April 21, 2009 Matls. IM 340
Supersedes April 28, 2008

# WEIGHT PER CUBIC FOOT, YIELD & AIR CONTENT (GRAVIMETRIC) OF CONCRETE

## SCOPE

This procedure covers the determination of density, or unit weight of freshly mixed concrete. It also provides formulas for calculating the volume of concrete produced from a mixture of known quantities of component materials.

## SIGNIFICANCE

The unit weight is a useful tool in determining the concrete batch yield and air content. Since air adds no weight to the concrete and only occupies a volume, the unit weight of the concrete gives a very good indication of the air content of the concrete. Normal weight concrete is in the range of 140 - 150 lbs./cu. ft. For normal weight concrete, a change in unit weight of 1.5 lbs./cu. ft. relates to approximately a 1 percent change in air content. Using the unit weight to indicate air content can also prevent any discrepancies between air meters.

## PROCEDURE

A. Apparatus

1. Measure: May be the base of the air meter used for determining air content from IM 318. Otherwise, it shall be a metal container meeting the requirements of AASHTO T-121. The capacity and dimensions of the measure shall conform to those specified in Table 1.
2. Balance or scale: Accurate to 0.3 percent of the test load at any point within the range of use.
3. Tamping Rod: 5/8 in. (16 mm) diameter, having a hemispherical tip.
4. Vibrator: 7000 vibrations per minute, 0.75 in. to 1.50 in. (19 mm to 38 mm) in diameter, at least 3 in. (75 mm) longer than the section being vibrated for use with low slump concrete.
5. Scoop
6. Strike off bar
7. A glass or acrylic strike off plate at least 1/2 in. (12 mm) thick, with a length and width at least 2 in. (50mm) greater than the diameter of the measure The edges of the plate shall be straight and smooth within tolerance of 1/16 in. (1.5mm).
8. Rubber Mallet

**Table 1**
**Dimensions of Measures**

| Capacity $M^3$ ($ft.^3$) | Inside Diameter mm (in.) | Inside Height mm (in.) | Minimum Thickness mm (in.) Bottom | Wall | Nominal Maximum Size of Coarse Aggr. 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) |

Measure may be the base of the air meter used in IM 318.

B. Calibration of Measuring Bowl

1. Determine the weight of the dry measure and strike-off plate.
2. Fill the measure with water at a temperature between 16ºC and 29ºC (60ºF and 85ºF) and cover with the strike-off plate in such a way as to eliminate bubbles and excess water.
3. Wipe dry the measure and cover plate, being careful not to lose any water from the measure.
4. Determine the weight of the measure, strike-off plate, and water in the measure.
5. Determine the weight of the water in the measure by subtracting the weight in Step 1 from the weight 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 weight of the water in the measure by the density of the water at the measured temperature, from Table 2.

Example: $V_m = \frac{15.57}{62.274}$ $V_m = 0.250 \text{ ft.}^3$

**Table 2**
**Unit Weight of Water**
**15ºC to 30ºC**

| ºC | (ºF) | kg/m³ | (lb./ft. ³) | ºC | (ºF) | kg/m³ | (lb./ft. ³) |
|---|---|---|---|---|---|---|---|
| 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) | 998.65 | (62.156) |

C. Testing Procedure

**NOTE:** There are two methods of consolidating the concrete – rodding and vibration. If the slump is greater than 3 in. (75 mm), consolidation is by rodding. When the slump is 1 to 3 in. (25 to 75 mm), 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 1 in. (25 mm), the sample may be consolidated by internal vibration.

1. Determine the weight of the dry measure.
2. Obtain the sample in accordance with IM 327. Testing may be performed in conjunction with IM 318. When doing so, this test should be performed prior to IM 318. **NOTE:** If the two tests are being performed using the same sample, this test shall begin within five minutes of obtaining the sample.
3. Dampen the inside of the measure.
4. Fill the measure approximately 1/3-full with concrete.
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.
8. Consolidate this layer with 25 strokes of the tamping rod, penetrating about 1 in. (25 mm) 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.

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

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

    **NOTE:** The measure should be slightly over full, about 1/8 in. (3 mm) 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 the surface of the concrete and finish it smoothly with a screening action of the strike off bar (sawing action of the strike-off plate) using great care to leave the pot just full. 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 weight of the measure and the concrete.

16. If the air content of the concrete is to be determined, proceed to Step E of IM 318.

D. Calculations

Unit Weight (density) – Calculate the net weight, $W_3$, of the concrete in the measure by subtracting the weight of the measure, W2, from the gross weight of the measure plus the concrete, W1. Calculate the density, ρ, by dividing the net weight, $W_3$, by the volume, $V_m$, of the measure as shown below.

$$W_1 - W_2 = W_3 \qquad \text{Example: } 42.8 – 7.6 = 35.2 \text{ lb.}$$

$$\rho = \frac{W_3}{V_m} \qquad \underline{\text{Example}}: \ \rho = \frac{35.2 \text{ lb.}}{0.249 \text{ cu. ft.}} = 141.37/\text{cu.ft.}$$

Theoretical unit weight (air-free basis) – The theoretical unit weight, T, is the total weight of materials batched divided by the absolute volume of materials batched on an air-free basis.

Using the actual batch weights and absolute volumes, sum the following:

| | Weight | SpGr | Abs. Vol. | Example Abs. Vol. Calc. |
|---|---|---|---|---|
| Cement | 477 | 3.14 | 0.090 | = 477/(3.14 x 62.4 x 27) |
| Fly Ash | 84 | 2.68 | 0.019 | |
| Total Water (Plant, aggr., grade) | 220 | 1.00 | 0.131 | |
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Aggregate, SSD Dry Batch Weights

| | | | |
|---|---|---|---|
| Fine | 1246 | 2.65 | 0.279 |
| Intermediate | 364 | 2.57 | 0.084 |
| Coarse | 1451 | 2.57 | 0.335 |
| Total | 3842 | | 0.938 |

$$\text{Theoretical unit weight (cu. Ft.)} = \frac{\text{Batch weight}}{\text{Abs. Vol. x 27}}$$

$$= \frac{3842}{0.938 \times 27}$$

$$= 151.7 \text{ lbs./cu. ft.}$$

Air Content – Air content is calculated by subtracting the unit weight, ρ, from the theoretical unit weight, T, divided by the theoretical unit weight, T, multiplied by 100 as shown below.

$$A = \frac{T - \rho}{T} \times 100$$

Example: $$A = \frac{151.7 \text{ lbs./cu. ft.} - 141.37 \text{ lbs./cu. ft.}}{151.7 \text{ lbs./cu. ft.}} \times 100 = 6.8\%$$

Theoretical Unit Weight = 151.7 lbs./cu. ft.

The theoretical unit weight, T, is the total weight of materials batched divided by the absolute volume of materials batched on an air free basis.

Relative Batch Yield – Calculate the yield, Y, or volume of concrete produced per cubic yard, by dividing the total weight of the cubic yard batched, $W_{t,}$ by 27, then dividing by the density, ρ, of the concrete as shown below.

$$Y = \frac{W_1 \div 27}{\rho}$$

Example: $$Y = \frac{3842 \text{ lbs. batched per cu. yd.} \div 27}{141.37 \text{ lb./cu. ft.}} = 1.007 \text{ cu. yd.}$$