Grain size depends on the rate of cooling. Rapid cooling, such as occurs when lava flows on land, tends to produce fine grained rock such as basalt. Molten material cooled within the earth at slow rates tends to consist of large grain rock such as granite.

Sedimentary rock results when sediments are deposited by wind, water, or glaciers, or by direct precipitation of dissolved material in water. Sandstone is an example of mechanically deposited rock, while limestone is an example of chemically created rock.

Metamorphic rocks result from the “re-working” of existing rock (igneous, sedimentary, or older metamorphic) under the influence of high temperatures and pressures within the earth. Quartzite is metamorphosed sandstone, while marble is metamorphosed limestone.

All three classes of rock have been used as aggregates in road construction. The suitability of aggregate from a given source must be determined from a combination of tests and mineralogical examinations.



08

Precise, standard methods of sampling and testing are essential to obtaining results that correctly describe the characteristics of the aggregate. Depending on the characteristics, the aggregate may be used for road base, concrete, or hot mix asphalt.

Properties

Physical, chemical, and mechanical properties influence the suitability of aggregate for roadway construction. Physical properties include particle shape, particle size, size distribution, surface texture, absorption, specific gravity, unit weight, and void content. Chemical or electrochemical properties encompass solubility, reactivity with or resistance to attack by other chemicals, and affinity to asphalt cement. Mechanical properties include resistance to effects of applied traffic loads.

Table 1 summarizes basic properties of aggregate relative to three specific uses:

- Base – Aggregate Base Course
- PCC – Portland Cement Concrete
- HMA – Hot Mix Asphalt

Summary

A knowledge and understanding of the characteristics, and the test methods used to determine these characteristics, are essential to the quality of concrete and HMA. It is also critical where aggregate is used in road base and embankment. As sources for aggregates are diminished, more emphasis on making the most of current resources is necessary.

Table 1
Effects of Aggregate Properties on Base, PCC, and HMA

Aggregate Property	Effect on Material Produced		
	Base	PCC	HMA
Grading – general	Impacts workability, density, strength, stability	Impacts workability, density, strength, stability	Impacts workability, density, strength, stability
Dense grading	Required for strength and stability	Not commonly used	Commonly used
Gap grading	May be OK	Commonly used	May be OK
Open grading	Good for drainage, poor for strength	Poor choice	May be OK
Rounded and rough	Poor interlocking causes weakness	Good for normal use	Good adhesion, poor interlocking
Rounded and smooth	Poorest choice	Lowers bond but good for normal use	Poorest choice
Angular and smooth	Acceptable	Lower bond may result	Good interlocking, poor adhesion
Angular and rough	Best for normal use	Workability will be poor, but high strength will result	Good adhesion, good interlocking
Flakiness	Weak base material	Weak mix may result	Bridging (high voids and low strength), may degrade
Porosity	Susceptible to frost action	Reduces bond and freeze/thaw resistance, lowers strength	Excessive values cause high binder absorption, reduces durability
Specific gravity	Related to toughness	Required for mix design calculations, related to toughness	Required for mix design calculations, related to toughness
Cleanliness	Impurities, dust increase frost susceptibility	Impurities, dust reduce adhesion	Impurities, dust reduce adhesion
Toughness	Critical to strength	Usually not important	Critical to mix stability
Chemistry	Usually not important	Alkali-silica reactivity is serious concern	Electrochemical charge of aggregates must be matched with appropriate binders

SAMPLING OF AGGREGATES FOP FOR AASHTO T 2



Sampling aggregate



Apparatus

01

Significance

Tests cannot be performed on all the material included in an entire project, so samples are taken from the whole. Proper material sampling is critical to all subsequent testing. If the representative portion obtained through sampling does not truly represent the material, any analysis of that portion is inappropriate for the project at hand. Since only a portion of the whole is used, that portion must be a reliable reflection of the whole. The size of the sample will depend upon the tests to be run and on the nominal maximum size of the aggregate.

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Scope

This procedure covers sampling of coarse, fine, or a combination of coarse and fine aggregates (CA and FA) in accordance with AASHTO T 2-91. Sampling from conveyor belts, transport units, roadways, and stockpiles is covered.

04

Apparatus

- Shovels or scoops, or both
- Sampling tubes of acceptable dimensions
- Mechanical sampling systems: normally a permanently attached device that allows a sample container to pass perpendicularly through the entire stream of material or diverts the entire stream of material into the container by manual, hydraulic, or pneumatic operation
- Belt template
- Sampling containers

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Procedure - General

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Sampling is as important as testing. The technician shall use every precaution to obtain samples that are representative of the material the sample represents. Determine the time or location for sampling in a random manner.

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1. Wherever samples are taken, obtain multiple increments of approximately equal size.

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2. Mix the increments thoroughly to form a field sample that meets or exceeds the minimum mass recommended in Table 1.

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TABLE 1
Recommended Sample Sizes
Nominal Maximum Minimum Mass
Size* mm (in.) g (lb)

2.36 (No. 8)	10,000 (25)
4.75 (No. 4)	10,000 (25)
9.5 (3/8)	10,000 (25)
12.5 (1/2)	15,000 (35)
19.0 (3/4)	25,000 (55)
25.0 (1)	50,000 (110)
37.5 (1 1/2)	75,000 (165)
50 (2)	100,000 (220)
63 (2 1/2)	125,000 (275)
75 (3)	150,000 (330)
90 (3 1/2)	175,000 (385)

11

* One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained. Where large gaps in specification sieves exist, intermediate sieve(s) may be inserted to determine nominal maximum size. Maximum size is one sieve larger than nominal maximum size.

Note 1: Sample size is based upon the test(s) required. As a general rule the field sample size should be such that, when split twice will provide a testing sample of proper size. For example the sample size may be four times that shown in Table 2 of the FOP for AASHTO T 27/T 11, if that mass is more appropriate.

Nominal maximum size and maximum size are not the same.

Example:

Sieve Size, mm (in)		Cumulative Percent Retained
75	(3)	0
63	(2 1/2)	0
50	(2)	0
37.5	(1 1/2)	7
25.0	(1)	32
19.0	(3/4)	38
12.5	(1/2)	47
9.5	(3/8)	58
4.75	(No.4)	72

First sieve to cumulatively retain >10 percent: 25.0 mm (1 in.)
 Nominal maximum size: 37.5 mm (1 1/2 in.) 12
 Maximum size: 50 mm (2 in.)



Sampling from the belt



Sampling Device

Procedure – Specific Situations

Conveyor Belts

Avoid sampling at the beginning or the end of an aggregate run due to the potential for segregation. Be careful when sampling in the rain. Make sure to capture fines that may stick to the belt or that the rain tends to wash away.

Method A (From the Belt)

1. Stop the belt.
2. Set the sampling template in place on the belt, avoiding intrusion by adjacent material.
3. Remove the material from inside the template, including all fines.
4. Obtain at least three approximately equal increments.
5. Combine the increments to form a single sample.

Method B (From the Belt Discharge)

1. Pass a sampling device through the full stream of the material as it runs off the end of the conveyor belt. The sampling device may be manually, semi-automatic or automatically powered.



**Automatic Sampling Device
in Stream**



Sampling from a Transport

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2. The sampling device shall pass through the stream at least twice, once in each direction, without overflowing while maintaining a constant speed during the sampling process.
3. When emptying the sampling device into the container, include all fines.
4. Combine the increments to form a single sample.

Transport Units

1. Visually divide the unit into four quadrants.
2. Identify one sampling location in each quadrant.
3. Dig down and remove approximately 0.3 m (1 ft) of material to avoid surface segregation. Obtain each increment from below this level.
4. Combine the increments to form a single sample.

Roadways

Method A (Berm or Windrow)

1. Obtain sample before spreading.
2. Take the increments from at least three random locations along the fully-formed windrow or berm.
3. Do not take the increments from the beginning or the end of the windrow or berm.
4. Obtain full cross-section samples of approximately equal size at each location. Take care to exclude the underlying material.
5. Combine the increments to form a single field sample.

Note 2: Obtaining samples from berms or windrows may yield extra-large samples and may not be the preferred sampling location.

Method B (In-Place)

1. Obtain sample after spreading and before compaction.
2. Take the increments from at least three random locations.

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3. Obtain full-depth increments of approximately equal size from each location. Take care to exclude the underlying material.
4. Combine the increments to form a single sample.

Stockpiles

Method A– Loader sampling

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1. Direct the loader operator to enter the stockpile with the bucket at least 150 mm (6 in.) above ground level without contaminating the stockpile.
2. Discard the first bucketful.
3. Have the loader re-enter the stockpile and obtain a full loader bucket of the material, tilt the bucket back and up.
4. Form a small sampling pile at the base of the stockpile by gently rolling the material out of the bucket with the bucket just high enough to permit free-flow of the material. (Repeat as necessary.)
5. Create a flat surface by having the loader back drag the small pile.
6. Visually divide the flat surface into four quadrants.
7. Collect an increment from each quadrant by fully inserting the shovel into the flat pile as vertically as possible, take care to exclude the underlying material, roll back the shovel and lift the material slowly out of the pile to avoid material rolling off the shovel.

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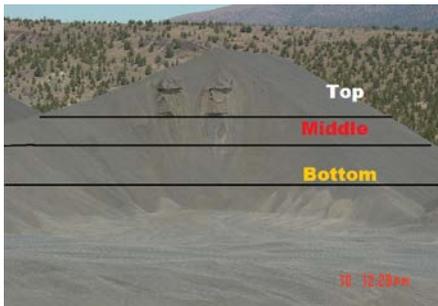
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Method B – Stockpile Face Sampling

1. Create horizontal surfaces with vertical faces in the top, middle, and bottom third of the stockpile with a shovel or loader.
2. Prevent sloughing by shoving a flat board against the vertical face. Sloughed material will be discarded to create the horizontal surface.

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Top, middle, bottom

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- 3. Obtain sample from the horizontal surface as close to the intersection as possible of the horizontal and vertical faces.
- 4. Obtain at least one increment of equal size from each of the top, middle, and bottom thirds of the pile.
- 5. Combine the increments to form a single sample.

Method C – Alternate Tube Method (Fine Aggregate)

38

- 1. Remove the outer layer that may have become segregated.
- 2. Using a sampling tube, obtain one increment of equal size from a minimum of five random locations on the pile.
- 3. Combine the increments to form a single sample.

Note 3: Obtaining samples at stockpiles should be avoided whenever possible due to problems involved in obtaining a representative gradation of material.

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Report

- On forms approved by the agency
- Date
- Time
- Sample ID
- Location
- Quantity represented

Tips!

- Remember, the sample must be representative of the whole.
- And the sample must be selected at random to avoid bias.
- Automatic mechanical sampling is preferred.

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REVIEW QUESTIONS

1. How can power equipment, such as loaders and backhoes, be used to collect aggregate samples?

2. Describe the process for sampling from a conveyor belt using method “A.”

3. Which sampling location should be avoided whenever possible due to problems involved in obtaining a representative gradation of material?

4. Describe sampling from roadways.

PERFORMANCE EXAM CHECKLIST

**SAMPLING OF AGGREGATES
FOP FOR AASHTO T 2**

Participant Name _____ Exam Date _____

Record the symbols “P” for passing or “F” for failing on each step of the checklist.

Procedure Element	Trial 1	Trial 2
Conveyor Belts – Method A (From the Belt)		
1. Belt stopped?	_____	_____
2. Sampling template set on belt, avoiding intrusion of adjacent material?	_____	_____
3. Sample, including all fines, scooped off?	_____	_____
4. Samples taken in at least three approximately equal increments?	_____	_____
Conveyor Belts – Method B (From the Belt Discharge)		
5. Sampling device passed through full stream of material twice (once in each direction) as it runs off end of belt?	_____	_____
Transport Units		
6. Unit divided into four quadrants?	_____	_____
7. Increment obtained from each quadrant, 0.3 m (1ft.) below surface?	_____	_____
8. Increments combined to make up the sample?	_____	_____
Roadways Method A (Berm or Windrow)		
9. Sample taken prior to spreading?	_____	_____
10. Full depth of material taken?	_____	_____
11. Underlying material excluded?	_____	_____
12. Samples taken in at least three approximately equal increments?	_____	_____
Roadways Method B (In-place)		
13. Sample taken after spreading?	_____	_____
14. Full depth of material taken?	_____	_____
15. Underlying material excluded?	_____	_____
16. Samples taken in at least three approximately equal increments?	_____	_____

OVER

Stockpile Method A– (Loader sampling)

- 17. Loader operator directed to enter the stockpile with the bucket at least 150 mm (6 in.) above ground level without contaminating the stockpile? _____
- 18. First bucketful discarded? _____
- 19. The loader re-entered the stockpile and obtained a full loader bucket of the material with the bucket tilted back and up? _____
- 20. A small sampling pile formed at the base of the stockpile by gently rolling the material out of the bucket with the bucket just high enough to permit free-flow of the material? _____
- 21. A flat surface created by the loader back dragging the small pile? _____
- 22. Increment sampled from each quadrant by fully inserting the shovel into the flat pile as vertically as possible, care taken to exclude the underlying material? _____

Stockpile Method B (Stockpile Face)

- 23. Created horizontal surfaces with vertical faces? _____
- 24. At least one increment taken from each of the top, middle, and bottom thirds of the stockpile. _____

Stockpile Method C – Alternate Tube Method (Fine Aggregate)

- 25. Outer layer removed? _____
- 26. Increments taken from at least five locations with a sampling tube? _____

General

- 27. Increments mixed thoroughly to form sample? _____

Comments: First attempt: Pass____ Fail____ Second attempt: Pass____ Fail _____

Examiner Signature _____ WAQTC #: _____

PERFORMANCE EXAM CHECKLIST (ORAL)

**SAMPLING OF AGGREGATES
FOP FOR AASHTO T 2**

Participant Name _____ Exam Date _____

Record the symbols “P” for passing or “F” for failing on each step of the checklist.

Procedure Element	Trial 1	Trial 2
1. How is a sample obtained from a conveyor belt using Method A?		
a) Stop the belt.	_____	_____
b) Set the sampling template on belt, avoiding intrusion of adjacent material.	_____	_____
c) All the material is removed from belt including all fines.	_____	_____
d) Take at least approximately three equal increments.	_____	_____
2. How is a sample obtained from a conveyor belt using Method B?		
a) Pass the sampling device through a full stream of material as it runs off the end of the belt.	_____	_____
b) The device must be passed through at least twice (once in each direction).	_____	_____
3. How is a sample obtained from a Transport Unit?		
a) Divide the unit into four quadrants.	_____	_____
b) Dig 0.3 m (1 ft.) below surface.	_____	_____
c) Obtain an increment from each quadrant.	_____	_____
4. Describe the procedure for sampling from roadways Method A (Berm or Windrow).		
a) Sample prior to spreading	_____	_____
b) Sample the material full depth without obtaining underlying material.	_____	_____
c) Take at least three approximately equal increments.	_____	_____
5. Describe the procedure for sampling from roadway Method B (In-place).		
a) Sample after spreading, prior to compaction.	_____	_____
b) Sample the material full depth without obtaining underlying material.	_____	_____
c) Take at least three approximately equal increments.	_____	_____
6. Describe the procedure for sampling a stockpile Method A (Loader Sampling).		
a) Loader creates sampling pile with a flat surface.	_____	_____
b) Divide the flat surface into four quadrants.	_____	_____
c) Take an approximately equal increment from each quadrant, excluding the underlying material.	_____	_____

OVER

7. Describe the procedure for sampling a stockpile Method B (Stockpile Face Sampling).

- a) Create horizontal surfaces with vertical faces and at least one increment taken from each of the top, middle, and bottom thirds of the stockpile. _____

8. Describe the procedure for sampling a stockpile Method C – Alternate Tube Method (Fine Aggregate).

- a) Remove the outer layer and increments taken from at least five locations. _____

9. After obtaining the increments what should you do before performing R 76?

- a) Increments mixed thoroughly to form sample. _____

Comments: First attempt: Pass____Fail_____ Second attempt: Pass____Fail_____

Examiner Signature _____ WAQTC #: _____

**REDUCING SAMPLES OF AGGREGATES TO TESTING SIZE
FOP FOR AASHTO R 76**



Adjustable Mechanical Splitter



Quartered sample



Mechanical splitter

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Significance

Aggregates and other materials sampled in the field in accordance with AASHTO T 2 are large composites and need to be reduced to the appropriate size for testing. It is extremely important that the procedure used to reduce the field sample not modify the material.

Scope

This procedure covers the reduction of samples to the appropriate size for testing in accordance with AASHTO R 76-16. Techniques are used that minimize variations in characteristics between test samples and field samples. Method A (Mechanical Splitter) and Method B (Quartering) are covered.

This FOP applies to fine aggregate (FA), coarse aggregate (CA), and mixes of the two (FA/CA), and may also be used on soils.

Apparatus

Method A – Mechanical Splitter

Splitter chutes:

- Even number of equal width chutes
- Discharge alternately to each side
- Minimum of 8 chutes total for CA and FA / CA, 12 chutes total for FA
- Width:
 - Minimum 50 percent larger than largest particle
 - Maximum chute width of 19 mm (3/4 in.) for fine aggregate passing 9.5 mm (3/8 in.) sieve
- Feed control:
 - Hopper or straightedge pan with a width equal to or slightly less than the overall width of the assembly of chutes
 - Capable of feeding the splitter at a controlled rate



Mechanical (riffle) splitter



Method B Apparatus



Canvas

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- Splitter Receptacles / Pans:
- Capable of holding two halves of the sample following splitting

The splitter and accessory equipment shall be so designed that the sample will flow smoothly without restriction or loss of material.

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Method B – Quartering

- Straightedge scoop, shovel, or trowel
- Broom or brush
- Canvas or plastic sheet, approximately 2 by 3 m (6 by 9 ft)

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Method Selection

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Samples of CA may be reduced by either Method A or Method B.

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Samples of FA which are drier than the saturated surface dry (SSD) condition, as described in AASHTO T 84, shall be reduced by a mechanical splitter according to Method A. As a quick approximation, if the fine aggregate will retain its shape when molded with the hand, it is wetter than SSD.

16

Samples of FA / CA which are drier than SSD may be reduced by Method A or Method B.

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Samples of FA that are at SSD or wetter than SSD shall be reduced by Method B, or the entire sample may be dried to the SSD condition – using temperatures that do not exceed those specified for any of the tests contemplated – and then reduced to test sample size using Method A.

Table 1

	Drier than SSD	Wetter than SSD
Fine Aggregate (FA)	Method A (Mechanical)	Method B (Quartering)
Mixture of FA/CA	Either Method	Method B (Quartering)
Coarse Aggregate (CA)	Either Method	Either Method

Procedure

Method A – Mechanical Splitter

1. Place the sample in the hopper or pan and uniformly distribute it from edge to edge so that approximately equal amounts flow through each chute. The rate at which the sample is introduced shall be such as to allow free flowing through the chutes into the pans below.
2. Reduce the sample from one of the two pans as many times as necessary to reduce the sample to meet the minimum size specified for the intended test. The portion of the material collected in the other pan may be reserved for reduction in size for other tests.
3. As a check for effective reduction, determine the mass of each reduced portion. If the percent difference of the two masses is greater than 5 percent, corrective action must be taken. In lieu of the check for effective reduction, use the method illustrated in Figure 1.

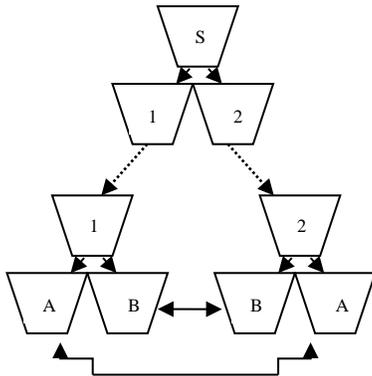


Figure 1

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Example:

- Sample (S) is an amount greater than or equal to twice the mass needed for testing. Sample (S) is split in a mechanical splitter to yield parts (1) and (2).
- Part (1) is further reduced, yielding (A) and (B), while Part (2) is reduced to yield (B) and (A).
- Final testing sample is produced by combining alternate pans, i.e. (A)/(A) or (B)/(B) only.

Calculation

$$\frac{\text{Smaller Mass}}{\text{Larger Mass}} = \text{Ratio} \quad (1 - \text{ratio}) \times 100 = \% \text{ Difference}$$

Splitter check: 5127 g total sample mass
 Splitter pan #1: 2583 g
 Splitter pan #2: 2544 g

23

$$\frac{2544 \text{ g}}{2583 \text{ g}} = 0.985 \quad (1 - 0.985) \times 100 = 1.5\%$$

Method B – Quartering

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Use either of the following two procedures or a combination of both.

Procedure #1: Quartering on a clean, hard, level surface:

1. Place the sample on a hard, clean, level surface where there will be neither loss of material nor the accidental addition of foreign material.
2. Mix the material thoroughly by turning the entire sample over a minimum of four times. With the last turning, shovel the entire sample into a conical pile by depositing each shovelful on top of the preceding one.
3. Flatten the conical pile to a uniform thickness and diameter by pressing down with a shovel. The diameter should be four to eight times the thickness.
4. Divide the flattened pile into four approximately equal quarters with a shovel or trowel.
5. Remove two diagonally opposite quarters, including all fine material, and brush the cleared spaces clean.
6. Successively mix and quarter the remaining material until the sample is reduced to the desired size.
7. The final test sample consists of two diagonally opposite quarters.



Flattening pile

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Dividing pile

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Mixing the sample



Quartered sample

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Procedure #2: Quartering on a canvas or plastic sheet:

1. Place the sample on the sheet.
2. Mix the material thoroughly a minimum of four times by pulling each corner of the sheet horizontally over the sample toward the opposite corner. After the last turn, form a conical pile.
3. Flatten the conical pile to a uniform thickness and diameter by pressing down with a shovel. The diameter should be four to eight times the thickness.
4. Divide the flattened pile into four approximately equal quarters with a shovel or trowel, or insert a stick or pipe beneath the sheet and under the center of the pile, then lift both ends of the stick, dividing the sample into two roughly equal parts. Remove the stick, leaving a fold of the sheet between the divided portions. Insert the stick under the center of the pile at right angles to the first division and again lift both ends of the stick, dividing the sample into four roughly equal quarters.
5. Remove two diagonally opposite quarters, being careful to clean the fines from the sheet.
6. Successively mix and quarter the remaining material until the sample size is reduced to the desired size.
7. The final test sample consists of two diagonally opposite quarters.

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Tips!

- Remember, the reduced sample must be representative of the whole.
- Method A – mechanical splitter – is preferred.
- Method A cannot be used for FA wetter than SSD condition.
- Keep the mechanical splitter dry to avoid having particles “stick” to it.
- Make sure your splitter is level.

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REVIEW QUESTIONS

1. When using the mechanical splitter for FA, the minimum width of the individual chutes should be approximately how much larger than the largest particles in the sample to be split?

2. What is the maximum width of the chute for material passing the 9.5 mm (3/8 in) sieve?

3. How does the moisture content of the sample influence reduction?

4. Define the SSD condition.

5. Describe two methods of mixing the sample.

PERFORMANCE EXAM CHECKLIST

**REDUCING FIELD SAMPLES OF AGGREGATES TO TESTING SIZE
FOP FOR AASHTO R 76**

Participant Name _____ Exam Date _____

Record the symbols "P" for passing or "F" for failing on each step of the checklist.

Trial 1 Trial 2

Method A - Splitting

- 1. Material spread uniformly on feeder? _____
- 2. Rate of feed slow enough so that sample flows freely through chutes? _____
- 3. Material in one pan re-split until desired mass is obtained? _____

Method B - Quartering

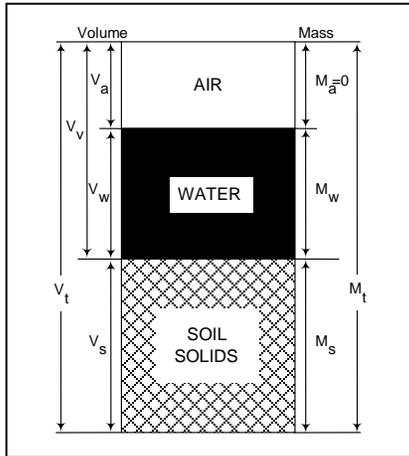
- 1. Sample placed on clean, hard, and level surface? _____
- 2. Mixed by turning over 4 times with shovel or by pulling sheet horizontally over pile? _____
- 3. Conical pile formed? _____
- 4. Diameter equal to about 4 to 8 times thickness? _____
- 5. Pile flattened to uniform thickness and diameter? _____
- 6. Divided into 4 equal portions with shovel or trowel? _____
- 7. Two diagonally opposite quarters, including all fine material, removed? _____
- 8. Cleared space between quarters brushed clean? _____
- 9. Process continued until desired sample size is obtained when two opposite quarters combined? _____

The sample may be placed upon a sheet and a stick or pipe may be placed under the sheet to divide the pile into quarters.

Comments: First attempt: Pass _____ Fail _____ Second attempt: Pass _____ Fail _____

Examiner Signature _____ WAQTC #: _____

**TOTAL EVAPORABLE MOISTURE CONTENT OF AGGREGATE BY DRYING
FOP FOR AASHTO T 255**



Phase diagram

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Significance

The amount of water contained in many materials influences design and construction practices. Road bases are difficult to compact if they are too dry or too wet. If too dry, water must be added, and the amount to be added depends on how much is already present.

Portland cement concrete (PCC) mix design must be adjusted to account for moisture present in aggregate. Careful determination of water content is crucial to many construction materials.

Scope

This procedure covers the determination of moisture content of aggregate in accordance with AASHTO T 255-00. It may also be used for other construction materials.

Overview

Moisture content is determined by comparing the wet mass of a sample and the mass of the sample after drying to constant mass. The term constant mass is used to define when a sample is dry.

Constant mass – the state at which a mass does not change more than a given percent, after additional drying for a defined time interval, at a required temperature.

Apparatus

- Balance or scale: Capacity sufficient for the principle sample mass, accurate to 0.1 percent of sample mass or readable to 0.1 g, meeting the requirements of AASHTO M 231
 - Containers: clean, dry and capable of being sealed



Apparatus

- Microwave safe container with ventilated lid
- Heat source, controlled
 - Forced draft oven
 - Ventilated Oven
 - Convection oven
- 08 • Heat source, uncontrolled
- 09 - Infrared heater, hot plate, fry pan, or
- 10 any other device/method that will dry
- 11 the sample without altering the material
- being dried
- Microwave oven (900 watts minimum)
- Hot pads or gloves
- Utensils, such as spoons

12 **Sample Preparation**

In accordance with the FOP for AASHTO T 2 obtain a representative sample in its existing condition. The representative sample size is based on Table 1 or other information that may be specified by the agency

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TABLE 1
Sample Sizes for Moisture Content of Aggregate

Nominal Maximum Size* mm (in.)	Minimum Sample Mass g (lb)
4.75 (No. 4)	500 (1.1)
9.5 (3/8)	1500 (3.3)
12.5 (1/2)	2000 (4)
19.0 (3/4)	3000 (7)
25.0 (1)	4000 (9)
37.5 (1 1/2)	6000 (13)
50 (2)	8000 (18)
63 (2 1/2)	10,000 (22)
75 (3)	13,000 (29)
90 (3 1/2)	16,000 (35)
100 (4)	25,000 (55)
150 (6)	50,000 (110)

* One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained. Where large gaps in specification sieves exist, intermediate sieve(s) may be inserted to determine nominal maximum.

Immediately seal or cover samples to prevent any change in moisture content or follow the steps in "Procedure."

Procedure

15

Determine and record all masses to the nearest 0.1 percent of the sample mass or to the nearest 0.1 g.

When determining the mass of hot samples or containers or both, place and tare a buffer between the sample container and the balance. This will eliminate damage to or interfere with the operation of the balance or scale.



Forced draft oven

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1. Determine and record the mass of the container (and lid for microwave drying).
2. Place the wet sample in the container:
 - a. For oven(s), hot plates, infrared heaters, etc.: Spread the sample in the container.
 - b. For microwave oven: Heap sample in the container; cover with ventilated lid.
3. Determine record the total mass of the container and wet sample.
4. Determine and record the wet mass of the sample by subtracting the container mass as determined in Step 1 from the mass of the container and sample in Step 3.

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5. Place the sample in one of the following drying apparatus:
 - a. Controlled heat source (oven): at $110 \pm 5^{\circ}\text{C}$ ($230 \pm 9^{\circ}\text{F}$).
 - b. Uncontrolled heat source (Hot plate, infrared heater, etc.): Stir frequently to avoid localized overheating.

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6. Dry until sample appears moisture free.
7. Determine mass of sample and container.
8. Determine and record the mass of the sample by subtracting the container mass determined in Step 1 from the mass of the container and sample determined in Step 7.
9. Return sample and container to the heat source for additional drying.
 - a. Controlled (oven): 30 minutes
 - b. Uncontrolled (Hot plate, infrared heater, etc.): 10 minutes
 - c. Uncontrolled (Microwave oven): 2 minutes

Caution: Some minerals in the sample may cause the aggregate to overheat, altering the aggregate gradation.



Infrared Oven



Uncontrolled drying

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10. Determine mass of sample and container.

11. Determine and record the mass of the sample by subtracting the container mass determined in Step 1 from the mass of the container and sample determined in Step 10.

12. Determine percent change by subtracting the new mass determination (M_n) from the previous mass determination (M_p) divide by the previous mass determination (M_p) multiply by 100.

13. Continue drying, performing steps 9 through 12, until there is less than a 0.10 percent change after additional drying time.

14. Constant mass has been achieved, sample is defined as dry.

15. Allow the sample to cool. Determine and record the total mass of the container and dry sample.

16. Determine and record the dry mass of the sample by subtracting the mass of the container determined in Step 1 from the mass of the container and sample determined in Step 15.

17. Determine and record percent moisture by subtracting the final dry mass determination (M_D) from the initial wet mass determination (M_W) divide by the final dry mass determination (M_D) multiply by 100.

Table 2
Methods of Drying

14

Heat Source	Specific Instructions	Drying intervals to achieve constant mass (minutes)
Controlled: Forced Draft Oven (preferred), Ventilated Oven, or Convection Oven	110 ±5°C (230 ±9°F)	30
Uncontrolled:		
Hot plate, Infrared heater, etc.	Stir frequently	10
Microwave	Heap sample and cover with ventilated lid	2

Calculation

Constant Mass:

Calculate constant mass using the following formula:

$$\frac{M_p - M_n}{M_p} \times 100 = \% \text{ Change}$$

Where:

M_p = previous mass measurement

M_n = new mass measurement

Example:

Mass of container: 1232.1 g

Mass of container after first drying cycle: 2637.2 g

Mass, M_p , of possibly dry sample: 2637.2 g - 1232.1 g = 1405.1 g

Mass of container and dry sample after second drying cycle: 2634.1 g

Mass, M_n , of dry sample: 2634.1 g - 1232.1 g = 1402.0 g

$$\frac{1405.1 \text{ g} - 1402.0 \text{ g}}{1405.1 \text{ g}} \times 100 = 0.22\%$$

0.22 percent is not less than 0.10 percent, so continue drying

Mass of container and dry sample after third drying cycle: 2633.0 g

Mass, M_n , of dry sample: 2633.0 g - 1232.1 g = 1400.9 g

24

$$\frac{1402.0 \text{ g} - 1400.9 \text{ g}}{1402.0 \text{ g}} \times 100 = 0.08\%$$

0.08 percent is less than 0.10 percent so constant mass has been reached

Moisture Content:

Calculate the moisture content, w , as a percent, using the following formula:

$$\frac{M_W - M_D}{M_D} \times 100 = \% \text{ Moisture Content}$$

where:

M_W = wet mass

M_D = dry mass

Example:

25

Mass of container: 1232.1 g

Mass of container and wet sample: 2764.7 g

Mass, M_w , of wet sample: 2764.7 g - 1232.1 g = 1532.6 g

Mass of container and dry sample (COOLED): 2633.0 g

Mass, M_D , of dry sample: 2633.0 g - 1232.1 g = 1400.9 g

$$w = \frac{1532.6 \text{ g} - 1400.9 \text{ g}}{1400.9 \text{ g}} \times 100 = \frac{131.7 \text{ g}}{1400.9 \text{ g}} = 9.40\% \text{ rounded to } 9.4\%$$

26

Report

- Results on forms approved by the agency
- Sample ID
- M_w , wet mass
- M_D , dry mass
- w , moisture content to nearest 0.1 percent

27

Tips!

- Let sample cool before determining final dry mass.
- Divide by M_D , not M_w .

REVIEW QUESTIONS

1. What extra care should be taken when using a microwave to dry aggregates?

2. What are the maximum temperatures that a sample should be allowed to attain when using the various types of ovens?

3. How is “constant mass” defined according to this FOP?

4. What is the maximum weight loss, in grams, that would still constitute constant mass for a 2180 g sample?

PERFORMANCE EXAM CHECKLIST

**TOTAL MOISTURE CONTENT OF AGGREGATE BY DRYING
FOP FOR AASHTO T 255**

Participant Name _____ Exam Date _____

Record the symbols “P” for passing or “F” for failing on each step of the checklist.

Procedure Element	Trial 1	Trial 2
1. Representative sample of appropriate mass obtained?	_____	_____
2. Mass of container determined to 0.1 percent or 0.1 g?	_____	_____
3. Sample placed in container and wet mass determined to 0.1 percent or 0.1 g?	_____	_____
4. Test sample mass conforms to the required mass?	_____	_____
5. Wet mass of sample determined to 0.1 percent or 0.1 g?	_____	_____
6. Loss of moisture avoided prior to mass determination?	_____	_____
7. Sample dried by a suitable heat source?	_____	_____
8. If aggregate heated by means other than a controlled oven, is sample stirred to avoid localized overheating?	_____	_____
9. Is aggregate heated for the additional, specified time (forced draft, ventilated, convection – 30 minutes; microwave – 2 minutes; other – 10 minutes) and then mass determined and compared to previous mass – showing less than 0.10 percent loss?	_____	_____
10. Sample cooled prior to dry mass determination to 0.1 percent or 0.1 g?	_____	_____
11. Calculations performed properly and results reported to the nearest 0.1 percent?	_____	_____

Comments: First attempt: Pass____Fail____ Second attempt: Pass____Fail____

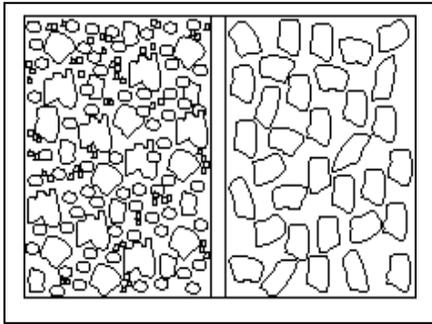
Examiner Signature _____ WAQTC #: _____

SIEVE ANALYSIS OF FINE AND COARSE AGGREGATES

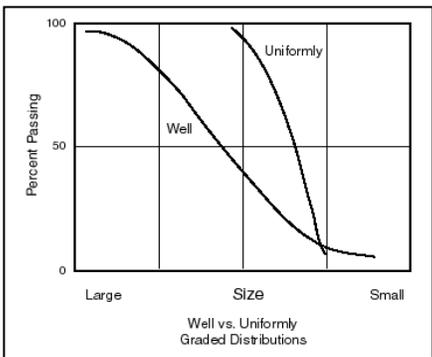
FOP FOR AASHTO T 27

MATERIALS FINER THAN 75 µm (No. 200) SIEVE IN MINERAL AGGREGATE BY WASHING

FOP FOR AASHTO T 11



Well- vs. uniformly graded



Gradation curves



Washing Sample

01

Significance

Sieve analyses are performed on aggregates used in roadway bases and in portland cement and asphalt cement concretes. Sieve analyses reveal the size makeup of aggregate particles – from the largest to the smallest. A gradation curve or chart showing how evenly or unevenly the sizes are distributed between largest and smallest is created in this test. How an aggregate is graded has a major impact on the strength of the base or on the properties and performance of concrete. In Portland Cement Concrete (PCC), for example, gradation influences shrinkage and shrinkage cracking, pumpability, finishability, permeability, and other characteristics.

02

03

04

Generally, well-graded material having an even distribution of particle sizes will have better load handling properties than poorly graded material consisting of a few size classes. Although other characteristics of aggregates contribute to its strength, the better a material is graded the less material will be needed.

05

Scope

06

Sieve analysis determines the gradation or distribution of aggregate particle sizes within a given sample.

Accurate determination of material smaller than 75 µm (No. 200) cannot be made with AASHTO T 27 alone. If quantifying this material is required, it is recommended that AASHTO T 27 be used in conjunction with AASHTO T 11.

This FOP covers sieve analysis in accordance with AASHTO T 27-14 and materials finer than 75 µm (No. 200) in accordance with AASHTO T 11-05 performed in conjunction with AASHTO T 27. The procedure includes three method choices: A, B, and C.



Apparatus



Large Sieve Shaker

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08
09
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Apparatus

- Balance or scale: Capacity sufficient for the masses shown in Table 1, accurate to 0.1 percent of the sample mass or readable to 0.1 g, meeting the requirements of AASHTO M 231
- Sieves: Meeting the requirements of AASHTO M 92
- Mechanical sieve shaker: Meeting the requirements of AASHTO T 27
- Suitable drying equipment (see FOP for AASHTO T 255)
- Containers and utensils: A pan or vessel of a size sufficient to contain the sample when covered with water and to permit vigorous agitation without loss of any part of the sample or water
- Optional mechanical washing device

Sample Sieving

- In all procedures, it is required to shake the sample over nested sieves. Sieves are selected to furnish information required by specification.
- Sieves are nested in order of decreasing size from the top to the bottom and the sample, or a portion of the sample, is placed on the top sieve.
- Sieves are shaken in a mechanical shaker for approximately 10 minutes, or the minimum time determined to provide complete separation for the sieve shaker being used. As established by the Time Evaluation.



Hand shaking

Time Evaluation

The sieving time for each mechanical sieve shaker shall be checked at least annually to determine the time required for complete separation of the sample by the following method:

1. Shake the sample over nested sieves for approximately 10 minutes.
2. Provide a snug-fitting pan and cover for each sieve, and hold in a slightly inclined position in one hand.
3. Hand-shake each sieve by striking the side of the sieve sharply and with an upward motion against the heel of the other hand at the rate of about 150 times per minute, turning the sieve about one sixth of a revolution at intervals of about 25 strokes.

If more than 0.5 percent by mass of the total sample prior to sieving passes any sieve after one minute of continuous hand sieving adjust shaker time and re-check.

In determining sieving time for sieve sizes larger than 4.75 mm (No. 4), limit the material on the sieve to a single layer of particles.

Overload Determination

- For sieves with openings smaller than 4.75 mm (No. 4), the mass retained on any sieve shall not exceed 7 kg/m^2 (4 g/in^2) of sieving surface.
- For sieves with openings 4.75 mm (No. 4) and larger, the mass, in grams shall not exceed the product of $2.5 \times (\text{sieve opening in mm}) \times (\text{effective sieving area})$. See Table 1.

Additional sieves may be necessary to provide other information, such as fineness modulus or to keep from overloading sieves. The sample may also be sieved in increments.

TABLE 1
Maximum Allowable Mass of Material Retained on a Sieve (g)
Nominal Sieve Size, mm (in.)—Exact size is smaller (see AASHTO T 27)

Sieve Size mm (in.)		203 dia (8)	305 dia (12)	305 by 305 (12 × 12)	350 by 350 (14 × 14)	372 by 580 (16 × 24)
		Sieving Area m ²				
		0.0285	0.0670	0.0929	0.1225	0.2158
90	(3 1/2)	*	15,100	20,900	27,600	48,500
75	(3)	*	12,600	17,400	23,000	40,500
63	(2 1/2)	*	10,600	14,600	19,300	34,000
50	(2)	3600	8400	11,600	15,300	27,000
37.5	(1 1/2)	2700	6300	8700	11,500	20,200
25.0	(1)	1800	4200	5800	7700	13,500
19.0	(3/4)	1400	3200	4400	5800	10,200
16.0	(5/8)	1100	2700	3700	4900	8600
12.5	(1/2)	890	2100	2900	3800	6700
9.5	(3/8)	670	1600	2200	2900	5100
6.3	(1/4)	440	1100	1500	1900	3400
4.75	(No. 4)	330	800	1100	1500	2600
-4.75	(-No. 4)	200	470	650	860	1510

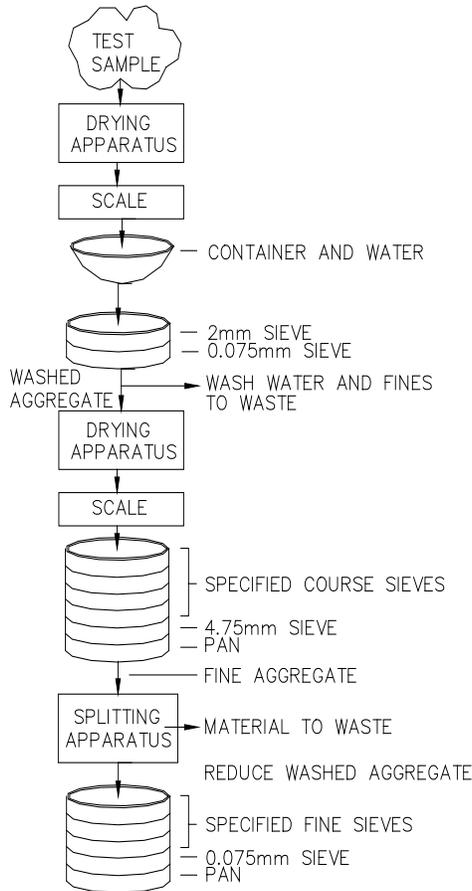
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Sample Preparation

Obtain samples in accordance with the FOP for AASHTO T 2 and reduce to the size shown in Table 2 in accordance with the FOP for AASHTO R 76.

These sample sizes are standard for aggregate testing but, due to equipment restraints, samples may need to be partitioned into several “subsamples.” For example, a gradation that requires 100 kg (220 lbs) of material would not fit into a large tray shaker in one batch.

Some agencies permit reduced sample sizes if it is proven that doing so is not detrimental to the test results. Some agencies require larger sample sizes. Check agency guidelines for required or permitted test sample sizes.



Washed sieve analysis Method B



Sieves

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**TABLE 2
Sample Sizes for Aggregate Gradation Test**

Nominal Maximum Size* mm (in.)	Minimum Mass g (lb)
4.75 (No. 4)	500 (1)
6.3 (1/4)	1000 (2)
9.5 (3/8)	1000 (2)
12.5 (1/2)	2000 (4)
19.0 (3/4)	5000 (11)
25.0 (1)	10,000 (22)
37.5 (1 1/2)	15,000 (33)
50 (2)	20,000 (44)
63 (2 1/2)	35,000 (77)
75 (3)	60,000 (130)
90 (3 1/2)	100,000 (220)
100 (4)	150,000 (330)
125 (5)	300,000 (660)

*Nominal maximum size: One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained. Where large gaps between specification sieves exist, intermediate sieve(s) may be inserted to determine nominal maximum size.

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Selection of Procedure

Agencies may specify what method will be performed. If a method is not specified, Method A will be performed.

Overview

Method A

- Determine dry mass of original sample
- Wash through a 75 µm (No. 200) sieve
- Determine dry mass of washed sample
- Sieve material

Method B

- Determine dry mass of original sample
- Wash through a 75 µm (No. 200) sieve

- Determine dry mass of washed sample
- Sieve coarse material
- Determine dry mass of fine material
- Reduce fine portion
- Determine mass of reduced portion
- Sieve fine portion

Method C

- Determine dry mass of original sample
- Sieve coarse material
- Determine mass of fine material
- Reduce fine portion
- Determine dry mass of reduced portion
- Wash through a 75µm (No. 200) sieve
- Determine dry mass of washed sample
- Sieve reduced fine portion

Procedure Method A

1. Dry the sample to a constant mass in accordance with the FOP for AASHTO T 255. Determine and record the total dry mass of the sample to the nearest 0.1 percent or 0.1 g.
2. When the specification requires that the amount of material finer than 75 µm (No. 200) be determined, perform Step 3 through Step 11, otherwise, skip to Step 12.
3. Nest a sieve, such as a 2.0 mm (No. 10), above the 75 µm (No. 200) sieve.
4. Place the test sample in a container and add sufficient water to cover it.

Note 1: A detergent, dispersing agent, or other wetting solution may be added to the water to assure a thorough separation of the material finer than the 75 µm (No. 200) sieve from the coarser particles. There should be enough wetting agent to produce a small amount of suds when the sample is agitated. Excessive suds may overflow the sieves and carry material away with them.



Determining Initial Dry Mass



Agitating



Pouring over nested sieves



Rinsing sieve



Nested sieves



12 inch diameter sieve shaker

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5. Agitate vigorously to ensure complete separation of the material finer than 75 μm (No. 200) from coarser particles and bring the fine material into suspension above the coarser material. When using a mechanical washing device, exercise caution to avoid degradation of the sample.
 6. Immediately pour the wash water containing the suspended and dissolved solids over the nested sieves, being careful not to pour out the coarser particles.
 7. Add a second change of water to the sample remaining in the container, agitate, and repeat Step 6. Repeat the operation until the wash water is reasonably clear. If detergent or dispersing agent is used, continue washing until the agent is removed.
 8. Remove the upper sieve, return material retained to the washed sample.
 9. Rinse the material retained on the 75 μm (No.200) sieve until water passing through the sieve is reasonably clear.
 10. Return all material retained on the 75 μm (No.200) sieve to the container by flushing into the washed sample.
- Note 2:* Excess water may be carefully removed with a bulb syringe as long as the removed water is discharged back over the No. 200 sieve to preclude loss of fines.
11. Dry the washed aggregate to constant mass in accordance with the FOP for AASHTO T 255, and then cool prior to sieving. Record the “dry mass after washing.”
 12. Select sieves to furnish information required by the specifications. Nest the sieves in order of decreasing size from top to bottom and place the sample, or a portion of the sample, on the top sieve.
 13. Place sieves in mechanical shaker and shake for the minimum time determined to provide complete separation for the sieve shaker being used (approximately 10 minutes).

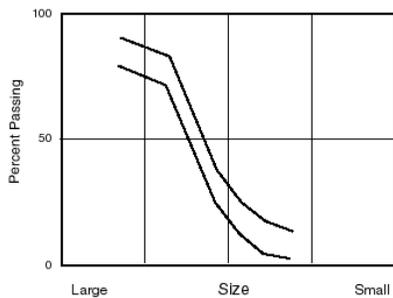
Note 3: Excessive shaking (more than 10 minutes) may result in degradation of the sample.



Cleaning Sieves



Determining Mass



Specifications envelope

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14. Determine the mass retained on each sieve to the nearest 0.1 g. Ensure that all material trapped in full openings of the sieve are cleaned out and included in the mass retained.

Note 4: For sieves No. 4 and larger, material trapped in less than a full opening shall be checked by sieving over a full opening. Use coarse wire brushes to clean the 600 µm (No. 30) and larger sieves, and soft bristle brushes for smaller sieves.

Note 5: In the case of coarse / fine aggregate mixtures, the minus 4.75 mm (No. 4) may be distributed among two or more sets of sieves to prevent overloading of individual sieves.

15. Verify the total mass of material after sieving agrees with the mass before sieving within 0.3 percent. (Check sum). If performing T 11 with T 27, this would be the dry mass after wash. If performing just T 27 this would be the original dry mass. When the masses before and after sieving differ by more than 0.3 percent, the results cannot be used for acceptance purposes.

16. Calculate the total percentages passing, individual or cumulative percentages retained or percentages in various size fractions to the nearest 0.1 percent by dividing the masses on the individual sieve masses or cumulative sieve masses by the total mass of the initial dry sample. If the same test sample was first tested by T 11, use the total dry sample mass before washing in T 11 as the basis for calculating all percentages.

17. Report percent passing as indicated in the "Report" section at the end of this FOP.

Method A Calculation

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$$\text{Check sum} = \frac{\text{dry mass after washing} - \text{total mass after sieving}}{\text{dry mass after washing}} \times 100$$

Percent Retained

$$IPR \frac{IMR}{M} \times 100 \quad \text{or} \quad CPR = \frac{CMR}{M} \times 100$$

61

Where:

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IPR = Individual Percent Retained

CPR = Cumulative Percent Retained

M = Total Dry Sample Mass Before Washing

IMR = Individual Mass Retained

CMR = Cumulative Mass Retained

63

Percent Passing (Calculated)

$$PP = PPP - IPR \quad \text{or} \quad PP = 100 - CPR$$

Where:

PP = Percent Passing

64

PPP = Previous Percent Passing

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Method A Example

Dry mass of total sample, before washing: 5168.7 g

Dry mass of sample, after washing out the 75 µm (No. 200) minus: 4911.3 g

Amount of 75 µm (No. 200) minus washed out: 5168.7 g – 4911.3 g = 257.4 g

Gradation on All Screens

Sieve Size mm (in.)	Individual Mass Retained g (IMR)	Individual Percent Retained (IPR)	Cumulative Mass Retained g (CMR)	Cumulative Percent Retained (CPR)	Calc'd Percent Passing (PP)	Reported Percent Passing* (RPP)
19.0 (3/4)	0	0	0	0.0	100.0	100
12.5 (1/2)	724.7	14.0	724.7	14.0	86.0	86
9.5 (3/8)	619.2	12.0	1343.9	26.0	74.0	74
4.75 (No. 4)	1189.8	23.0	2533.7	49.0	51.0	51
2.36 (No. 8)	877.6	17.0	3411.3	66.0	34.0	34
1.18 (No. 16)	574.8	11.1	3986.1	77.1	22.9	23
0.600 (No. 30)	329.8	6.4	4315.9	83.5	16.5	17
0.300 (No. 50)	228.5	4.4	4544.4	87.9	12.1	12
0.150 (No. 100)	205.7	4.0	4750.1	91.9	8.1	8
0.075 (No. 200)	135.4	2.6	4885.5	94.5	5.5	5.5
Pan	20.4		4905.9			

*Report 75 µm (No.200) sieve to 0.1 percent. Report all others to 1 percent.

66, 67,
68, 69,
70, 71,
72, 73

Check sum:

$$\frac{4911.3 \text{ g} - 4905.9 \text{ g}}{4911.3 \text{ g}} \times 100 = 0.1\%$$

This is less than 0.3 percent therefore the results can be used for acceptance purposes.

Percent Retained:

9.5 mm (3/8) sieve

Percent Passing (Calculated):

$$\frac{619.2 \text{ g}}{5168.7 \text{ g}} \times 100 = 12.0\% \quad \text{or} \quad \frac{1343.9 \text{ g}}{5168.7 \text{ g}} \times 100 = 26.0\%$$

9.5 mm (3/8) sieve

$$86.0\% - 12.0\% = 74.0\% \quad \text{or} \quad 100.0\% - 26.0\% = 74.0\%$$

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Procedure Method B

1. Perform steps 1 through 11 from the “Procedure Method A,” then continue as follows:
2. Select sieves to furnish information required by the specifications. Nest the sieves in order of decreasing size from top to bottom through the 4.75 mm (No. 4) with the pan at the bottom to retain the minus 4.75 mm (No. 4).
3. Place the sample, or a portion of the sample, on the top sieve. Sieves may already be in the mechanical shaker, or place the sieves in the mechanical shaker and shake for the minimum time determined to provide complete separation for the sieve shaker being used (approximately 10 minutes).

Note 3: Excessive shaking (more than 10 minutes) may result in degradation of the sample.
4. Determine the individual or cumulative mass retained on each sieve to the nearest 0.1 percent or 0.1 g. Ensure that all particles trapped in full openings of the sieve are cleaned out and include in the mass retained.

Note 4: For sieves No. 4 and larger, material trapped in less than a full opening shall be checked by sieving over a full opening. Use coarse wire brushes to clean the 600 µm (No. 30) and larger sieves, and soft bristle brushes for smaller sieves.
5. Determine the mass of the material in the pan [minus 4.75 mm (No. 4)] (M_1).
6. Verify the total mass of material after sieving agrees with the mass before sieving within 0.3 percent. (Coarse check sum). If performing T 11 with T 27, this would be the dry mass after wash. If performing just T 27 this would be the original dry mass. When the masses before and after sieving differ by more than 0.3 percent, the results cannot be used for acceptance purposes.
7. Reduce the minus 4.75 mm (No. 4) using a mechanical splitter in accordance with the FOP for AASHTO R 76 to produce a sample with a



Large sieve



Pan and -No. 4

- 53
thru
65
- mass of 500 g minimum. Determine and record the mass of the minus 4.75 mm (No. 4) split (M_2).
8. Select sieves to furnish information required by the specifications. Nest the sieves in order of decreasing size from top to bottom through the 75 μm (No. 200) with a pan at the bottom to retain the minus 75 μm (No. 200).
 9. Repeat steps 3 through 5, Method B, with the minus 4.75 mm (No. 4) split including determining the mass of the material in the pan.
 10. Verify the total mass of material after sieving agrees with the mass before sieving within 0.3 percent. (Fine check sum). This would be the dry mass from Step 7. When the masses before and after sieving differ by more than 0.3 percent, the results cannot be used for acceptance purposes.
 11. Calculate the Individual Mass Retained (IMR) or Cumulative Mass Retained (CMR) of the size increment of the original sample.
 12. Calculate the total percent passing and report as indicated in the "Report" section at the end of this FOP.

Method B Calculations

$$\text{Coarse check sum} = \frac{\text{dry mass after washing} - \text{total mass after coarse sieving}}{\text{dry mass after washing}} \times 100$$

$$\text{Fine check sum} = \frac{M_2 - \text{total mass after fine sieving}}{M_2} \times 100$$

Individual Mass Retained (IMR):

$$IMR = \frac{M_1}{M_2} \times B$$

where:

IMR = adjusted individual mass retained of the size increment on a total sample basis

M_1 = mass of minus 4.75mm (No. 4) sieve in total sample

M_2 = mass of minus 4.75mm (No. 4) sieve actually sieved

B = individual mass of the size increment in the reduced portion sieved

Cumulative Mass Retained (CMR):

$$CMR = \left(\frac{M_1}{M_2} \times B \right) + D$$

where:

CMR = Total cumulative mass retained of the size increment based on a total sample

M_1 = mass of minus 4.75mm (No. 4) sieve in total sample

M_2 = mass of minus 4.75mm (No. 4) sieve actually sieved

B = cumulative mass of the size increment in the reduced portion sieved

D = cumulative mass of plus 4.75mm (No. 4) portion of sample

Method B Example

Sample calculation for percent retained and percent passing each sieve in accordance with Method B when the previously washed 4.75 mm (No. 4) minus material is split:

Example:

Dry mass of total sample, before washing: 3214.0 g

Dry mass of sample, after washing out the 75 μm (No. 200) minus: 3085.1 g

Amount of 75 μm (No. 200) minus washed out: 3214.0 g – 3085.1 g = 128.9 g

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Gradation on Coarse Screens

Sieve Size mm (in.)	Individual Mass Retained g (IMR)	Individual Percent Retained (IPR)	Cumulative Mass Retained g (CMR)	Cumulative Percent Retained (CPR)	Calculated Percent Passing (CPP)
16.0 (5/8)	0	0	0	0	100
12.5 (1/2)	161.1	5.0	161.1	5.0	95.0
9.50 (3/8)	481.4	15.0	642.5	20.0	80.0
4.75 (No. 4)	475.8	14.8	1118.3	34.8	65.2
Pan	1966.7 (M ₁)		3085.0		

Coarse check sum:

69, 70, 71

$$\frac{3085.1 \text{ g} - 3085.0 \text{ g}}{3085.1 \text{ g}} \times 100 = 0.0\%$$

This is less than 0.3 percent therefore the results can be used for acceptance purposes.

Note 5: The pan mass determined in the laboratory (M₁) and the calculated mass (3085.1 – 1118.3 = 1966.7) should be the same if no material was lost.

The pan (1966.7 grams) was reduced in accordance with the FOP for AASHTO R 76, so that at least 500 g are available. In this case, the mass determined was **512.8 g**. This is M₂.

In order to account for the fact that only a portion of the minus 4.75 mm (No. 4) material was sieved, the mass of material retained on the smaller sieves is adjusted by a factor equal to M₁/M₂. The factor determined from M₁/M₂ must be carried to three decimal places. Both the individual mass retained and cumulative mass retained formulas are shown.

Individual Mass Retained:

M_1 = total mass in the pan of the 4.75 (No. 4) minus before reducing

M_2 = mass of the split minus 4.75 mm (No. 4)

$$\frac{M_1}{M_2} = \frac{1,966.7 \text{ g}}{512.8 \text{ g}} = 3.835$$

72

Each “individual mass retained” on the fine sieves must be multiplied by this adjustment factor.

Example:

$$\text{Overall mass retained on the 2.00 mm (No. 10)} = 3.835 \times 207.1 \text{ g} = 794.2 \text{ g}$$

As shown in the following table.

**Final Gradation on All Screens
Calculation by Individual Mass**

Sieve Size mm (in.)	Individual Mass Retained g (IMR)	Adjusted Individual Mass Retained g (AIMR)	Individual Percent Retained (IPP)	Calc'd Percent Passing (CPP)	Reported Percent Passing* (RPP)
16.0 (5/8)	0	0	0.0	100.0	100
12.5 (1/2)	161.1	161.1	5.0	95.0	95
9.5 (3/8)	481.4	481.4	15.0	80.0	80
4.75 (No. 4)	475.8	475.8	14.8	65.2	65
2.0 (No. 10)	207.1×3.835	794.2	24.7	40.5	41
0.425 (No. 40)	187.9×3.835	720.6	22.4	18.1	18
0.210 (No. 80)	59.9×3.835	229.7	7.1	11.0	11
0.075 (No. 200)	49.1×3.835	188.3	5.9	5.1	5.1
Pan	7.8×3.835	29.9			
Dry mass of total sample, before washing: 3214.0 g					

*Report 75 μm (No.200) sieve to 0.1 percent. Report all others to 1 percent.

73

Fine check sum:

$$\frac{512.8 \text{ g} - 511.8 \text{ g}}{512.8 \text{ g}} \times 100 = 0.2\%$$

This is less than 0.3 percent therefore the results can be used for acceptance purposes.

Percent Passing (Calculated) see “Calculation” under Method A.

Cumulative Mass Retained:

M₁ = total mass in the pan of the minus 4.75 mm (No. 4) before reducing

M₂ = mass of the split minus 4.75 mm (No. 4)

$$\frac{M_1}{M_2} = \frac{1,966.7 \text{ g}}{512.8 \text{ g}} = 3.835$$

Each “cumulative mass retained” on the fine sieves must be multiplied by this adjustment factor then the cumulative mass of plus 4.75 mm (No. 4) portion of sample is added to equal the adjusted cumulative mass retained.

75, 76

Example:

Adjusted Cumulative Mass Retained on the 2.00 mm (No. 10) =

$$3.835 \times 207.1 \text{ g} = 794.2 \text{ g}$$

Total Cumulative Mass Retained on the 2.00 mm (No. 10) =

$$794.2 \text{ g} + 1118.3 \text{ g} = 1912.5 \text{ g}$$

As shown in the following table:

**Final Gradation on All Screens
Calculation by Cumulative Mass**

Sieve Size mm (in.)	Cumulative Mass Retained g (CMR)	Adjusted Cumulative Mass Retained g (ACMR)	Total Cumulative Mass Retnd. g (TCMR)	Cumulative Percent Retnd. (CPR)	Calc'd Percent Passing (PP)	Reported Percent Passing* (RPP)
16.0 (5/8)	0		0	0.0	100.0	100.0
12.5 (1/2)	161.1		161.1	5.0	95.0	95
9.5 (3/8)	642.5		642.5	20.0	80.0	80
4.75 (No. 4)	1118.3		1118.3	34.8	65.2	65
2.0 (No. 10)	207.1 × 3.835	794.2 + 1118.3	1912.5	59.5	40.5	41
0.425 (No. 40)	395.0 × 3.835	1514.8 + 1118.3	2633.1	81.9	18.1	18
0.210 (No. 80)	454.9 × 3.835	1744.5 + 1118.3	2862.8	89.1	10.9	11
0.075 (No. 200)	504.0 × 3.835	1932.8 + 1118.3	3051.1	94.9	5.1	5.1
Pan	511.8 × 3.835	1962.8 + 1118.3	3081.1			

*Report 75 µm (No.200) sieve to 0.1 percent. Report all others to 1 percent.

78, 79, 80

Fine check sum:

$$\frac{512.8\text{ g} - 511.8\text{ g}}{512.8\text{ g}} \times 100 = 0.2\%$$

This is less than 0.3 percent therefore the results can be used for acceptance purposes.

Percent Passing (Calculated) see “Calculation” under Method A.

Procedure Method C

1. Dry sample in accordance with the FOP for AASHTO T 255. Determine and record the total dry mass of the sample to the nearest 0.1 percent or 1g.

Note 6: AASHTO T 27 allows for coarse aggregate to be run in a moist condition unless the nominal maximum size of the aggregate is smaller than 12.5 mm (1/2 in.), the coarse aggregate (CA) contains appreciable material finer than 4.75 mm (No. 4), or the coarse aggregate is highly absorptive.

2. Break up any aggregations or lumps of clay, silt or adhering fines to pass the 4.75 mm (No. 4) sieve. If substantial coatings remain on the coarse particles in amounts that would affect the percent passing any of the specification sieves, the sample should be tested with either Method A or Method B.

3. Select sieves to furnish information required by the specifications. Nest the sieves in order of decreasing size from top to bottom through the 4.75 mm (No.4) with a pan at the bottom to retain the minus 4.75 mm (No. 4).

4. Place the sample, or a portion of the sample, on the top sieve. Sieves may already be in the mechanical shaker or place the sieves in the mechanical shaker and shake for the minimum time determined to provide complete separation for the sieve shaker being used (approximately 10 minutes).

Note 3: Excessive shaking (more than 10 minutes) may result in degradation of the sample.



Lumps of clay



Large sieve

31
30
32
34
thru
54
33
55
thru
67
68

5. Determine the cumulative mass retained on each sieve to the nearest 0.1 percent or 0.1 g. Ensure that all material trapped in full openings of the sieve are cleaned out and included in the mass retained.

Note 4: For sieves No. 4 and larger, material trapped in less than a full opening shall be checked by sieving over a full opening. Use coarse wire brushes to clean the 600 μm (No. 30) and larger sieves, and soft bristle brushes for smaller sieves.
6. Determine the mass of the material in the pan [minus 4.75 mm (No. 4)] (M_1).
7. Verify the total mass of material after sieving agrees with the mass before sieving within 0.3 percent. (Coarse check sum). If performing T 11 with T 27, this would be the dry mass after wash. If performing just T 27 this would be the original dry mass. When the masses before and after sieving differ by more than 0.3 percent, the results cannot be used for acceptance purposes.
8. Reduce the minus 4.75 mm (No. 4) using a mechanical splitter in accordance with the FOP for AASHTO R 76 to produce a sample with a mass of 500 g minimum.
9. Determine and record the mass of the minus 4.75mm (No. 4) split (M_3).
10. Perform steps 3 through 11 of Method A (Wash) on the minus 4.75 mm (No. 4) split.
11. Select fine sieves to furnish information required by the specifications. Nest the sieves in order of decreasing size from top to bottom through the 75 μm (No. 200) with a pan at the bottom to retain the minus 75 μm (No. 200).
12. Repeat steps 4 through 6, Method C, with the minus 4.75 mm (No. 4).
13. Verify the total mass of material after sieving agrees with the mass before sieving within 0.3 percent. (Fine check sum). This would be the dry mass from Step 10. When the masses before and after sieving differ by



Pan and –No. 4



Reducing minus material

more than 0.3 percent, the results cannot be used for acceptance purposes.

14. Calculate the Cumulative Percent Retained (CPR) or Cumulative Percent Passing (CPP) for the 4.75 mm (No. 4) and larger.
15. Calculate the Cumulative Percent Retained (CPR-#4) and/or Cumulative Percent Passing (CPP-#4) for the minus 4.75 mm (No. 4).
16. Calculate the CPP for the minus 4.75 mm (No. 4).
17. Report Percent Passing (RPP) as indicated in the “Report” section at the end of this FOP.

Method C Calculations

$$\text{Coarse check sum} = \frac{\text{dry mass after washing} - \text{total mass after coarse sieving}}{\text{dry mass after washing}} \times 100$$

$$\text{Fine check sum} = \frac{M_3 - \text{total mass after fine sieving}}{M_3} \times 100$$

Cumulative Percent Retained (CPR) and Cumulative Percent Passing (CPP)

$$CPR = \frac{CMR}{M} \times 100 \quad CPP = 100 - CPR$$

where:

CMR = Cumulative Mass Retained

CPR = Cumulative Percent Retained

M = Total Dry Sample mass before washing

CPP = Cumulative Percent Passing

Cumulative Percent Retained ($CPR_{\#4}$) and Cumulative Percent Passing ($CPP_{\#4}$)

$$CPR_{\#4} = \frac{CMR_{\#4}}{M_3} \times 100 \quad CPP_{\#4} = 100 - CPR_{\#4}$$

$$CPP = \frac{(CPP_{\#4} \times CPP_{\#4})}{100} \text{ or } CPP = \frac{CPP_{\#4} \times (M_3 - CMR_{\#4})}{M_3}$$

where:

$CMR_{\#4}$ = Cumulative mass retained for the sieve size based on a minus No. 4 split sample

$CPR_{\#4}$ = Calculated cumulative percent retained based on the minus No. 4 split

$CPP_{\#4}$ = Calculated percent passing based on the minus No. 4 split

M_3 = Total mass of the minus No. 4 split before washing

$CPP_{\#4}$ = Calculated percent passing the No. 4 sieve

Method C Example

Sample calculation for percent retained and percent passing each sieve in accordance with Method C when the minus 4.75 mm (No. 4) material is reduced and then washed:

Dry Mass of total sample (M):	3304.5 g
Dry Mass of minus 4.75 mm (No. 4) reduced portion before wash ($M_{\#4}$):	527.6 g
Dry Mass of minus 4.75 mm (No. 4) reduced portion after wash:	495.3 g

Gradation on Coarse Sieves

Sieve Size mm (in.)	Cumulative Mass Retained g (CMR)	Cumulative Percent Retained (CPR)	Cumulative Percent Passing (CPP)	Reported Percent Passing* (RPP)
16.0 (5/8)	0	0.0	100.0	100
12.5 (1/2)	125.9	3.8	96.2	96
9.50 (3/8)	604.1	18.3	81.7	82
4.75 (No. 4)	1295.6	39.2	60.8	61
Pan	2008.9			
Total Dry Sample (M) = 3304.5				

Coarse check sum:

$$\frac{3304.5 \text{ g} - 3304.5 \text{ g}}{3304.5 \text{ g}} \times 100 = 0.0\% \quad 75, 76$$

This is less than 0.3 percent therefore the results can be used for acceptance purposes.

The pan (2008.9 g) was reduced in accordance with the FOP for AASHTO R 76, so that at least 500 g are available. In this case, the mass determined was M₃ = **527.6 g**.

Gradation on Minus No. 4 Sieves

Sieve Size mm (in.)	Cumulative Mass Retained g (CMR _{#4})	Cumulative Percent Retained _{#4} (CPR _{#4})	Cumulative Percent Passing _{#4} (CPP _{#4})	Cumulative Percent Passing (CPP)	Reported Percent Passing* (RPP)
2.0 (No. 10)	194.3	36.8	63.2	38.4	38
0.425 (No. 40)	365.6	69.3	30.7	18.7	19
0.210 (No. 80)	430.8	81.7	18.3	11.1	11
0.075 (No. 200)	484.4	91.8	8.2	5.0	5.0
Pan	495.1				
Dry mass of minus 4.75 mm (No. 4) sample, before washing (M ₃) : 527.6 g					
Dry mass of minus 4.75 mm (No. 4) sample, after washing: 495.3 g					
Calculated percent passing the No. 4 sieve (CPP _{#4}) = 60.8%					

Fine check sum:

79,80,81,82, 83

$$\frac{495.3 \text{ g} - 495.1 \text{ g}}{495.3 \text{ g}} \times 100 = 0.04\%$$

This is less than 0.3 percent therefore the results can be used for acceptance purposes.

Final Gradation on All Sieves

80

Calculation by Cumulative Mass

Sieve Size mm (in.)	Cumulative Mass Retained g (CMR)	Cumulative Percent Retained (CPR)	Cumulative Percent Passing (CPP)	Cumulative Percent Passing (CPP)	Reported Percent Passing* (RPP)
16.0 (5/8)	0	0.0		100.0	100
12.5 (1/2)	125.9	3.8		96.2	96
9.5 (3/8)	604.1	18.3		81.7	82
4.75 (No. 4)	1295.6	39.2		60.8	61
2.0 (No. 10)	194.3	36.8	63.2	38.4	38
0.425 (No. 40)	365.6	69.3	30.7	18.7	19
0.210 (No. 80)	430.8	81.7	18.3	11.1	11
0.075 (No. 200)	484.4	91.8	8.2	5.0	5.0
Pan	495.1				

*Report 75 µm (No. 200) sieve to 0.1 percent. Report all others to 1 percent

Fineness Modulus

Fineness Modulus (FM) is used in determining the degree of uniformity of the aggregate gradation in PCC mix designs. It is an empirical number relating to the fineness of the aggregate. The higher the FM the coarser the aggregate. Values of 2.40 to 3.00 are common for FA in PCC. Variations in the FM from the same source could lead to concerns for the uniformity of the PCC being produced due to changes in the surface area the paste must cover. If these variations exceed agency set limits, changes to the mix design may be required.

73, 74,
75,

The sum of the cumulative percentages retained on specified sieves in the following table divided by 100 gives the FM.

Sample Calculation

	Example A			Example B		
	Percent			Percent		
		Retained			Retained	
Sieve Size mm (in)	Passing		On Spec'd Sieves*	Passing		On Spec'd Sieves*
75*(3)	100	0	0	100	0	0
37.5*(1 1/2)	100	0	0	100	0	0
19*(3/4)	15	85	85	100	0	0
9.5*(3/8)	0	100	100	100	0	0
4.75*(No. 4)	0	100	100	100	0	0
2.36*(No. 8)	0	100	100	87	13	13
1.18*(No. 16)	0	100	100	69	31	31
0.60*(No. 30)	0	100	100	44	56	56
0.30*(No. 50)	0	100	100	18	82	82
0.15*(No. 100)	0	100	100	4	96	96
			$\Sigma = 785$			$\Sigma = 278$
			FM = 7.85			FM = 2.78

76, 77

In decreasing size order, each * sieve is one-half the size of the preceding * sieve.

84

Report

- Results on forms approved by the agency
- Sample ID
- Individual mass retained on each sieve
- Individual percent retained on each sieve
- Cumulative mass retained on each sieve
- Cumulative percent retained on each sieve
- FM to the nearest 0.01

Report percentages to the nearest 1 percent except for the percent passing the 75 μm (No. 200) sieve, which shall be reported to the nearest 0.1 percent.

Tips!

85

- Check specification to see if material must be washed and split.
- Comply with Agency Method selection requirements.
- Do not lose any material when running the test.
- Remember to base calculations on the total mass of the initial dry sample.
- Check calculations, and sieves for damage or plugging, if results look “odd” or if the material suddenly goes out of spec.
- Save all material for rerunning.

72

REVIEW QUESTIONS

1. What are the differences between methods A, B, and C?

2. Describe how sieves should be cleaned.

3. What should be done to protect the 75 μm (No.200) sieve during washing?

4. Once a washed sample is placed in the oven and dried to a constant mass, what is the next step?

5. The maximum mass, in g/m^2 , of material retained on any sieve 4.75 mm (No.4) and larger may not exceed 2.5 times the sieve opening in mm. How much may be retained on the 12.5 mm (1/2 in) sieve, 203 mm (8in) in diameter?

6. For how long should material be sieved on the shaker?

7. How much unexplained sample mass may be lost before you would have to rerun an aggregate sample?

8. Calculate the FM for the material below.

Sieve Size mm (in.)	Percent Passing	Percent Retained	
100 (4)	100		
75 (3)	100		
63 (2 1/2)	100		
50 (2)	100		
37.5 (1 1/2)	100		
25.0 (1)	100		
19.0 (3/4)	100		
12.5 (1/2)	100		
9.5 (3/8)	97		
6.3 (1/4)	52		
4.75 (No. 4)	33		
2.36 (No. 8)	27		
1.18 (No. 16)	16		
0.60 (No. 30)	12		
0.30 (No. 50)	8		
0.15 (No. 100)	3		

PERFORMANCE EXAM CHECKLIST

**METHOD A
SIEVE ANALYSIS OF FINE AND COARSE AGGREGATES
FOP FOR AASHTO T 27
MATERIALS FINER THAN 75 µm (No. 200) SIEVE IN MINERAL AGGREGATE
BY WASHING
FOP FOR AASHTO T 11**

Participant Name _____ Exam Date _____

Record the symbols “P” for passing or “F” for failing on each step of the checklist.

Procedure Element	Trial 1	Trial 2
1. Minimum sample mass meets requirement of Table 2?	_____	_____
2. Test sample dried to a constant mass by FOP for AASHTO T 255?	_____	_____
3. Test sample cooled and mass determined to nearest 0.1 percent or 0.1 g?	_____	_____
4. Sample placed in container and covered with water? (If specification requires that the amount of material finer than the 75 µm (No. 200) sieve is to be determined.)	_____	_____
5. Contents of the container vigorously agitated?	_____	_____
6. Complete separation of coarse and fine particles achieved?	_____	_____
7. Wash water poured through nested sieves such as 2 mm (No. 10) and 75 µm (No. 200)?	_____	_____
8. Operation continued until wash water is clear?	_____	_____
9. Material retained on sieves returned to washed sample?	_____	_____
10. Washed aggregate dried to a constant mass by FOP for AASHTO T 255?	_____	_____
11. Washed aggregate cooled and mass determined to nearest 0.1 percent or 0.1 g?	_____	_____
12. Sample placed in nest of sieves specified? (Additional sieves may be used to prevent overloading as allowed in FOP.)	_____	_____
13. Material sieved in verified mechanical shaker for proper time?	_____	_____
14. Mass of residue on each sieve and pan determined to 0.1 g?	_____	_____
15. Total mass of material after sieving agrees with mass before sieving to within 0.3 percent?	_____	_____

OVER

Procedure Element

Trial 1 Trial 2

16. Percentages calculated to the nearest 0.1 percent and reported to the nearest whole number, except 75 μm (No.200) which is reported to the nearest 0.1 percent?

17. Percentage calculations based on original dry sample mass?

18. Calculations performed properly?

Comments: First attempt: Pass _____ Fail _____ Second attempt: Pass _____ Fail _____

Examiner Signature _____

WAQTC #: _____

PERFORMANCE EXAM CHECKLIST

**METHOD B
SIEVE ANALYSIS OF FINE AND COARSE AGGREGATES
FOP FOR AASHTO T 27
MATERIALS FINER THAN 75 µm (No. 200) SIEVE IN MINERAL AGGREGATE
BY WASHING
FOP FOR AASHTO T 11**

Participant Name _____ Exam Date _____

Record the symbols “P” for passing or “F” for failing on each step of the checklist.

Procedure Element	Trial 1	Trial 2
1. Minimum sample mass meets requirement of Table 2?	_____	_____
2. Test sample dried to a constant mass by FOP for AASHTO T 255?	_____	_____
3. Test sample cooled and mass determined to nearest 0.1 percent or 0.1 g?	_____	_____
4. Sample placed in container and covered with water? (If specification requires that the amount of material finer than the 75 µm (No. 200) sieve is to be determined.)	_____	_____
5. Contents of the container vigorously agitated?	_____	_____
6. Complete separation of coarse and fine particles achieved?	_____	_____
7. Wash water poured through nested sieves such as 2 mm (No. 10) and 75 µm (No. 200)?	_____	_____
8. Operation continued until wash water is clear?	_____	_____
9. Material retained on sieves returned to washed sample?	_____	_____
10. Washed aggregate dried to a constant mass by FOP for AASHTO T 255?	_____	_____
11. Washed aggregate cooled and mass determined to nearest 0.1 percent or 0.1 g?	_____	_____
12. Sample placed in nest of sieves specified? (Additional sieves may be used to prevent overloading as allowed in FOP.)	_____	_____
13. Material sieved in verified mechanical shaker for proper time?	_____	_____
0.1 Mass of residue on each sieve and pan determined to the nearest percent or 0.1 g?	_____	_____
15 Total mass of material after sieving agrees with mass before sieving to within 0.3 percent?	_____	_____

OVER

Procedure Element	Trial 1	Trial 2
16. Material in pan reduced in accordance with FOP for AASHTO R 76 to a minimum sample size of 500 g and weighed to the nearest 0.1 g?	_____	_____
17. Sample placed in nest of sieves specified? (Additional sieves may be used to prevent overloading as allowed in FOP.)	_____	_____
18. Material sieved in verified mechanical shaker for proper time?	_____	_____
19. Mass of residue on each sieve and pan determined to the nearest percent or 0.1 g?	_____	_____
20. Total mass of material after sieving agrees with mass before sieving to within 0.3 percent?	_____	_____
21. Percentages calculated to the nearest 0.1 percent and reported to the nearest whole number, except 75 μm (No.200) which is reported to the nearest 0.1 percent?	_____	_____
22. Percentage calculations based on original dry sample mass?	_____	_____
23. Calculations performed properly?	_____	_____

Comments: First attempt: Pass_____Fail_____ Second attempt: Pass_____Fail_____

Examiner Signature _____

WAQTC #: _____

PERFORMANCE EXAM CHECKLIST

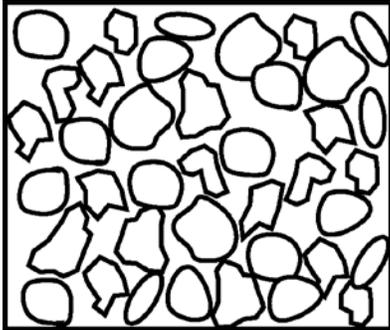
**METHOD C
SIEVE ANALYSIS OF FINE AND COARSE AGGREGATES
FOP FOR AASHTO T 27
MATERIALS FINER THAN 75 µm (No. 200) SIEVE IN MINERAL AGGREGATE
BY WASHING
FOP FOR AASHTO T 11**

Participant Name _____ Exam Date _____

Record the symbols “P” for passing or “F” for failing on each step of the checklist.

Procedure Element	Trial 2	Trial 1
1. Minimum sample mass meets requirement of Table 2?	_____	_____
2. Test sample dried to a constant mass by FOP for AASHTO T 255?	_____	_____
3. Test sample cooled and mass determined to the nearest 0.1 percent or 0.1 g?	_____	_____
4. Sample placed in nest of sieves specified? (Additional sieves may be used to prevent overloading as allowed in FOP.)	_____	_____
5. Material sieved in verified mechanical shaker for proper time?	_____	_____
6. Mass of residue on each sieve and in pan determined to the nearest 0.1 percent or 0.1 g?	_____	_____
7. Complete separation of coarse and fine particles achieved?	_____	_____
8. Total mass of material after sieving agrees with mass before sieving to within 0.3 percent?	_____	_____
9. Material in pan reduced to test size for washing in accordance with FOP for AASHTO R 76?	_____	_____
10. Mass of the fine aggregate wash sample determined to nearest 0.1 g?	_____	_____
11. Sample placed in container and covered with water?	_____	_____
12. Contents of the container vigorously agitated?	_____	_____
13. Complete separation of coarse and fine particles achieved?	_____	_____
14. Wash water poured through a set of nested sieves, such as a No. 10 over the No. 200?	_____	_____
15. Operation continued until wash water is clear?	_____	_____
16. Material retained on sieves returned to washed sample?	_____	_____

**DETERMINING THE PERCENTAGE OF FRACTURE IN COARSE AGGREGATE
FOP FOR AASHTO T 335**



Fractured and Unfractured

01

Significance

Aggregate particles can be round or smooth, as is often the case for material mined from the bottom of a river. This material has been rounded or smoothed as the stone has been transported downstream through the years. Aggregate can also be fractured, exhibiting a rough surface. Material that has been mechanically crushed has at least one fractured, rough surface per particle.

02

03

04

Fractured material often exhibits better interlocking between particles than smooth material does. This improved interlocking results in stronger material from the standpoint of supporting a load in a road base. Using stronger material results in a lesser depth of material being used. Fractured material may also be used in Portland cement (PCC) or asphalt cement concretes (ACC) to obtain a better bond between aggregate particles and the cement. Again, a stronger structure results.

05

Scope

This procedure covers the determination of the percentage, by mass, of a coarse aggregate (CA) sample that consists of fractured particles meeting specified requirements in accordance with AASHTO T 335-09.

In this FOP, a sample of aggregate is screened on the sieve separating CA and fine aggregate (FA). This sieve will be identified in the agency's specifications, but might be the 4.75 mm (No. 4) sieve. CA particles are visually evaluated to determine conformance to the specified fracture. The percentage of conforming particles, by mass, is calculated for comparison to the specifications.



Fractured aggregate

06

Apparatus

- Balance or scale: Capacity sufficient for the principle sample mass, accurate to 0.1 percent of the sample mass or readable to 0.1 g., and meeting the requirements of AASHTO M 231.
- Sieves: Meeting requirements of AASHTO M 92.
- Splitter: Meeting the requirements of the FOP for AASHTO R 76.

07

Terminology

1. Fractured Face: An angular, rough, or broken surface of an aggregate particle created by crushing, or other means. A face is considered a “fractured face” whenever one-half or more of the projected area, when viewed normal to that face, is fractured with sharp and well defined edges. This excludes small nicks.
2. Fractured particle: A particle of aggregate having at least the minimum number of fractured faces specified. (This is usually one or two.)

08

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Sample Preparation

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1. Sample and reduce the aggregate in accordance with the FOP’s for AASHTO T 2 and R 76.
2. When the specifications list only a total fracture percentage, the sample shall be prepared in accordance with Method 1. When the specifications require that the fracture be counted and reported on each sieve, the sample shall be prepared in accordance with Method 2.
3. Method 1 - Combined Fracture Determination
 - a. Dry the sample sufficiently to obtain a clean separation of CA and FA material in the sieving operation.

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- b. Sieve the sample in accordance with the FOP for AASHTO T 27/T 11 over the 4.75 mm (No. 4) sieve, or the appropriate sieve listed in the agency’s specifications for this material.

Note 1: Where necessary, wash the sample over the sieve designated for the determination of fractured particles to remove any remaining fine material, and dry to a constant mass in accordance with the FOP for AASHTO T 255.

- c. Reduce the sample using Method A – Mechanical Splitter, in accordance with the FOP for AASHTO R 76, to the appropriate test size. This test size should be slightly larger than shown in Table 1, to account for loss of fines through washing if necessary.

TABLE 1
Sample Size

Method 1 (Combined Sieve Fracture)

Nominal Maximum Size* mm (in.)	Minimum Cumulative Sample Mass Retained on 4.75 mm (No. 4) Sieve g (lb)
37.5 (1 1/2)	2500 (6)
25.0 (1)	1500 (3.5)
19.0 (3/4)	1000 (2.5)
12.5 (1/2)	700 (1.5)
9.5 (3/8)	400 (0.9)
4.75 (No. 4)	200 (0.4)

* One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained. Where large gaps in specification sieves exist, intermediate sieve(s) may be inserted to determine nominal maximum size.

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3. Method 2 – Individual Sieve Fracture Determination

- a. Dry the sample sufficiently to obtain a clean separation of CA and FA material in the sieving operation. A washed sample from the gradation determination (FOP for T 27/T 11) may be used.
- b. If not, sieve the sample in accordance with FOP for AASHTO T 27 over the sieves listed in the specifications for this material.

Note 2: If overload (buffer) sieves are used the material from that sieve must be added to the next specification sieve.

- c. The size of test sample for each sieve shall meet the minimum size shown in Table 2. Utilize the total retained sieve mass or select a representative portion from each sieve mass by splitting or quartering in accordance with the FOP for AASHTO R 76.

Note 3: Where necessary, wash the sample over the sieves designated for the determination of fractured particles to remove any remaining fine material, and dry to a constant mass in accordance with FOP for AASHTO T 255.

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TABLE 2
Sample Size
Method 2 (Individual Sieve Fracture)

Sieve Size mm (in.)	Minimum Sample Mass g (lb)
31.5 (1 1/4)	1500 (3.5)
25.0 (1)	1000 (2.2)
19.0 (3/4)	700 (1.5)
16.0 (5/8)	500 (1.0)
12.5 (1/2)	300 (0.7)
9.5 (3/8)	200 (0.5)
6.3 (1/4)	100 (0.2)
4.75 (No. 4)	100 (0.2)
2.36 (No. 8)	25 (0.1)
2.00 (No. 10)	25 (0.1)

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Note 4: If fracture is determined on a sample obtained for gradation, use the mass retained on the individual sieves, even if it is less than the minimum listed in Table 2.

16

If less than 5 percent of the total mass is retained on a single specification sieve, include that material on the next smaller specification sieve. If a smaller specification sieve does not exist, this material shall not be included in the fracture determination.

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Procedure

1. After cooling, spread the dried sample on a clean, flat surface large enough to permit careful inspection of each particle. To verify that a particle meets the fracture criteria, hold the aggregate particle so that the face is viewed directly.
2. To aid in making the fracture determination, separate the sample into three categories:
 - fractured particles meeting the criteria
 - particles not meeting the criteria
 - questionable or borderline particles
3. Determine the dry mass of particles in each category to the nearest 0.1 g.
4. Resort the questionable particles when more than 15 percent is present. Continue sorting until there is less than 15 percent in the questionable category.

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Calculation

Calculate the mass percentage of questionable fractured particles to the nearest 1 percent using the following formula:

$$\%Q = \frac{Q}{F + Q + N} \times 100 \quad 21$$

where: %Q = Percent of questionable fractured particles
 F = Mass of fractured particles
 Q = Mass of questionable particles
 N = Mass of unfractured particles

Example:

$$F = 632.6 \text{ g}, \quad Q = 97.6 \text{ g}, \quad N = 352.6 \text{ g} \quad 22$$

$$\%Q = \frac{97.6 \text{ g}}{632.6 \text{ g} + 97.6 \text{ g} + 352.6 \text{ g}} \times 100 = 9.0\% \quad \%Q = \mathbf{9\%}$$

Calculate the mass percentage of fractured faces to the nearest 1 percent using the following formula:

$$P = \frac{\frac{Q}{2} + F}{F + Q + N} \times 100 \quad 23$$

where: P = Percent of fracture

F = Mass of fractured particles

Q = Mass of questionable or borderline particles.

N = Mass of unfractured particles

Example:

$$F = 632.6 \text{ g}, \quad Q = 97.6 \text{ g}, \quad N = 352.6 \text{ g} \quad 24$$

$$P = \frac{\frac{97.6 \text{ g}}{2} + 632.6 \text{ g}}{632.6 \text{ g} + 97.6 \text{ g} + 352.6 \text{ g}} \times 100 \quad P = \mathbf{63\%}$$

25

Report

- Results on forms approved by the agency
- Sample ID
- Fractured particles to the nearest 1 percent

REVIEW QUESTIONS

1. Describe a fractured face.
2. Describe a fractured particle.
3. Is washing of the sample always required?
4. What is the difference between Method 1 and Method 2?

PERFORMANCE EXAM CHECKLIST

DETERMINING THE PERCENTAGE OF FRACTURE IN COARSE AGGREGATE FOP FOR AASHTO T 335

Participant Name _____ Exam Date _____

Record the symbols "P" for passing or "F" for failing on each step of the checklist.

Procedure Element	Trial 1	Trial 2
1. Sample properly sieved through specified sieve(s)?	_____	_____
2. Sample reduced to correct size?	_____	_____
3. Sample dried and cooled, if necessary?	_____	_____
4. Particles separated into fractured, unfractured, and questionable categories?	_____	_____
5. Dry mass of each category determined to nearest 0.1 g?	_____	_____
6. Questionable category resorted if more than 15 percent of total mass falls in that category?	_____	_____
7. Fracture calculation performed correctly?	_____	_____

Comments: First attempt: Pass ____ Fail ____ Second attempt: Pass ____ Fail ____

Examiner Signature _____

WAQTC #: _____

**PLASTIC FINES IN GRADED AGGREGATES AND SOILS BY THE USE OF THE SAND EQUIVALENT TEST
FOP FOR AASHTO T 176**

01

Significance

02

Excessive amounts of fine dust or clay-like materials – materials smaller than the 75 μm (No. 200) sieve – may cause problems in aggregate and soils. For example, road base with a high fine content may not drain freely. Trapped moisture will freeze and thaw during winter months, causing damage to the road.

03

Scope

This procedure covers the determination of plastic fines in accordance with AASHTO T 176-08. It serves as a rapid test to show the relative proportion of fine dust or clay-like materials in fine aggregates (FA) and soils.

04

Apparatus

See AASHTO T 176 for a detailed listing of sand equivalent apparatus. Note that the siphon tube and blow tube may be glass or stainless steel as well as copper.

05

- Graduated plastic cylinder.
- Rubber stopper.
- Irrigator tube.

06

- Weighted foot assembly: Having a mass of 1000 \pm 5 g. There are two models of the weighted foot assembly. The older model has a guide cap that fits over the upper end of the graduated cylinder and centers the rod in the cylinder. It is read using a slot in the centering screws. The newer model has a sand-reading indicator 254 mm (10 in.) above this point and is preferred for testing clay-like materials.
- Bottle: clean, glass or plastic, of sufficient size to hold working solution
- Siphon assembly: The siphon assembly will be fitted to a 4 L (1 gal.) bottle of working



Apparatus

calcium chloride solution placed on a shelf 915 ±25 mm (36 ±1 in.) above the work surface.

- Measuring can: Having a capacity of 85 ±5 mL (3 oz.).
- Funnel: Having a wide-mouth for transferring sample into the graduated cylinder.
- Quartering cloth: 600 mm (2 ft) square nonabsorbent cloth, such as plastic or oilcloth.
- Mechanical splitter: See FOP for AASHTO R 76.
- Strike-off bar: A straightedge or spatula.
- Clock or watch reading in minutes and seconds.
- Manually-operated sand equivalent shaker: Capable of producing an oscillating motion at a rate of 100 complete cycles in 45 ±5 seconds, with a hand assisted half stroke length of 127 ±5 mm (5 ±0.2 in.). It may be held stable by hand during the shaking operation. It is recommended that this shaker be fastened securely to a firm and level mount, by bolts or clamps, if a large number of determinations are to be made.
- Mechanical shaker: See AASHTO T 176 for equipment and procedure.
- Oven: Capable of maintaining a temperature of 110 ±5°C (230 ±9°F).
- Thermometer: Calibrated liquid-in-glass or electronic digital type designed for total immersion and accurate to 0.1°C (0.2°F).

Materials

07

- Stock calcium chloride solution: Obtain commercially prepared calcium chloride stock solution meeting AASHTO requirements.
- Working calcium chloride solution: Dilute one 3 oz. measuring can (85 ±5 mL) of stock calcium chloride solution with 3.8 L (1 gal)

distilled or demineralized water. Thoroughly mix the solution by filling the bottle with 2 L (1/2 gal) of water. Add the stock solution and agitate vigorously for 1 to 2 minutes. Add the remainder of the water, approximately 2 L (1/2 gal.). Repeat the agitation process. The shelf life of the working solution is approximately 30 days. Discard working solutions more than 30 days old.

Note 1: The graduated cylinder filled to 4.4 in. contains 88 mL and may be used to measure the stock solution.

Note 2: Tap water may be used if it is proven to be non-detrimental to the test and if it is allowed by the agency.

Control

08

The temperature of the working solution should be maintained at $22 \pm 3^{\circ}\text{C}$ ($72 \pm 5^{\circ}\text{F}$) during the performance of the test. If field conditions preclude the maintenance of the temperature range, reference samples should be submitted to the Central/Regional Laboratory, as required by the agency, where proper temperature control is possible. Samples that meet the minimum sand equivalent requirement at a working solution temperature outside of the temperature range need not be subject to reference testing.

Sample Preparation

09

1. Obtain the sample in accordance with the FOP for AASHTO T 2 and reduce in accordance with the FOP for AASHTO R 76.
2. Prepare sand equivalent test samples from the material passing the 4.75 mm (No. 4) sieve. If the material is in clods, break it up and rescreen it over a 4.75 mm (No. 4) sieve. All fines shall be cleaned from particles retained on the 4.75 mm (No. 4) sieve and included with the material passing that sieve.
3. Split or quarter 1000 to 1500 g of material from the portion passing the 4.75 mm (No. 4) sieve. Use extreme care to obtain a truly representative portion of the original sample.

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Note 3: Experiments show that, as the amount of material being reduced by splitting or quartering is decreased, the accuracy of providing representative portions is reduced. It is imperative that the sample be split or quartered carefully. When it appears necessary, dampen the material before splitting or quartering to avoid segregation or loss of fines.

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Note 4: All tests, including reference tests, will be performed using Alternative Method No. 2 as described in AASHTO T 176, unless otherwise specified.

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- 4. The sample must have the proper moisture content to achieve reliable results. This condition is determined by tightly squeezing a small portion of the thoroughly mixed sample in the palm of the hand. If the cast that is formed permits careful handling without breaking, the correct moisture content has been obtained.



Checking a cast

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Note 5: Clean sands having little 75 µm (No. 200), such as sand for Portland Cement Concrete (PCC), may not form a cast.

If the material is too dry, the cast will crumble and it will be necessary to add water and remix and retest until the material forms a cast. When the moisture content is altered to provide the required cast, the altered sample should be placed in a pan, covered with a lid or with a damp cloth that does not touch the material, and allowed to stand for a minimum of 15 minutes. Samples that have been sieved without being air-dried and still retain enough natural moisture are exempted from this requirement.

If the material shows any free water, it is too wet to test and must be drained and air dried. Mix frequently to ensure uniformity. This drying process should continue until squeezing provides the required cast.

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- 5. Place the sample on the quartering cloth and mix by alternately lifting each corner of the cloth and pulling it over the sample toward the diagonally opposite corner, being careful to keep the top of the cloth parallel to the bottom, thus causing the material to be rolled. When the material appears homogeneous, finish the



Filling measuring can



Siphoning solution into cylinder



Mechanical Shaker

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mixing with the sample in a pile near the center of the cloth.

6. Fill the measuring can by pushing it through the base of the pile while exerting pressure with the hand against the pile on the side opposite the measuring can. As the can is moved through the pile, hold enough pressure with the hand to cause the material to fill the tin to overflowing. Press firmly with the palm of the hand, compacting the material, and place the maximum amount in the can. Strike off the can level full with the straightedge or spatula.
7. When required, repeat steps 5 and 6 to obtain additional samples.

Procedure

1. Start the siphon by forcing air into the top of the solution bottle through the tube while the pinch clamp is open.
2. Siphon 101.6 ±2.5 mm (4 ±0.1 in.) of working calcium chloride solution into the plastic cylinder. Pour the prepared test sample from the measuring can into the plastic cylinder, using the funnel to avoid spilling. Tap the bottom of the cylinder sharply on the heel of the hand several times to release air bubbles and to promote thorough wetting of the sample.
3. Allow the wetted sample to stand undisturbed for 10 ±1 minutes. At the end of the 10-minute period, stopper the cylinder and loosen the material from the bottom by simultaneously partially inverting and shaking the cylinder.
4. After loosening the material from the bottom of the cylinder, shake the cylinder and contents by any one of the following methods:
 - a. Mechanical Method – Place the stoppered cylinder in the mechanical shaker, set the timer, and allow the machine to shake the cylinder and contents for 45 ±1 seconds.

Caution: Agencies may require additional operator qualifications for the next two methods.



Manually-operated shaker

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- b. Manually-operated Shaker Method – Secure the stoppered cylinder in the three spring clamps on the carriage of the manually-operated sand equivalent shaker and set the stroke counter to zero. Stand directly in front of the shaker and force the pointer to the stroke limit marker painted on the backboard by applying an abrupt horizontal thrust to the upper portion of the right hand spring strap.

Remove the hand from the strap and allow the spring action of the straps to move the carriage and cylinder in the opposite direction without assistance or hindrance. Apply enough force to the right hand spring steel strap during the thrust portion of each stroke to move the pointer to the stroke limit marker by pushing against the strap with the ends of the fingers to maintain a smooth oscillating motion. The center of the stroke limit marker is positioned to provide the proper stroke length and its width provides the maximum allowable limits of variation.

Proper shaking action is accomplished when the tip of the pointer reverses direction within the marker limits. Proper shaking action can best be maintained by using only the forearm and wrist action to propel the shaker.

Continue shaking for 100 strokes.

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- c. Hand Method – Hold the cylinder in a horizontal position and shake it vigorously in a horizontal linear motion from end to end. Shake the cylinder 90 cycles in approximately 30 seconds using a throw of 229 mm ±25 mm (9 ±1 in.). A cycle is defined as a complete back and forth motion. To properly shake the cylinder at this speed, it will be necessary for the operator to shake with the forearms only, relaxing the body and shoulders.



Hand shaking

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- 5. Set the cylinder upright on the work table and remove the stopper.

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6. Insert the irrigator tube in the cylinder and rinse material from the cylinder walls as the irrigator is lowered. Force the irrigator through the material to the bottom of the cylinder by applying a gentle stabbing and twisting action while the working solution flows from the irrigator tip. Work the irrigator tube to the bottom of the cylinder as quickly as possible, since it becomes more difficult to do this as the washing proceeds. This flushes the fine material into suspension above the coarser sand particles.

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Continue to apply a stabbing and twisting action while flushing the fines upward until the cylinder is filled to the 381 mm (15 in.) mark. Then raise the irrigator slowly without shutting off the flow so that the liquid level is maintained at about 381 mm (15 in.) while the irrigator is being withdrawn. Regulate the flow just before the irrigator is entirely withdrawn and adjust the final level to 381 mm (15 in.).

Note 6: Occasionally the holes in the tip of the irrigator tube may become clogged by a particle of sand. If the obstruction cannot be freed by any other method, use a pin or other sharp object to force it out (such as a tooth pick), using extreme care not to enlarge the size of the opening. Also, keep the tip sharp as an aid to penetrating the sample.

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7. Allow the cylinder and contents to stand undisturbed for 20 minutes \pm 15 seconds. Start timing immediately after withdrawing the irrigator tube.

Note 7: Any vibration or movement of the cylinder during this time will interfere with the normal settling rate of the suspended clay and will cause an erroneous result.

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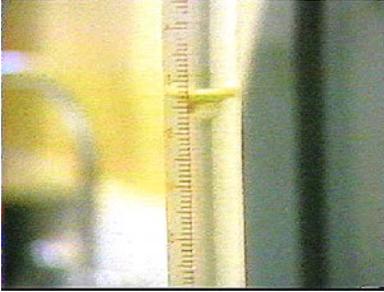
8. Clay and sand readings:
 a. At the end of the 20-minute sedimentation period, read and record the level of the top of the clay suspension. This is referred to as the clay reading.

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Note 8: If no clear line of demarcation has formed at the end of the 20-minute sedimentation period, allow the sample to stand undisturbed until a clay reading can be obtained, then immediately read and record the level of the top of the clay suspension and the total sedimentation time. If



Reading



Sand reading

the total sedimentation time exceeds 30 minutes, rerun the test using three individual samples of the same material. Read and record the clay column height of the sample requiring the shortest sedimentation period only. Once a sedimentation time has been established, subsequent tests will be run using that time. The time will be recorded along with the test results on all reports.

- b. After the clay reading has been taken, place the weighted foot assembly over the cylinder and gently lower the assembly until it comes to rest on the sand. Do not allow the indicator to hit the mouth of the cylinder as the assembly is being lowered. Subtract 254 mm (10 in.) from the level indicated by the extreme top edge of the indicator and record this value as the sand reading.
- c. If clay or sand readings fall between 2.5 mm (0.1 in.) graduations, record the level of the higher graduation as the reading. For example, a clay reading that appears to be 7.95 would be recorded as 8.0; a sand reading that appears to be 3.22 would be recorded as 3.3.
- d. If two Sand Equivalent (SE) samples are run on the same material and the second varies by more than ± 4 , based on the first cylinder results, additional tests shall be run.
- e. If three or more Sand Equivalent (SE) samples are run on the same material, average the results. If an individual result varies by more than ± 4 , based on the average result, additional tests shall be run.

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Calculations

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1. Calculate the SE to the nearest 0.1 using the following formula:

$$SE = \frac{\text{Sand Reading}}{\text{Clay Reading}} \times 100$$

For example: Sand Reading = 3.3 and Clay Reading = 8.0

$$SE = \frac{3.3}{8.0} \times 100 = 41.25 \text{ or } 41.3$$

Note 9: This example reflects the use of equipment made with English units. At this time, equipment made with metric units is not available.

2. Report the SE as the next higher whole number. In the example above, the 41.3 would be reported as 42. An SE of 41.0 would be reported as 41.
3. In determining the average of the two or more samples, raise each calculated SE value to the next higher whole number before averaging. For example, calculated values of 41.3 and 42.8 would be reported as 42 and 43, respectively.

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Then average the two values:

$$\frac{42 + 43}{2} = 42.5$$

If the average value is not a whole number, raise it to the next higher whole number, or in this case: 43.

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Report

- Results on forms approved by the agency
- Sample ID
- Results to the whole number.
- Sedimentation time if over 20 minutes.

Tips!

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- Make sure you have enough working solution before you start the procedure.
- Be careful when reducing and dampen the material, if necessary, to avoid segregation or loss of fines.
- Make sure both holes in irrigator tube are clear.
- 100 percent crushed material interlocks when inserting the irrigator tube the first time. You must apply a firm, twisting action to lower the irrigator tube in subsequent flushings.
- Do not run equipment that causes vibrations during settling.

REVIEW QUESTIONS

1. Describe the proper way to acquire the SE test sample.

2. After tapping the bottom of the cylinder to release air bubbles, how long should the wetted sample stand?

3. What happens if no clear line of demarcation occurs in 20 minutes? In 30 minutes?

4. Describe how the rounding of numbers in this FOP differs from the standard mathematical approach.

5. How much material passing the 4.75 mm (No. 4) sieve is required for an SE test?

6. Explain the difference in calculating two cylinder results and three or more cylinder results.

PERFORMANCE EXAM CHECKLIST

**PLASTIC FINES IN GRADED AGGREGATES AND SOILS BY THE USE OF THE SAND EQUIVALENT TEST
FOP FOR AASHTO T 176**

Participant Name _____ Exam Date _____

Record the symbols “P” for passing or “F” for failing on each step of the checklist.

Procedure Element	Trial 1	Trial 2
Sample Preparation		
1. Sample passed through 4.75 mm (No. 4) sieve?	_____	_____
2. Material in clods broken up and re-screened?	_____	_____
3. Split or quarter 1,000 to 1,500g of material passing the 4.75 mm (No. 4) sieve? NOTE: If necessary, the material may be dampened before splitting to avoid segregation or loss of fines.	_____	_____
4. No fines lost?	_____	_____
5. Working solution dated?	_____	_____
6. Temperature of working solution 22 ±3°C (72 ±5°F)?	_____	_____
7. Working calcium chloride solution 915 ±25 mm (36 ±1in) above the work surface?	_____	_____
8. 101.6 ±2.5 mm (4 ±0.1in) working calcium chloride solution siphoned into cylinder?	_____	_____
9. Material checked for moisture condition by tightly squeezing small portion in palm of hand and forming a cast?	_____	_____
10. Sample at proper water content?		
a. If too dry (cast crumbles easily) water added, re-mixed, covered, and allowed to stand for at least 15 minutes?	_____	_____
b. If too wet (shows free water) sample drained, air dried and mixed frequently?	_____	_____
11. Sample placed on splitting cloth and mixed by alternately lifting each corner of the cloth and pulling it over the sample toward diagonally opposite corner, causing material to be rolled?	_____	_____
12. Is material thoroughly mixed?	_____	_____
13. When material appears to be homogeneous, mixing finished with sample in a pile near center of cloth?	_____	_____
14. Fill the 85 mL (3 oz) tin by pushing through base of pile with other hand on opposite side of pile?	_____	_____
15. Material fills tin to overflowing?	_____	_____

OVER

Procedure Element	Trial 1	Trial 2
16. Material compacted into tin with palm of hand?	_____	_____
17. Tin struck off level full with spatula or straightedge?	_____	_____
18. Prepared sample funneled into cylinder with no loss of fines?	_____	_____
19. Bottom of cylinder tapped sharply on heel of hand several times to release air bubbles?	_____	_____
20. Wetted sample allowed to stand undisturbed for 10 min. ±1 min.?	_____	_____
21. Cylinder stoppered and material loosened from bottom by shaking?	_____	_____
22. Stoppered cylinder placed properly in mechanical shaker and cylinder shaken 45 ±1 seconds?	_____	_____
23. Following shaking, cylinder set vertical on work surface and stopper removed?	_____	_____
24. Irrigator tube inserted in cylinder and material rinsed from cylinder walls as irrigator is lowered?	_____	_____
25. Irrigator tube forced through material to bottom of cylinder by gentle stabbing and twisting action?	_____	_____
26. Stabbing and twisting motion applied until cylinder filled to 381 mm (15 in.) mark?	_____	_____
27. Liquid raised and maintained at 381 mm (15 in.) mark while irrigator is being withdrawn?	_____	_____
28. Liquid at the 381 mm (15 in.) mark?	_____	_____
29. Contents let stand 20 minutes ±15 seconds?	_____	_____
30. Timing started immediately after withdrawal of irrigator?	_____	_____
31. No vibration or disturbance of the sample?	_____	_____
32. Readings taken at 20 minutes or up to 30 minutes, when a definite line appears?	_____	_____
33. Clay level correctly read, rounded, and recorded?	_____	_____
34. Weighted foot assembly lowered into cylinder without hitting mouth of cylinder?	_____	_____
35. Sand level correctly read, rounded, and recorded?	_____	_____
36. Calculations performed correctly?	_____	_____

Comments: First attempt: Pass_____Fail_____ Second attempt: Pass_____Fail_____

Examiner Signature _____

WAQTC #: _____

**APPENDIX A
FIELD OPERATING PROCEDURES - SHORT FORMS**

<u>Chapter</u>	<u>Section</u>
9	AASHTO T 2 Sampling of Aggregates
10	AASHTO R 76 Reducing Samples of Aggregate to Testing Size
11	AASHTO T 255 Total Evaporable Moisture Content of Aggregate by Drying
12	AASHTO T 27 Sieve Analysis of Fine and Coarse Aggregates; AASHTO T 11 Materials Finer than 75 μm (No. 200) Sieve in Mineral Aggregates by Washing
13	AASHTO T 335 Determining the Percentage of Fracture in Coarse Aggregate
14	AASHTO T 176 Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test

SAMPLING OF AGGREGATES FOP FOR AASHTO T 2

Scope

This procedure covers sampling of coarse, fine, or a combination of coarse and fine aggregates (CA and FA) in accordance with AASHTO T 2-91. Sampling from conveyor belts, transport units, roadways, and stockpiles is covered.

Apparatus

- Shovels or scoops, or both
- Sampling tubes of acceptable dimensions
- Mechanical sampling systems: normally a permanently attached device that allows a sample container to pass perpendicularly through the entire stream of material or diverts the entire stream of material into the container by manual, hydraulic, or pneumatic operation
- Belt template
- Sampling containers

Procedure – General

Sampling is as important as testing. The technician shall use every precaution to obtain samples that are representative of the material. Determine the time or location for sampling in a random manner.

1. Wherever samples are taken, obtain multiple increments of approximately equal size.
2. Mix the increments thoroughly to form a field sample that meets or exceeds the minimum mass recommended in Table 1.

TABLE 1
Recommended Sample Sizes

Nominal Maximum Size* mm (in.)	Minimum Mass g (lb)
2.36 (No. 8)	10,000 (25)
4.75 (No. 4)	10,000 (25)
9.5 (3/8)	10,000 (25)
12.5 (1/2)	15,000 (35)
19.0 (3/4)	25,000 (55)
25.0 (1)	50,000 (110)
37.5 (1 1/2)	75,000 (165)
50 (2)	100,000 (220)
63 (2 1/2)	125,000 (275)
75 (3)	150,000 (330)
90 (3 1/2)	175,000 (385)

* One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained. Where large gaps in specification sieves exist, intermediate sieve(s) may be inserted to determine nominal maximum size. Maximum size is one size larger than nominal maximum size.

Note 1: Sample size is based upon the test(s) required. As a general rule the field sample size should be such that, when split twice will provide a testing sample of proper size. For example the sample size may be four times that shown in Table 2 of the FOP for AASHTO T 27/T 11, if that mass is more appropriate.

Procedure – Specific Situations

Conveyor Belts

Avoid sampling at the beginning or end of the aggregate run due to the potential for segregation. Be careful when sampling in the rain. Make sure to capture fines that may stick to the belt or that the rain tends to wash away.

Method A (From the Belt)

1. Stop the belt.
2. Set the sampling template in place on the belt, avoiding intrusion by adjacent material.
3. Remove the material from inside the template, including all fines.
4. Obtain at least three approximately equal increments.
5. Combine the increments to form a single sample.

Method B (From the Belt Discharge)

1. Pass a sampling device through the full stream of the material as it runs off the end of the conveyor belt. The sampling device may be manually, semi-automatic or automatically powered.
2. The sampling device shall pass through the stream at least twice, once in each direction, without overfilling while maintaining a constant speed during the sampling process.
3. When emptying the sampling device into the container, include all fines.
4. Combine the increments to form a single sample.

Transport Units

1. Visually divide the unit into four quadrants.
2. Identify one sampling location in each quadrant.
3. Dig down and remove approximately 0.3 m (1 ft.) of material to avoid surface segregation. Obtain each increment from below this level.
4. Combine the increments to form a single sample.

Roadways**Method A (Berm or Windrow)**

1. Obtain sample before spreading.
2. Take the increments from at least three random locations along the fully-formed windrow or berm. Do not take the increments from the beginning or the end of the windrow or berm.
3. Obtain full cross-section samples of approximately equal size at each location. Take care to exclude the underlying material.
4. Combine the increments to form a single sample.

Note 2: Obtaining samples from berms or windrows may yield extra-large samples and may not be the preferred sampling location.

Method B (In-Place)

1. Obtain sample after spreading and before compaction.

2. Take the increments from at least three random locations.
3. Obtain full-depth increments of approximately equal size from each location. Take care to exclude the underlying material.
4. Combine the increments to form a single sample.

Stockpiles

Method A– Loader sampling

1. Direct the loader operator to enter the stockpile with the bucket at least 150 mm (6 in.) above ground level without contaminating the stockpile.
2. Discard the first bucketful.
3. Have the loader re-enter the stockpile and obtain a full loader bucket of the material, tilt the bucket back and up.
4. Form a small sampling pile at the base of the stockpile by gently rolling the material out of the bucket with the bucket just high enough to permit free-flow of the material. (Repeat as necessary.)
5. Create a flat surface by having the loader back drag the small pile.
6. Visually divide the flat surface into four quadrants.
7. Collect an increment from each quadrant by fully inserting the shovel into the flat pile as vertically as possible, take care to exclude the underlying material, roll back the shovel and lift the material slowly out of the pile to avoid material rolling off the shovel.

Method B – Stockpile Face Sampling

1. Create horizontal surfaces with vertical faces in the top, middle, and bottom third of the stockpile with a shovel or loader.
2. Prevent continued sloughing by shoving a flat board against the vertical face. Sloughed material will be discarded to create the horizontal surface.
3. Obtain sample from the horizontal surface as close to the intersection as possible of the horizontal and vertical faces.
4. Obtain at least one increment of equal size from each of the top, middle, and bottom thirds of the pile.

5. Combine the increments to form a single sample.

Method C – Alternate Tube Method (Fine Aggregate)

1. Remove the outer layer that may have become segregated.
2. Using a sampling tube, obtain one increment of equal size from a minimum of five random locations on the pile.
3. Combine the increments to form a single sample.

Note 3: Obtaining samples at stockpiles should be avoided whenever possible due to problems involved in obtaining a representative gradation of material.

Report

- On forms approved by the agency
- Date
- Time
- Sample ID
- Location
- Quantity represented

REDUCING SAMPLES OF AGGREGATES TO TESTING SIZE FOP FOR AASHTO R 76

Scope

This procedure covers the reduction of samples to the appropriate size for testing in accordance with AASHTO R 76-16. Techniques are used that minimize variations in characteristics between test samples and field samples. Method A (Mechanical Splitter) and Method B (Quartering) are covered.

This FOP applies to fine aggregate (FA), coarse aggregate (CA), and mixes of the two (FA / CA), and may also be used on soils.

Apparatus

Method A – Mechanical Splitter

Splitter chutes:

- Even number of equal width chutes
- Discharge alternately to each side
- Minimum of 8 chutes total for CA and FA / CA , 12 chutes total for FA
- Width:
 - Minimum 50 percent larger than largest particle
 - Maximum chute width of 19 mm (3/4 in.) for fine aggregate passing the 9.5 mm (3/8 in.) sieve

Feed control:

- Hopper or straightedge pan with a width equal to or slightly less than the overall width of the assembly of chutes
- Capable of feeding the splitter at a controlled rate

Splitter receptacles / pans:

- Capable of holding two halves of the sample following splitting

The splitter and accessory equipment shall be so designed that the sample will flow smoothly without restriction or loss of material.

Method B – Quartering

- Straightedge scoop, shovel, or trowel
- Broom or brush
- Canvas or plastic sheet, approximately 2 by 3 m (6 by 9 ft)

Method Selection

Samples of CA may be reduced by either Method A or Method B.

Samples of FA which are drier than the saturated surface dry (SSD) condition, as described in AASHTO T 84, shall be reduced by a mechanical splitter according to Method A. As a quick approximation, if the fine aggregate will retain its shape when molded with the hand, it is wetter than SSD.

Samples of FA / CA which are drier than SSD may be reduced by Method A or Method B.

Samples of FA and FA / CA that are at SSD or wetter than SSD shall be reduced by Method B, or the entire sample may be dried to the SSD condition – using temperatures that do not exceed those specified for any of the tests contemplated – and then reduced to test sample size using Method A.

Table 1

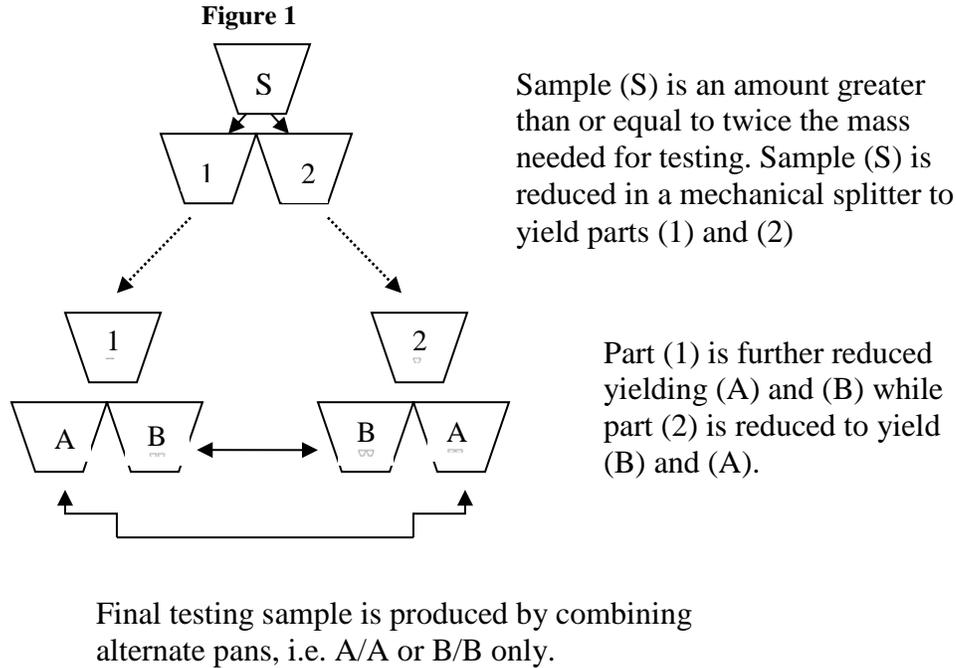
	Drier than SSD	Wetter than SSD
Fine Aggregate (FA)	Method A (Mechanical)	Method B (Quartering)
Mixture of FA/CA	Either Method	Method B (Quartering)
Coarse Aggregate (CA)	Either Method	Either Method

Procedure

Method A – Mechanical Splitter

1. Place the sample in the hopper or pan and uniformly distribute it from edge to edge so that approximately equal amounts flow through each chute. The rate at which the sample is introduced shall be such as to allow free flowing through the chutes into the pans below.

2. Reduce the sample from one of the two pans as many times as necessary to reduce the sample to meet the minimum size specified for the intended test. The portion of the material collected in the other pan may be reserved for reduction in size for other tests.
3. As a check for effective reduction, determine the mass of each reduced portion. If the percent difference of the two masses is greater than 5 percent, corrective action must be taken. In lieu of the check for effective reduction, use the method illustrated in Figure 1.



Calculation

$$\frac{\text{Smaller Mass}}{\text{Larger Mass}} = \text{Ratio} \quad (1 - \text{ratio}) \times 100 = \% \text{ Difference}$$

Splitter check: 5127 g total sample mass

Splitter pan #1: 2583 g

Splitter pan #2: 2544 g

$$\frac{2544 \text{ g}}{2583 \text{ g}} = 0.985 \quad (1 - 0.985) \times 100 = 1.5\%$$

Procedure

Method B – Quartering

Use either of the following two procedures or a combination of both.

Procedure # 1: Quartering on a clean, hard, level surface:

1. Place the sample on a hard, clean, level surface where there will be neither loss of material nor the accidental addition of foreign material.
2. Mix the material thoroughly by turning the entire sample over a minimum of four times. With the last turning, shovel the entire sample into a conical pile by depositing each shovelful on top of the preceding one.
3. Flatten the conical pile to a uniform thickness and diameter by pressing down with a shovel. The diameter should be four to eight times the thickness.
4. Divide the flattened pile into four approximately equal quarters with a shovel or trowel.
5. Remove two diagonally opposite quarters, including all fine material, and brush the cleared spaces clean.
6. Successively mix and quarter the remaining material until the sample is reduced to the desired size.
7. The final test sample consists of two diagonally opposite quarters.

Procedure # 2: Quartering on a canvas or plastic sheet:

1. Place the sample on the sheet.
2. Mix the material thoroughly a minimum of four times by pulling each corner of the sheet horizontally over the sample toward the opposite corner. After the last turn, form a conical pile.
3. Flatten the conical pile to a uniform thickness and diameter by pressing down with a shovel. The diameter should be four to eight times the thickness.
4. Divide the flattened pile into four approximately equal quarters with a shovel or trowel, or, insert a stick or pipe beneath the sheet and under the center of the pile, then lift both ends of the stick, dividing the sample into two roughly equal parts. Remove the stick leaving a fold of the sheet between the divided portions. Insert the stick under the center of the pile at right angles to the first division and again lift both ends of the stick, dividing the sample into four roughly equal quarters.

5. Remove two diagonally opposite quarters, being careful to clean the fines from the sheet.
6. Successively mix and quarter the remaining material until the sample size is reduced to the desired size.
7. The final test sample consists of two diagonally opposite quarters.

TOTAL EVAPORABLE MOISTURE CONTENT OF AGGREGATE BY DRYING FOP FOR AASHTO T 255

Scope

This procedure covers the determination of moisture content of aggregate in accordance with AASHTO T 255-00. It may also be used for other construction materials.

Overview

Moisture content is determined by comparing the wet mass of a sample and the mass of the sample after drying to constant mass. The term constant mass is used to define when a sample is dry.

Constant mass – the state at which a mass does not change more than a given percent, after additional drying for a defined time interval, at a required temperature.

Apparatus

- Balance or scale: Capacity sufficient for the principle sample mass, accurate to 0.1 percent of sample mass or readable to 0.1 g, meeting the requirements of AASHTO M 231.
- Containers: clean, dry and capable of being sealed
- Suitable drying containers
- Microwave safe container with ventilated lids
- Heat source, controlled
 - Forced draft oven
 - Ventilated oven
 - Convection oven
- Heat source, uncontrolled
 - Infrared heater, hot plate, fry pan, or any other device/method that will dry the sample without altering the material being dried
 - Microwave oven (900 watts minimum)

- Hot pads or gloves
- Utensils such as spoons

Sample Preparation

In accordance with the FOP for AASHTO T 2 obtain a representative sample in its existing condition. The representative sample size is based on Table 1 or other information that may be specified by the agency

TABLE 1
Sample Sizes for Moisture Content of Aggregate

Nominal Maximum Size* mm (in.)	Minimum Sample Mass g (lb)
4.75 (No. 4)	500 (1.1)
9.5 (3/8)	1500 (3.3)
12.5 (1/2)	2000 (4)
19.0 (3/4)	3000 (7)
25.0 (1)	4000 (9)
37.5 (1 1/2)	6000 (13)
50 (2)	8000 (18)
63 (2 1/2)	10,000 (22)
75 (3)	13,000 (29)
90 (3 1/2)	16,000 (35)
100 (4)	25,000 (55)
150 (6)	50,000 (110)

* One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained. Where large gaps in specification sieves exist, intermediate sieve(s) may be inserted to determine nominal maximum size.

Immediately seal or cover samples to prevent any change in moisture content or follow the steps in “Procedure.”

Procedure

Determine all masses to the nearest 0.1 percent of the sample mass or to the nearest 0.1 g.

When determining the mass of hot samples or containers or both, place and tare a buffer between the sample container and the balance. This will eliminate damage to or interference with the operation of the balance or scale.

1. Determine and record the mass of the container (and lid for microwave drying).

2. Place the wet sample in the container.
 - a. For oven(s), hot plates, infrared heaters, etc.: Spread the sample in the container.
 - b. For microwave oven: Heap sample in the container; cover with ventilated lid.
 3. Determine and record the total mass of the container and wet sample.
 4. Determine and record the wet mass of the sample by subtracting the container mass determined in Step 1 from the mass of the container and sample determined in Step 3.
 5. Place the sample in one of the following drying apparatus :
 - a. Controlled heat source (oven): at $110 \pm 5^{\circ}\text{C}$ ($230 \pm 9^{\circ}\text{F}$).
 - b. Uncontrolled heat source (Hot plate, infrared heater, etc.): Stir frequently to avoid localized overheating.
 6. Dry until sample appears moisture free.
 7. Determine mass of sample and container.
 8. Determine and record the mass of the sample by subtracting the container mass determined in Step 1 from the mass of the container and sample determined in Step 7.
 9. Return sample and container to the heat source for additional drying.
 - a. Controlled (oven): 30 minutes
 - b. Uncontrolled (Hot plate, infrared heater, etc.): 10 minutes
 - c. Uncontrolled (Microwave oven): 2 minutes
- Caution:** Some minerals in the sample may cause the aggregate to overheat, altering the aggregate gradation.
10. Determine mass of sample and container.
 11. Determine and record the mass of the sample by subtracting the container mass determined in Step 1 from the mass of the container and sample determined in Step 10.
 12. Determine percent change by subtracting the new mass determination (M_n) from the previous mass determination (M_p) divide by the previous mass determination (M_p) multiply by 100.

13. Continue drying, performing steps 9 through 12, until there is less than a 0.10 percent change after additional drying time.
14. Constant mass has been achieved, sample is defined as dry.
15. Allow the sample to cool. Determine and record the total mass of the container and dry sample.
16. Determine and record the dry mass of the sample by subtracting the mass of the container determined in Step 1 from the mass of the container and sample determined in Step 15.
17. Determine and record percent moisture by subtracting the final dry mass determination (M_D) from the initial wet mass determination (M_W) divide by the final dry mass determination (M_D) multiply by 100.

**Table 2
Methods of Drying**

Heat Source	Specific Instructions	Drying intervals to achieve constant mass (minutes)
Controlled: Forced Draft Oven (preferred), Ventilated Oven, or Convection Oven	110 ±5°C (230 ±9°F)	30
Uncontrolled:		
Hot plate, Infrared heater, etc.	Stir frequently	10
Microwave	Heap sample and cover with ventilated lid	2

Calculation

Constant Mass:

Calculate constant mass using the following formula:

$$\frac{M_p - M_n}{M_p} \times 100 = \% \text{ Change}$$

Where:

M_p = previous mass measurement

M_n = new mass measurement

Example:

Mass of container: 1232.1 g

Mass of container after first drying cycle: 2637.2 g

Mass, M_p , of possibly dry sample: 2637.2 g - 1232.1 g = 1405.1 g

Mass of container and dry sample after second drying cycle: 2634.1 g

Mass, M_n , of dry sample: 2634.1 g - 1232.1 g = 1402.0 g

$$\frac{1405.1 \text{ g} - 1402.0 \text{ g}}{1405.1 \text{ g}} \times 100 = 0.22\%$$

0.22 percent is not less than 0.10 percent, so continue drying

Mass of container and dry sample after third drying cycle: 2633.0 g

Mass, M_n , of dry sample: 2633.0 g - 1232.1 g = 1400.9 g

$$\frac{1402.0 \text{ g} - 1400.9 \text{ g}}{1402.0 \text{ g}} \times 100 = 0.08\%$$

0.08 percent is less than 0.10 percent, so constant mass has been reached

Moisture Content:

Calculate the moisture content, w , as a percent, using the following formula:

$$\frac{M_W - M_D}{M_D} \times 100 = \% \text{ Moisture Content}$$

where:

M_W = wet mass

M_D = dry mass

Example:

Mass of container: 1232.1 g

Mass of container and wet sample: 2764.7 g

Mass, M_W , of wet sample: 2764.7 g - 1232.1 g = 1532.6 g

Mass of container and dry sample (COOLED): 2633.0 g

Mass, M_D , of dry sample: 2633.0 g - 1232.1 g = 1400.9 g

$$w = \frac{1532.6\text{g} - 1400.9\text{g}}{1400.9\text{g}} \times 100 = \frac{131.7\text{g}}{1400.9\text{g}} = 9.40\% \text{ rounded to } 9.4\%$$

Report

- Results on forms approved by the agency
- Sample ID
- M_W , wet mass
- M_D , dry mass
- w , moisture content to nearest 0.1 percent

SIEVE ANALYSIS OF FINE AND COARSE AGGREGATES FOP FOR AASHTO T 27

MATERIALS FINER THAN 75 µm (No. 200) SIEVE IN MINERAL AGGREGATE BY WASHING FOP FOR AASHTO T 11

Scope

Sieve analysis determines the gradation or distribution of aggregate particle sizes within a given sample.

Accurate determination of material smaller than 75 µm (No. 200) cannot be made with AASHTO T 27 alone. If quantifying this material is required, it is recommended that AASHTO T 27 be used in conjunction with AASHTO T 11.

This FOP covers sieve analysis in accordance with AASHTO T 27-14 and materials finer than 75 µm (No. 200) in accordance with AASHTO T 11-05 performed in conjunction with AASHTO T 27. The procedure includes three method choices: A, B, and C.

Apparatus

- Balance or scale: Capacity sufficient for the masses shown in Table 1, accurate to 0.1 percent of the sample mass or readable to 0.1 g, and meeting the requirements of AASHTO M 231
- Sieves: Meeting the requirements of AASHTO M 92
- Mechanical sieve shaker: Meeting the requirements of AASHTO T 27
- Suitable drying equipment (see FOP for AASHTO T 255)
- Containers and utensils: A pan or vessel of a size sufficient to contain the sample covered with water and to permit vigorous agitation without loss of any part of the sample or water
- Optional mechanical washing device

Sample Sieving

- In all procedures, it is required to shake the sample over nested sieves. Sieves are selected to furnish information required by specification.
- The sieves are nested in order of decreasing size from the top to the bottom and the sample, or a portion of the sample, is placed on the top sieve.

- Sieves are shaken in a mechanical shaker for approximately 10 minutes, or the minimum time determined to provide complete separation for the sieve shaker being used. As established by the Time Evaluation.

Time Evaluation

The sieving time for each mechanical sieve shaker shall be checked at least annually to determine the time required for complete separation of the sample by the following method:

1. Shake the sample over nested sieves for approximately 10 minutes.
2. Provide a snug-fitting pan and cover for each sieve, and hold in a slightly inclined position in one hand.
3. Hand-shake each sieve by striking the side of the sieve sharply and with an upward motion against the heel of the other hand at the rate of about 150 times per minute, turning the sieve about one sixth of a revolution at intervals of about 25 strokes.

If more than 0.5 percent by mass of the total sample prior to sieving passes any sieve after one minute of continuous hand sieving adjust shaker time and re-check.

In determining sieving time for sieve sizes larger than 4.75 mm (No. 4), limit the material on the sieve to a single layer of particles.

Overload Determination

- For sieves with openings smaller than 4.75 mm (No. 4), the mass retained on any sieve shall not exceed 7 kg/m^2 (4 g/in^2) of sieving surface.
- For sieves with openings 4.75 mm (No. 4) and larger, the mass, in grams shall not exceed the product of $2.5 \times (\text{sieve opening in mm}) \times (\text{effective sieving area})$. See Table 1.

Additional sieves may be necessary to keep from overloading sieves or to provide other information, such as fineness modulus. The sample may also be sieved in increments to prevent overload.

TABLE 1
Maximum Allowable Mass of Material Retained on a Sieve, g
Nominal Sieve Size, mm (in.)
Exact size is smaller (see AASHTO T 27)

Sieve Size mm (in.)	203 dia (8)	305 dia (12)	305 by 305 (12 × 12)	350 by 350 (14 × 14)	372 by 580 (16 × 24)
Sieving Area m ²					
	0.0285	0.0670	0.0929	0.1225	0.2158
90 (3 1/2)	*	15,100	20,900	27,600	48,500
75 (3)	*	12,600	17,400	23,000	40,500
63 (2 1/2)	*	10,600	14,600	19,300	34,000
50 (2)	3600	8400	11,600	15,300	27,000
37.5 (1 1/2)	2700	6300	8700	11,500	20,200
25.0 (1)	1800	4200	5800	7700	13,500
19.0 (3/4)	1400	3200	4400	5800	10,200
16.0 (5/8)	1100	2700	3700	4900	8600
12.5 (1/2)	890	2100	2900	3800	6700
9.5 (3/8)	670	1600	2200	2900	5100
6.3 (1/4)	440	1100	1500	1900	3400
4.75 (No. 4)	330	800	1100	1500	2600
-4.75 (-No. 4)	200	470	650	860	1510

Sample Preparation

Obtain samples in accordance with the FOP for AASHTO T 2 and reduce to the size shown in Table 2 in accordance with the FOP for AASHTO R 76. These sample sizes are standard for aggregate testing but, due to equipment restraints, samples may need to be partitioned into several “subsamples.” For example, a gradation that requires 100 kg (220 lbs) of material would not fit into a large tray shaker in one batch.

Some agencies permit reduced sample sizes if it is proven that doing so is not detrimental to the test results. Some agencies require larger sample sizes. Check agency guidelines for required or permitted test sample sizes.

TABLE 2
Sample Sizes for Aggregate Gradation Test

Nominal Maximum Size* mm (in.)	Minimum Dry Mass g (lb)
4.75 (No. 4)	500 (1)
6.3 (1/4)	1000 (2)
9.5 (3/8)	1000 (2)
12.5 (1/2)	2000 (4)
19.0 (3/4)	5000 (11)
25.0 (1)	10,000 (22)
37.5 (1 1/2)	15,000 (33)
50 (2)	20,000 (44)
63 (2 1/2)	35,000 (77)
75 (3)	60,000 (130)
90 (3 1/2)	100,000 (220)
100 (4)	150,000 (330)
125 (5)	300,000 (660)

*Nominal maximum size: One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained. Where large gaps between specification sieves exist, intermediate sieve(s) may be inserted to determine nominal maximum size.

Selection of Procedure

Agencies may specify what method will be performed. If a method is not specified method A will be performed.

Overview

Method A

- Determine dry mass of original sample
- Wash through a 75µm (No. 200) sieve
- Determine dry mass of washed sample
- Sieve material

Method B

- Determine dry mass of original sample
- Wash through a 75µm (No. 200) sieve
- Determine dry mass of washed sample
- Sieve coarse material
- Determine dry mass of fine material
- Reduce fine portion
- Determine mass of reduced portion
- Sieve fine portion

Method C

- Determine dry mass of original sample
- Sieve coarse material
- Determine mass of fine material
- Reduce fine portion
- Determine mass of reduced portion
- Wash through a 75 μ m (No. 200) sieve
- Determine dry mass of washed sample
- Sieve reduced fine portion

Procedure Method A

1. Dry the sample to a constant mass in accordance with the FOP for AASHTO T 255. Determine and record the total dry mass of the sample to the nearest 0.1 percent or 0.1 g.
2. When the specification requires that the amount of material finer than 75 μ m (No. 200) be determined, perform Step 3 through Step 11; otherwise, skip to Step 12.
3. Nest a sieve, such as a 2.0 mm (No. 10), above the 75 μ m (No. 200) sieve.
4. Place the test sample in a container and add sufficient water to cover it.
Note 1: A detergent, dispersing agent, or other wetting solution may be added to the water to assure a thorough separation of the material finer than the 75 μ m (No. 200) sieve from the coarser particles. There should be enough wetting agent to produce a small amount of suds when the sample is agitated. Excessive suds may overflow the sieves and carry material away with them.
5. Agitate vigorously to ensure complete separation of the material finer than 75 μ m (No. 200) from coarser particles and bring the fine material into suspension above the coarser material. When using a mechanical washing device, exercise caution to avoid degradation of the sample.
6. Immediately pour the wash water containing the suspended and dissolved solids over the nested sieves, being careful not to pour out the coarser particles.
7. Add a second change of water to the sample remaining in the container, agitate, and repeat Step 6. Repeat the operation until the wash water is reasonably clear. If a detergent or dispersing agent is used, continue washing until the agent is removed.
8. Remove the upper sieve, return material retained to the washed sample.
9. Rinse the material retained on the 75 μ m (No.200) sieve until water passing through the sieve is reasonably clear.
10. Return all material retained on the 75 μ m (No.200) sieve to the container by flushing into the washed sample.

Note 2: Excess water may be carefully removed with a bulb syringe as long as the removed water is discharged back over the No. 200 sieve to preclude loss of fines.

11. Dry the washed aggregate to constant mass in accordance with the FOP for AASHTO T 255, and then cool prior to sieving. Record the “dry mass after washing.”
12. Select sieves to furnish the information required by the specifications. Nest the sieves in order of decreasing size from top to bottom and place the sample, or a portion of the sample, on the top sieve.

13. Place sieves in mechanical shaker and shake for the minimum time determined to provide complete separation for the sieve shaker being used (approximately 10 minutes).

Note 3: Excessive shaking (more than 10 minutes) may result in degradation of the sample.

14. Determine the individual or cumulative mass retained on each sieve and the pan to the nearest 0.1 percent or 0.1 g. Ensure that all material trapped in full openings of the sieve are cleaned out and included in the mass retained.

Note 4: For sieves No. 4 and larger, material trapped in less than a full opening shall be checked by sieving over a full opening. Use coarse wire brushes to clean the 600 μm (No. 30) and larger sieves, and soft bristle brushes for smaller sieves.

Note 5: In the case of coarse / fine aggregate mixtures, the minus 4.75 mm (No. 4) may be distributed among two or more sets of sieves to prevent overloading of individual sieves.

15. Verify the total mass of material after sieving agrees with the mass before sieving within 0.3 percent. (Check sum). If performing T 11 with T 27, this would be the dry mass after wash. If performing just T 27 this would be the original dry mass. When the masses before and after sieving differ by more than 0.3 percent, the results cannot be used for acceptance purposes.
16. Calculate the total percentages passing, individual or cumulative percentages retained or percentages in various size fractions to the nearest 0.1 percent by dividing the masses on the individual sieve masses or cumulative sieve masses by the total mass of the initial dry sample. If the same test sample was first tested by T 11, use the total dry sample mass before washing in T 11 as the basis for calculating all percentages.
17. Report percent passing as indicated in the “Report” section at the end of this FOP.

Method A Calculations

$$\text{Check sum} = \frac{\text{dry mass after washing} - \text{total mass after sieving}}{\text{dry mass after washing}} \times 100$$

Percent Retained

$$IPR = \frac{IMR}{M} \times 100 \quad \text{or} \quad CPR = \frac{CMR}{M} \times 100$$

Where:

IPR= Individual Percent Retained
 CPR= Cumulative Percent Retained
 M= Total Dry Sample mass before washing
 IMR= Individual Mass Retained
 CMR= Cumulative Mass Retained

Percent Passing (Calculated):

$$PP = PPP - IPR \quad \text{or} \quad PP = 100 - CPR$$

Where:

PP= Percent Passing
 PPP= Previous Percent Passing

Method A Example

Dry mass of total sample, before washing: 5168.7 g
 Dry mass of sample, after washing out the 75 μ m (No. 200) minus: 4911.3 g
 Amount of 75 μ m (No. 200) minus washed out: 5168.7 g – 4911.3 g = 257.4 g

Gradation on All Sieves

Sieve Size mm (in.)	Individual Mass Retained g (IMR)	Individual Percent Retained (IPR)	Cumulative Mass Retained g (CMR)	Cumulative Percent Retained (CPR)	Calc'd Percent Passing (CPP)	Reported Percent Passing* (RPP)
19.0 (3/4)	0	0	0	0.0	100.0	100
12.5 (1/2)	724.7	14.0	724.7	14.0	86.0	86
9.5 (3/8)	619.2	12.0	1343.9	26.0	74.0	74
4.75 (No. 4)	1189.8	23.0	2533.7	49.0	51.0	51
2.36 (No. 8)	877.6	17.0	3411.3	66.0	34.0	34
1.18 (No. 16)	574.8	11.1	3986.1	77.1	22.9	23
0.600 (No. 30)	329.8	6.4	4315.9	83.5	16.5	17
0.300 (No. 50)	228.5	4.4	4544.4	87.9	12.1	12
0.150 (No. 100)	205.7	4.0	4750.1	91.9	8.1	8
0.075 (No. 200)	135.4	2.6	4885.5	94.5	5.5	5.5
Pan	20.4		4905.9			

*Report 75 µm (No. 200) sieve to 0.1 percent. Report all others to 1 percent.

Check sum:

$$\frac{4911.3 \text{ g} - 4905.9 \text{ g}}{4911.3 \text{ g}} \times 100 = 0.1\%$$

This is less than 0.3 percent therefore the results can be used for acceptance purposes.

Percent Retained:

9.5 mm (3/8) sieve:

$$\frac{619.2 \text{ g}}{5168.7 \text{ g}} \times 100 = 12.0\% \quad \text{or} \quad \frac{1343.9 \text{ g}}{5168.7 \text{ g}} \times 100 = 26.0\%$$

Percent Passing (Calculated):

9.5 mm (3/8) sieve:

$$86.0\% - 12.0\% = 74.0\% \quad \text{or} \quad 100.0\% - 26.0\% = 74.0\%$$

Procedure Method B

1. Perform steps 1 through 11 from the “Procedure – Method A,” then continue as follows:
2. Select sieves to furnish information required by the specifications. Nest the sieves in order of decreasing size from top to bottom through the 4.75 mm (No. 4) with a pan at the bottom to retain the minus 4.75 mm (No. 4).
3. Place the sample, or a portion of the sample, on the top sieve. Sieves may already be in the mechanical shaker, or place the sieves in the mechanical shaker and shake for the minimum time determined to provide complete separation for the sieve shaker being used (approximately 10 minutes).
Note 3: Excessive shaking (more than 10 minutes) may result in degradation of the sample.
4. Determine the individual or cumulative mass retained on each sieve to the nearest 0.1 percent or 0.1 g. Ensure that all particles trapped in full openings of the sieve are cleaned out and included in the mass retained.
Note 4: For sieves No. 4 and larger, material trapped in less than a full opening shall be checked by sieving over a full opening. Use coarse wire brushes to clean the 600 μm (No. 30) and larger sieves, and soft hair bristle for smaller sieves.
5. Determine the mass of the material in the pan [minus 4.75 mm (No. 4)] (M_1).
6. Verify the total mass of material after sieving agrees with the mass before sieving within 0.3 percent. (Coarse check sum). If performing T 11 with T 27, this would be the dry mass after wash. If performing just T 27 this would be the original dry mass. When the masses before and after sieving differ by more than 0.3 percent, the results cannot be used for acceptance purposes.
7. Reduce the minus 4.75 mm (No. 4) using a mechanical splitter in accordance with the FOP for AASHTO R 76 to produce a sample with a mass of 500 g minimum. Determine and record the mass of the minus 4.75 mm (No. 4) split (M_2).
8. Select fine sieves to furnish information required by the specifications. Nest the sieves in order of decreasing size from top to bottom through the 75 μm (No. 200) with a pan at the bottom to retain the minus 75 μm (No. 200).
9. Repeat steps 3 through 5, Method B, with the minus 4.75 mm (No. 4).
10. Verify the total mass of material after sieving agrees with the mass before sieving within 0.3 percent. (Fine check sum). This would be the dry mass from Step 7. When the masses before and after sieving differ by more than 0.3 percent, the results cannot be used for acceptance purposes.
11. Calculate the Individual Mass Retained (IMR) or Cumulative Mass Retained (CMR) of the size increment of the original sample.

12. Calculate the total percent passing and report as indicated in the “Report” section at the end of this FOP.

Method B Calculations

$$\text{Coarse check sum} = \frac{\text{dry mass after washing} - \text{total mass after coarse sieving}}{\text{dry mass after washing}} \times 100$$

$$\text{Fine check sum} = \frac{M_2 - \text{total mass after fine sieving}}{M_2} \times 100$$

Individual Mass Retained (IMR):

$$IMR = \frac{M_1}{M_2} \times B$$

where:

- IMR = adjusted individual mass retained of the size increment on a total sample basis
- M_1 = mass of minus 4.75mm (No. 4) sieve in total sample
- M_2 = mass of minus 4.75mm (No. 4) sieve actually sieved
- B = individual mass of the size increment in the reduced portion sieved

Cumulative Mass Retained (CMR):

$$CMR = \left(\frac{M_1}{M_2} \times B \right) + D$$

where:

- CMR = Total cumulative mass retained of the size increment based on a total sample
- M_1 = mass of minus 4.75mm (No. 4) sieve in total sample
- M_2 = mass of minus 4.75mm (No. 4) sieve actually sieved
- B = cumulative mass of the size increment in the reduced portion sieved
- D = cumulative mass of plus 4.75mm (No. 4) portion of sample

Method B Example

- Dry mass of total sample, before washing: 3214.0 g
- Dry mass of sample, after washing out the 75 μm (No. 200) minus: 3085.1 g
- Amount of 75 μm (No. 200) minus washed out: 3214.0 g – 3085.1 g = 128.9 g

Gradation on Coarse Sieves

Sieve Size mm (in.)	Individual Mass Retained g (IMR)	Individual Percent Retained (IPR)	Cumulative Mass Retained g (CMR)	Cumulative Percent Retained (CPR)	Calculated Percent Passing (CPP)
16.0 (5/8)	0	0	0	0	100
12.5 (1/2)	161.1	5.0	161.1	5.0	95.0
9.50 (3/8)	481.4	15.0	642.5	20.0	80.0
4.75 (No. 4)	475.8	14.8	1118.3	34.8	65.2
Pan	1966.7 (M_1)		3085.0		

Coarse check sum:

$$\frac{3085.1 \text{ g} - 3085.0 \text{ g}}{3085.1 \text{ g}} \times 100 = 0.0\%$$

This is less than 0.3 percent therefore the results can be used for acceptance purposes.

Note 5: The pan mass determined in the laboratory (M_1) and the calculated mass ($3085.1 - 1118.3 = 1966.7$) should be the same if no material was lost.

The pan (1966.7 g) was reduced in accordance with the FOP for AASHTO R 76, so that at least 500 g are available. In this case, the mass determined was **512.8 g**. This is M_2 .

In order to account for the fact that only a portion of the minus 4.75mm (No. 4) material was sieved, the mass of material retained on the smaller sieves is adjusted by a factor equal to M_1/M_2 . The factor determined from M_1/M_2 must be carried to three decimal places. Both the individual mass retained and cumulative mass retained formulas are shown.

Individual Mass Retained:

M_1 = total mass in the pan of the minus 4.75mm (No. 4) before reducing
 M_2 = mass of the split minus 4.75 mm (No. 4)

$$\frac{M_1}{M_2} = \frac{1,966.7 \text{ g}}{512.8 \text{ g}} = 3.835$$

Each “individual mass retained” on the fine sieves must be multiplied by this adjustment factor.

Example:

$$\text{Overall mass retained on the 2.00 mm (No. 10)} = 3.835 \times 207.1 \text{ g} = 794.2 \text{ g}$$

As shown in the following table.

**Final Gradation on All Sieves
Calculation by Individual Mass**

Sieve Size mm (in.)	Individual Mass Retained, g (IMR)	Adjusted Individual Mass Retained (AIMR)	Individual Percent Retained (IPR)	Calc'd Percent Passing (CPP)	Reported Percent Passing* (RPP)
16.0 (5/8)	0	0	0.0	100.0	100
12.5 (1/2)	161.1	161.1	5.0	95.0	95
9.5 (3/8)	481.4	481.4	15.0	80.0	80
4.75 (No. 4)	475.8	475.8	14.8	65.2	65
2.0 (No. 10)	207.1 × 3.835	794.2	24.7	40.5	41
0.425 (No. 40)	187.9 × 3.835	720.6	22.4	18.1	18
0.210 (No. 80)	59.9 × 3.835	229.7	7.1	11.0	11
0.075 (No. 200)	49.1 × 3.835	188.3	5.9	5.1	5.1
Pan	7.8 × 3.835	29.9			
Dry mass of total sample, before washing: 3214.0 g					

*Report 75 µm (No. 200) sieve to 0.1 percent. Report all others to 1 percent.

Fine check sum:

$$\frac{512.8 \text{ g} - 511.8 \text{ g}}{512.8 \text{ g}} \times 100 = 0.2\%$$

This is less than 0.3 percent therefore the results can be used for acceptance purposes.

Percent Passing (Calculated) see “Calculation” under Method A.

Cumulative Mass Retained:

M₁ = total mass in the pan of the minus 4.75 mm (No. 4) before split

M₂ = mass of the split minus 4.75 mm (No. 4)

$$\frac{M_1}{M_2} = \frac{1,966.7 \text{ g}}{512.8 \text{ g}} = 3.835$$

Each “cumulative mass retained” on the fine sieves must be multiplied by this adjustment factor then the cumulative mass of plus 4.75 mm (No. 4) portion of sample is added to equal the adjusted cumulative mass retained.

Example:

$$\text{Adjusted Cumulative Mass Retained on the 2.00 mm (No. 10)} = 3.835 \times 207.1 \text{ g} = 794.2 \text{ g}$$

$$\text{Total Cumulative Mass Retained on the 2.00 mm (No. 10)} = 794.2 \text{ g} + 1118.3 \text{ g} = 1912.5 \text{ g}$$

As shown in the following table.

**Final Gradation on All Sieves
Calculation by Cumulative Mass**

Sieve Size mm (in.)	Cumulative Mass Retained g (CMR)	Adjusted Cumulative Mass Retained, g (ACMR)	Total Cumulative Mass Retnd. g (TCMR)	Cumulative Percent Retnd. (CPR)	Calc'd Percent Passing (CPP)	Reported Percent Passing* (RPP)
16.0 (5/8)	0		0	0.0	100.0	100
12.5 (1/2)	161.1		161.1	5.0	95.0	95
9.5 (3/8)	642.5		642.5	20.0	80.0	80
4.75 (No. 4)	1118.3		1118.3	34.8	65.2	65
2.0 (No. 10)	207.1×3.835	$794.2 + 1118.3$	1912.5	59.5	40.5	41
0.425 (No. 40)	395.0×3.835	$1514.8 + 1118.3$	2633.1	81.9	18.1	18
0.210 (No. 80)	454.9×3.835	$1744.5 + 1118.3$	2862.8	89.1	10.9	11
0.075 (No. 200)	504.0×3.835	$1932.8 + 1118.3$	3051.1	94.9	5.1	5.1
Pan	511.8×3.835	$1962.8 + 1118.3$	3081.1			

*Report 75 μm (No. 200) sieve to 0.1 percent. Report all others to 1 percent.

Fine check sum:

$$\frac{512.8 \text{ g} - 511.8 \text{ g}}{512.8 \text{ g}} \times 100 = 0.2\%$$

This is less than 0.3 percent therefore the results can be used for acceptance purposes. For Percent Passing (Calculated) see "Calculation" under Method A.

Procedure Method C

1. Dry sample in accordance with the FOP for AASHTO T 255. Determine and record the total dry mass of the sample to the nearest 0.1 percent or 1 g.

Note 6: AASHTO T 27 allows for coarse aggregate to be run in a moist condition unless the nominal maximum size of the aggregate is smaller than 12.5 mm (1/2 in.), the coarse aggregate (CA) contains appreciable material finer than 4.75 mm (No. 4), or the coarse aggregate is highly absorptive.

2. Break up any aggregations or lumps of clay, silt or adhering fines to pass the 4.75 mm (No. 4) sieve. If substantial coatings remain on the coarse particles in amounts that would affect the percent passing any of the specification sieves, the sample should be tested with either Method A or Method B.
3. Select sieves to furnish information required by the specifications. Nest the sieves in order of decreasing size from top to bottom through the 4.75 mm (No.4) with a pan at the bottom to retain the minus 4.75 mm (No. 4).
4. Place the sample, or a portion of the sample, on the top sieve. Sieves may already be in the mechanical shaker or place the sieves in the mechanical shaker and shake for the minimum time determined to provide complete separation for the sieve shaker being used (approximately 10 minutes).

Note 3: Excessive shaking (more than 10 minutes) may result in degradation of the sample.

5. Determine the cumulative mass retained on each sieve to the nearest 0.1 percent or 0.1 g. Ensure that all material trapped in full openings of the sieve are cleaned out and included in the mass retained.

Note 4: For sieves No. 4 and larger, material trapped in less than a full opening shall be checked by sieving over a full opening. Use coarse wire brushes to clean the 600 μm (No. 30) and larger sieves, and soft bristle brush for smaller sieves.

6. Determine the mass of material in the pan [minus 4.75 mm (No. 4)] (M_1).
7. Verify the total mass of material after sieving agrees with the mass before sieving within 0.3 percent. (Coarse check sum). If performing T 11 with T 27, this would be the dry mass after wash. If performing just T 27 this would be the original dry mass. When the masses before and after sieving differ by more than 0.3 percent, the results cannot be used for acceptance purposes.
8. Reduce the minus 4.75mm (No. 4), using a mechanical splitter in accordance with the FOP for AASHTO R 76, to produce a sample with a mass of 500 g minimum.
9. Determine and record the mass of the minus 4.75mm (No. 4) split (M_3).
10. Perform steps 3 through 11 of Method A (Wash) on the minus 4.75mm (No. 4) split.
11. Select fine sieves to furnish information required by the specifications. Nest the sieves in order of decreasing size from top to bottom through the 75 μm (No. 200) with a pan at the bottom to retain the minus 75 μm (No. 200).

12. Repeat steps 4 through 6, Method C, with the minus 4.75mm (No. 4).
13. Verify the total mass of material after sieving agrees with the mass before sieving within 0.3 percent. (Fine check sum). This would be the dry mass from Step 10. When the masses before and after sieving differ by more than 0.3 percent, the results cannot be used for acceptance purposes.
14. Calculate the Cumulative Percent Retained (CPR) or Cumulative Percent Passing (CPP) for the 4.75 mm (No. 4) and larger.
15. Calculate the Cumulative Percent Retained (CPR-#4) and/or Cumulative Percent Passing (CPP-#4) for the minus 4.75 mm (No. 4).
16. Calculate the CPP for the minus 4.75 mm (No. 4).
17. Report Percent Passing (RPP) as indicated in the “Report” section at the end of this FOP.

Method C Calculations

$$\text{Coarse check sum} = \frac{\text{dry mass after washing} - \text{total mass after coarse sieving}}{\text{dry mass after washing}} \times 100$$

$$\text{Fine check sum} = \frac{M_3 - \text{total mass after fine sieving}}{M_3} \times 100$$

Cumulative Percent Retained (CPR) and Cumulative Percent Passing (CPP)

$$CPR = \frac{CMR}{M} \times 100 \quad CPP = 100 - CPR$$

where:

- CMR = Cumulative Mass Retained
- CPR = Cumulative Percent Retained
- M = Total Dry Sample mass before washing
- CPP = Cumulative Percent Passing

Cumulative Percent Retained (CPR_{#4}) and Cumulative Percent Passing (CPP_{#4})

$$CPR_{\#4} = \frac{CMR_{\#4}}{M_3} \times 100 \quad CPP_{\#4} = 100 - CPR_{\#4}$$

$$CPP = \frac{(CPP_{\#4} \times CPP_{\#4})}{100} \text{ or } CPP = \frac{CPP_{\#4} \times (M_3 - CMR_{\#4})}{M_3}$$

where:

- CMR_{#4} = Cumulative mass retained for the sieve size based on a minus No. 4 split sample
- CPR_{#4} = Calculated cumulative percent retained based on the minus No. 4 split
- CPP_{#4} = Calculated percent passing based on the minus No. 4 split
- M₃ = Total mass of the minus No. 4 split before washing
- CPP_{#4} = Calculated percent passing the No. 4 sieve

Method C Example

Sample calculation for percent retained and percent passing each sieve in accordance with Method C when the minus 4.75mm (No. 4) material is reduced and then washed:

Dry Mass of total sample (M): 3304.5 g

Dry Mass of minus 4.75mm (No. 4) reduced portion before wash (M₃): 527.6 g

Dry Mass of minus 4.75mm (No. 4) reduced portion after wash: 495.3 g

Gradation on Coarse Sieves

Sieve Size mm (in.)	Cumulative Mass Retained g (CMR)	Cumulative Percent Retained (CPR)	Cumulative Percent Passing (CPP)	Reported Percent Passing* (RPP)
16.0 (5/8)	0	0.0	100.0	100
12.5 (1/2)	125.9	3.8	96.2	96
9.50 (3/8)	604.1	18.3	81.7	82
4.75 (No. 4)	1295.6	39.2	60.8	61
Pan	2008.9			
Total Dry Sample (M) = 3304.5				

Coarse check sum:

$$\frac{3304.5 \text{ g} - 3304.5 \text{ g}}{3304.5 \text{ g}} \times 100 = 0.0\%$$

This is less than 0.3 percent therefore the results can be used for acceptance purposes.

The pan (2008.9 g) was reduced in accordance with the FOP for AASHTO R 76, so that at least 500 g are available. In this case, the mass determined was $M_3 = 527.6$ g.

Gradation on Minus No. 4 Sieves

Sieve Size mm (in.)	Cumulative Mass Retained g (CMR _{#4})	Cumulative Percent Retained _{#4} (CPR _{#4})	Cumulative Percent Passing _{#4} (CPP _{#4})	Cumulative Percent Passing (CPP)	Reported Percent Passing* (RPP)
2.0 (No. 10)	194.3	36.8	63.2	38.4	38
0.425 (No. 40)	365.6	69.3	30.7	18.7	19
0.210 (No. 80)	430.8	81.7	18.3	11.1	11
0.075 (No. 200)	484.4	91.8	8.2	5.0	5.0
Pan	495.1				
Dry mass of minus 4.75 mm (No. 4) sample, before washing (M_3) : 527.6 g					
Dry mass of minus 4.75 mm (No. 4) sample, after washing: 495.3 g					
Calculated percent passing the No. 4 sieve (CPP _{#4}) = 60.8%					

Fine check sum:

$$\frac{495.3 \text{ g} - 495.1 \text{ g}}{495.3 \text{ g}} \times 100 = 0.04\%$$

This is less than 0.3 percent therefore the results can be used for acceptance purposes.

Final Gradation on All Sieves Calculation by Cumulative Mass

Sieve Size mm (in.)	Cumulative Mass Retained, g (CMR)	Cumulative Percent Retained (CPR)	Cumulative Percent Passing (CPP)	Cumulative Percent Passing (CPP)	Reported Percent Passing* (RPP)
16.0 (5/8)	0	0.0		100.0	100
12.5 (1/2)	125.9	3.8		96.2	96
9.5 (3/8)	604.1	18.3		81.7	82
4.75 (No. 4)	1295.6	39.2		60.8	61
2.0 (No. 10)	194.3	36.8	63.2	38.4	38
0.425 (No. 40)	365.6	69.3	30.7	18.7	19
0.210 (No. 80)	430.8	81.7	18.3	11.1	11
0.075 (No. 200)	484.4	91.8	8.2	5.0	5.0
Pan	495.1				

*Report 75 μ m (No. 200) sieve to 0.1 percent. Report all others to 1 percent

Fineness Modulus

Fineness Modulus (FM) is used in determining the degree of uniformity of the aggregate gradation in PCC mix designs. It is an empirical number relating to the fineness of the aggregate. The higher the FM the coarser the aggregate. Values of 2.40 to 3.00 are common for FA in PCC.

The sum of the cumulative percentages retained on specified sieves in the following table divided by 100 gives the FM.

Sample Calculation

	Example A				Example B		
	Percent				Percent		
		Retained			Retained		
Sieve Size mm (in)	Passing		On Spec'd Sieves*	Passing		On Spec'd Sieves*	
75*(3)	100	0	0	100	0	0	
37.5*(11/2)	100	0	0	100	0	0	
19*(3/4)	15	85	85	100	0	0	
9.5*(3/8)	0	100	100	100	0	0	
4.75*(No.4)	0	100	100	100	0	0	
2.36*(No.8)	0	100	100	87	13	13	
1.18*(No.16)	0	100	100	69	31	31	
0.60*(No.30)	0	100	100	44	56	56	
0.30*(No.50)	0	100	100	18	82	82	
0.15*(100)	0	100	100	4	96	96	
			$\Sigma = 785$			$\Sigma = 278$	
			FM = 7.85			FM = 2.78	

In decreasing size order, each * sieve is one-half the size of the preceding * sieve.

Report

- Results on forms approved by the agency
- Sample ID
- Individual mass retained on each sieve
- Individual percent retained on each sieve
- Cumulative mass retained on each sieve
- Cumulative percent retained on each sieve
- FM to the nearest 0.01

Report percentages to the nearest 1 percent except for the percent passing the 75 μm (No. 200) sieve, which shall be reported to the nearest 0.1 percent.

DETERMINING THE PERCENTAGE OF FRACTURE IN COARSE AGGREGATE FOP FOR AASHTO T 335

Scope

This procedure covers the determination of the percentage, by mass, of a coarse aggregate (CA) sample that consists of fractured particles meeting specified requirements in accordance with AASHTO T 335-09.

In this FOP, a sample of aggregate is screened on the sieve separating CA and fine aggregate (FA). This sieve will be identified in the agency's specifications, but might be the 4.75 mm (No. 4) sieve. CA particles are visually evaluated to determine conformance to the specified fracture. The percentage of conforming particles, by mass, is calculated for comparison to the specifications.

Apparatus

- Balance or scale: Capacity sufficient for the principle sample mass, accurate to 0.1 percent of the sample mass or readable to 0.1 g, and meeting the requirements of AASHTO M 231.
- Sieves: Meeting requirements of AASHTO M 92.
- Splitter: Meeting the requirements of FOP for AASHTO R 76.

Terminology

1. Fractured Face: An angular, rough, or broken surface of an aggregate particle created by crushing or by other means. A face is considered a "fractured face" whenever one-half or more of the projected area, when viewed normal to that face, is fractured with sharp and well defined edges. This excludes small nicks.
2. Fractured particle: A particle of aggregate having at least the minimum number of fractured faces specified. (This is usually one or two.)

Sampling and Sample Preparation

1. Sample and reduce the aggregate in accordance with the FOPs for AASHTO T 2 and R 76.
2. When the specifications list only a total fracture percentage, the sample shall be prepared in accordance with Method 1. When the specifications require that the fracture be counted and reported on each sieve, the sample shall be prepared in accordance with Method 2.

3. Method 1 - Combined Fracture Determination

- a. Dry the sample sufficiently to obtain a clean separation of FA and CA material in the sieving operation.
- b. Sieve the sample in accordance with the FOP for AASHTO T 27/ T 11 over the 4.75 mm (No. 4) sieve, or the appropriate sieve listed in the agency’s specifications for this material.

Note 1: Where necessary, wash the sample over the sieve designated for the determination of fractured particles to remove any remaining fine material, and dry to a constant mass in accordance with the FOP for AASHTO T 255.

- c. Reduce the sample using Method A – Mechanical Splitter, in accordance with the FOP for AASHTO R 76, to the appropriate test size. This test size should be slightly larger than shown in Table 1, to account for loss of fines through washing if necessary.

TABLE 1
Sample Size
Method 1 (Combined Sieve Fracture)

Nominal Maximum Size* mm (in.)	Minimum Cumulative Sample Mass Retained on 4.75 mm (No. 4) Sieve g (lb)
37.5 (1 1/2)	2500 (6)
25.0 (1)	1500 (3.5)
19.0 (3/4)	1000 (2.5)
12.5 (1/2)	700 (1.5)
9.5 (3/8)	400 (0.9)
4.75 (No. 4)	200 (0.4)

* One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained. Where large gaps in specification sieves exist, intermediate sieve(s) may be inserted to determine nominal maximum size.

4. Method 2 – Individual Sieve Fracture Determination

- a. Dry the sample sufficiently to obtain a clean separation of FA and CA material in the sieving operation. A washed sample from the gradation determination (the FOP for T 27/T 11) may be used.
- b. If not, sieve the sample in accordance with the FOP for AASHTO T 27 over the sieves listed in the specifications for this material.

Note 2: If overload (buffer) sieves are used the material from that sieve must be added to the next specification sieve.

- c. The size of test sample for each sieve shall meet the minimum size shown in Table 2. Utilize the total retained sieve mass or select a representative portion from each sieve mass by splitting or quartering in accordance with the FOP for AASHTO R 76.

Note 3: Where necessary, wash the sample over the sieves designated for the determination of fractured particles to remove any remaining fine material, and dry to a constant mass in accordance with the FOP for AASHTO T 255.

TABLE 2
Sample Size
Method 2 (Individual Sieve Fracture)

Sieve Size mm (in.)	Minimum Sample Mass g (lb)
31.5 (1 1/4)	1500 (3.5)
25.0 (1)	1000 (2.2)
19.0 (3/4)	700 (1.5)
16.0 (5/8)	500 (1.0)
12.5 (1/2)	300 (0.7)
9.5 (3/8)	200 (0.5)
6.3 (1/4)	100 (0.2)
4.75 (No. 4)	100 (0.2)
2.36 (No. 8)	25 (0.1)
2.00 (No. 10)	25 (0.1)

Note 4: If fracture is determined on a sample obtained for gradation, use the mass retained on the individual sieves, even if it is less than the minimum listed in Table 2. If less than 5 percent of the total mass is retained on a single specification sieve, include that material on the next smaller specification sieve. If a smaller specification sieve does not exist, this material shall not be included in the fracture determination.

Procedure

1. After cooling, spread the dried sample on a clean, flat surface large enough to permit careful inspection of each particle. To verify that a particle meets the fracture criteria, hold the aggregate particle so that the face is viewed directly.
2. To aid in making the fracture determination, separate the sample into three categories:
 - fractured particles meeting the criteria
 - particles not meeting the criteria
 - questionable or borderline particles
3. Determine the dry mass of particles in each category to the nearest 0.1 g.
4. Resort the questionable particles when more than 15 percent is present. Continue sorting until there is less than 15 percent in the questionable category.

Calculation

Calculate the mass percentage of questionable fractured particles to the nearest 1 percent using the following formula:

$$\%Q = \frac{Q}{F + Q + N} \times 100$$

where: %Q = Percent of questionable fractured particles
 F = Mass of fractured particles
 Q = Mass of questionable or borderline particles
 N = Mass of unfractured particles

Example:

F = 632.6 g, Q = 97.6 g, N = 352.6 g

$$\%Q = \frac{97.6 \text{ g}}{632.6 \text{ g} + 97.6 \text{ g} + 352.6 \text{ g}} \times 100 = 9.0\% \quad \%Q = 9\%$$

Calculate the mass percentage of fractured faces to the nearest 1 percent using the following formula:

$$P = \frac{\frac{Q}{2} + F}{F + Q + N} \times 100$$

where: P = Percent of fracture
 F = Mass of fractured particles
 Q = Mass of questionable particles
 N = Mass of unfractured particles

Example:

F = 632.6 g, Q = 97.6 g, N = 352.6 g

$$P = \frac{\frac{97.6 \text{ g}}{2} + 632.6 \text{ g}}{632.6 \text{ g} + 97.6 \text{ g} + 352.6 \text{ g}} \times 100 \quad P = 63\%$$

Report

- Results on forms approved by the agency
- Sample ID
- Fractured particles to the nearest 1 percent.

PLASTIC FINES IN GRADED AGGREGATES AND SOILS BY THE USE OF THE SAND EQUIVALENT TEST FOP FOR AASHTO T 176

Scope

This procedure covers the determination of plastic fines in accordance with AASHTO T 176-08. It serves as a rapid test to show the relative proportion of fine dust or clay-like materials in fine aggregates (FA) and soils.

Apparatus

See AASHTO T 176 for a detailed listing of sand equivalent apparatus. Note that the siphon tube and blow tube may be glass or stainless steel as well as copper.

- Graduated plastic cylinder.
- Rubber stopper.
- Irrigator tube.
- Weighted foot assembly: Having a mass of 1000 ± 5 g. There are two models of the weighted foot assembly. The older model has a guide cap that fits over the upper end of the graduated cylinder and centers the rod in the cylinder. It is read using a slot in the centering screws. The newer model has a sand-reading indicator 254 mm (10 in.) above this point and is preferred for testing clay-like materials.
- Bottle: clean, glass or plastic, of sufficient size to hold working solution
- Siphon assembly: The siphon assembly will be fitted to a 4 L (1 gal.) bottle of working calcium chloride solution placed on a shelf 915 ± 25 mm (36 ± 1 in.) above the work surface.
- Measuring can: With a capacity of 85 ± 5 mL (3 oz.).
- Funnel: With a wide-mouth for transferring sample into the graduated cylinder.
- Quartering cloth: 600 mm (2 ft.) square nonabsorbent cloth, such as plastic or oilcloth.
- Mechanical splitter: See the FOP for AASHTO R 76.
- Strike-off bar: A straightedge or spatula.
- Clock or watch reading in minutes and seconds.

- Manually-operated sand equivalent shaker: Capable of producing an oscillating motion at a rate of 100 complete cycles in 45 ± 5 seconds, with a hand assisted half stroke length of 127 ± 5 mm (5 ± 0.2 in.). It may be held stable by hand during the shaking operation. It is recommended that this shaker be fastened securely to a firm and level mount, by bolts or clamps, if a large number of determinations are to be made.
- Mechanical shaker: See AASHTO T 176 for equipment and procedure.
- Oven: Capable of maintaining a temperature of $110 \pm 5^\circ\text{C}$ ($230 \pm 9^\circ\text{F}$).
- Thermometer: Calibrated liquid-in-glass or electronic digital type designed for total immersion and accurate to 0.1°C (0.2°F).

Materials

- Stock calcium chloride solution: Obtain commercially prepared calcium chloride stock solution meeting AASHTO requirements.
- Working calcium chloride solution: Dilute one 3 oz. measuring can (85 ± 5 mL) of stock calcium chloride solution with 3.8 L (1 gal) distilled or demineralized water. Thoroughly mix the solution by filling the bottle with 2 L (1/2 gal) of water. Add the stock solution and agitate vigorously for 1 to 2 minutes. Add the remainder of the water, approximately 2 L (1/2 gal.). Repeat the agitation process. The shelf life of the working solution is approximately 30 days. Discard working solutions more than 30 days old.

Note 1: The graduated cylinder filled to 4.4 in. contains 88 mL and may be used to measure the stock solution.

Note 2: Tap water may be used if it is proven to be non-detrimental to the test and if it is allowed by the agency.

Control

The temperature of the working solution should be maintained at $22 \pm 3^\circ\text{C}$ ($72 \pm 5^\circ\text{F}$) during the performance of the test. If field conditions preclude the maintenance of the temperature range, reference samples should be submitted to the Central/Regional Laboratory, as required by the agency, where proper temperature control is possible. Samples that meet the minimum sand equivalent requirement at a working solution temperature outside of the temperature range need not be subject to reference testing.

Sample Preparation

1. Obtain the sample in accordance with the FOP for AASHTO T 2 and reduce in accordance with the FOP for AASHTO R 76.
2. Prepare sand equivalent test samples from the material passing the 4.75 mm (No. 4) sieve. If the material is in clods, break it up and re-screen it over a 4.75 mm (No. 4)

- sieve. All fines shall be cleaned from particles retained on the 4.75 mm (No. 4) sieve and included with the material passing that sieve.
3. Split or quarter 1000 to 1500 g of material from the portion passing the 4.75 mm (No. 4) sieve. Use extreme care to obtain a truly representative portion of the original sample.

Note 3: Experiments show that, as the amount of material being reduced by splitting or quartering is decreased, the accuracy of providing representative portions is reduced. It is imperative that the sample be split or quartered carefully. When it appears necessary, dampen the material before splitting or quartering to avoid segregation or loss of fines.

Note 4: All tests, including reference tests, will be performed utilizing Alternative Method No. 2 as described in AASHTO T 176, unless otherwise specified.
 4. The sample must have the proper moisture content to achieve reliable results. This condition is determined by tightly squeezing a small portion of the thoroughly mixed sample in the palm of the hand. If the cast that is formed permits careful handling without breaking, the correct moisture content has been obtained.

Note 5: Clean sands having little 75 μm (No. 200), such as sand for Portland Cement Concrete (PCC), may not form a cast.

If the material is too dry, the cast will crumble and it will be necessary to add water and remix and retest until the material forms a cast. When the moisture content is altered to provide the required cast, the altered sample should be placed in a pan, covered with a lid or with a damp cloth that does not touch the material, and allowed to stand for a minimum of 15 minutes. Samples that have been sieved without being air-dried and still retain enough natural moisture are exempted from this requirement.

If the material shows any free water, it is too wet to test and must be drained and air dried. Mix frequently to ensure uniformity. This drying process should continue until squeezing provides the required cast.
 5. Place the sample on the quartering cloth and mix by alternately lifting each corner of the cloth and pulling it over the sample toward the diagonally opposite corner, being careful to keep the top of the cloth parallel to the bottom, thus causing the material to be rolled. When the material appears homogeneous, finish the mixing with the sample in a pile near the center of the cloth.
 6. Fill the measuring can by pushing it through the base of the pile while exerting pressure with the hand against the pile on the side opposite the measuring can. As the can is moved through the pile, hold enough pressure with the hand to cause the material to fill the tin to overflowing. Press firmly with the palm of the hand, compacting the material and placing the maximum amount in the can. Strike off the can level full with the straightedge or spatula.
 7. When required, repeat steps 5 and 6 to obtain additional samples.

Procedure

1. Start the siphon by forcing air into the top of the solution bottle through the tube while the pinch clamp is open.
2. Siphon 101.6 ± 2.5 mm (4 ± 0.1 in.) of working calcium chloride solution into the plastic cylinder. Pour the prepared test sample from the measuring can into the plastic cylinder, using the funnel to avoid spilling. Tap the bottom of the cylinder sharply on the heel of the hand several times to release air bubbles and to promote thorough wetting of the sample.
3. Allow the wetted sample to stand undisturbed for 10 ± 1 minutes. At the end of the 10-minute period, stopper the cylinder and loosen the material from the bottom by simultaneously partially inverting and shaking the cylinder.
4. After loosening the material from the bottom of the cylinder, shake the cylinder and contents by any one of the following methods:
 - a. Mechanical Method – Place the stoppered cylinder in the mechanical shaker, set the timer, and allow the machine to shake the cylinder and contents for 45 ± 1 seconds.

Caution: Agencies may require additional operator qualifications for the next two methods.

- b. Manually-operated Shaker Method – Secure the stoppered cylinder in the three spring clamps on the carriage of the manually-operated sand equivalent shaker and set the stroke counter to zero. Stand directly in front of the shaker and force the pointer to the stroke limit marker painted on the backboard by applying an abrupt horizontal thrust to the upper portion of the right hand spring strap.

Remove the hand from the strap and allow the spring action of the straps to move the carriage and cylinder in the opposite direction without assistance or hindrance. Apply enough force to the right-hand spring steel strap during the thrust portion of each stroke to move the pointer to the stroke limit marker by pushing against the strap with the ends of the fingers to maintain a smooth oscillating motion. The center of the stroke limit marker is positioned to provide the proper stroke length and its width provides the maximum allowable limits of variation.

Proper shaking action is accomplished when the tip of the pointer reverses direction within the marker limits. Proper shaking action can best be maintained by using only the forearm and wrist action to propel the shaker. Continue shaking for 100 strokes.

- c. Hand Method – Hold the cylinder in a horizontal position and shake it vigorously in a horizontal linear motion from end to end. Shake the cylinder 90 cycles in approximately 30 seconds using a throw of 229 ± 25 mm (9 ± 1 in.). A cycle is defined as a complete back and forth motion. To properly shake the cylinder at this speed, it will be necessary for the operator to shake with the forearms only, relaxing the body and shoulders.

5. Set the cylinder upright on the work table and remove the stopper.
6. Insert the irrigator tube in the cylinder and rinse material from the cylinder walls as the irrigator is lowered. Force the irrigator through the material to the bottom of the cylinder by applying a gentle stabbing and twisting action while the working solution flows from the irrigator tip. Work the irrigator tube to the bottom of the cylinder as quickly as possible, since it becomes more difficult to do this as the washing proceeds. This flushes the fine material into suspension above the coarser sand particles.

Continue to apply a stabbing and twisting action while flushing the fines upward until the cylinder is filled to the 381 mm (15 in.) mark. Then raise the irrigator slowly without shutting off the flow so that the liquid level is maintained at about 381 mm (15 in.) while the irrigator is being withdrawn. Regulate the flow just before the irrigator is entirely withdrawn and adjust the final level to 381 mm (15 in.).

Note 6: Occasionally the holes in the tip of the irrigator tube may become clogged by a particle of sand. If the obstruction cannot be freed by any other method, use a pin or other sharp object to force it out, using extreme care not to enlarge the size of the opening. Also, keep the tip sharp as an aid to penetrating the sample.

7. Allow the cylinder and contents to stand undisturbed for 20 minutes \pm 15 seconds. Start timing immediately after withdrawing the irrigator tube.

Note 7: Any vibration or movement of the cylinder during this time will interfere with the normal settling rate of the suspended clay and will cause an erroneous result.
8. Clay and sand readings:
 - a. At the end of the 20-minute sedimentation period, read and record the level of the top of the clay suspension. This is referred to as the clay reading.

Note 8: If no clear line of demarcation has formed at the end of the 20-minute sedimentation period, allow the sample to stand undisturbed until a clay reading can be obtained, then immediately read and record the level of the top of the clay suspension and the total sedimentation time. If the total sedimentation time exceeds 30 minutes, rerun the test using three individual samples of the same material. Read and record the clay column height of the sample requiring the shortest sedimentation period only. Once a sedimentation time has been established, subsequent tests will be run using that time. The time will be recorded along with the test results on all reports.

- b. After the clay reading has been taken, place the weighted foot assembly over the cylinder and gently lower the assembly until it comes to rest on the sand. Do not allow the indicator to hit the mouth of the cylinder as the assembly is being lowered. Subtract 254 mm (10 in.) from the level indicated by the extreme top edge of the indicator and record this value as the sand reading.
 - c. If clay or sand readings fall between 2.5 mm (0.1 in.) graduations, record the level of the higher graduation as the reading. For example, a clay reading that appears to be 7.95 would be recorded as 8.0; a sand reading that appears to be 3.22 would be recorded as 3.3.

- d. If two Sand Equivalent (SE) samples are run on the same material and the second varies by more than ± 4 , based on the first cylinder result, additional tests shall be run.
- e. If three or more Sand Equivalent (SE) samples are run on the same material, average the results. If an individual result varies by more than ± 4 , based on the average result, additional tests shall be run.

Calculations

1. Calculate the SE to the nearest 0.1 using the following formula:

$$SE = \frac{\text{Sand Reading}}{\text{Clay Reading}} \times 100$$

For example: Sand Reading = 3.3 and Clay Reading = 8.0

$$SE = \frac{3.3}{8.0} \times 100 = 41.25 \text{ or } 41.3$$

Note 9: This example reflects the use of equipment made with English units. At this time, equipment made with metric units is not available.

2. Report the SE as the next higher whole number. In the example above, the 41.3 would be reported as 42. An SE of 41.0 would be reported as 41.
3. In determining the average of the two or more samples, raise each calculated SE value to the next higher whole number before averaging. For example, calculated values of 41.3 and 42.8 would be reported as 42 and 43, respectively.

Then average the two values:

$$\frac{42 + 43}{2} = 42.5$$

If the average value is not a whole number, raise it to the next higher whole number – in this case: 43.

Report

- Results on forms approved by the agency
- Sample ID
- Results to the whole number
- Sedimentation time if over 20 minutes