Trial Mix Design

Mix Design Example

Nominal maximum aggregate size = 3/4"
Design strength (f'_c) = 4500 psi
Specified slump = 1-2"

	Coarse Aggregate	Fine Aggregate
Unit weight (lb/ft^3) =	101	106
Bulk specific gravity (dry) =	2.574	2.548
Bulk specific gravity (SSD) =	2.623	2.592
Apparent specific gravity =	2.705	2.664
Absorption capacity (%) =	1.89	1.70
Fineness modulus =	2.51	3.00

Step 1: Select the slump

Equivalent to Table 7-13

Table 9-6. Recommended Slumps for Various Types of Construction

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

Source: Design and Control of Concrete Mixtures (PCA, 2003)

Step 2: Select the NMAS

$$\text{NMAS} \le \frac{\text{narrowest dimension}}{5}$$

$$\text{NMAS} \le \frac{\text{depth of slab}}{3}$$

$$\text{NMAS} \le 0.75 \times \text{clear space}$$

Step 3: Estimate the water and air

Equivalent to Table 7-14

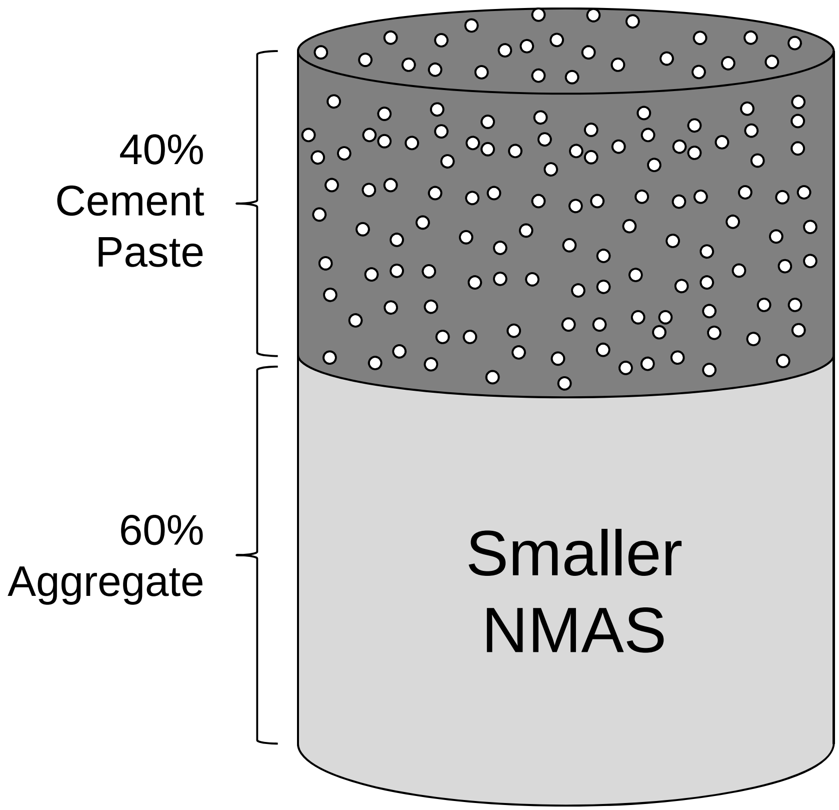
Table 9-5 (Inch-Pound Units). Approximate Mixing Water and Target Air Content Requirements for Different Slumps and Nominal Maximum Sizes of Aggregate

Slump, in.	Water, pounds per cubic yard of concrete, for indicated sizes of aggregate*							
	⅜ in.	½ in.	¾ in.	1 in.	1½ in.	2 in.**	3 in.**	6 in.**
	Non-air-entrained concrete							
1 to 2	350	335	315	300	275	260	220	190
3 to 4	385	365	340	325	300	285	245	210
6 to 7	410	385	360	340	315	300	270	—
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2
	Air-entrained concrete							
1 to 2	305	295	280	270	250	240	205	180
3 to 4	340	325	305	295	275	265	225	200
6 to 7	365	345	325	310	290	280	260	—
Recommended average total air content, percent, for level of exposure:†								
Mild exposure	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	3.5	3.5	3.0
Severe exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

* These quantities of mixing water are for use in computing cement factors for trial batches. They are maximums for reasonably well-shaped angular coarse aggregates graded within limits of accepted specifications.

Source: Design and Control of Concrete Mixtures (PCA, 2003)

Air Content



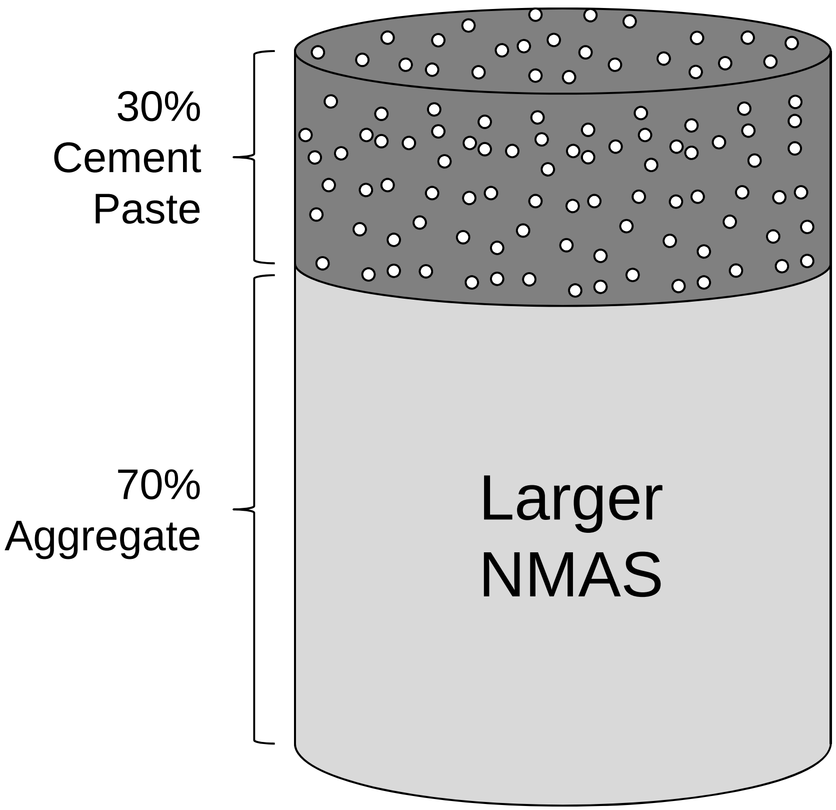
Paste Air Content

Assume 7%

Concrete Air Content

$0.4 \times 7\% = 2.8\%$

Air Content



<u>Paste Air Content</u>

Assume 7%

<u>Concrete Air Content</u>

$0.3 \times 7\% = 2.1\%$

Step 3: Estimate the water and air

Equivalent to Table 7-14

Table 9-5 (Inch-Pound Units). Approximate Mixing Water and Target Air Content Requirements for Different Slumps and Nominal Maximum Sizes of Aggregate

Slump, in.	Water, pounds per cubic yard of concrete, for indicated sizes of aggregate*							
	⅜ in.	½ in.	¾ in.	1 in.	1½ in.	2 in.**	3 in.**	6 in.**
	Non-air-entrained concrete							
1 to 2	350	335	315	300	275	260	220	190
3 to 4	385	365	340	325	300	285	245	210
6 to 7	410	385	360	340	315	300	270	—
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2
	Air-entrained concrete							
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Recommended average total air content, percent, for level of exposure:†								
Mild exposure	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	3.5	3.5	3.0
Severe exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

* These quantities of mixing water are for use in computing cement factors for trial batches. They are maximums for reasonably well-shaped angular coarse aggregates graded within limits of accepted specifications.

Source: Design and Control of Concrete Mixtures (PCA, 2003)

Adjust for Aggregate Shape

Different slumps are needed for various types of concrete construction. Slump is usually indicated in the job specifications as a range, such as 50 to 100 mm (2 to 4 in.), or as a maximum value not to be exceeded. ASTM C 94 addresses slump tolerances in detail. When slump is not specified, an approximate value can be selected from Table 9-6 for concrete consolidated by mechanical vibration. For batch adjustments, the slump can be increased by about 10 mm by adding 2 kilograms of water per cubic meter of concrete (1 in. by adding 10 lb of water per cubic yard of concrete).

Water Content

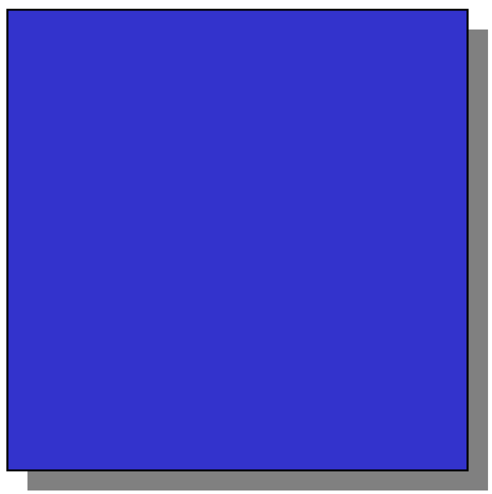
The water content of concrete is influenced by a number of factors: aggregate size, aggregate shape, aggregate texture, slump, water to cementing materials ratio, air content, cementing materials type and content, admixtures, and environmental conditions. An increase in air content and aggregate size, a reduction in water-cementing materials ratio and slump, and the use of rounded aggregates, water-reducing admixtures, or fly ash will reduce water demand. On the other hand, increased temperatures, cement contents, slump, water-cement ratio, aggregate angularity, and a decrease in the proportion of coarse aggregate to fine aggregates (crushed stone). For some concretes and aggregates, the water estimates in Table 9-5 and Fig. 9-5 can be reduced by approximately 10 kg (20 lb) for subangular aggregate, 20 kg (35 lb) for gravel with some crushed particles, and 25 kg (45 lb) for a rounded gravel to produce the slumps shown. This illustrates the need for trial batch testing of local materials, as each aggregate source is different and can influence concrete properties differently.

Table 9-6. Recommended Slumps for Various Types of Construction

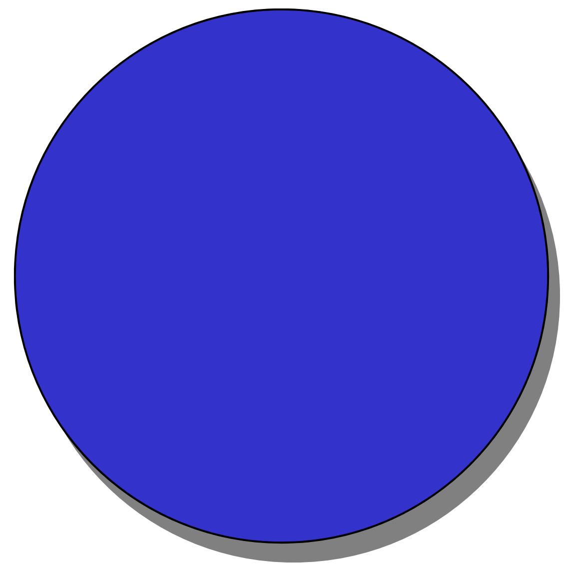
Concrete construction	Slump, mm (in.) Maximum*	Slump, mm (in.) Minimum
Reinforced foundation walls and footings	75 (3)	25 (1)
Plain footings, caissons, and substructure walls	75 (3)	25 (1)
Beams and reinforced walls	100 (4)	25 (1)
Building columns	100 (4)	25 (1)
Pavements and slabs	75 (3)	25 (1)
Mass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

Source: Design and Control of Concrete Mixtures (PCA, 2003)

Minimizing Surface Area



surface area = 6.0 ft^2/ft^3



surface area = 4.8 ft^2/ft^3

Step 4: Select the w/c ratio

Equivalent to Table 7-15

Table 9-3 (Inch-Pound Units). Relationship Between Water to Cementitious Material Ratio and Compressive Strength of Concrete

$f'_{cr} \Rightarrow$

Compressive strength at 28 days, psi	Water-cementitious materials ratio by mass	
	Non-air-entrained concrete	Air-entrained concrete
7000	0.33	—
6000	0.41	0.32
5000	0.48	0.40
4000	0.57	0.48
3000	0.68	0.59
2000	0.82	0.74

Strength is based on cylinders moist-cured 28 days in accordance with ASTM C 31 (AASHTO T 23). Relationship assumes nominal maximum size aggregate of about ¾ in. to 1 in.

Source: Design and Control of Concrete Mixtures (PCA, 2003)

Overdesign Factors

Table 7-12 Overdesign Necessary to Meet Strength Requirements[A]

Number of Tests[B]	Standard Deviation, psi					
	300	400	500	600	700	Unknown
15	470	620	850	1120	1390	C
20	430	580	760	1010	1260	C
30 or more	400	530	670	900	1130	C
	Standard Deviation, MPa					
	2.0	3.0	4.0	5.0		Unknown
15	3.1	4.7	7.3	10.0		C
20	2.9	4.3	6.6	9.1		C
30 or more	2.7	4.0	5.8	8.2		C

[A] Add the tabulated amounts to the specified strength to obtain the required average strengths.

[B] Number of tests of a concrete mixture used to estimate the standard deviation of a concrete production facility. The mixture used must have a strength within 1000 psi of that specified and be made with similar materials. See ACI 318.

[C] If less than 15 prior tests are available, the overdesign should be 1000 psi [7.0 MPa] for specified strength less than 3000 psi [20 MPa], 1200 psi [8.5 MPa] for specified strengths from 3000 to 5000 psi [20 to 35 MPa] and 1400 psi [10.0 MPa] for specified strengths greater than 5000 psi [35 MPa].

Step 4: Select the w/c ratio

Equivalent to Table 7-15

Table 9-3 (Inch-Pound Units). Relationship Between Water to Cementitious Material Ratio and Compressive Strength of Concrete

$f'_{cr} \Rightarrow$

Compressive strength at 28 days, psi	Water-cementitious materials ratio by mass	
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2000	0.82	0.74

Strength is based on cylinders moist-cured 28 days in accordance with ASTM C 31 (AASHTO T 23). Relationship assumes nominal maximum size aggregate of about ¾ in. to 1 in.

Source: Design and Control of Concrete Mixtures (PCA, 2003)

Step 5: Calculate the cement weight

$$W_{cement} = \frac{W_{water}}{\text{w/c ratio}}$$

Step 6: Estimate coarse aggregate

Equivalent to Table 7-17

Table 9-4. Bulk Volume of Coarse Aggregate Per Unit Volume of Concrete

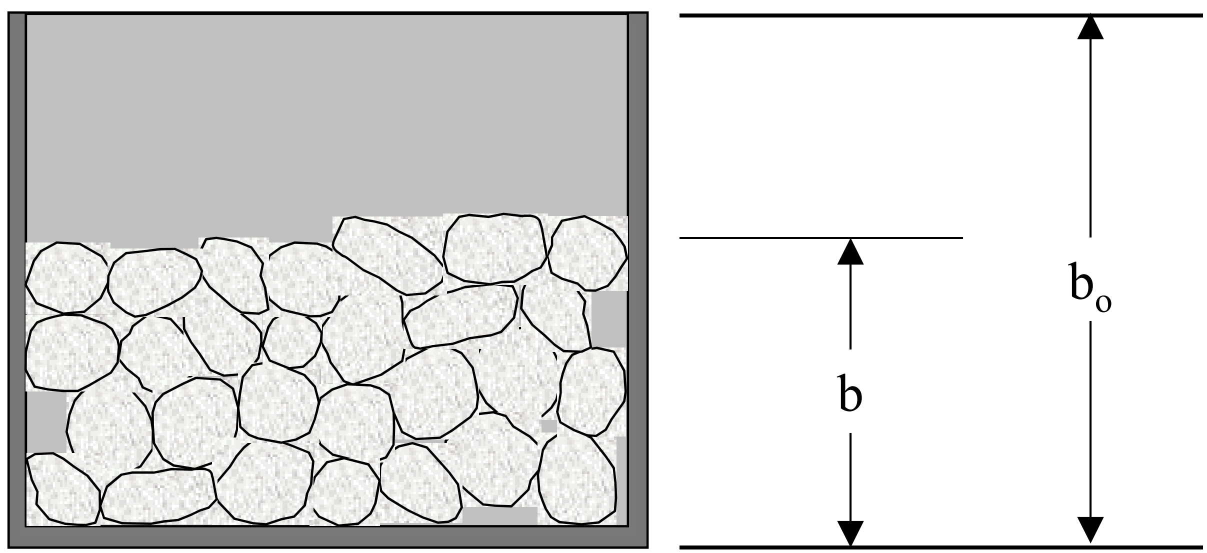
Nominal maximum size of aggregate, mm (in.)	Bulk volume of dry-rodded coarse aggregate per unit volume of concrete for different fineness moduli of fine aggregate*			
	2.40	2.60	2.80	3.00
9.5 (⅜)	0.50	0.48	0.46	0.44
12.5 (½)	0.59	0.57	0.55	0.53
19 (¾)	0.66	0.64	0.62	0.60
25 (1)	0.71	0.69	0.67	0.65
37.5 (1½)	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

$\Leftarrow b/b_o$

*Bulk volumes are based on aggregates in a dry-rodded condition as described in ASTM C 29 (AASHTO T 19). Adapted from ACI 211.1.

Source: Design and Control of Concrete Mixtures (PCA, 2003)

b/b_o



Step 6: Estimate coarse aggregate

$$V_{gravel}^{bulk} = (b/b_o)\, V_{concrete}^{bulk}$$

$$W_{gravel} = V_{gravel}^{bulk}\, \gamma_{gravel}^{bulk} \Leftarrow \text{dry-rodded unit weight}$$

$$W_{gravel} = (b/b_o)\, V_{concrete}^{bulk}\, \gamma_{gravel}^{bulk}$$

Step 7: Estimate fine aggregate

Estimated Weight Method (Section 7-8.1)

NMAS (in)	First Estimate of Concrete Unit Mass (lb/ft^3) Non-Air-Entrained Concrete	Air-Entrained Concrete
⅜	142.0	137.5
½	144.0	139.0
¾	146.5	141.5
1	148.5	143.5
1½	151.0	146.0
2	153.0	147.5
3	155.5	150.0
6	157.5	152.0

Equivalent to Table 7-18

Step 7: Estimate fine aggregate

Estimated Weight Method (Section 7-8.1)

$$W_{\text{total}} = W_{\text{cement}} + W_{\text{gravel}} + W_{\text{sand}} + W_{\text{water}}$$

$$W_{\text{sand}} = W_{\text{total}} - \left(W_{\text{cement}} + W_{\text{gravel}} + W_{\text{water}} \right)$$

Step 7: Estimate fine aggregate

Absolute Volume Method
(Section 7-8.2)

$$V_{total} = V_{cement} + V_{gravel} + V_{sand} + V_{water} + V_{air}$$

$$V_{sand} = V_{total} - \left(V_{cement} + V_{gravel} + V_{water} + V_{air}\right)$$

Step 7: Estimate fine aggregate

Absolute Volume Method
(Section 7-8.2)

$$V_{sand} = V_{total} - \left(V_{cement} + V_{gravel} + V_{water} + V_{air} \right)$$

$$V_{sand} = V_{total} - \frac{1}{\gamma_w}\left(\frac{W_{cement}}{3.15} + \frac{W_{gravel}}{G_{gravel}^{bulk}} + \frac{W_{water}}{1.00} \right) - V_{air}$$

$$W_{sand} = V_{sand} \times G_{sand}^{bulk} \times \gamma_w$$

Mix Design Example

Nominal maximum aggregate size = 3/4"
Design strength (f'_c) = 4500 psi
Specified slump = 1-2"

	Coarse Aggregate	Fine Aggregate
Unit weight (lb/ft^3) =	101	106
Bulk specific gravity (dry) =	2.574	2.548
Bulk specific gravity (SSD) =	2.623	2.592
Apparent specific gravity =	2.705	2.664
Absorption capacity (%) =	1.89	1.70
Fineness modulus =	2.51	3.00

Step 8: Adjust for Aggregate Moisture

1. Increase W_{water} by an amount equal to the weight of water needed to saturate the fine and coarse aggregate.

Step 8: Adjust for Aggregate Moisture

1. Increase W_{water} by an amount equal to the weight of water needed to saturate the fine and coarse aggregate.
2. Increase W_{sand} and W_{gravel} by an amount equal to the moisture contents of the aggregate stockpiles.

Step 8: Adjust for Aggregate Moisture

1. Increase W_{water} by an amount equal to the weight of water needed to saturate the fine and coarse aggregate.
2. Increase W_{sand} and W_{gravel} by an amount equal to the moisture contents of the aggregate stockpiles.
3. Decrease W_{water} by the same amount you increased W_{sand} and W_{gravel}.

[redacted]