# ACI Method Example

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# ACI Method Example

We require a mix with a *mean* 28-day compressive strength (measured on standard cylinders) of 35 MPa and a slump of 50 mm, ordinary Portland cement being used. The maximum size of well-shaped, angular aggregate is 20 mm, its bulk density is 1600 kg/m$^3$, and its specific gravity is 2.64. The available fine aggregate has a fineness modulus of 2.60 and a specific gravity of 2.58. No air entrainment is required. For the sake of completeness, all steps, even when obvious, will be given.

# Solution

Step 1: **Choice of slump:** A slump of 50 mm is specified.

Step 2: **Choice of maximum size of aggregate:** The maximum size of aggregate of 20 mm is specified.

# Solution

Step 3: **Estimate of water content and air content:**

From Table 14.5 for a slump of 50 mm and a maximum size of aggregate of 20 mm (or 19 mm), the water requirement is approximately 190 kg per cubic metre of concrete.

# Solution

| Table 14.5 Approximate Mixing Water and Air Content Requirements for Different Slumps and Nominal Maximum Sizes of Aggregates given in ACI 211.1-91 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Slump, mm | Water, kg/m$^3$ of concrete for indicated nominal maximum sizes of aggregate in mm | | | | | | | |
| | 9.5 | 12.5 | 19 | 25 | 37.5 | *50* | 75 | *150* |
| **Non-air-entrained Concrete** | | | | | | | | |
| 25 to 50 | 207 | 199 | 190 | 179 | 166 | 154 | 130 | 113 |
| 75 to 100 | 228 | 216 | 205 | 193 | 181 | 169 | 145 | 124 |
| 150 to 175 | 243 | 228 | 216 | 202 | 190 | 178 | 160 | - |
| Amount of entrapped air, per cent | 3 | 2.5 | 2 | 1.5 | 1 | 0.5 | 0.3 | 0.2 |
| **Air-entrained concrete** | | | | | | | | |
| 25 to 50 | 181 | 175 | 168 | 160 | 150 | 142 | 122 | 107 |
| 75 to 100 | 202 | 193 | 184 | 175 | 165 | 157 | 133 | 119 |
| 150 to 175 | 216 | 205 | 197 | 184 | 174 | 166 | 154 | - |
| Total air content, (per cent) for: | | | | | | | | |
| Improvement of workability | 4.5 | 4.0 | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 1.0 |
| Moderate exposure | 6.0 | 5.5 | 5.0 | 4.5 | 4.5 | 4.0 | 3.5 | 3.0 |
| Extreme exposure | 7.5 | 7.0 | 6.0 | 6.0 | 5.5 | 5.0 | 4.5 | 4.0 |

# Solution

Step 4: **Selection of water/cement ratio:**

From past experience, a water/cement ratio of 0.48 is expected to result in concrete with a compressive strength, measured on cylinders, of 35 Mpa (5076.31) see (Table 2). There are no special durability requirements.

- When different cementitious materials are used, it should be remembered that they have varying values of specific gravity: typical values are 3.15 for Portland cement, 2.90 for ground granulated blast furnace slag, and 2.30 for fly ash.

# Solution

| Table 2: Selection of w/c ratio | | |
|---|---|---|
| 28-day Compressive Strength (psi) | Non-AE | AE |
| 2000 | 0.82 | 0.74 |
| 3000 | 0.68 | 0.59 |
| 4000 | 0.57 | 0.48 |
| 5000 | 0.48 | 0.40 |
| 6000 | 0.41 | |

# Solution

Step 5: **Calculation of cement content:**

The cement content is 190/0.48=395 kg/$m^3$.

# Solution

Step 6: **Estimate of coarse aggregate content:**

From Table 14.6, when used with a fine aggregate having a fineness modulus of 2.60, the bulk volume of oven-dry rodded coarse aggregate with a maximum size of 20 mm is 0.64. Given that the bulk density of the coarse aggregate is 1600 $kg/m^3$, the mass of coarse aggregate is 0.64 x 1600= 1020$kg/m^3$.

# Solution

| Table 14.6: Bulk Volume of Coarse Aggregate per Unit Volume of Concrete | | | | | |
|---|---|---|---|---|---|
| Maximum size of aggregate | | Bulk volume of oven-dry rodded coarse aggregate per unit volume of concrete for fineness modulus of fine aggregate of: | | | |
| mm | inch | *2.40* | *2.60* | *2.80* | *3.00* |
| 9.5 | $\frac{3}{8}$ | 0.50 | 0.48 | 0.46 | 0.44 |
| 12.5 | $\frac{1}{2}$ | 0.59 | 0.57 | 0.55 | 0.53 |
| 20 | $\frac{3}{4}$ | 0.66 | 0.64 | 0.62 | 0.60 |
| 25 | 1 | 0.71 | 0.69 | 0.67 | 0.65 |
| 37.5 | $1\frac{1}{2}$ | 0.75 | 0.73 | 0.71 | 0.69 |
| 50 | 2 | 0.78 | 0.76 | 0.74 | 0.72 |
| 75 | 3 | 0.82 | 0.80 | 0.78 | 0.76 |
| 150 | 6 | 0.87 | 0.85 | 0.83 | 0.81 |

# Solution

Step 7: **Estimate of fine aggregate content:**

To calculate the mass of fine aggregate, we need first to calculate the volume of all the other ingredients. The required values are as follows.

Volume of water is 190/1000 = 0.19 $m^3$

Solid volume of cement, assuming usual specific gravity of

3.15, is 395/ (3.15 x 1000) = 0.126 $m^3$

Solid volume of coarse aggregate = 0.396 $m^3$

is 1020/ (2.64 x 1000)

Volume of entrapped air, given in Table 14.5,

is 0.02 x 1000 = 0.020 $m^3$

# Solution

Hence, total volume of all ingredients except fine aggregate = 0.732 $m^3$

Therefore, the required volume of fine aggregate is 1.000-0.732 = 0.268 $m^3$

Hence, the mass of fine aggregate is 0.268 x 2.58 x 1000 = 690 kg/ $m^3$,

From the various steps, we can list the estimated mass of each of the ingredients in kilograms per cubic meter of concrete as follows:

# Solution

| | |
|---|---|
| • Water | 190 |
| • Cement | 395 |
| • Coarse aggregate, dry | 1020 |
| • Fine aggregate, dry | 690 |
| • Density of concrete is | 2295 kg/ $m^3$ |

# Design Example 2

Design the concrete for an unreinforced, air-entrained pavement, in a very cold climate where there is no statistical data available for the proposed mix design; 25 cm thick; specified 28-day concrete flexural strength of 4.7 MPa; the coarse aggregates have a bulk specific gravity of 2.70; a rodded density of 1650 kg/m3 at the saturated surface dry (SSD) condition and a moisture content of 1.5% above the SSD condition; the fine aggregates have a bulk specific gravity of 2.65 with a fineness modulus of 2.75 and a moisture of 5% above the (SSD) condition. The apparent specific gravity of the Portland cement = 3.15.

# Design Solution

For structural concrete, the required compressive strength is specified. Only in the case of pavements is the flexural strength criterion used instead. However, since the mix design tables are predicated on compressive strength, Equation in next slide is used to determine the approximate equivalent compressive strength, f’c.

- f’c = (MR/K)^2 — in MPa for the SI System

K = 0.7 to 0.8

- f’c = (MR/K)^2 — in psi for the Standard U.S.

K = 7.5 to 10

MR stands for Modulus of Rapture

f’c = (MR/0.8)^2 = (4.7/0.8)^2 = 34.5 MPa

# Step 1

Determine the required mix design strength, f'cr, from Table 7 = 34.5 + 8.3 = 42.8 MPa.

**TABLE 7**
**Required Average Compressive Strength When Data to Establish a Standard Deviation Is Not Available**

| Specified Compressive Strength, $f'_c$, MPa (psi) | Required Average Compressive Strength, $f'_{cr}$, MPa (psi) |
|---|---|
| Less than 20 MPa (3000 psi) | $f'_c$ + 6.9 MPa (1000 psi) |
| 20 to 35 MPa (3000–5000 psi) | $f'_c$ + 8.3 MPa (1200 psi) |
| Over 35 MPa (5000 psi) | $f'_c$ + 9.6 MPa (1400 psi) |

Adapted from the ACI Committee Report, "Building Code Requirements for Reinforced Concrete."

# Step 2

This is the estimated water/cement ratio from Table 9. Since the table does not show the w/c ratio beyond a strength of 35 MPa, a questimate was made to specify a 0.35 w/c ratio, which is very low.

TABLE 9
Approximate Relationship between W/C Ratio and the Concrete Compressive Strength

| Compressive Strength at 28 Days, MPa (See Table 9 for Percent Air Allowed) | Water/Portland Cement Ratio by Mass | |
|---|---|---|
| | Non-Air-Entrained Concrete | Air-Entrained Concrete |
| 40 | 0.42 | — |
| 35 | 0.47 | 0.39 |
| 30 | 0.54 | 0.45 |
| 25 | 0.61 | 0.52 |
| 20 | 0.69 | 0.60 |
| 15 | 0.79 | 0.70 |

Adapted from the ACI Committee 211 Report, "Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete."

In practice, a water-reducing or superplastizer additive would very likely have to be added in order that the concrete mix be sufficiently workable at the 0.35 w/c ratio. Check Table 4 to assure that the maximum w/c ratio is not exceeded. However, because of the fairly high percent of entrained air, the mix may still prove to be sufficiently workable.

**TABLE 4**
**Maximum Water/Cement Ratio for Various Exposure Conditions**

| Exposure Condition | Maximum W/C Ratio by Weight for Normal Weight Concrete |
|---|---|
| Concrete protected from exposure to freezing and thawing or the application of deicer chemicals | Select the W/C ratio on the basis of strength, workability, and finishing needs |
| Concrete intended to be watertight: | |
| a. Concrete exposed to fresh water | 0.50 |
| b. Concrete exposed to brackish water or seawater | 0.45 |
| Concrete exposed to freezing and thawing in a moist condition:[a] | |
| a. Curbs, gutters, guardrails, or other thin sections | 0.45 |
| b. Other elements | 0.50 |
| c. In the presence of deicing chemicals | 0.45 |
| For corrosion protection for reinforced concrete exposed to deicing salts, brackish water, seawater, or spray from these sources | 0.40 |

[a] Air-entrained concrete.
Adapted from the ACI 318 Committee Report, "Building Code Requirements for Reinforced Concrete."

# Step 3

In selecting the maximum size of coarse aggregate, there are a number of criteria that need to be met. They will all be enumerated here even though not all are applicable in this illustrative design problem. The criteria for the maximum permissible size of aggregate are as follows:

1. Not to exceed one-fifth the narrowest dimension between the insides of a form.

2. Three-quarters of the clear space between reinforcing bars, ducts, or any other appurtenances embedded in the concrete.

# Step 3

3. Three-quarters of the clear space between the reinforcing bars and the inside face of the forms.

4. In the case of an unreinforced concrete slab, one-third the minimum slab thickness, where the concrete is not a uniform depth.

- In the case of the 25-cm pavement thickness, this would translate to a 75-mm aggregate, which is on the high side, but if available and economical, should be used. Generally speaking, a 50-mm aggregate is the largest size that is commonly encountered.

# Step 4

- The air content depends principally upon the environment under which the structure will be functioning. Refer to Table 10. The structure in this problem would qualify as a Category 1, exposed to freezing and thawing, for an air content of 4 to 7%. Table 11 indicates a target percent of entrained air at 4.5, which is in the 4 to 7% range shown in Table 10. For any number of reasons it is not possible to specify and expect to repeatedly obtain an exact % of air.

# Step 4

Furthermore, the author is of the opinion that slightly more air is preferable to less air. Therefore, a target percent air will be chosen of −1% to +2%. In the case of this illustrative design example, a target percent of air of 5% (–1% to +2%) for a range of 4 to 7% was chosen.

**TABLE 10**
**Air Content Requirements According to Category**

| | Range of Air Content in % at Indicated Nominal Maximum Sizes of Coarse Aggregates | | |
|---|---|---|---|
| Air[a] Content Category | 10 mm | 14–20 mm | 28–40 mm |
| 1 | 6–9 | 5–8 | 4–7 |
| 2 | 5–8 | 4–7 | 3–6 |

[a] Category 1 is for concrete exposed to freezing and thawing. Category 2 is for concrete not exposed to freezing and thawing.

# Step 4

**TABLE 11**
**Approximate Water and Air Content Requirements for Various Slumps and Maximum Size Aggregates in the Concrete Mix**

| | Water per kg/m$^3$ of Concrete for Indicated Maximum Size of Aggregate in mm[a] | | | |
|---|---|---|---|---|
| Slump, mm | 10 | 20 | 40 | 80 |
| **Non-air-entrained concrete** | | | | |
| 25–50 | 207 | 190 | 166 | 130 |
| 75–100 | 228 | 205 | 181 | 145 |
| 150–175 | 243 | 216 | 190 | 160 |
| Approximate % entrained air | 3 | 2 | 1 | 0.3 |
| **Air-entrained concrete** | | | | |
| 25–50 | 181 | 168 | 150 | 122 |
| 75–100 | 202 | 184 | 165 | 133 |
| 150–175 | 216 | 197 | 174 | 154 |
| **Recommended % air for level of exposure** | Slumps for Concrete with Aggregates Larger Than 40 mm Are Made after the Removal of the +40-mm Particles by Wet Screening. | | | |
| Mild exposure | 4.5 | 3.5 | 2.5 | 1.5 |
| Moderate exposure | 6.0 | 5.0 | 4.5 | 3.5 |
| Severe exposure | 7.5 | 6.0 | 5.5 | 4.5 |

Adapted from the ACI Committee 211 Report, "Standard Practice for Normal, Heavyweight and Mass Concrete."

# Step 5

The desired concrete slump must be specified. For this purpose, refer to Table 6, which shows 2.5 to 7.5 cm.

TABLE 6
Recommended Slumps for Various Types of Construction[a]

| | Slump in mm (inches) | |
|---|---|---|
| Concrete Construction | Maximum | Minimum |
| Reinforced foundation and footings | 75 mm (3 in.) | 25 mm (1 in.) |
| Plain footings, caissons, and substructure walls | 75 mm (3 in.) | 25 mm (1 in.) |
| Beams and reinforced walls | 100 mm (4 in.) | 25 mm (1 in.) |
| Building columns | 75 mm (3 in.) | 25 mm (1 in.) |
| Pavements and slabs | 75 mm (3 in.) | 25 mm (1 in.) |
| Mass concrete | 50 mm (2 in.) | 25 mm (1 in.) |

[a] In designing for slump, try to aim for the middle of the range.
Adapted from the ACI 211 Report, "Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete."

# Step 6

Coarse aggregate quantity is estimated from Table 5, bearing in mind the maximum size of coarse aggregates and the fineness modulus of the fine aggregates. In the case of this illustrative problem, they are 7.5 cm and 2.75, respectively. This results in an interpolated volume of dry rodded coarse aggregates of 0.78.

# Step 6

**TABLE 5**
**Volume of Coarse Aggregate per Unit Volume of Concrete as per ASTM Designation: C 29**

| Maximum Size of Aggregate, mm (inches) | Volume of Rodded Coarse Aggregates per Unit Volume of Concrete for Different Fineness Moduli of Fine Aggregates as per ASTM Designation: C 29[a] | | | |
|---|---|---|---|---|
| | 2.40 | 2.60 | 2.80 | 3.00 |
| 9.5 mm (⅜ in.) | 0.50 | 0.48 | 0.46 | 0.44 |
| 12.5 mm (½ in.) | 0.59 | 0.57 | 0.55 | 0.53 |
| 19 mm (¾ in.) | 0.66 | 0.64 | 0.62 | 0.60 |
| 25 mm (1 in.) | 0.71 | 0.69 | 0.67 | 0.65 |
| 37.5 mm (1.5 in.) | 0.75 | 0.73 | 0.71 | 0.69 |
| 50 mm (2 in.) | 0.78 | 0.76 | 0.74 | 0.72 |
| 76 mm (3 in.) | 0.82 | 0.80 | 0.78 | 0.76 |

[a] Volume of either Dry- or SSD-Rodded. It is important to differentiate in computing the adjusted moisture content for the concrete mix.

Adapted from the ACI 211 Report, "Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete."

# Step 6

Slump from Table 6 shows 2.5 to 7.5 cm. Water content from Table 11 = 122 kg/m^3, using the lower slump of 2.5 to 5.0 cm and the more desirable range from the author's experience in slip form paving operations.

TABLE 11
**Approximate Water and Air Content Requirements for Various Slumps and Maximum Size Aggregates in the Concrete Mix**

| | Water per kg/m³ of Concrete for Indicated Maximum Size of Aggregate in mm[a] | | | |
|---|---|---|---|---|
| Slump, mm | 10 | 20 | 40 | 80 |
| **Non-air-entrained concrete** | | | | |
| 25–50 | 207 | 190 | 166 | 130 |
| 75–100 | 228 | 205 | 181 | 145 |
| 150–175 | 243 | 216 | 190 | 160 |
| Approximate % entrained air | 3 | 2 | 1 | 0.3 |
| **Air-entrained concrete** | | | | |
| 25–50 | 181 | 168 | 150 | 122 |
| 75–100 | 202 | 184 | 165 | 133 |
| 150–175 | 216 | 197 | 174 | 154 |
| **Recommended % air for level of exposure** | Slumps for Concrete with Aggregates Larger Than 40 mm Are Made after the Removal of the +40-mm Particles by Wet Screening. | | | |
| Mild exposure | 4.5 | 3.5 | 2.5 | 1.5 |
| Moderate exposure | 6.0 | 5.0 | 4.5 | 3.5 |
| Severe exposure | 7.5 | 6.0 | 5.5 | 4.5 |

Adapted from the ACI Committee 211 Report, "Standard Practice for Normal, Heavyweight and Mass Concrete."

# Step 6

Cement content is based upon a w/c ratio of 0.35 = 122/0.35 = 349 kg/m3. Referring to Table 8, the minimum recommended Portland cement content for this mix is 335 kilograms. Table 4 permits a w/c ratio of 0.45 for this concrete. Therefore, the design w/c ratio and design cement quantity is satisfactory for the trial mix.

TABLE 8
Minimum Portland Cement Requirements for Normal-Density Concrete Placed in Slabs and Pavements

| Maximum Size of Aggregates, mm | Portland Cement,[a] kg/m$^3$ |
|---|---|
| 40 | 282 |
| 20 | 324 |
| 14 | 354 |
| 10 | 366 |

[a] Cement quantities need to be increased in cases of severe environmental conditions; for tremie concrete (that is, concrete placed under water) quantities should be ≥390 kg/m$^3$, or for a very cold climate, where the concrete is subject to freezing and thawing cycles, the cement content should be ≥335 kg/m$^3$.

Adapted from the ACI Committee 302 Report, "Guide for Concrete Floor and Slab Construction."

TABLE 4
Maximum Water/Cement Ratio for Various Exposure Conditions

| Exposure Condition | Maximum W/C Ratio by Weight for Normal Weight Concrete |
|---|---|
| Concrete protected from exposure to freezing and thawing or the application of deicer chemicals | Select the W/C ratio on the basis of strength, workability, and finishing needs |
| Concrete intended to be watertight: | |
| a. Concrete exposed to fresh water | 0.50 |
| b. Concrete exposed to brackish water or seawater | 0.45 |
| Concrete exposed to freezing and thawing in a moist condition:[a] | |
| a. Curbs, gutters, guardrails, or other thin sections | 0.45 |
| b. Other elements | 0.50 |
| c. In the presence of deicing chemicals | 0.45 |
| For corrosion protection for reinforced concrete exposed to deicing salts, brackish water, seawater, or spray from these sources | 0.40 |

[a] Air-entrained concrete.

Adapted from the ACI 318 Committee Report, "Building Code Requirements for Reinforced Concrete."

# Step 6

Coarse aggregates were found to have a rodded SSD condition density of 1650 kg/m3. For a cubic meter batch of concrete, the required C.A. weight = 0.78 × 1650 = 1287 + 10% (as explained on page 13) = 1416 kg.

# Step 7

At this point the quantity of all the materials in the mix has been accounted for except for the fine aggregates. The latter is found by subtracting the volume of the air, cement, coarse aggregates, and water from a cubic meter to estimate the fine aggregate quantity in the batch.

- Air = 0.05 = 0.050 m3
- Cement = 349/(3.15 × 1000) = 0.111 m3
- Coarse aggregates = 1416/(2.70 × 1000) = 0.524 m3
- Water = 122/(1 × 1000 = 0.122 m3
- Total volume of the above materials = 0.807 m3
- Computed volume of fine aggregates = 1.000 – 0.807 = 0.193 m3, Weight of fine aggregates in the concrete batch = 0.193 × 2.65 × 1000 = 511 kg

- Total weight of all the ingredients in the 1-cubic-meter concrete batch = 349 kg (cement) + 1416 kg (coarse aggregates) + 511 kg (fine aggregates) + 122 kg (water) = 2398 kg.

# Step 8 (Adjustment)

- A moisture correction at this point is needed to compensate for the moisture in the aggregates above that
- present for the SSD condition. The new trial batch weights are as follows:
- Coarse aggregates = 1416 × 1.015 = 1437 kg
- Fine aggregates = 511 × 1.05 = 537 kg
- Water = 122 − 1416 × 0.015 − 511 × 0.05 = 75 kg
- Cement = 349 kg
- Total materials after water adjustment remains the same: 2398 kg

- In the laboratory, mixes will normally be based on batches made from 5, 10, or at the most 15 kg of Portland cement. For example, consider a 10-kg batch. The quantities would be as follows:
- Cement =
- C.A. =
- F.A. =
- Water =

# H.W

- Design the concrete for an unreinforced, air-entrained pavement in a mild climate. Assume that there is no available statistical data for the proposed mix design, and use the following parameters: 10 inches thick; specified 28-day concrete flexural strength of 700 psi; the coarse aggregates have a bulk specific gravity of 2.70, with a rodded density of 110 lb/ft3 at the saturated surface dry (SSD) condition, and a moisture content of 1.5% above the SSD condition; the fine aggregates have a bulk specific gravity of 2.65 with a fineness modulus of 2.75 and a moisture of 5% above the (SSD) condition.

# H.W

**TABLE 12**
**Approximate Relationship between W/C and the Concrete Compressive Strength**

| Compressive Strength at 28 Days, psi[a] | Water/Cement Ratio by Weight | |
|---|---|---|
| | Non-Air-Entrained Concrete | Air-Entrained Concrete |
| 6000 | 0.41 | 0.35 |
| 5000 | 0.48 | 0.40 |
| 4000 | 0.57 | 0.48 |
| 3000 | 0.68 | 0.59 |
| 2000 | 0.82 | 0.74 |

[a] Values are the estimated average strengths for concrete containing not more than the percentage of entrained air shown in Table 14 for a maximum size aggregate of 1 inch.

Adapted from the ACI Committee 211 Report, "Standard Practice for Normal, Heavyweight, and Mass Concrete."

# H.W

**TABLE 14**
**Approximate Mixing Water and Air Content for Different Slumps and Aggregate Sizes**

| Slump in Inches | Water in Pounds per Cubic Yard of Concrete for the Indicated Slumps and Maximum Sizes of Aggregates[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| | ⅜ in. | ½ in. | ¾ in. | 1 in. | 1½ in. | 2 in. | 3 in. |
| **Non-air-entrained concrete** | | | | | | | |
| 1–2 | 350 | 335 | 315 | 300 | 275 | 260 | 220 |
| 3–4 | 385 | 365 | 340 | 325 | 300 | 285 | 245 |
| 6–7 | 410 | 385 | 360 | 340 | 315 | 300 | 270 |
| Approximate % of entrapped air in non-air-entrained concrete | 3 | 2.5 | 2 | 1.5 | 1 | 0.5 | 0.3 |
| **Air-entrained concrete** | | | | | | | |
| 1–2 | 305 | 295 | 280 | 270 | 240 | 205 | 180 |
| 3–4 | 340 | 325 | 305 | 295 | 275 | 265 | 225 |
| 6–7 | 365 | 345 | 325 | 310 | 290 | 280 | 260 |
| **Average % air content for level of exposure** | Slump for Concrete with Aggregates >40 mm Are Made after Removal of the +40-mm Particles by Wet Screening. | | | | | | |
| Mild exposure | 4.5 | 4.0 | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 |
| Moderate exposure | 6.0 | 5.5 | 5.0 | 4.5 | 4.5 | 4.0 | 3.5 |
| Severe exposure | 7.5 | 7.0 | 6.0 | 6.0 | 5.5 | 5.0 | 4.5 |

[a] The water estimates in this table are for angular crushed stone. The quantities may be reduced by about 10 lb for subangular coarse aggregates, 35 lb for gravel with some crushed particles, and 45 lb for rounded gravel to produce the slumps shown. A change in water content of 10 lb/yd$^3$ will affect the slump by about 1 inch. Of course an increase in water will raise the slump and conversely. A decrease in air content of 1% will increase water demand for the same slump by about 5 lb/yd$^3$.

Adapted from ACI Committee 211, "Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete" and from ACI Committee Report 318-83, "Building Code Requirements for Reinforced Concrete."

# Rreference


- Engineered Concrete Mix Design & Test Methods, second edition, IRVING KETT.