DENSITY (UNIT WEIGHT), YIELD, AND AIR CONTENT (GRAVIMETRIC) OF CONCRETE
FOP FOR AASHTO T 121

Scope

This procedure covers the determination of density, or unit weight, of freshly mixed concrete in accordance with AASHTO T 121-12. It also provides formulas for calculating the volume of concrete produced from a mixture of known quantities of component materials, and provides a method for calculating cement content and cementitious material content – the mass of cement or cementitious material per unit volume of concrete. A procedure for calculating water/cement ratio is also covered.

Warning—Fresh Hydraulic cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged exposure.

Apparatus

- Measure: May be the bowl portion of the air meter used for determining air content under the FOP for AASHTO T 152. Otherwise, it shall be a metal cylindrical container meeting the requirements of AASHTO T 121. The capacity and dimensions of the measure shall conform to those specified in Table 1.

- Balance or scale: Accurate to within 45 g (0.1 lb) or 0.3 percent of the test load, whichever is greater, at any point within the range of use.

- Tamping rod: 16 mm (5/8 in.) diameter and approximately 600 mm (24 in.) long, having a hemispherical tip the same diameter as the rod. (Hemispherical means "half a sphere"; the tip is rounded like half of a ball.)

- Vibrator: 7000 vibrations per minute, 19 to 38 mm (3/4 to 1 1/2 in.) in diameter, and the length of the shaft shall be at least 610 mm (24 in.).

- Scoop: a receptacle of appropriate size so that each representative increment of the concrete sample can be placed in the container without spillage.

- Strike-off plate: A flat rectangular metal plate at least 6 mm (1/4 in.) thick or a glass or acrylic plate at least 12 mm (1/2 in.) thick, with a length and width at least 50 mm (2 in.) greater than the diameter of the measure with which it is to be used. The edges of the plate shall be straight and smooth within tolerance of 1.5 mm (1/16 in.).

- Mallet: With a rubber or rawhide head having a mass of 0.57 ±0.23 kg (1.25 ±0.5 lb) for use with measures of 0.014 m^3 (1/2 ft^3) or less, or having a mass of 1.02 ±0.23 kg (2.25 ±0.5 lb) for use with measures of 0.028 m^3 (1 ft^3).

Table 1
Dimensions of Measures

Capacity m^3 (ft^3)	Inside Diameter mm (in.)	Inside Height mm (in.)	Minimum Thicknesses mm (in.) Bottom	Minimum Thicknesses mm (in.) Wall	Nominal Maximum Size of Coarse Aggregate** mm (in.)
0.0071	203 ±2.54	213 ±2.54	5.1	3.0	25
(1/4)*	(8.0 ±0.1)	(8.4 ±0.1)	(0.20)	(0.12)	(1)
0.0142	254 ±2.54	279 ±2.54	5.1	3.0	50
(1/2)	(10.0 ±0.1)	(11.0 ±0.1)	(0.20)	(0.12)	(2)
0.0283	356 ±2.54	284 ±2.54	5.1	3.0	76
(1)	(14.0 ±0.1)	(11.2 ±0.1)	(0.20)	(0.12)	(3)

Note: Measure may be the base of the air meter used in the FOP for AASHTO T 152.

** 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.

Standardization of Measure

Standardization is a critical step to ensure accurate test results when using this apparatus. Failure to perform the standardization procedures as described herein will produce inaccurate or unreliable test results.

1. Determine the mass of the dry measure and strike-off plate.

2. Fill the measure with water at a temperature between 16°C and 29°C (60°F and 85°F) and cover with the strike-off plate in such a way as to eliminate bubbles and excess water.

3. Wipe the outside of the measure and cover plate dry, being careful not to lose any water from the measure.

4. Determine the mass of the measure, strike-off plate, and water in the measure.

5. Determine the mass of the water in the measure by subtracting the mass in Step 1 from the mass in Step 4.

6. Measure the temperature of the water and determine its density from Table 2, interpolating as necessary.

7. Calculate the volume of the measure, V_m, by dividing the mass of the water in the measure by the density of the water at the measured temperature, from Table 2.

$$V_m = \frac{Mass\ of\ Water}{Density\ of\ Water}$$

Example: at 23°C (73.4°F)

$$V_m = \frac{7.062\ kg}{997.54\ kg/m^3} = 0.007079 m^3 \qquad V_m = \frac{15.53 lb}{62.274\ lb/ft^3} = 0.2494 ft^3$$

Table 2
Unit Mass of Water
15°C to 30°C

°C	(°F)	kg/m³	(lb/ft³)	°C	(°F)	kg/m³	(lb/ft³)
15	(59.0)	999.10	(62.372)	23	(73.4)	997.54	(62.274)
15.6	(60.0)	999.01	(62.366)	23.9	(75.0)	997.32	(62.261)
16	(60.8)	998.94	(62.361)	24	(75.2)	997.29	(62.259)
17	(62.6)	998.77	(62.350)	25	(77.0)	997.03	(62.243)
18	(64.4)	998.60	(62.340)	26	(78.8)	996.77	(62.227)
18.3	(65.0)	998.54	(62.336)	26.7	(80.0)	996.59	(62.216)
19	(66.2)	998.40	(62.328)	27	(80.6)	996.50	(62.209)
20	(68.0)	998.20	(62.315)	28	(82.4)	996.23	(62.192)
21	(69.8)	997.99	(62.302)	29	(84.2)	995.95	(62.175)
21.1	(70.0)	997.97	(62.301)	29.4	(85.0)	995.83	(62.166)
22	(71.6)	997.77	(62.288)	30	(86.0)	995.65	(62.156)

Procedure Selection

There are two methods of consolidating the concrete – rodding and vibration. If the slump is greater than 75 mm (3 in.), consolidation is by rodding. When the slump is 25 to 75 mm (1 to 3 in.), internal vibration or rodding can be used to consolidate the sample, but the method used must be that required by the agency in order to obtain consistent, comparable results. For slumps less than 25 mm (1 in.), consolidate the sample by internal vibration. When using measures greater than 0.0142 m^3 (1/2 ft^3) see AASHTO T 121.

Procedure – Rodding

1. Obtain the sample in accordance with the FOP for WAQTC TM 2. Testing may be performed in conjunction with the FOP for AASHTO T 152. When doing so, this FOP should be performed prior to the FOP for AASHTO T 152.

   Note 1: If the two tests are being performed using the same sample, this test shall begin within five minutes of obtaining the sample.

2. Determine the mass of the dry empty measure.

3. Dampen the inside of the measure.

4. Use the scoop to fill the measure approximately 1/3 full with concrete. Evenly distribute the concrete in a circular motion around the inner perimeter of the measure.

5. Consolidate the layer with 25 strokes of the tamping rod, using the rounded end. Distribute the strokes evenly over the entire cross section of the concrete. Rod throughout its depth without hitting the bottom too hard.

6. Tap the sides of the measure smartly 10 to 15 times with the mallet to close voids and release trapped air.

7. Add the second layer, filling the measure about 2/3 full. Evenly distribute the concrete in a circular motion around the inner perimeter of the measure.

8. Consolidate this layer with 25 strokes of the tamping rod, penetrating about 25 mm (1 in.) into the bottom layer.

9. Tap the sides of the measure smartly 10 to 15 times with the mallet.

10. Add the final layer, slightly overfilling the measure. Evenly distribute the concrete in a circular motion around the inner perimeter of the measure.

11. Consolidate this layer with 25 strokes of the tamping rod, penetrating about 25 mm (1 in.) into the second layer.

12. Tap the sides of the measure smartly 10 to 15 times with the mallet.

    Note 2: The measure should be slightly over full, about 3 mm (1/8 in.) above the rim. If there is a great excess of concrete, remove a portion with the scoop. If the measure is under full, add a small quantity. This adjustment may be done only after consolidating the final layer and before striking off the surface of the concrete.

13. Strike off by pressing the strike-off plate flat against the top surface, covering approximately 2/3 of the measure. Withdraw the strike-off plate with a sawing motion to finish the 2/3 originally covered. Cover the original 2/3 again with the plate; finishing the remaining 1/3 with a sawing motion (do not lift the plate; continue the sawing motion until the plate has cleared the surface of the measure). Final finishing may be accomplished with several strokes with the inclined edge of the strike-off plate. The surface should be smooth and free of voids.

14. Clean off all excess concrete from the exterior of the measure including the rim.

15. Determine and record the mass of the measure and the concrete.

16. If the air content of the concrete is to be determined, proceed to Rodding Procedure Step 13 of the FOP for AASHTO T 152.

Procedure - Internal Vibration

1. Perform Steps 1 through 3 of the rodding procedure.

2. Use the scoop to fill the measure approximately 1/2 full with concrete. Evenly distribute the concrete in a circular motion around the inner perimeter of the measure.

3. Insert the vibrator at three different points in each layer. Do not let the vibrator touch the bottom or sides of the measure.

   Note 3: Remove the vibrator slowly, so that no air pockets are left in the material.

   Note 4: Continue vibration only long enough to achieve proper consolidation of the concrete. Over vibration may cause segregation and loss of appreciable quantities of intentionally entrained air.

4. Fill the measure a bit over full. Evenly distribute the concrete in a circular motion around the inner perimeter of the measure.

5. Insert the vibrator as in Step 3. Do not let the vibrator touch the sides of the measure, but do penetrate the first layer approximately 25 mm (1 in.).

6. Return to Step 13 of the rodding procedure and continue.

Calculations

- **Density –** Calculate the net mass, M_m, of the concrete in the measure by subtracting the mass of the measure from the gross mass of the measure plus the concrete. Calculate the density, W, by dividing the net mass, M_m, by the volume, V_m, of the measure as shown below.

$$W = \frac{M_m}{V_m}$$

Example: $W = \frac{16.920\ kg}{0.007079\ m^3} = 2390\ \ kg/m^3$ $W = \frac{36.06\ lb}{0.2494\ ft^3} = 144.6\ \ lb/ft^3$

- **Yield –** Calculate the yield, Y (m^3 or yd^3), or volume of concrete produced per batch, by dividing the total mass of the batch, W_1, by the density, W, of the concrete as shown below.

$$Y_{m^3} = \frac{W_1}{W}$$ Example: $Y_{m^3} = \frac{2436\ kg}{2390\ kg/m^3} = 1.02 m^3$

$$Y_{ft^3} = \frac{W_1}{W} \qquad Y_{yd^3} = \frac{Y_{ft^3}}{27 ft^3/yd^3}$$

Example: $Y_{ft^3} = \frac{3978\ lb}{144.6\ lb/ft^3} = 27.51\ ft^3$ $Y_{yd^3} = \frac{27.51\ ft^3}{27\ ft^3/yd^3} = 1.02\ yd^3$

Note 5: The total mass, W_1, includes the masses of the cement, water, and aggregates in the concrete.

- **Cement Content –** Calculate the actual cement content, N, by dividing the mass of the cement, N_t, by the yield, Y, as shown below.

  Note 6: Specifications may require Portland cement content and cementitious materials content

$$N = \frac{N_t}{Y} \quad \text{Example: } N = \frac{261\ kg}{1.02\ m^3} = 256\ kg/m^3 \quad N = \frac{602\ lb}{1.02\ yd^3} = 590\ lb/yd^3$$

- **Water Content –** Calculate the mass of water in a batch of concrete by summing the:
  - water added at batch plant
  - water added in transit
  - water added at jobsite
  - free water on coarse aggregate
  - free water on fine aggregate
  - liquid admixtures (if the agency requires this)

This information is obtained from concrete batch tickets collected from the driver. Use the following conversion factors.

To Convert From	To	Multiply By
Liters, L	Kilograms, kg	1.0
Gallons, gal	Kilograms, kg	3.785
Gallons, gal	Pounds, lb	8.34
Milliliters, mL	Kilograms, kg	0.001
Ounces, oz	Milliliters, mL	28.4
Ounces, oz	Kilograms, kg	0.0284
Ounces, oz	Pounds, lb	0.0625
Pounds, lb	Kilograms, kg	0.4536

Calculate the mass of free water on aggregate as follows:

$$Free\ Water\ Mass = Total\ Aggregate\ Mass - \frac{Total\ Aggregate\ Mass}{1 + (Free\ Water\ Percentage/100)}$$

Example:

Total Aggregate Mass = 3540 kg (7804 lb)

Free Water Percentage = 1.7*

∗ To determine Free Water percentage:

Total moisture content of the aggregates – absorbed moisture = Free Water

$$Free\ Water\ Mass = 3540\ kg - \frac{3540\ kg}{1 + (1.7\%/100)} \quad 7804\ lb - \frac{7804\ lb}{1 + (1.7\%/100)}$$

Example for actual water content:

Water added at batch plant =	300 L	79 gal
Water added in transit =	0 L	
Water added at jobsite =	40 L	11 gal
	340 L = 340 kg	90 gal = 751 lb

Coarse aggregate: 3540 kg (7804 lbs) @ 1.7% free water

Fine aggregate: 2490 kg (5489 lb) @ 5.9% free water

$$CA\ Free\ Water = 3540kg - \frac{3540\ kg}{1 + (1.7\%/100)} = 59\ kg \quad 7804\ lb - \frac{7804\ lb}{1 + (1.7\%/100)} = 130\ lb$$

$$FA\ Free\ Water = 2490kg - \frac{2490\ kg}{1 + (5.9\%/100)} = 139kg\ or\ 5489lb - \frac{5489\ lb}{1 + (5.9\%/100)} = 306lb$$

Mass of water in batch = 340 kg + 59 + 139 kg = 538 kg   751 lb + 130 + 306 lb = 1187 lb

Water/Cement Ratio – Calculate the water/cement ratio by dividing the mass of water in a batch of concrete by the mass of cementitious material in the batch. The masses of the cementitious materials are obtained from concrete batch tickets collected from the driver.

Example:

Cement:	950 kg	2094 lb
Fly Ash:	180 kg	397 lb
Water:	538 kg (from previous example)	1187 lb

$$W/C = \frac{538\ kg}{950\ kg + 180\ kg} = 0.476 \quad W/C = \frac{1187\ lb}{2094\ lb + 397\ lb} = 0.477$$

Report 0.48

Report

- Results on forms approved by the agency
- Density (unit weight) to 1 kg/m^3 (0.1 lb/ft^3)
- Yield to 0.01 m^3 (0.01 yd^3)
- Cement content to 1 kg/m^3 (1 lb/yd^3)
- Cementitious material content to 1 kg/m^3 (1 lb/yd^3)
- Water/Cement ratio to 0.01