CHAPTER 9

Designing and Proportioning Normal Concrete Mixtures

The process of determining required and specifiable characteristics of a concrete mixture is called mix design. Characteristics can include: (1) fresh concrete properties; (2) required mechanical properties of hardened concrete such as strength and durability requirements; and (3) the inclusion, exclusion, or limits on specific ingredients. Mix design leads to the development of a concrete specification.

Mixture proportioning refers to the process of determining the quantities of concrete ingredients, using local materials, to achieve the specified characteristics of the concrete. A properly proportioned concrete mix should possess these qualities:

1. Acceptable workability of the freshly mixed concrete
2. Durability, strength, and uniform appearance of the hardened concrete
3. Economy

Understanding the basic principles of mixture design is as important as the actual calculations used to establish mix proportions. Only with proper selection of materials and mixture characteristics can the above qualities be obtained in concrete construction (Fig. 9-1) (Abrams 1918, Hover 1998, and Shilstone 1990).

Fig. 9-1. Trial batching (inset) verifies that a concrete mixture meets design requirements prior to use in construction. (69899, 70008).

SELECTING MIX CHARACTERISTICS

Before a concrete mixture can be proportioned, mixture characteristics are selected based on the intended use of the concrete, the exposure conditions, the size and shape of building elements, and the physical properties of the concrete (such as frost resistance and strength) required for the structure. The characteristics should reflect the needs of the structure; for example, resistance to chloride ions should be verifiable and the appropriate test methods specified.

Once the characteristics are selected, the mixture can be proportioned from field or laboratory data. Since most of the desirable properties of hardened concrete depend primarily upon the quality of the cementitious paste, the first step in proportioning a concrete mixture is the selection of the appropriate water-cementing materials ratio for the durability and strength needed. Concrete mixtures should be kept as simple as possible, as an excessive number of ingredients often make a concrete mixture difficult to control. The concrete technologist should not, however, overlook the opportunities provided by modern concrete technology.

Water-Cementing Materials Ratio and Strength Relationship

Strength (compressive or flexural) is the most universally used measure for concrete quality. Although it is an important characteristic, other properties such as durability, permeability, and wear resistance are now recognized as being equal and in some cases more important, especially when considering life-cycle design of structures.

Within the normal range of strengths used in concrete construction, the compressive strength is inversely related to the water-cement ratio or water-cementing materials ratio. For fully compacted concrete made with clean, sound aggregates, the strength and other desirable properties of concrete under given job conditions are governed by the quantity of mixing water used per unit of cement or cementing materials (Abrams 1918).

The strength of the cementitious paste binder in concrete depends on the quality and quantity of the reacting paste components and on the degree to which the hydration reaction has progressed. Concrete becomes stronger with time as long as there is moisture and a favorable temperature available. Therefore, the strength at any particular age is both a function of the original water-cementitious material ratio and the degree to which the cementitious materials have hydrated. The importance of prompt and thorough curing is easily recognized.

Differences in concrete strength for a given water-cementing materials ratio may result from: (1) changes in the aggregate size, grading, surface texture, shape, strength, and stiffness; (2) differences in types and sources of cementing materials; (3) entrained-air content; (4) the presence of admixtures; and (5) the length of curing time.

Strength

The specified compressive strength, f'_c, at 28 days is the strength that is expected to be equal to or exceeded by the average of any set of three consecutive strength tests. ACI 318 requires for f'_c to be at least 17.5 MPa (2500 psi). No individual test (average of two cylinders) can be more than 3.5 MPa (500 psi) below the specified strength. Specimens must be cured under laboratory conditions for an individual class of concrete (ACI 318). Some specifications allow alternative ranges.

The average strength should equal the specified strength plus an allowance to account for variations in materials; variations in methods of mixing, transporting, and placing the concrete; and variations in making, curing, and testing concrete cylinder specimens. The average strength, which is greater than f'_c, is called f'_{cr}; it is the strength required in the mix design. Requirements for f'_{cr} are discussed in detail under "Proportioning" later in this chapter. Tables 9-1 and 9-2 show strength requirements for various exposure conditions.

Table 9-1. Maximum Water-Cementitious Material Ratios and Minimum Design Strengths for Various Exposure Conditions

Exposure condition	Maximum water-cementitious material ratio by mass for concrete	Minimum design compressive strength, f'_c, MPa (psi)
Concrete protected from exposure to freezing and thawing, application of deicing chemicals, or aggressive substances	Select water-cementitious material ratio on basis of strength, workability, and finishing needs	Select strength based on structural requirements
Concrete intended to have low permeability when exposed to water	0.50	28 (4000)
Concrete exposed to freezing and thawing in a moist condition or deicers	0.45	31 (4500)
For corrosion protection for reinforced concrete exposed to chlorides from deicing salts, salt water, brackish water, seawater, or spray from these sources	0.40	35 (5000)

Adapted from ACI 318 (2002).

Table 9-2. Requirements for Concrete Exposed to Sulfates in Soil or Water

Sulfate exposure	Water-soluble sulfate (SO_4) in soil, percent by mass*	Sulfate (SO_4) in water, ppm*	Cement type**	Maximum water-cementitious material ratio, by mass	Minimum design compressive strength, f'_c, MPa (psi)
Negligible	Less than 0.10	Less than 150	No special type required	—	—
Moderate†	0.10 to 0.20	150 to 1500	II, MS, IP(MS), IS(MS), P(MS), I(PM)(MS), I(SM)(MS)	0.50	28 (4000)
Severe	0.20 to 2.00	1500 to10,000	V, HS	0.45	31 (4500)
Very severe	Over 2.00	Over 10,000	V, HS	0.40	35 (5000)

* Tested in accordance with the Method for Determining the Quantity of Soluble Sulfate in Solid (Soil and Rock) and Water Samples, Bureau of Reclamation, Denver, 1977.

** Cement Types II and V are in ASTM C 150 (AASHTO M 85), Types MS and HS in ASTM C 1157, and the remaining types are in ASTM C 595 (AASHTO M 240). Pozzolans or slags that have been determined by test or service record to improve sulfate resistance may also be used.

† Seawater.

Flexural strength is sometimes used on paving projects instead of compressive strength; however, flexural strength is avoided due to its greater variability. For more information on flexural strength, see "Strength" in Chapter 1 and "Strength Specimens" in Chapter 16.

Water-Cementitious Material Ratio

The water-cementitious material ratio is simply the mass of water divided by the mass of cementitious material (portland cement, blended cement, fly ash, slag, silica fume, and natural pozzolans). The water-cementitious material ratio selected for mix design must be the lowest value required to meet anticipated exposure conditions. Tables 9-1 and 9-2 show requirements for various exposure conditions.

When durability does not control, the water-cementitious materials ratio should be selected on the basis of concrete compressive strength. In such cases the water-cementitious materials ratio and mixture proportions for the required strength should be based on adequate field data or trial mixtures made with actual job materials to determine the relationship between the ratio and strength. Fig. 9-2 or Table 9-3 can be used to select a water-cementitious materials ratio with respect to the required average strength, f'_{cr}, for trial mixtures when no other data are available.

In mix design, the water to cementitious materials ratio, *W/CM*, is often used synonymously with water to cement ratio *(W/C)*; however, some specifications differentiate between the two ratios. Traditionally, the water to cement ratio referred to the ratio of water to portland cement or water to blended cement.

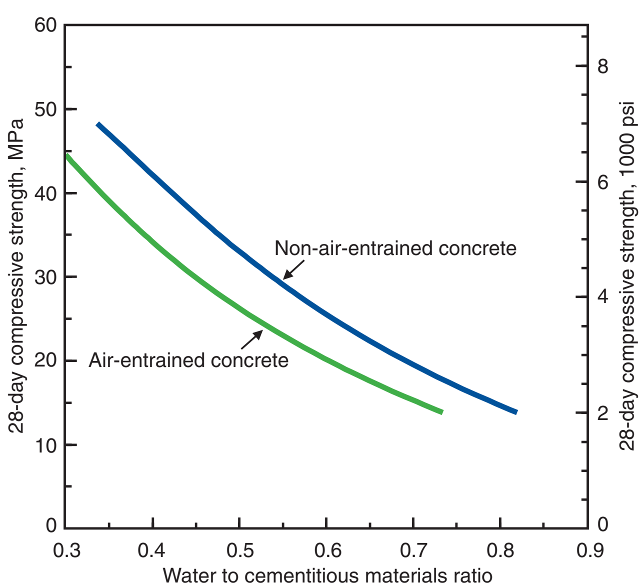

Fig. 9-2. Approximate relationship between compressive strength and water to cementing materials ratio for concrete using 19-mm to 25-mm (¾-in. to 1-in.) nominal maximum size coarse aggregate. Strength is based on cylinders moist cured 28 days per ASTM C 31 (AASHTO T 23). Adapted from Table 9-3, ACI 211.1, ACI 211.3, and Hover 1995.

Aggregates

Video

Two characteristics of aggregates have an important influence on proportioning concrete mixtures because they affect the workability of the fresh concrete. They are:

1. Grading (particle size and distribution)
2. Nature of particles (shape, porosity, surface texture)

Grading is important for attaining an economical mixture because it affects the amount of concrete that can be made with a given amount of cementitious materials and water. Coarse aggregates should be graded up to the largest size practical under job conditions. The maximum size that can be used depends on factors such as the size and shape of the concrete member to be cast, the amount and distribution of reinforcing steel in the member, and the thickness of slabs. Grading also influences the workability and placeability of the concrete. Sometimes mid-sized aggregate, around the 9.5 mm (⅜ in.) size, is lacking in an aggregate supply; this can result in a concrete with

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

Compressive strength at 28 days, MPa	Water-cementitious materials ratio by mass	
	Non-air-entrained concrete	Air-entrained concrete
45	0.38	0.30
40	0.42	0.34
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

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 19 to 25 mm.
Adapted from ACI 211.1 and ACI 211.3.

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

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.
Adapted from ACI 211.1 and ACI 211.3.

high shrinkage properties, high water demand, and poor workability and placeability. Durability may also be affected. Various options are available for obtaining optimal grading of aggregate (Shilstone 1990).

The maximum size of coarse aggregate should not exceed one-fifth the narrowest dimension between sides of forms nor three-fourths the clear space between individual reinforcing bars or wire, bundles of bars, or prestressing tendons or ducts. It is also good practice to limit aggregate size to not more than three-fourths the clear space between reinforcement and the forms. For unreinforced slabs on ground, the maximum size should not exceed one third the slab thickness. Smaller sizes can be used when availability or economic consideration require them.

The amount of mixing water required to produce a unit volume of concrete of a given slump is dependent on the shape and the maximum size and amount of coarse aggregate. Larger sizes minimize the water requirement and thus allow the cement content to be reduced. Also, rounded aggregate requires less mixing water than a crushed aggregate in concretes of equal slump (see "Water Content").

The maximum size of coarse aggregate that will produce concrete of maximum strength for a given cement content depends upon the aggregate source as well as its shape and grading. For high compressive-strength concrete (greater than 70 MPa or 10,000 psi), the maximum size is about 19 mm (¾ in.). Higher strengths can also sometimes be achieved through the use of crushed stone aggregate rather than rounded-gravel aggregate.

The most desirable fine-aggregate grading will depend upon the type of work, the paste content of the mixture, and the size of the coarse aggregate. For leaner mixtures, a fine grading (lower fineness modulus) is desirable for workability. For richer mixtures, a coarse grading (higher fineness modulus) is used for greater economy.

In some areas, the chemically bound chloride in aggregate may make it difficult for concrete to pass chloride limits set by ACI 318 or other specifications. However, some or all of the chloride in the aggregate may not be available for participation in corrosion of reinforcing steel, thus that chloride may be ignored. ASTM PS 118 (to be redesignated ASTM C 1500), Soxhlet extracted chloride test, can be used to evaluate the amount of chloride available from aggregate. ACI 222.1 also provides guidance.

The bulk volume of coarse aggregate can be determined from Fig. 9-3 or Table 9-4. These bulk volumes are based on aggregates in a dry-rodded condition as described in ASTM C 29 (AASHTO T 19); they are selected from empirical relationships to produce concrete with a degree of workability suitable for general reinforced concrete construction. For less workable concrete, such as required for concrete pavement construction, they may be increased about 10%. For more workable concrete, such as may be required when placement is by pump, they may be reduced up to 10%.

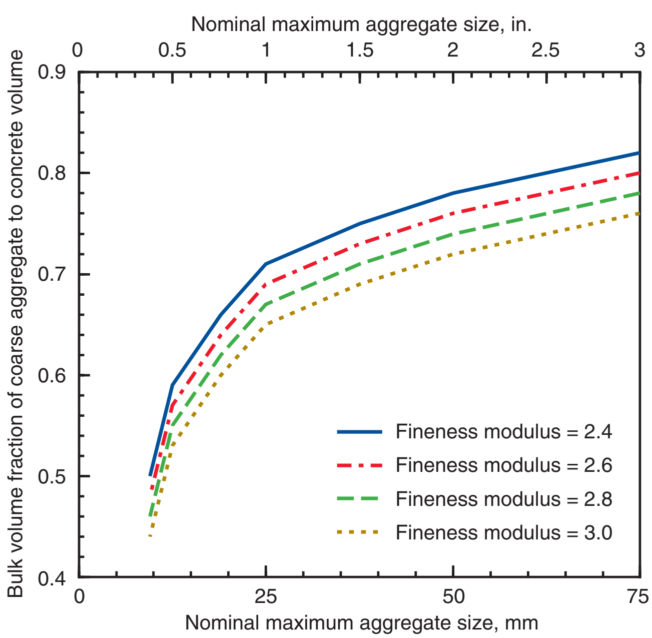

Fig. 9-3. Bulk volume of coarse aggregate per unit volume of concrete. Bulk volumes are based on aggregates in a dry-rodded condition as described in ASTM C 29 (AASHTO T 19). For more workable concrete, such as may be required when placement is by pump, they may be reduced up to 10%. Adapted from Table 9-4, ACI 211.1 and Hover (1995 and 1998).

Air Content

Entrained air must be used in all concrete that will be exposed to freezing and thawing and deicing chemicals and can be used to improve workability even where not required.

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

*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.

Air entrainment is accomplished by using an air-entraining portland cement or by adding an air-entraining admixture at the mixer. The amount of admixture should be adjusted to meet variations in concrete ingredients and job conditions. The amount recommended by the admixture manufacturer will, in most cases, produce the desired air content.

Recommended target air contents for air-entrained concrete are shown in Fig. 9-4 and Table 9-5. Note that the amount of air required to provide adequate freeze-thaw resistance is dependent upon the nominal maximum size of aggregate and the level of exposure. In properly proportioned mixes, the mortar content decreases as maximum aggregate size increases, thus decreasing the required concrete air content. This is evident in Fig. 9-4. The levels of exposure are defined by ACI 211.1 as follows:

Mild Exposure. This exposure includes indoor or outdoor service in a climate where concrete will not be exposed to freezing or deicing agents. When air entrainment is desired for a beneficial effect other than durability, such as to improve workability or cohesion or in low cement content concrete to improve strength, air contents lower than those needed for durability can be used.

Moderate Exposure. Service in a climate where freezing is expected but where the concrete will not be continually exposed to moisture or free water for long periods prior to freezing and will not be exposed to deicing or other aggressive chemicals. Examples include exterior beams, columns, walls, girders, or slabs that are not in contact with wet soil and are so located that they will not receive direct applications of deicing chemicals.

Severe Exposure. Concrete that is exposed to deicing or other aggressive chemicals or where the concrete may become highly saturated by continual contact with moisture or free water prior to freezing. Examples include pavements, bridge decks, curbs, gutters, sidewalks, canal linings, or exterior water tanks or sumps.

When mixing water is held constant, the entrainment of air will increase slump. When cement content and slump are held constant, the entrainment of air results in the need for less mixing water, particularly in leaner concrete mixtures. In batch adjustments, in order to maintain a constant slump while changing the air content, the water should be decreased by about 3 kg/m³ (5 lb/yd³) for each percentage point increase in air content or increased 3 kg/m³ (5 lb/yd³) for each percentage point decrease.

A specific air content may not be readily or repeatedly achieved because of the many variables affecting air content; therefore, a permissible range of air contents around a target value must be provided. Although a range of ±1% of the Fig. 9-4 or Table 9-5 values is often used in project specifications, it is sometimes an impractically tight limit. The solution is to use a wider range, such as –1 to +2 percentage points of the target values. For example, for a target value of 6% air, the specified range for the concrete delivered to the jobsite could be 5% to 8%.

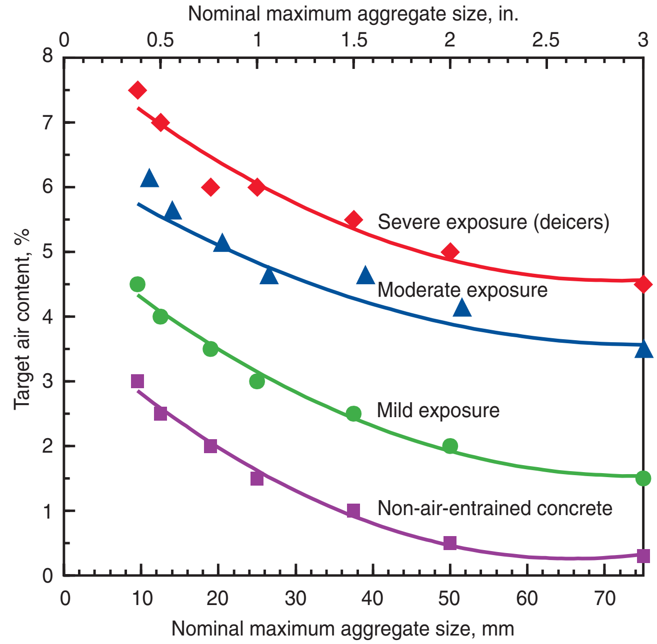

Fig. 9-4. Target total air content requirements for concretes using different sizes of aggregate. The air content in job specifications should be specified to be delivered within –1 to +2 percentage points of the target value for moderate and severe exposures. Adapted from Table 9-5, ACI 211.1 and Hover (1995 and 1998).

Slump

Concrete must always be made with a workability, consistency, and plasticity suitable for job conditions. Workability is a measure of how easy or difficult it is to place, consolidate, and finish concrete. Consistency is the ability of freshly mixed concrete to flow. Plasticity determines concrete's ease of molding. If more aggregate is used in a concrete mixture, or if less water is added, the mixture becomes stiff (less plastic and less workable) and difficult to mold. Neither very dry, crumbly mixtures nor very watery, fluid mixtures can be regarded as having plasticity.

The slump test is used to measure concrete consistency. For a given proportion of cement and aggregate without admixtures, the higher the slump, the wetter the mixture. Slump is indicative of workability when assessing similar mixtures. However, slump should not be used to compare mixtures of totally different proportions. When used with different batches of the same mix design, a change in slump indicates a change in consistency and in the characteristics of materials, mixture proportions, water content, mixing, time of test, or the testing itself.

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

Slump, mm	Water, kilograms per cubic meter of concrete, for indicated sizes of aggregate*							
	9.5 mm	12.5 mm	19 mm	25 mm	37.5 mm	50 mm**	75 mm**	150 mm**
	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	—
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							
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	—
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	4.0	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 cementitious material contents for trial batches. They are maximums for reasonably well-shaped angular coarse aggregates graded within limits of accepted specifications.
** The slump values for concrete containing aggregates larger than 37.5 mm are based on slump tests made after removal of particles larger than 37.5 mm by wet screening.
† The air content in job specifications should be specified to be delivered within –1 to +2 percentage points of the table target value for moderate and severe exposures.
Adapted from ACI 211.1 and ACI 318. Hover (1995) presents this information in graphical form.

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.
** The slump values for concrete containing aggregates larger than 1½ in. are based on slump tests made after removal of particles larger than 1½ in. by wet screening.
† The air content in job specifications should be specified to be delivered within –1 to +2 percentage points of the table target value for moderate and severe exposures.
Adapted from ACI 211.1. Hover (1995) presents this information in graphical form.

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 aggregate will increase water demand.

The approximate water contents in Table 9-5 and Fig. 9-5, used in proportioning, are for angular coarse 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)

*May be increased 25 mm (1 in.) for consolidation by hand methods, such as rodding and spading.
Plasticizers can safely provide higher slumps.
Adapted from ACI 211.1.

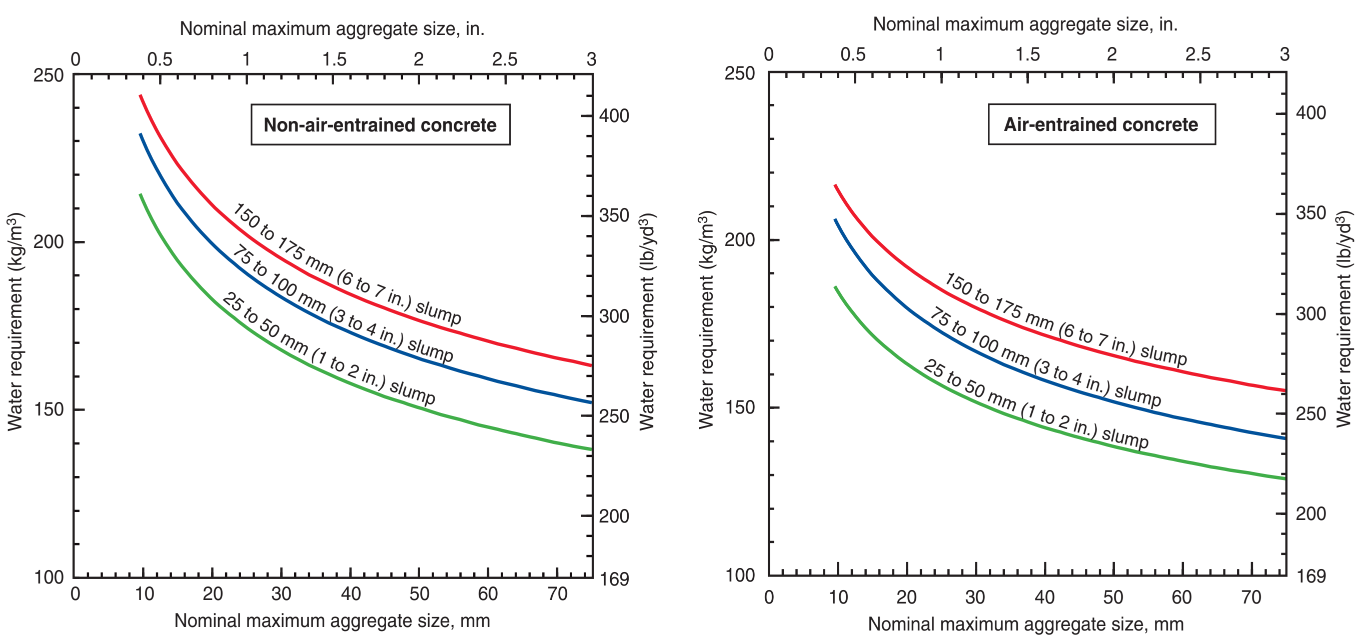

Fig. 9-5. Approximate water requirement for various slumps and crushed aggregate sizes for (left) non-air-entrained concrete and (right) air-entrained concrete. Adapted from Table 9-5, ACI 211.1 and Hover (1995 and 1998).

It should be kept in mind that changing the amount of any single ingredient in a concrete mixture normally effects the proportions of other ingredients as well as alter the properties of the mixture. For example, the addition of 2 kg of water per cubic meter will increase the slump by approximately 10 mm (10 lb of water per cubic yard will increase the slump by approximately 1 in.); it will also increase the air content and paste volume, decrease the aggregate volume, and lower the density of the concrete. In mixture adjustments, for the same slump, a decrease in air content by 1 percentage point will increase the water demand by about 3 kg per cubic meter of concrete (5 lb per cu yd of concrete).

Cementing Materials Content and Type

The cementing materials content is usually determined from the selected water-cementing materials ratio and water content, although a minimum cement content frequently is included in specifications in addition to a maximum water-cementing materials ratio. Minimum cement content requirements serve to ensure satisfactory durability and finishability, to improve wear resistance of slabs, and to guarantee a suitable appearance of vertical surfaces. This is important even though strength requirements may be met at lower cementing materials contents. However, excessively large amounts of cementing materials should be avoided to maintain economy in the mixture and to not adversely affect workability and other properties.

For severe freeze-thaw, deicer, and sulfate exposures, it is desirable to specify: (1) a minimum cementing materials content of 335 kg per cubic meter (564 lb per cubic yard) of concrete, and (2) only enough mixing water to achieve the desired consistency without exceeding the maximum water-cementing materials ratios shown in Tables 9-1 and 9-2. For placing concrete underwater, usually not less than 390 kg of cementing materials per cubic meter (650 lb of cementing materials per cubic yard) of concrete should be used with a water to cementing materials ratio not exceeding 0.45. For workability, finishability, abrasion resistance, and durability in flatwork, the quantity of cementing materials to be used should be not less than shown in Table 9-7.

Table 9-7. Minimum Requirements of Cementing Materials for Concrete Used in Flatwork

Nominal maximum size of aggregate, mm (in.)	Cementing materials, kg/m³ (lb/yd³)*
37.5 (1½)	280 (470)
25 (1)	310 (520)
19 (¾)	320 (540)
12.5 (½)	350 (590)
9.5 (⅜)	360 (610)

* Cementing materials quantities may need to be greater for severe exposure. For example, for deicer exposures, concrete should contain at least 335 kg/m³ (564 lb/yd³) of cementing materials.
Adapted from ACI 302.

To obtain economy, proportioning should minimize the amount of cement required without sacrificing concrete quality. Since quality depends primarily on water-cementing materials ratio, the water content should be held to a minimum to reduce the cement requirement. Steps to minimize water and cement requirements include use of (1) the stiffest practical mixture, (2) the largest practical maximum size of aggregate, and (3) the optimum ratio of fine-to-coarse aggregate.

Concrete that will be exposed to sulfate conditions should be made with the type of cement shown in Table 9-2.

Seawater contains significant amounts of sulfates and chlorides. Although sulfates in seawater are capable of attacking concrete, the presence of chlorides in seawater inhibits the expansive reaction that is characteristic of sulfate attack. This is the major factor explaining observations from a number of sources that the performance of concretes in seawater have shown satisfactory durability; this is despite the fact these concretes were made with portland cements having tricalcium aluminate (C_3A) contents as high as 10%, and sometimes greater. However, the permeability of these concretes was low, and the reinforcing steel had adequate cover. Portland cements meeting a C_3A requirement of not more than 10% or less than 4% (to ensure durability of reinforcement) are acceptable (ACI 357R).

Supplementary cementitious materials have varied effects on water demand and air contents. The addition of fly ash will generally reduce water demand and decrease the air content if no adjustment in the amount of air-entraining admixture is made. Silica fume increases water demand and decreases air content. Slag and metakaolin have a minimal effect at normal dosages.

Table 9-8. Cementitious Materials Requirements for Concrete Exposed to Deicing Chemicals

Cementitious materials*	Maximum percent of total cementitious materials by mass**
Fly ash and natural pozzolans	25
Slag	50
Silica fume	10
Total of fly ash, slag, silica fume and natural pozzolans	50†
Total of natural pozzolans and silica fume	35†

* Includes portion of supplementary cementing materials in blended cements.
** Total cementitious materials include the summation of portland cements, blended cements, fly ash, slag, silica fume and other pozzolans.
† Silica fume should not constitute more than 10% of total cementitious materials and fly ash or other pozzolans shall not constitute more than 25% of cementitious materials.
Adapted from ACI 318.

Table 9-8 shows limits on the amount of supplementary cementing materials in concrete to be exposed to deicers. Local practices should be consulted as dosages smaller or larger than those shown in Table 9-8 can be used without jeopardizing scale-resistance, depending on the exposure severity.

Admixtures

Water-reducing admixtures are added to concrete to reduce the water-cementing materials ratio, reduce cementing materials content, reduce water content, reduce paste content, or to improve the workability of a concrete without changing the water-cementing materials ratio. Water reducers will usually decrease water contents by 5% to 10% and some will also increase air contents by ½ to 1 percentage point. Retarders may also increase the air content.

High-range water reducers (plasticizers) reduce water contents between 12% and 30% and some can simultaneously increase the air content up to 1 percentage point; others can reduce or not affect the air content.

Calcium chloride-based admixtures reduce water contents by about 3% and increase the air content by about ½ percentage point.

When using a chloride-based admixture, the risks of reinforcing steel corrosion should be considered. Table 9-9 provides recommended limits on the water-soluble chloride-ion content in reinforced and prestressed concrete for various conditions.

When using more than one admixture in concrete, the compatibility of intermixing admixtures should be assured by the admixture manufacturer or the combination of admixtures should be tested in trial batches. The water contained in admixtures should be considered part of the mixing water if the admixture's water content is sufficient to affect the water-cementing materials ratio by 0.01 or more.

An excessive use of multiple admixtures should be minimized to allow better control of the concrete mixture in production and to reduce the risk of admixture incompatibility.

Table 9-9. Maximum Chloride-Ion Content for Corrosion Protection

Type of member	Maximum water-soluble chloride ion (Cl^-) in concrete, percent by mass of cement*
Prestressed concrete	0.06
Reinforced concrete exposed to chloride in service	0.15
Reinforced concrete that will be dry or protected from moisture in service	1.00
Other reinforced concrete construction	0.30

*ASTM C 1218.
Adapted from ACI 318.

PROPORTIONING

The design of concrete mixtures involves the following: (1) the establishment of specific concrete characteristics, and (2) the selection of proportions of available materials to produce concrete of required properties, with the greatest economy. Proportioning methods have evolved from the arbitrary volumetric method (1:2:3—cement:sand: coarse aggregate) of the early 1900s (Abrams 1918) to the present-day weight and absolute-volume methods described in ACI's Committee 211 *Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete* (ACI 211.1).

Weight proportioning methods are fairly simple and quick for estimating mixture proportions using an assumed or known weight of concrete per unit volume. A more accurate method, absolute volume, involves use of relative density (specific gravity) values for all the ingredients to calculate the absolute volume each will occupy in a unit volume of concrete. The absolute volume method will be illustrated. A concrete mixture also can be proportioned from field experience (statistical data) or from trial mixtures.

Other valuable documents to help proportion concrete mixtures include the *Standard Practice for Selecting Proportions for Structural Lightweight Concrete* (ACI 211.2); *Guide for Selecting Proportions for No-Slump Concrete* (ACI 211.3); *Guide for Selecting Proportions for High-Strength Concrete with Portland Cement and Fly Ash* (ACI 211.4R); and *Guide for Submittal of Concrete Proportions* (ACI 211.5). Hover (1995 and 1998) provides a graphical process for designing concrete mixtures in accordance with ACI 211.1.

Proportioning from Field Data

A presently or previously used concrete mixture design can be used for a new project if strength-test data and standard deviations show that the mixture is acceptable. Durability aspects previously presented must also be met. Standard deviation computations are outlined in ACI 318. The statistical data should essentially represent the same materials, proportions, and concreting conditions to be used in the new project. The data used for proportioning should also be from a concrete with an f'_c that is within 7 MPa (1000 psi) of the strength required for the proposed work. Also, the data should represent at least 30 consecutive tests or two groups of consecutive tests totaling at least 30 tests (one test is the average strength of two cylinders from the same sample). If only 15 to 29 consecutive tests are available, an adjusted standard deviation can be

Table 9-10. Modification Factor for Standard Deviation When Less Than 30 Tests Are Available

Number of tests*	Modification factor for standard deviation**
Less than 15	Use Table 9-11
15	1.16
20	1.08
25	1.03
30 or more	1.00

* Interpolate for intermediate numbers of tests.
** Modified standard deviation to be used to determine required average strength, f'_{cr}.
Adapted from ACI 318.

obtained by multiplying the standard deviation (S) for the 15 to 29 tests and a modification factor from Table 9-10. The data must represent 45 or more days of tests.

The standard or modified deviation is then used in Equations 9-1 to 9-3. The average compressive strength from the test record must equal or exceed the ACI 318 required average compressive strength, f'_{cr}, in order for the concrete proportions to be acceptable. The f'_{cr} for the selected mixture proportions is equal to the larger of Equations 9-1 and 9-2 (for $f'_c \leq 35$ MPa [5000 psi]) or Equations 9-1 and 9-3 (for $f'_c > 35$ MPa [5000 psi]).

$f'_{cr} = f'_c + 1.34S$ Eq. 9-1

$f'_{cr} = f'_c + 2.33S - 3.45$ (MPa) Eq. 9-2

$f'_{cr} = f'_c + 2.33S - 500$ (psi) Eq. 9-2

$f'_{cr} = 0.90\, f'_c + 2.33S$ Eq. 9-3

where

f'_{cr} = required average compressive strength of concrete used as the basis for selection of concrete proportions, MPa (psi)

f'_c = specified compressive strength of concrete, MPa (psi)

S = standard deviation, MPa (psi)

When field strength test records do not meet the previously discussed requirements, f'_{cr} can be obtained from Table 9-11. A field strength record, several strength test records, or tests from trial mixtures must be used for documentation showing that the average strength of the mixture is equal to or greater than f'_{cr}.

If less than 30, but not less than 10 tests are available, the tests may be used for average strength documentation if the time period is not less than 45 days. Mixture proportions may also be established by interpolating between two or more test records if each meets the above and project requirements. If a significant difference exists between the mixtures that are used in the interpolation, a trial mixture should be considered to check strength gain. If the test records meet the above requirements and limitations of ACI 318, the proportions for the mixture may then be considered acceptable for the proposed work.

If the average strength of the mixtures with the statistical data is less than f'_{cr}, or statistical data or test records are insufficient or not available, the mixture should be proportioned by the trial-mixture method. The approved mixture must have a compressive strength that meets or exceeds f'_{cr}. Three trial mixtures using three different water to cementing materials ratios or cementing materials contents should be tested. A water to cementing materials ratio to strength curve (similar to Fig. 9-2) can then be plotted and the proportions interpolated from the data. It is also good practice to test the properties of the newly proportioned mixture in a trial batch.

ACI 214 provides statistical analysis methods for monitoring the strength of the concrete in the field to ensure that the mix properly meets or exceeds the design strength, f'_c.

Proportioning by Trial Mixtures

When field test records are not available or are insufficient for proportioning by field experience methods, the concrete proportions selected should be based on trial mixtures. The trial mixtures should use the same materials proposed for the work. Three mixtures with three different water-cementing materials ratios or cementing materials contents should be made to produce a range of strengths that encompass f'_{cr}. The trial mixtures should have a slump and air content within ±20 mm (±0.75 in.) and ± 0.5%, respectively, of the maximum permitted. Three cylinders for each water-cementing materials ratio should be made and cured according to ASTM C 192 (AASHTO T 126). At 28 days, or the designated test age, the compressive

Table 9-11 (Metric). Required Average Compressive Strength When Data Are Not Available to Establish a Standard Deviation

Specified compressive strength, f'_c, MPa	Required average compressive strength, f'_{cr}, MPa
Less than 21	$f'_c + 7.0$
21 to 35	$f'_c + 8.5$
Over 35	$1.10 f'_c + 5.0$

Adapted from ACI 318.

Table 9-11 (Inch-Pound Units). Required Average Compressive Strength When Data Are Not Available to Establish a Standard Deviation

Specified compressive strength, f'_c, psi	Required average compressive strength, f'_{cr}, psi
Less than 3000	$f'_c + 1000$
3000 to 5000	$f'_c + 1200$
Over 5000	$1.10 f'_c + 700$

Adapted from ACI 318.

strength of the concrete should be determined by testing the cylinders in compression. The test results should be plotted to produce a strength versus water-cementing materials ratio curve (similar to Fig. 9-2) that is used to proportion a mixture.

A number of different methods of proportioning concrete ingredients have been used at one time or another, including:

Arbitrary assignment (1:2:3), volumetric
Void ratio
Fineness modulus
Surface area of aggregates
Cement content

Any one of these methods can produce approximately the same final mixture after adjustments are made in the field. The best approach, however, is to select proportions based on past experience and reliable test data with an established relationship between strength and water to cementing materials ratio for the materials to be used in the concrete. The trial mixtures can be relatively small batches made with laboratory precision or job-size batches made during the course of normal concrete production. Use of both is often necessary to reach a satisfactory job mixture.

The following parameters must be selected first: (1) required strength, (2) minimum cementing materials content or maximum water-cementing materials ratio, (3) nominal maximum size of aggregate, (4) air content, and (5) desired slump. Trial batches are then made varying the relative amounts of fine and coarse aggregates as well as other ingredients. Based on considerations of workability and economy, the proper mixture proportions are selected.

When the quality of the concrete mixture is specified by water-cementitious material ratio, the trial-batch procedure consists essentially of combining a paste (water, cementing materials, and, generally, a chemical admixture) of the correct proportions with the necessary amounts of fine and coarse aggregates to produce the required slump and workability. Representative samples of the cementing materials, water, aggregates, and admixtures must be used.

Quantities per cubic meter (cubic yard) are then calculated. To simplify calculations and eliminate error caused by variations in aggregate moisture content, the aggregates should be prewetted then dried to a saturated surface-dry (SSD) condition; place the aggregates in covered containers to keep them in this SSD condition until they are used. The moisture content of the aggregates should be determined and the batch weights corrected accordingly.

The size of the trial batch is dependent on the equipment available and on the number and size of test specimens to be made. Larger batches will produce more accurate data. Machine mixing is recommended since it more nearly represents job conditions; it is mandatory if the concrete is to contain entrained air. The mixing procedures outlined in ASTM C 192 (AASHTO T 126) should be used.

Measurements and Calculations

Tests for slump, air content, and temperature should be made on the trial mixture, and the following measurements and calculations should also be performed:

Density (Unit Weight) and Yield. The density (unit weight) of freshly mixed concrete is expressed in kilograms per cubic meter (pounds per cubic foot). The yield is the volume of fresh concrete produced in a batch, usually expressed in cubic meters (cubic feet). The yield is calculated by dividing the total mass of the materials batched by the density of the freshly mixed concrete. Density and yield are determined in accordance with ASTM C 138.

Absolute Volume. The absolute volume of a granular material (such as cement and aggregates) is the volume of the solid matter in the particles; it does not include the volume of air spaces between particles. The volume (yield) of freshly mixed concrete is equal to the sum of the absolute volumes of the concrete ingredients—cementing materials, water (exclusive of that absorbed in the aggregate), aggregates, admixtures when applicable, and air. The absolute volume is computed from a material's mass and relative density (specific gravity) as follows:

Absolute volume

$$= \frac{\text{mass of loose material}}{\text{relative density of a material x density of water}}$$

A value of 3.15 can be used for the relative density (specific gravity) of portland cement. Blended cements have relative densities ranging from 2.90 to 3.15. The relative density of fly ash varies from 1.9 to 2.8, slag from 2.85 to 2.95, and silica fume from 2.20 to 2.25. The relative density of water is 1.0 and the density of water is

Table 9-12. Density of Water Versus Temperature

Temperature, °C	Density, kg/m³	Temperature, °F	Density, lb/ft³
16	998.93	60	62.368
18	998.58	65	62.337
20	998.19	70	62.302
22	997.75	75	62.261
24	997.27	80	62.216
26	996.75	85	62.166
28	996.20		
30	995.61		

1000 kg/m³ (62.4 lb/ft³) at 4°C (39°F)—accurate enough for mix calculations at room temperature. More accurate water density values are given in Table 9-12. Relative density of normal aggregate usually ranges between 2.4 and 2.9.

The relative density of aggregate as used in mix-design calculations is the relative density of either saturated surface-dry (SSD) material or ovendry material. Relative densities of admixtures, such as water reducers, can also be considered if needed. Absolute volume is usually expressed in cubic meters (cubic feet).

The absolute volume of air in concrete, expressed as cubic meters per cubic meter (cubic feet per cubic yard), is equal to the total air content in percent divided by 100 (for example, 7% ÷ 100) and then multiplied by the volume of the concrete batch.

The volume of concrete in a batch can be determined by either of two methods: (1) if the relative densities of the aggregates and cementing materials are known, these can be used to calculate concrete volume; or (2) if relative densities are unknown, or they vary, the volume can be computed by dividing the total mass of materials in the mixer by the density of concrete. In some cases, both determinations are made, one serving as a check on the other.

EXAMPLES OF MIXTURE PROPORTIONING

Example 1. Absolute Volume Method (Metric)

Conditions and Specifications. Concrete is required for a pavement that will be exposed to moisture in a severe freeze-thaw environment. A specified compressive strength, f'_c, of 35 MPa is required at 28 days. Air entrainment is required. Slump should be between 25 mm and 75 mm. A nominal maximum size aggregate of 25 mm is required. No statistical data on previous mixes are available. The materials available are as follows:

Cement: Type GU (ASTM C 1157) with a relative density of 3.0.

Coarse aggregate: Well-graded, 25-mm nominal maximum-size rounded gravel (ASTM C 33 or AASHTO M 80) with an ovendry relative density of 2.68, absorption of 0.5% (moisture content at SSD condition) and ovendry rodded bulk density (unit weight) of 1600 kg/m³. The laboratory sample for trial batching has a moisture content of 2%.

Fine aggregate: Natural sand (ASTM C 33 or AASHTO M 6) with an ovendry relative density of 2.64 and absorption of 0.7%. The laboratory sample moisture content is 6%. The fineness modulus is 2.80.

Air-entraining admixture: Wood-resin type (ASTM C 260 or AASHTO M 154).

Water reducer: ASTM C 494 (AASHTO M 194). This particular admixture is known to reduce water demand by 10% when used at a dosage rate of 3 g (or 3 mL) per kg of cement. Assume that the chemical admixtures have a density close to that of water, meaning that 1 mL of admixture has a mass of 1 g.

From this information, the task is to proportion a trial mixture that will meet the above conditions and specifications.

Strength. The design strength of 35 MPa is greater than the 31 MPa required in Table 9-1 for the exposure condition. Since no statistical data is available, f'_{cr} (required compressive strength for proportioning) from Table 9-11 is equal to f'_c + 8.5. Therefore, f'_{cr} = 35 + 8.5 = 43.5 MPa.

Water to Cement Ratio. For an environment with moist freezing and thawing, the maximum water to cementitious material ratio should be 0.45. The recommended water to cementitious material ratio for an f'_{cr} of 43.5 MPa is 0.31 from Fig. 9-2 or interpolated from Table 9-3 [{(45 – 43.5)(0.34 – 0.30) /(45 – 40)} + 0.30 = 0.31]. Since the lower water to cement ratio governs, the mix must be designed for 0.31. If a plot from trial batches or field tests had been available, the water to cement ratio could have been extrapolated from that data.

Air Content. For a severe freeze-thaw exposure, Table 9-5 recommends a target air content of 6.0% for a 25-mm aggregate. Therefore, design the mix for 5% to 8% air and use 8% (or the maximum allowable) for batch proportions. The trial-batch air content must be within ±0.5 percentage points of the maximum allowable air content.

Slump. The slump is specified at 25 mm to 75 mm. Use 75 mm ±20 mm for proportioning purposes.

Water Content. Table 9-5 and Fig. 9-5 recommend that a 75-mm slump, air-entrained concrete made with 25-mm nominal maximum-size aggregate should have a water content of about 175 kg/m³. However, rounded gravel should reduce the water content of the table value by about 25 kg/m³. Therefore, the water content can be estimated to be about 150 kg/m³ (175 kg/m³ minus 25 kg/m³). In addition, the water reducer will reduce water demand by 10% resulting in an estimated water demand of 135 kg/m³.

Cement Content. The cement content is based on the maximum water-cement ratio and the water content. Therefore, 135 kg/m³ of water divided by a water-cement ratio of 0.31 requires a cement content of 435 kg/m³; this is greater than the 335 kg/m³ required for frost resistance (Table 9-7).

Coarse-Aggregate Content. The quantity of 25-mm nominal maximum-size coarse aggregate can be estimated from Fig. 9-3 or Table 9-4. The bulk volume of coarse aggregate recommended when using sand with a fineness modulus of 2.80 is 0.67. Since it has a bulk density of 1600 kg/m^3, the ovendry mass of coarse aggregate for a cubic meter of concrete is

$$1600 \times 0.67 = 1072 \text{ kg}$$

Admixture Content. For an 8% air content, the air-entraining admixture manufacturer recommends a dosage rate of 0.5 g per kg of cement. From this information, the amount of air-entraining admixture per cubic meter of concrete is

$$0.5 \times 435 = 218 \text{ g or } 0.218 \text{ kg}$$

The water reducer dosage rate of 3 g per kg of cement results in

$$3 \times 435 = 1305 \text{ g or } 1.305 \text{ kg of water reducer per cubic meter of concrete}$$

Fine-Aggregate Content. At this point, the amounts of all ingredients except the fine aggregate are known. In the absolute volume method, the volume of fine aggregate is determined by subtracting the absolute volumes of the known ingredients from 1 cubic meter. The absolute volume of the water, cement, admixtures and coarse aggregate is calculated by dividing the known mass of each by the product of their relative density and the density of water. Volume computations are as follows:

$$\text{Water} = \frac{135}{1 \times 1000} = 0.135 \text{ m}^3$$

$$\text{Cement} = \frac{435}{3.0 \times 1000} = 0.145 \text{ m}^3$$

$$\text{Air} = \frac{8.0}{100} = 0.080 \text{ m}^3$$

$$\text{Coarse aggregate} = \frac{1072}{2.68 \times 1000} = 0.400 \text{ m}^3$$

Total volume of known ingredients 0.760 m^3

The calculated absolute volume of fine aggregate is then

$$1 - 0.76 = 0.24 \text{ m}^3$$

The mass of dry fine aggregate is

$$0.24 \times 2.64 \times 1000 = 634 \text{ kg}$$

The mixture then has the following proportions before trial mixing for one cubic meter of concrete:

Water	135 kg
Cement	435 kg
Coarse aggregate (dry)	1072 kg
Fine aggregate (dry)	634 kg
Total mass	2276 kg
Air-entraining admixture	0.218 kg
Water reducer	1.305 kg

Slump 75 mm (±20 mm for trial batch)

Air content 8% (±0.5% for trial batch)

Estimated concrete density (using SSD aggregate) = 135 + 435 + (1072 x 1.005*) + (634 x 1.007*) = 2286 kg/m^3

The liquid admixture volume is generally too insignificant to include in the water calculations. However, certain admixtures, such as shrinkage reducers, plasticizers, and corrosion inhibitors are exceptions due to their relatively large dosage rates; their volumes should be included.

Moisture. Corrections are needed to compensate for moisture in and on the aggregates. In practice, aggregates will contain some measurable amount of moisture. The dry-batch weights of aggregates, therefore, have to be increased to compensate for the moisture that is absorbed in and contained on the surface of each particle and between particles. The mixing water added to the batch must be reduced by the amount of free moisture contributed by the aggregates. Tests indicate that for this example, coarse-aggregate moisture content is 2% and fine-aggregate moisture content is 6%.

With the aggregate moisture contents (MC) indicated, the trial batch aggregate proportions become

Coarse aggregate (2% MC) = 1072 x 1.02 = 1093 kg

Fine aggregate (6% MC) = 634 x 1.06 = 672 kg

Water absorbed by the aggregates does not become part of the mixing water and must be excluded from the water adjustment. Surface moisture contributed by the coarse aggregate amounts to 2% – 0.5% = 1.5%; that contributed by the fine aggregate is, 6% – 0.7% = 5.3%. The estimated requirement for added water becomes

$$135 - (1072 \times 0.015) - (634 \times 0.053) = 85 \text{ kg}$$

The estimated batch weights for one cubic meter of concrete are revised to include aggregate moisture as follows:

Water (to be added)	85 kg
Cement	435 kg
Coarse aggregate (2% MC, wet)	1093 kg
Fine aggregate (6% MC, wet)	672 kg
Total	2285 kg
Air-entraining admixture	0.218 kg
Water reducer	1.305 kg

Trial Batch. At this stage, the estimated batch weights should be checked by means of trial batches or by full-size field batches. Enough concrete must be mixed for appropriate air and slump tests and for casting the three cylinders required for 28-day compressive-strength tests, plus beams for flexural tests if necessary. For a laboratory trial batch it is convenient, in this case, to scale down the weights to produce 0.1 m^3 of concrete as follows:

* (0.5% absorption ÷ 100) + 1 = 1.005
(0.7% absorption ÷ 100) + 1 = 1.007

Water	85 x 0.1	=	8.5 kg
Cement	435 x 0.1	=	43.5 kg
Coarse aggregate (wet)	1093 x 0.1	=	109.3 kg
Fine aggregate (wet)	672 x 0.1	=	67.2 kg
Total			228.5 kg

Air-entraining admixture 218 g x 0.1 = 21.8 g or 21.8 mL
Water reducer 1305 g x 0.1 = 130 g or 130 mL

The above concrete, when mixed, had a measured slump of 100 mm, an air content of 9%, and a density of 2274 kg per cubic meter. During mixing, some of the premeasured water may remain unused or additional water may be added to approach the required slump. In this example, although 8.5 kg of water was calculated to be added, the trial batch actually used only 8.0 kg. The mixture excluding admixtures therefore becomes

Water	8.0 kg
Cement	43.5 kg
Coarse aggregate (2% MC)	109.3 kg
Fine aggregate (6% MC)	67.2 kg
Total	228.0 kg

The yield of the trial batch is

$$\frac{228.0 \text{ kg}}{2274 \text{ kg/m}^3} = 0.10026 \text{ m}^3$$

The mixing water content is determined from the added water plus the free water on the aggregates and is calculated as follows:

Water added 8.0 kg

Free water on coarse aggregate

$$= \frac{109.3}{1.02} \times 0.015^* = 1.61 \text{ kg}$$

Free water on fine aggregate

$$= \frac{67.2}{1.06} \times 0.053^* = 3.36 \text{ kg}$$

Total water 12.97 kg

The mixing water required for a cubic meter of the same slump concrete as the trial batch is

$$\frac{12.97}{0.10026} = 129 \text{ kg}$$

Batch Adjustments. The measured 100-mm slump of the trial batch is unacceptable (above 75 mm ±20 mm max.), the yield was slightly high, and the 9.0% air content as measured in this example is also too high (more than 0.5% above 8.5% max.). Adjust the yield and reestimate the amount of air-entraining admixture required for an 8% air content and adjust the water to obtain a 75-mm slump. Increase the mixing water content by 3 kg/m³ for each 1% by which the air content is decreased from that of the trial batch and reduce the water content by 2 kg/m³ for each 10 mm reduction in slump. The adjusted mixture water for the reduced slump and air content is

(3 kg water x 1 percentage point difference for air) – (2 kg water x 25/10 for slump change) + 129 = 127 kg of water

With less mixing water needed in the trial batch, less cement also is needed to maintain the desired water-cement ratio of 0.31. The new cement content is

$$\frac{127}{0.31} = 410 \text{ kg}$$

The amount of coarse aggregate remains unchanged because workability is satisfactory. The new adjusted batch weights based on the new cement and water contents are calculated after the following volume computations:

$$\text{Water} = \frac{127}{1 \times 1000} = 0.127 \text{ m}^3$$

$$\text{Cement} = \frac{410}{3.0 \times 1000} = 0.137 \text{ m}^3$$

$$\text{Coarse aggregate (dry)} = \frac{1072}{2.68 \times 1000} = 0.400 \text{ m}^3$$

$$\text{Air} = \frac{8}{100} = 0.080 \text{ m}^3$$

Total 0.744 m³

Fine aggregate volume = 1 – 0.744 = 0.256 m³

The weight of dry fine aggregate required is
0.256 x 2.64 x 1000 = 676 kg

Air-entraining admixture (the manufacturer suggests reducing the dosage by 0.1 g to reduce air 1 percentage point) = 0.4 x 410 = 164 g or mL

Water reducer = 3.0 x 410 = 1230 g or mL

Adjusted batch weights per cubic meter of concrete are

Water	127 kg
Cement	410 kg
Coarse aggregate (dry)	1072 kg
Fine aggregate (dry)	676 kg
Total	2285 kg

Air-entraining admixture 164 g or mL
Water reducer 1230 g or mL

Estimated concrete density (aggregates at SSD) = 127 + 410 + (1072 x 1.005) + (676 x 1.007) = 2295 kg/m³

After checking these adjusted proportions in a trial batch, it was found that the concrete had the desired slump, air content, and yield. The 28-day test cylinders had an average compressive strength of 48 MPa, which exceeds the f'_{cr} of 43.5 MPa. Due to fluctuations in moisture content, absorption rates, and relative density (specific gravity) of the aggregate, the density determined by volume calculations may not always equal the density determined by ASTM C 138 (AASHTO T 121). Occasion-

*(2% MC – 0.5% absorption) ÷ 100 = 0.015
(6% MC – 0.7% absorption) ÷ 100 = 0.053

ally, the proportion of fine to coarse aggregate is kept constant in adjusting the batch weights to maintain workability or other properties obtained in the first trial batch. After adjustments to the cementitious materials, water, and air content have been made, the volume remaining for aggregate is appropriately proportioned between the fine and coarse aggregates.

Additional trial concrete mixtures with water-cement ratios above and below 0.31 should also be tested to develop a strength to water-cement ratio relationship. From that data, a new more economical mixture with a compressive strength closer to f'_{cr} and a lower cement content can be proportioned and tested. The final mixture would probably look similar to the above mixture with a slump range of 25 mm to 75 mm and an air content of 5% to 8%. The amount of air-entraining admixture must be adjusted to field conditions to maintain the specified air content.

Example 2. Absolute Volume Method (Inch-Pound Units)

Conditions and Specifications. Concrete is required for a building foundation. A specified compressive strength, f'_c, of 3500 psi is required at 28 days using a Type I cement. The design calls for a minimum of 3 in. of concrete cover over the reinforcing steel. The minimum distance between reinforcing bars is 4 in. The only admixture allowed is for air entrainment. No statistical data on previous mixes are available. The materials available are as follows:

Cement: Type I, ASTM C 150, with a relative density of 3.15.

Coarse aggregate: Well-graded ¾-in. maximum-size gravel containing some crushed particles (ASTM C 33) with an ovendry relative density (specific gravity) of 2.68, absorption of 0.5% (moisture content at SSD condition) and ovendry rodded bulk density (unit weight) of 100 lb per cu ft. The laboratory sample for trial batching has a moisture content of 2%.

Fine aggregate: Natural sand (ASTM C 33) with an ovendry relative density (specific gravity) of 2.64 and absorption of 0.7%. The laboratory sample moisture content is 6%. The fineness modulus is 2.80.

Air-entraining admixture: Wood-resin type, ASTM C 260.

From this information, the task is to proportion a trial mixture that will meet the above conditions and specifications.

Strength. Since no statistical data is available, f'_{cr} (required compressive strength for proportioning) from Table 9-11 is equal to $f'_c + 1200$. Therefore, $f'_{cr} = 3500 + 1200 = 4700$ psi.

Water to Cement Ratio. Table 9-1 requires no maximum water to cement ratio. The recommended water to cement ratio for an f'_{cr} of 4700 psi is 0.42 interpolated from Fig. 9-2 or Table 9-3 [water to cement ratio = {(5000 – 4700)(0.48 – 0.40)/(5000 – 4000)} + 0.40 = 0.42].

Coarse-Aggregate Size. From the specified information, a ¾-in. nominal maximum-size aggregate is adequate as it is less than ¾ of the distance between reinforcing bars and between the rebars and forms (cover).

Air Content. A target air content of 6.0% is specified in this instance not for exposure conditions but to improve workability and reduce bleeding. Therefore, design the mix for 6% ±1.0% air and use 7% (or the maximum allowable) for batch proportions. The trial batch air content must be within ±0.5 percentage points of the maximum allowable air content.

Slump. As no slump was specified, a slump of 1 to 3 in. would be adequate as indicated by Table 9-6. Use 3 in. for proportioning purposes, the maximum recommended for foundations.

Water Content. Fig. 9-5 and Table 9-5 recommend that a 3-in. slump, air-entrained concrete made with ¾-in. nominal maximum-size aggregate should have a water content of about 305 lb per cu yd. However, gravel with some crushed particles should reduce the water content of the table value by about 35 lb. Therefore, the water content can be estimated to be about 305 lb minus 35 lb, which is 270 lb.

Cement Content. The cement content is based on the maximum water-cement ratio and the water content. Therefore, 270 lb of water divided by a water-cement ratio of 0.42 requires a cement content of 643 lb.

Coarse-Aggregate Content. The quantity of ¾-in. nominal maximum-size coarse aggregate can be estimated from Fig. 9-3 or Table 9-4. The bulk volume of coarse aggregate recommended when using sand with a fineness modulus of 2.80 is 0.62. Since it weighs 100 lb per cu ft, the ovendry weight of coarse aggregate for a cubic yard of concrete (27 cu ft) is

$$100 \times 27 \times 0.62 = 1674 \text{ lb per cu yd of concrete}$$

Admixture Content. For a 7% air content, the air-entraining admixture manufacturer recommends a dosage rate of 0.9 fl oz per 100 lb of cement. From this information, the amount of air-entraining admixture is

$$0.9 \times \frac{643}{100} = 5.8 \text{ fl oz per cu yd}$$

Fine-Aggregate Content. At this point, the amount of all ingredients except the fine aggregate are known. In the absolute volume method, the volume of fine aggregate is determined by subtracting the absolute volumes of the known ingredients from 27 cu ft (1 cu yd). The absolute volume of the water, cement, and coarse aggregate is calculated by dividing the known weight of each by the product of their relative density (specific gravity) and the density of water. Volume computations are as follows:

$$\text{Water} = \frac{270}{1 \times 62.4} = 4.33 \text{ cu ft}$$

$$\text{Cement} = \frac{643}{3.15 \times 62.4} = 3.27 \text{ cu ft}$$

$$\text{Air} = \frac{7.0}{100} \times 27 = 1.89 \text{ cu ft}$$

$$\text{Coarse aggregate} = \frac{1674}{2.68 \times 62.4} = 10.01 \text{ cu ft}$$

Total volume of known ingredients 19.50 cu ft

The liquid admixture volume is generally too insignificant to include in these calculations. However, certain admixtures such as shrinkage reducers, plasticizers, and corrosion inhibitors are exceptions due to their relatively large dosage rates; their volumes should be included.

The calculated absolute volume of fine aggregate is then

27 – 19.50 = 7.50 cu ft

The weight of dry fine aggregate is

7.50 x 2.64 x 62.4 = 1236 lb

The mixture then has the following proportions before trial mixing for one cubic yard of concrete:

Water	270 lb
Cement	643 lb
Coarse aggregate (dry)	1674 lb
Fine aggregate (dry)	1236 lb
Total weight	3823 lb
Air-entraining admixture	5.8 fl oz
Slump	3 in. (±¾ in. for trial batch)
Air content	7% (±0.5% for trial batch)
Estimated density (using SSD aggregate)	= [270 + 643 + (1674 x 1.005*) + (1236 x 1.007*)] ÷ 27 = 142.22 lb per cubic foot

Moisture. Corrections are needed to compensate for moisture in the aggregates. In practice, aggregates will contain some measurable amount of moisture. The dry-batch weights of aggregates, therefore, have to be increased to compensate for the moisture that is absorbed in and contained on the surface of each particle and between particles. The mixing water added to the batch must be reduced by the amount of free moisture contributed by the aggregates. Tests indicate that for this example, coarse-aggregate moisture content is 2% and fine-aggregate moisture content is 6%.

*(0.5% absorption ÷ 100) + 1 = 1.005;
(0.7% absorption ÷ 100) + 1 = 1.007

With the aggregate moisture contents (MC) indicated, the trial batch aggregate proportions become

Coarse aggregate (2% MC) = 1674 x 1.02 = 1707 lb
Fine aggregate (6% MC) = 1236 x 1.06 = 1310 lb

Water absorbed by the aggregates does not become part of the mixing water and must be excluded from the water adjustment. Surface moisture contributed by the coarse aggregate amounts to 2% – 0.5% = 1.5%; that contributed by the fine aggregate is 6% – 0.7% = 5.3%. The estimated requirement for added water becomes

270 – (1674 x 0.015) – (1236 x 0.053) = 179 lb

The estimated batch weights for one cubic yard of concrete are revised to include aggregate moisture as follows:

Water (to be added)	179 lb
Cement	643 lb
Coarse aggregate (2% MC, wet)	1707 lb
Fine aggregate (6% MC, wet)	1310 lb
Total	3839 lb
Air-entraining admixture	5.8 fl oz

Trial Batch. At this stage, the estimated batch weights should be checked by means of trial batches or by full-size field batches. Enough concrete must be mixed for appropriate air and slump tests and for casting the three cylinders required for compressive-strength tests at 28 days. For a laboratory trial batch it is convenient, in this case, to scale down the weights to produce 2.0 cu ft of concrete or $\frac{2}{27}$ cu yd.

$$\text{Water} \quad 179 \times \frac{2}{27} = 13.26 \text{ lb}$$

$$\text{Cement} \quad 643 \times \frac{2}{27} = 47.63 \text{ lb}$$

$$\text{Coarse aggregate (wet)} \quad 1707 \times \frac{2}{27} = 126.44 \text{ lb}$$

$$\text{Fine aggregate (wet)} \quad 1310 \times \frac{2}{27} = 97.04 \text{ lb}$$

Total 284.37 lb

$$\text{Air-entraining admixture} \quad 5.8 \times \frac{2}{27} = 0.43 \text{ fl oz}$$

[Laboratories often convert fluid ounces to milliliters by multiplying fluid ounces by 29.57353 to improve measurement accuracy. Also, most laboratory pipets used for measuring fluids are graduated in milliliter units]

The above concrete, when mixed, had a measured slump of 4 in., an air content of 8%, and a density (unit weight) of 141.49 lb per cubic foot. During mixing, some of the premeasured water may remain unused or additional water may be added to approach the required slump. In this example, although 13.26 lb of water was calculated to be added, the trial batch actually used only 13.12 lb. The mixture excluding admixture therefore becomes:

Water	13.12 lb
Cement	47.63 lb
Coarse aggregate (2% MC)	126.44 lb
Fine aggregate (6% MC)	97.04 lb
Total	284.23 lb

The yield of the trial batch is

$$\frac{284.23}{141.49} = 2.009 \text{ cu ft}$$

The mixing water content is determined from the added water plus the free water on the aggregates and is calculated as follows:

Water added		= 13.12 lb
Free water on coarse aggregate	$= \frac{126.44}{1.02^*} \times 0.015^{**}$	= 1.86 lb
Free water on fine aggregate	$= \frac{97.04}{1.06^*} \times 0.053^{**}$	= 4.85 lb
Total		= 19.83 lb

The mixing water required for a cubic yard of the same slump concrete as the trial batch is

$$\frac{19.83 \times 27}{2.009} = 267 \text{ lb}$$

Batch Adjustments. The measured 4-in. slump of the trial batch is unacceptable (more than 0.75 in. above 3-in. max.), the yield was slightly high, and the 8.0% air content as measured in this example is also too high (more than 0.5% above 7% max.). Adjust the yield, reestimate the amount of air-entraining admixture required for a 7% air content, and adjust the water to obtain a 3-in. slump. Increase the mixing water content by 5 lb for each 1% by which the air content is decreased from that of the trial batch and reduce the water content by 10 lb for each 1-in. reduction in slump. The adjusted mixture water for the reduced slump and air content is

$$(5 \times 1) - (10 \times 1) + 267 = 262 \text{ lb per cu yd}$$

With less mixing water needed in the trial batch, less cement also is needed to maintain the desired water-cement ratio of 0.42. The new cement content is

$$\frac{262}{0.42} = 624 \text{ lb per cu yd}$$

The amount of coarse aggregate remains unchanged because workability is satisfactory. The new adjusted batch weights based on the new cement and water contents are calculated after the following volume computations:

Water	$= \frac{262}{1 \times 62.4}$	= 4.20 cu ft
Cement	$= \frac{624}{3.15 \times 62.4}$	= 3.17 cu ft
Coarse aggregate	$= \frac{1674}{2.68 \times 62.4}$	= 10.01 cu ft
Air	$= \frac{7.0}{100} \times 27$	= 1.89 cu ft
Total		19.27 cu ft
Fine aggregate volume	= 27 – 19.27	= 7.73 cu ft

The weight of dry fine aggregate required is

$$7.73 \times 2.64 \times 62.4 = 1273 \text{ lb}$$

An air-entraining admixture dosage of 0.8 fluid ounces per 100 pounds of cement is expected to achieve the 7% air content in this example. Therefore, the amount of air-entraining admixture required is:

$$= \frac{0.8 \times 624}{100} = 5.0 \text{ fl oz}$$

Adjusted batch weights per cubic yard of concrete are

Water	262 lb
Cement	624 lb
Coarse aggregate (dry)	1674 lb
Fine aggregate (dry)	1273 lb
Total	3833 lb
Air-entraining admixture	5.0 fl oz

Estimated concrete density (unit weight) with the aggregates at SSD:

$$= \frac{[262 + 624 + (1674 \times 1.005) + (1273 \times 1.007)]}{27}$$

$$= 142.60 \text{ lb per cu ft}$$

Upon completion of checking these adjusted proportions in a trial batch, it was found that the proportions were adequate for the desired slump, air content, and yield. The 28-day test cylinders had an average compressive strength of 4900 psi, which exceeds the f'_{cr} of 4700 psi. Due to fluctuations in moisture content, absorption rates, and specific gravity of the aggregate, the density determined by volume calculations may not always equal the unit weight determined by ASTM C 138 (AASHTO T 121). Occasionally, the proportion of fine to coarse aggregate is kept constant in adjusting the batch weights to maintain workability or other properties obtained in the first trial batch. After adjustments to the cement, water, and air content have been made, the volume remaining for aggregate is appropriately proportioned between the fine and coarse aggregates.

Additional trial concrete mixtures with water-cement ratios above and below 0.42 should also be tested to develop a strength curve. From the curve, a new more economical mixture with a compressive strength closer to f'_{cr}, can be proportioned and tested. The final mixture would probably look similar to the above mixture with a slump range of 1 in. to 3 in. and an air content of 5% to 7%. The

* 1 + (2% MC/100) = 1.02; 1 + (6% MC/100) = 1.06;

** (2% MC – 0.5% absorption)/100 = 0.015; (6% MC – 0.7% absorption)/100 = 0.053

amount of air-entraining admixture must be adjusted to field conditions to maintain the specified air content.

Water Reducers. Water reducers are used to increase workability without the addition of water or to reduce the water-cement ratio of a concrete mixture to improve permeability or other properties.

Using the final mixture developed in the last example, assume that the project engineer approves the use of a water reducer to increase the slump to 5 in. to improve workability for a difficult placement area. Assuming that the water reducer has a manufacturer's recommended dosage rate of 4 oz per 100 lb of cement to increase slump 2 in., the admixture amount becomes

$$\frac{624}{100} \times 4 = 25.0 \text{ oz per cu yd}$$

The amount of air-entraining agent may also need to be reduced (up to 50%), as many water reducers also entrain air. If a water reducer was used to reduce the water-cement ratio, the water and sand content would also need adjustment.

Pozzolans and Slag. Pozzolans and slag are sometimes added in addition to or as a partial replacement of cement to aid in workability and resistance to sulfate attack and alkali reactivity. If a pozzolan or slag were required for the above example mixture, it would have been entered in the first volume calculation used in determining fine aggregate content. For example:

Assume that 75 lb of fly ash with a relative density (specific gravity) of 2.5 were to be used in addition to the originally derived cement content. The ash volume would be

$$\frac{75}{2.5 \times 62.4} = 0.48 \text{ cu ft}$$

The water to cementing materials ratio would be

$$\frac{W}{C + P} = \frac{270}{643 + 75} = 0.38 \text{ by weight}$$

The water to portland cement only ratio would still be

$$\frac{W}{C} = \frac{270}{643} = 0.42 \text{ by weight}$$

The fine aggregate volume would have to be reduced by 0.48 cu ft to allow for the volume of ash.

The pozzolan amount and volume computation could also have been derived in conjunction with the first cement content calculation using a water to cementing materials ratio of 0.42 (or equivalent). For example, assume 15% of the cementitious material is specified to be a pozzolan and

W/CM or $W/(C + P)$ = 0.42.

Then with W = 270 lb and $C + P$ = 643 lb,

$P = 643 \times \frac{15}{100}$ = 96 lb

and C = 643 – 96 = 547 lb

Appropriate proportioning computations for these and other mix ingredients would follow.

Example 3. Laboratory Trial Mixture Using the PCA Water-Cement Ratio Method (Metric)

With the following method, the mix designer develops the concrete proportions directly from the laboratory trial batch rather than the absolute volume of the constituent ingredients.

Conditions and Specifications. Concrete is required for a plain concrete pavement to be constructed in North Dakota. The pavement specified compressive strength is 35 MPa at 28 days. The standard deviation of the concrete producer is 2.0 MPa. Type IP cement and 19-mm nominal maximum-size coarse aggregate is locally available. Proportion a concrete mixture for these conditions and check it by trial batch. Enter all data in the blank spaces on a trial mixture data sheet (Fig. 9-6).

Durability Requirements. The pavement will be exposed to freezing, thawing, and deicers and therefore should have a maximum water to cementitious material ratio of 0.45 (Table 9-1) and at least 335 kg of cement per cubic meter of concrete.

Strength Requirements. For a standard deviation of 2.0 MPa, the f'_{cr} (required compressive strength for proportioning) must be the larger of

$$f'_{cr} = f'_c + 1.34S = 35 + 1.34(2.0) = 37.7 \text{ MPa}$$

or

$$f'_{cr} = f'_c + 2.33S - 3.45 = 35 + 2.33(2.0) - 3.45 = 36.2 \text{ MPa}$$

Therefore the required average compressive strength = 37.7 MPa.

Aggregate Size. The 19-mm maximum-size coarse aggregate and the fine aggregate are in saturated-surface dry condition for the trial mixtures.

Air Content. The target air content should be 6% (Table 9-5) and the range is set at 5% to 8%.

Slump. The specified target slump for this project is 40 (±20) mm.

Batch Quantities. For convenience, a batch containing 10 kg of cement is to be made. The quantity of mixing water required is 10 x 0.45 = 4.5 kg. Representative samples of fine and coarse aggregates are measured in suitable containers. The values are entered as initial mass in Column 2 of the trial-batch data sheet (Fig. 9-6).

All of the measured quantities of cement, water, and air-entraining admixture are used and added to the mixer. Fine and coarse aggregates, previously brought to a saturated, surface-dry condition, are added until a workable concrete mixture with a slump deemed adequate for placement is produced. The relative proportions of fine and coarse aggregate for workability can readily be judged by an experienced concrete technician or engineer.

Workability. Results of tests for slump, air content, density, and a description of the appearance and workability are noted in the data sheet and Table 9-13.

The amounts of fine and coarse aggregates not used are recorded on the data sheet in Column 3, and mass of aggregates used (Column 2 minus Column 3) are noted in Column 4. If the slump when tested had been greater than that required, additional fine or coarse aggregates (or both) would have been added to reduce slump. Had the slump been less than required, water and cement in the appropriate ratio (0.45) would have been added to increase slump. It is important that any additional quantities be measured accurately and recorded on the data sheet.

Data and Calculations for Trial Batch
(saturated surface-dry aggregates)

Batch size: 10 kg ✓ 20 kg ______ 40 kg ______ of cement

Note: Complete Columns 1 through 4, fill in items below, the complete 5 and 6.

1 Material	2 Initial mass, kg	3 Final mass, kg	4 Mass. used, (Col. 2 minus Col. 3)	5 Mass per m³ No. of batches (C) x Col. 4	6 Remarks
Cement	10.0	0	10.0	341	
Water	4.5	0	4.5	153	
Fine aggregate	37.6	17.3	20.3	691 (a)	% F.A.* = $\frac{a}{a+b}$ x 100 = 38%
Coarse aggregate	44.1	11.0	33.1	1128 (b)	
Air-entraining admixture	10 ml	Total (T) =	67.9	2313	
	T x C = 67.9 x 34.0648 = 2313				Math check

Measured slump: 45 mm Measured air content 7.5 %

Appearance: Sandy ______ Good ✓ Rocky ______

Workability: Good ✓ Fair ______ Poor ______

Mass of container + concrete = 42.7 kg

Mass of container = 8.0 kg

Mass of concrete (A) = 34.7 kg

Volume of container (B) = 0.015 m³

Density of concrete (D) = $\frac{A}{B}$ = 34.7/0.015 = 2313 kg/m³

Volume of concrete produced = $\frac{\text{Total mass of material per batch}}{\text{Density}} = \frac{T}{D}$

= 67.9/2313 = 0.0293558 m³

Number of 67.9 kg batches per m³ (C) = $\frac{1.0 \text{ m}^3}{\text{Volume}} = \frac{1.0}{0.0293558}$ = 34.0648 batches

*Percentage fine aggregate of total aggregates = $\frac{\text{Mass of fine aggregate}}{\text{Total mass of aggregates}}$ x 100

Fig. 9-6. Trial mixture data sheet (metric).

Mixture Proportions. Mixture proportions for a cubic meter of concrete are calculated in Column 5 of Fig. 9-6 by using the batch yield (volume) and density (unit weight). For example, the number of kilograms of cement per cubic meter is determined by dividing one cubic meter by the volume of concrete in the batch and multiplying the result by the number of kilograms of cement in the batch. The percentage of fine aggregate by mass of total aggregate is also calculated. In this trial batch, the cement content was 341 kg/m³ and the fine aggregate made up 38% of the total aggregate by mass. The air content and slump were acceptable. The 28-day strength was 39.1 MPa, greater than f'_{cr}. The mixture in Column 5, along with slump and air content limits of 40 (±20) mm and 5% to 8%, respectively, is now ready for submission to the project engineer.

Table 9-13. Example of Results of Laboratory Trial Mixtures (Metric)*

Batch no.	Slump, mm	Air content, percent	Density, kg/m³	Cement content, kg/m³	Fine aggregate, percent of total aggregate	Workability
1	50	5.7	2341	346	28.6	Harsh
2	40	6.2	2332	337	33.3	Fair
3	45	7.5	2313	341	38.0	Good
4	36	6.8	2324	348	40.2	Good

*Water-cement ratio was 0.45.

Example 4. Laboratory Trial Mixture Using the PCA Water-Cement Ratio Method (Inch-Pound Units)

With the following method, the mix designer develops the concrete proportions directly from a laboratory trial batch, rather than the absolute volume of the constituent ingredients as in Example 2.

Conditions and Specifications. Air-entrained concrete is required for a foundation wall that will be exposed to moderate sulfate soils. A compressive strength, f'_c, of 4000 psi at 28 days using Type II cement is specified. Minimum thickness of the wall is 10 in. and concrete cover over ½-in.-diameter reinforcing bars is 3 in. The clear distance between reinforcing bars is 3 in. The water-cement ratio versus compressive strength relationship based on field and previous laboratory data for the example ingredients is illustrated by Fig. 9-7. Based on the test records of the materials to be used, the standard deviation is 300 psi. Proportion and evaluate by trial batch a mixture meeting the above conditions and specifications. Enter all data in the appropriate blanks on a trial-mixture data sheet (Fig. 9-8).

Water-Cement Ratio. For these exposure conditions, Table 9-2 indicates that concrete with a maximum water-cement ratio of 0.50 should be used and the minimum design strength should be 4000 psi.

The water-cement ratio for strength is selected from a graph plotted to show the relationship between the water-cement ratio and compressive strength for these specific concrete materials (Fig. 9-7).

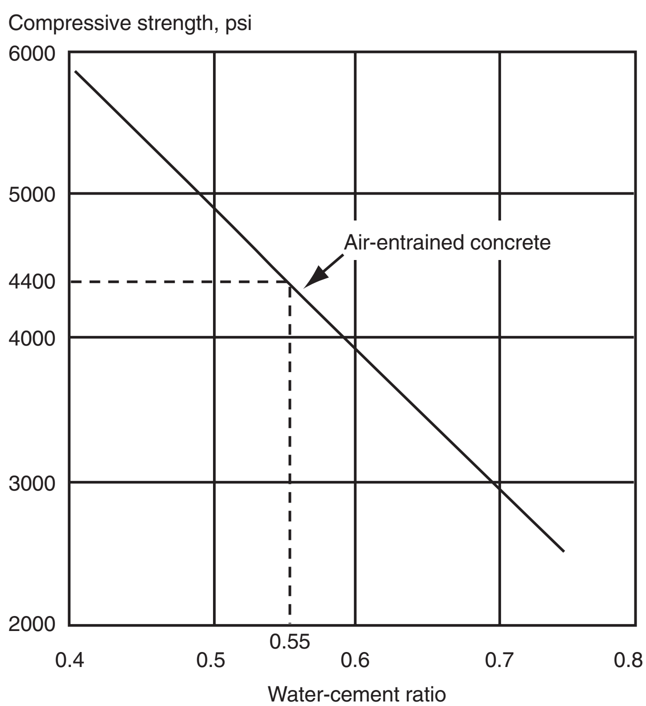

Fig. 9-7. Relationship between strength and water to cement ratio based on field and laboratory data for specific concrete ingredients.

For a standard deviation of 300 psi, f'_{cr} must be the larger of

$f'_{cr} = f'_c + 1.34S = 4000 + 1.34(300) = 4402$ psi

or

$f'_{cr} = f'_c + 2.33S - 500 = 4000 + 2.33(300) - 500 = 4199$ psi

Therefore, $f'_{cr} = 4400$ psi

From Fig. 9-7, the water-cement ratio for air-entrained concrete is 0.55 for an f'_{cr} of 4400 psi. This is greater than the 0.50 permitted for the exposure conditions; therefore, the exposure requirements govern. A water-cement ratio of 0.50 must be used, even though this may produce strengths higher than needed to satisfy structural requirements.

Aggregate Size. Assuming it is economically available, 1½-in. maximum-size aggregate is satisfactory; it is less than ⅕ the wall thickness and less than ¾ the clear distance between reinforcing bars and between reinforcing bars and the form. If this size were not available, the next smaller available size would be used. Aggregates are to be in a saturated surface-dry condition for these trial mixtures.

Air Content. Because of the exposure conditions and to improve workability, a moderate level of entrained air is needed. From Table 9-5, the target air content for concrete with 1½-in. aggregate in a moderate exposure is 4.5%. Therefore, proportion the mixture with an air content range of 4.5% ±1% and aim for 5.5% ±0.5% in the trial batch.

Slump. The recommended slump range for placing a reinforced concrete foundation wall is 1 in. to 3 in., assuming that the concrete will be consolidated by vibration (Table 9-6). Batch for 3 in. ±0.75 in.

Batch Quantities. For convenience, a batch containing 20 lb of cement is to be made. The quantity of mixing water required is 20 x 0.50 = 10 lb. Representative samples of fine and coarse aggregates are weighed into suitable containers. The values are entered as initial weights in Column 2 of the trial-batch data sheet (Fig. 9-8).

All of the measured quantities of cement, water, and air-entraining admixture are used and added to the mixer. Fine and coarse aggregates, previously brought to a saturated surface-dry condition, are added in proportions similar to those used in mixes from which Fig. 9-7 was developed. Mixing continues until a workable concrete with a 3-in. slump deemed adequate for placement is produced. The relative proportions of fine and coarse aggregate for workability can readily be judged by an experienced concrete technician or engineer.

Workability. Results of tests for slump, air content, unit weight, and a description of the appearance and workability ("Good" for this example) are noted on the data sheet.

The amounts of fine and coarse aggregates not used are recorded on the data sheet in Column 3, and masses of aggregates used (Column 2 minus Column 3) are noted in Column 4. If the slump when tested had been greater than that required, additional fine or coarse aggregates (or both) would have been added to reduce slump. Had the slump been less than required, water and cement in the appropriate ratio (0.50) would have been added to increase slump. It is important that any additional quantities be measured accurately and recorded on the data sheet.

Data and Calculations for Trial Batch
(saturated surface-dry aggregates)

Batch size: 10 lb ______ 20 lb ✓ 40 lb ______ of cement

Note: Complete Columns 1 through 4, fill in items below, the complete 5 and 6.

1 Material	2 Initial mass, lb	3 Final mass, lb	4 Mass. used, (Col. 2 minus Col. 3)	5 Mass per cubic yard (C) x Col. 4	6 Remarks
Cement	20.0	0	20.0	539	
Water	10.0	0	10.0	269	
Fine aggregate	66.2	27.9	38.3	1032 (a)	% fine aggregate = $\frac{a}{a+b}$ x 100 = 33.5 %
Coarse aggregate	89.8	13.8	76.0	2048 (b)	
Air-entraining admixture	0.3 oz	Total (T) =	144.3	3888	
		T x C = 144.3 x 26.943 = 3888			Math check

Measured slump: 3 in. Measured air content 5.4 %

Appearance: Sandy ______ Good ✓ Rocky ______

Workability: Good ✓ Fair ______ Poor ______

Weight of container + concrete = 93.4 lb

Weight of container = 21.4 lb

Weight of concrete (A) = 72.0 lb

Volume of container (B) = 0.50 cu ft

Density of concrete (D) = $\frac{A}{B}$ = $\frac{72.0}{0.50}$ = 144.0 lb/cu ft

Yield (volume of concrete produced) = $\frac{\text{Total weight of material per batch}}{\text{Density of concrete}}$ = $\frac{144.3}{144.0}$ = 1.0021 cu ft

Number of 144.3 lb batches per cu yd (C) = $\frac{\text{27 cu ft*}}{\text{Yield}}$ = $\frac{27}{1.0021}$ = 26.943 batches

*One cubic yard has 27 cu ft.

Fig. 9-8. Trial mixture data sheet (inch-pound units).

Mixture Proportions. Mixture proportions for a cubic yard of concrete are calculated in Column 5 of Fig. 9-8 by using the batch yield (volume) and density (unit weight). For example, the number of pounds of cement per cubic yard is determined by dividing 27 cu ft (1 cu yd) by the volume of concrete in the batch and multiplying the result by the number of pounds of cement in the batch. The percentage of fine aggregate by weight of total aggregate is also calculated. In this trial batch, the cement content was 539 lb per cubic yard and the fine aggregate made up 33.5% of the total aggregate by weight. The air content and slump were acceptable. The 28-day strength was 4950 psi (greater than f'_{cr}). The mixture in Column 5, along with slump and air content limits of 1 in. to 3 in. and 3.5% to 5.5%, respectively, is now ready for submission to the project engineer.

Mixture Adjustments. To determine the most workable and economical proportions, additional trial batches could be made varying the percentage of fine aggregate. In each batch the water-cement ratio, aggregate gradation, air content, and slump should remain about the same. Results of four such trial batches are summarized in Table 9-14.

Table 9-14. Example of Results of Laboratory Trial Mixtures (Inch-Pound Units)*

Batch no.	Slump, in.	Air content, percent	Density, lb/cu ft³	Cement content, lb/cu yd³	Fine aggregate, percent of total aggregate	Workability
1	3	5.4	144	539	33.5	Good
2	2¾	4.9	144	555	27.4	Harsh
3	2½	5.1	144	549	35.5	Excellent
4	3	4.7	145	540	30.5	Excellent

*Water-cement ratio was 0.50.

Table 9-15 illustrates the change in mix proportions for various types of concrete mixtures using a particular aggregate source. Information for concrete mixtures using particular ingredients can be plotted in several ways to illustrate the relationship between ingredients and properties. This is especially useful when optimizing concrete mixtures for best economy or to adjust to specification or material changes (Fig. 9-9).

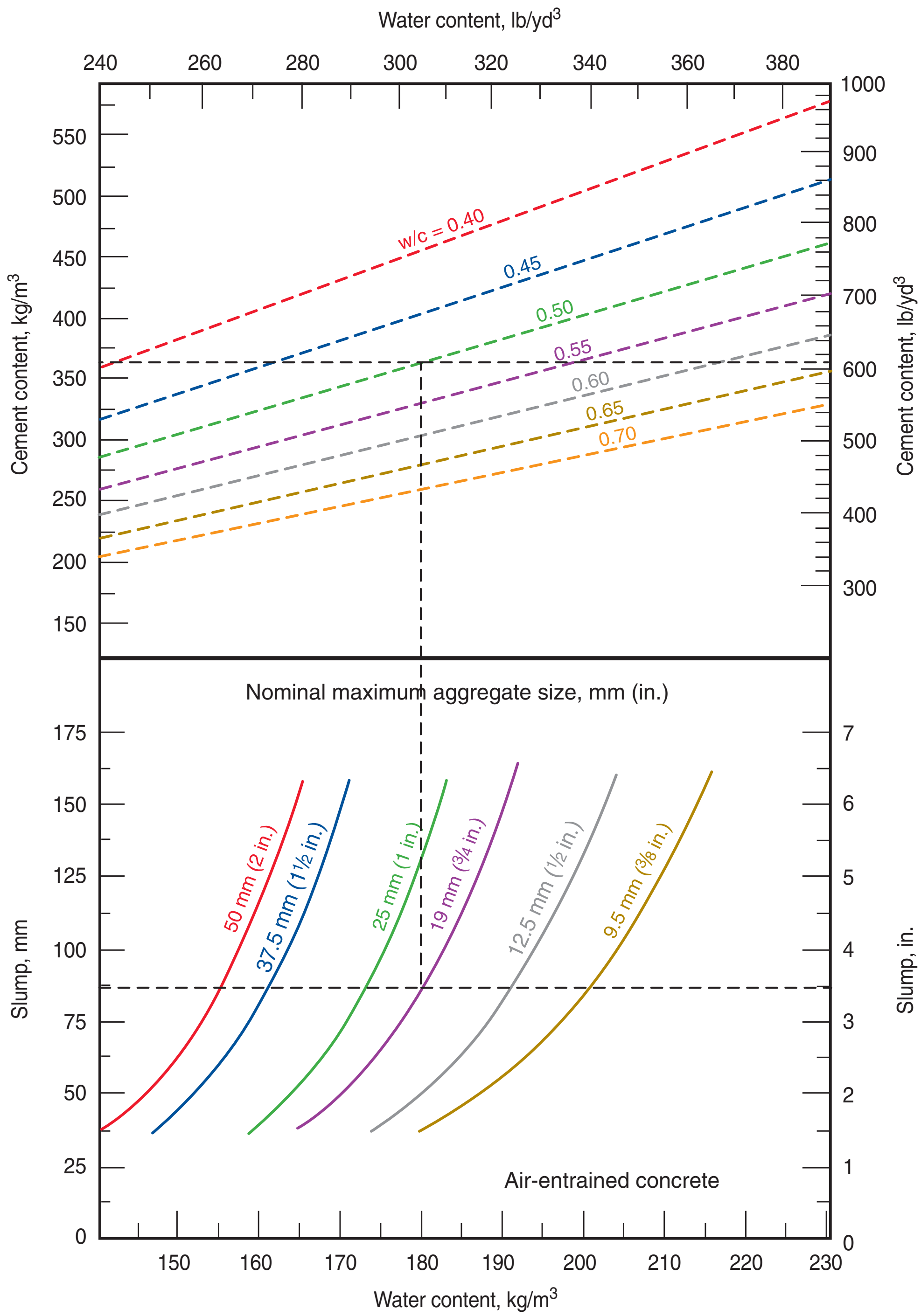

Fig. 9-9. Example graphical relationship for a particular aggregate source demonstrating the relationship between slump, aggregate size, water to cement ratio, and cement content (Hover 1995).

Table 9-15 (Metric). Example Trial Mixtures for Air-Entrained Concrete of Medium Consistency, 75-mm to 100-mm slump

					With fine sand, fineness modulus = 2.50			With coarse sand, fineness modulus = 2.90		
Water-cement ratio, kg per kg	Nominal maximum size of aggregate, mm	Air content, percent	Water, kg per cu meter of concrete	Cement, kg per cu meter of concrete	Fine aggregate, percent of total aggregate	Fine aggregate, kg per cu meter of concrete	Coarse aggregate, kg per cu meter of concrete	Fine aggregate, percent of total aggregate	Fine aggregate, kg per cu meter of concrete	Coarse aggregate, kg per cu meter of concrete
0.40	9.5	7.5	202	505	50	744	750	54	809	684
	12.5	7.5	194	485	41	630	904	46	702	833
	19.0	6	178	446	35	577	1071	39	648	1000
	25.0	6	169	424	32	534	1151	36	599	1086
	37.5	5	158	395	29	518	1255	33	589	1184
0.45	9.5	7.5	202	450	51	791	750	56	858	684
	12.5	7.5	194	387	43	678	904	47	750	833
	19.0	6	178	395	37	619	1071	41	690	1000
	25.0	6	169	377	33	576	1151	37	641	1086
	37.5	5	158	351	31	553	1225	35	625	1184
0.50	9.5	7.5	202	406	53	833	750	57	898	684
	12.5	7.5	194	387	44	714	904	49	785	833
	19.0	6	178	357	38	654	1071	42	726	1000
	25.0	6	169	338	34	605	1151	38	670	1086
	37.5	5	158	315	32	583	1225	36	654	1184
0.55	9.5	7.5	202	369	54	862	750	58	928	684
	12.5	7.5	194	351	45	744	904	49	815	833
	19.0	6	178	324	39	678	1071	43	750	1000
	25.0	6	169	309	35	629	1151	39	694	1086
	37.5	5	158	286	33	613	1225	37	684	1184
0.60	9.5	7.5	202	336	54	886	750	58	952	684
	12.5	7.5	194	321	46	768	904	50	839	833
	19.0	6	178	298	40	702	1071	44	773	1000
	25.0	6	169	282	36	653	1151	40	718	1086
	37.5	5	158	262	33	631	1225	37	702	1184
0.65	9.5	7.5	202	312	55	910	750	59	976	684
	12.5	7.5	194	298	47	791	904	51	863	833
	19.0	6	178	274	40	720	1071	44	791	1000
	25.0	6	169	261	37	670	1151	40	736	1086
	37.5	5	158	244	34	649	1225	38	720	1184
0.70	9.5	7.5	202	288	55	928	750	59	994	684
	12.5	7.5	194	277	47	809	904	51	880	833
	19.0	6	178	256	41	738	1071	45	809	1000
	25.0	6	169	240	37	688	1151	41	753	1086
	37.5	5	158	226	34	660	1225	38	732	1184

Table 9-15 (Inch-Pound Units). Example Trial Mixtures for Air-Entrained Concrete of Medium Consistency, 3-in. to 4-in. slump

					With fine sand, fineness modulus = 2.50			With coarse sand, fineness modulus = 2.90		
Water-cement ratio, lb per lb	Nominal maximum size of aggregate, in.	Air content, percent	Water, lb per cu yd of concrete	Cement, lb per cu yd of concrete	Fine aggregate, percent of total aggregate	Fine aggregate, lb per cu yd of concrete	Coarse aggregate, lb per cu yd of concrete	Fine aggregate, percent of total aggregate	Fine aggregate, lb per cu yd of concrete	Coarse aggregate, lb per cu yd of concrete
0.40	⅜	7.5	340	850	50	1250	1260	54	1360	1150
	½	7.5	325	815	41	1060	1520	46	1180	1400
	¾	6	300	750	35	970	1800	39	1090	1680
	1	6	285	715	32	900	1940	36	1010	1830
	1½	5	265	665	29	870	2110	33	990	1990
0.45	⅜	7.5	340	755	51	1330	1260	56	1440	1150
	½	7.5	325	720	43	1140	1520	47	1260	1400
	¾	6	300	665	37	1040	1800	41	1160	1680
	1	6	285	635	33	970	1940	37	1080	1830
	1½	5	265	590	31	930	2110	35	1050	1990

Table 9-15 (Inch-Pound Units). Example Trial Mixtures for Air-Entrained Concrete of Medium Consistency, 3-in. to 4-in. slump (Continued)

					With fine sand, fineness modulus = 2.50			With coarse sand, fineness modulus = 2.90		
Water-cement ratio, lb per lb	Nominal maximum size of aggregate, in.	Air content, percent	Water, lb per cu yd of concrete	Cement, lb per cu yd of concrete	Fine aggregate, percent of total aggregate	Fine aggregate, lb per cu yd of concrete	Coarse aggregate, lb per cu yd of concrete	Fine aggregate, percent of total aggregate	Fine aggregate, lb per cu yd of concrete	Coarse aggregate, lb per cu yd of concrete
0.50	⅜	7.5	340	680	53	1400	1260	57	1510	1150
	½	7.5	325	650	44	1200	1520	49	1320	1400
	¾	6	300	600	38	1100	1800	42	1220	1680
	1	6	285	570	34	1020	1940	38	1130	1830
	1½	5	265	530	32	980	2110	36	1100	1990
0.55	⅜	7.5	340	620	54	1450	1260	58	1560	1150
	½	7.5	325	590	45	1250	1520	49	1370	1400
	¾	6	300	545	39	1140	1800	43	1260	1680
	1	6	285	520	35	1060	1940	39	1170	1830
	1½	5	265	480	33	1030	2110	37	1150	1990
0.60	⅜	7.5	340	565	54	1490	1260	58	1600	1150
	½	7.5	325	540	46	1290	1520	50	1410	1400
	¾	6	300	500	40	1180	1800	44	1300	1680
	1	6	285	475	36	1100	1940	40	1210	1830
	1½	5	265	440	33	1060	2110	37	1180	1990
0.65	⅜	7.5	340	525	55	1530	1260	59	1640	1150
	½	7.5	325	500	47	1330	1520	51	1450	1400
	¾	6	300	460	40	1210	1800	44	1330	1680
	1	6	285	440	37	1130	1940	40	1240	1830
	1½	5	265	410	34	1090	2110	38	1210	1990
0.70	⅜	7.5	340	485	55	1560	1260	59	1670	1150
	½	7.5	325	465	47	1360	1520	51	1480	1400
	¾	6	300	430	41	1240	1800	45	1360	1680
	1	6	285	405	37	1160	1940	41	1270	1830
	1½	5	265	380	34	1110	2110	38	1230	1990

Example 5. Absolute Volume Method Using Multiple Cementing Materials and Admixtures (Metric)

The following example illustrates how to develop a mix using the absolute volume method when more than one cementing material and admixture are used.

Conditions and Specifications. Concrete with a structural design strength of 40 MPa is required for a bridge to be exposed to freezing and thawing, deicers, and very severe sulfate soils. A coulomb value not exceeding 1500 is required to minimize permeability to chlorides. Water reducers, air entrainers, and plasticizers are allowed. A shrinkage reducer is requested to keep shrinkage under 300 millionths. Some structural elements exceed a thickness of 1 meter, requiring control of heat development. The concrete producer has a standard deviation of 2 MPa for similar mixes to that required here. For difficult placement areas, a slump of 200 mm to 250 mm is required. The following materials are available:

Cement: Type HS, silica fume modified portland cement, ASTM C 1157. Relative density of 3.14. Silica fume content of 5%.

Fly ash: Class F, ASTM C 618 (AASHTO M 295). Relative density of 2.60.

Slag: Grade 120, ASTM C 989 (AASHTO M 302). Relative density of 2.90.

Coarse aggregate: Well-graded 19-mm nominal maximum-size crushed rock (ASTM C 33 or AASHTO M 80) with an ovendry relative density of 2.68, absorption of 0.5%, and ovendry density of 1600 kg/m³. The laboratory sample has a moisture content of 2.0%. This aggregate has a history of alkali-silica reactivity in the field.

Fine aggregate: Natural sand with some crushed particles (ASTM C 33 or AASHTO M 6) with an ovendry relative density of 2.64 and an absorption of 0.7%. The laboratory sample has a moisture content of 6%. The fineness modulus is 2.80.

Air entrainer: Synthetic, ASTM C 260 (AASHTO M 154).

Retarding water reducer: Type D, ASTM C 494 (AASHTO M 194). Dosage of 3 g per kg of cementing materials.

Plasticizer:	Type 1, ASTM C 1017. Dosage of 30 g per kg of cementing materials.
Shrinkage reducer:	Dosage of 15 g per kg of cementing materials.

Strength. For a standard deviation of 2.0 MPa, the f'_{cr} must be the greater of

$f'_{cr} = f'_c + 1.34S = 40 + 1.34(2) = 42.7$

or

$f'_{cr} = 0.9\ f'_c + 2.33S = 36 + 2.33(2) = 40.7$

therefore $f'_{cr} = 42.7$

Water to Cementing Materials Ratio. Past field records using these materials indicate that a water to cementing materials ratio of 0.35 is required to provide a strength level of 42.7 MPa.

For a deicer environment and to protect embedded steel from corrosion, Table 9-1 requires a maximum water to cementing materials ratio of 0.40 and a strength of at least 35 MPa. For a severe sulfate environment, Table 9-2 requires a maximum water to cementing materials ratio of 0.40 and a strength of at least 35 MPa. Both the water to cementing materials ratio requirements and strength requirements are met and exceeded using the above determined 0.35 water to cementing materials ratio and 40 MPa design strength.

Air Content. For a severe exposure, Fig. 9-4 suggests a target air content of 6% for 19-mm aggregate. Therefore, design the mix for 5% to 8% and use 8% for batch proportions. The trial batch air content must be within ±0.5 percentage points of the maximum allowable air content.

Slump. Assume a slump of 50 mm without the plasticizer and a maximum of 200 mm to 250 mm after the plasticizer is added. Use 250 ± 20 mm for proportioning purposes.

Water Content. Fig. 9-5 recommends that a 50-mm slump, air-entrained concrete with 19-mm aggregate should have a water content of about 168 kg/m³. Assume the retarding water reducer and plasticizer will jointly reduce water demand by 15% in this case, resulting in an estimated water demand of 143 kg per cubic meter, while achieving the 250-mm slump.

Cementing Materials Content. The amount of cementing materials is based on the maximum water-cementing materials ratio and water content. Therefore, 143 kg of water divided by a water-cementing materials ratio of 0.35 requires a cement content of 409 kg. Fly ash and slag will be used to help control alkali-silica reactivity and control temperature rise. Local use has shown that a fly ash dosage of 15% and a slag dosage of 30% by mass of cementing materials are adequate. Therefore, the suggested cementing materials for one cubic meter of concrete are as follows:

Cement:	55% of 409	=	225 kg
Fly ash:	15% of 409	=	61 kg
Slag:	30% of 409	=	123 kg

These dosages meet the requirements of Table 9-8 (2.8% silica fume from the cement + 15% fly ash + 30% slag = 47.8% which is less than the 50% maximum allowed).

Coarse-Aggregate Content. The quantity of 19-mm nominal maximum-size coarse aggregate can be estimated from Fig. 9-3. The bulk volume of coarse aggregate recommended when using sand with a fineness modulus of 2.80 is 0.62. Since the coarse aggregate has a bulk density of 1600 kg/m³, the ovendry mass of coarse aggregate for a cubic meter of concrete is

1600 x 0.62 = 992 kg/m³

Admixture Content. For an 8% air content, the air-entraining admixture manufacturer recommends a dosage of 0.5 g per kg of cementing materials. The amount of air entrainer is then

0.5 x 409 = 205 g = 0.205 kg

The retarding water reducer dosage rate is 3 g per kg of cementing materials. This results in

3 x 409 = 1227 g or 1.227 kg of water reducer per cubic meter of concrete.

The plasticizer dosage rate is 30 g per kg of cementing materials. This results in

30 x 409 = 12,270 g or 12.270 kg of plasticizer per cubic meter of concrete.

The shrinkage reducer dosage rate is 15 g per kg of cementing materials. This results in

15 x 409 = 6135 g or 6.135 kg of shrinkage reducer per cubic meter of concrete.

Fine-Aggregate Content. At this point, the amounts of all ingredients except the fine aggregate are known. The volume of fine aggregate is determined by subtracting the absolute volumes of all known ingredients from 1 cubic meter. The absolute volumes of the ingredients is calculated by dividing the known mass of each by the product of their relative density and the density of water. Assume a relative density of 1.0 for the chemical admixtures. Assume a density of water of 997.75 kg/m³ as all materials in the laboratory are maintained at a room temperature of 22°C (Table 9-12). Volumetric computations are as follows:

Water (including chemical admixtures)	=	$\frac{143}{1.0 \times 997.75}$	=	0.143 m³
Cement	=	$\frac{225}{3.14 \times 997.75}$	=	0.072 m³
Fly ash	=	$\frac{61}{2.60 \times 997.75}$	=	0.024 m³
Slag	=	$\frac{123}{2.90 \times 997.75}$	=	0.043 m³
Air	=	$\frac{8.0}{100}$	=	0.080 m³
Coarse aggregate	=	$\frac{992}{2.68 \times 997.75}$	=	0.371 m³
Total				0.733 m³

The calculated absolute volume of fine aggregate is then
$1 - 0.733 = 0.267\ m^3$

The mass of dry fine aggregate is
0.267 x 2.64 x 997.75 = 703 kg

The admixture volumes are

$$\text{Air entrainer} = \frac{0.205}{(1.0 \times 997.75)} = 0.0002\ m^3$$

$$\text{Water reducer} = \frac{1.227}{(1.0 \times 997.75)} = 0.0012\ m^3$$

$$\text{Plasticizer} = \frac{12.270}{(1.0 \times 997.75)} = 0.0123\ m^3$$

$$\text{Shrinkage reducer} = \frac{6.135}{(1.0 \times 997.75)} = 0.0062\ m^3$$

Total = 19.84 kg of admixture with a volume of $0.0199\ m^3$

Consider the admixtures part of the mixing water

Mixing water minus admixtures = 143 – 19.84 = 123 kg

The mixture then has the following proportions before trial mixing for 1 cubic meter of concrete:

Water	123 kg
Cement	225 kg
Fly ash	61 kg
Slag	123 kg
Coarse aggregate (dry)	992 kg
Fine aggregate (dry)	703 kg
Air entrainer	0.205 kg
Water reducer	1.227 kg
Plasticizer	12.27 kg
Shrinkage reducer	6.135 kg
Total	= 2247 kg

Slump = 250 mm (± 20 mm for trial batch)

Air content = 8% (± 0.5% for trial batch)

Estimated concrete density using SSD aggregate (adding absorbed water)

= 123 + 225 + 61 + 123 + (992 x 1.005) + (703 x 1.007) + 20 (admixtures) = 2257 kg/m^3

Moisture. The dry batch weights of aggregates have to be increased to compensate for the moisture on and in the aggregates and the mixing water reduced accordingly. The coarse aggregate and fine aggregate have moisture contents of 2% and 6%, respectively. With the moisture contents indicated, the trial batch aggregate proportions become

Coarse aggregate (2% MC) = 992 x 1.02 = 1012 kg
Fine aggregate (6% MC) = 703 x 1.06 = 745 kg

Absorbed water does not become part of the mixing water and must be excluded from the water adjustment. Surface moisture contributed by the coarse aggregate amounts to 2% – 0.5% = 1.5% and that contributed by the fine aggregate, 6% – 0.7% = 5.3%. The estimated added water becomes

123 – (992 x 0.015) – (703 x 0.053) = 71 kg

The batch quantities for one cubic meter of concrete are revised to include aggregate moisture as follows:

Water (to be added)	71 kg
Cement	225 kg
Fly ash	61 kg
Slag	123 kg
Coarse aggregate (2% MC)	1012 kg
Fine aggregate (6% MC)	745 kg
Air entrainer	0.205 kg
Water reducer	1.227 kg
Plasticizer	12.27 kg
Shrinkage reducer	6.14 kg

Trial Batch. The above mixture is tested in a 0.1 m^3 batch in the laboratory (multiply above quantities by 0.1 to obtain batch quantities). The mixture had an air content of 7.8%, a slump of 240 mm, a density of 2257 kg/m^3, a yield of 0.1 m^3, and a compressive strength of 44 MPa. Rapid chloride testing resulted in a coulomb value of 990 (ASTM C 1202 or AASHTO T 277). A modified version of ASTM C 1260 was used to evaluate the potential of the mix for alkali-silica reactivity, resulting in an acceptable expansion of 0.02%. Temperature rise was acceptable and shrinkage was within specifications. The water-soluble chloride content was 0.06%, meeting the requirements of Table 9-9. The following mix proportions meet all applicable requirements and are ready for submission to the project engineer for approval:

Water added	123 kg (143 kg total including admixtures)
Cement, Type HS	225 kg
Fly ash, Class F	61 kg
Slag, Grade 120	123 kg
Coarse aggregate	992 kg (ovendry) or 997 kg (SSD)
Fine aggregate	703 kg (ovendry) or 708 kg (SSD)
Air entrainer*	0.205 kg
Water reducer*	1.227 kg
Plasticizer*	12.27 kg
Shrinkage reducer*	6.14 kg
Slump	200 mm to 250 mm
Air content	5% to 8%
Density (SSD agg.)	2257 kg/m^3
Yield	1 m^3
Water-cementing materials ratio	0.35

*Liquid admixture dosages are often provided in liters or milliliters in mix proportion documents.

CONCRETE FOR SMALL JOBS

Although well-established ready mixed concrete mixtures are used for most construction, ready mix is not always practical for small jobs, especially those requiring one cubic meter (yard) or less. Small batches of concrete mixed at the site are required for such jobs.

Table 9-16 (Metric). Proportions by Mass to Make One Tenth Cubic Meter of Concrete for Small Jobs

Nominal maximum size coarse aggregate, mm	Air-entrained concrete				Non-air-entrained concrete			
	Cement, kg	Wet fine aggregate, kg	Wet coarse aggregate, kg*	Water, kg	Cement, kg	Wet fine aggregate, kg	Wet coarse aggregate, kg	Water, kg
9.5	46	85	74	16	46	94	74	18
12.5	43	74	88	16	43	85	88	18
19.0	40	67	104	16	40	75	104	16
25.0	38	62	112	15	38	72	112	15
37.5	37	61	120	14	37	69	120	14

*If crushed stone is used, decrease coarse aggregate by 5 kg and increase fine aggregate by 5 kg.

Table 9-16 (Inch-Pound). Proportions by Mass to Make One Cubic Foot of Concrete for Small Jobs

Nominal maximum size coarse aggregate, in.	Air-entrained concrete				Non-air-entrained concrete			
	Cement, lb	Wet fine aggregate, lb	Wet coarse aggregate, lb*	Water, lb	Cement, lb	Wet fine aggregate, lb	Wet coarse aggregate, lb	Water, lb
⅜	29	53	46	10	29	59	46	11
½	27	46	55	10	27	53	55	11
¾	25	42	65	10	25	47	65	10
1	24	39	70	9	24	45	70	10
1½	23	38	75	9	23	43	75	9

*If crushed stone is used, decrease coarse aggregate by 3 lb and increase fine aggregate by 3 lb.

Table 9-17. Proportions by Bulk Volume* of Concrete for Small Jobs

Nominal maximum size coarse aggregate, mm (in.)	Air-entrained concrete				Non-air-entrained concrete			
	Cement	Wet fine aggregate	Wet coarse aggregate	Water	Cement	Wet fine aggregate	Wet coarse aggregate	Water
9.5 (⅜)	1	2¼	1½	½	1	2½	1½	½
12.5 (½)	1	2¼	2	½	1	2½	2	½
19.0 (¾)	1	2¼	2½	½	1	2½	2½	½
25.0 (1)	1	2¼	2¾	½	1	2½	2¾	½
37.5 (1½)	1	2¼	3	½	1	2½	3	½

*The combined volume is approximately ⅔ of the sum of the original bulk volumes.

If mixture proportions or mixture specifications are not available, Tables 9-16 and 9-17 can be used to select proportions for concrete for small jobs. Recommendations with respect to exposure conditions discussed earlier should be followed.

The proportions in Tables 9-16 and 9-17 are only a guide and may need adjustments to obtain a workable mix with locally available aggregates (PCA 1988). Packaged, combined, dry concrete ingredients (ASTM C 387) are also available.

DESIGN REVIEW

In practice, concrete mixture proportions will be governed by the limits of data available on the properties of materials, the degree of control exercised over the production of concrete at the plant, and the amount of supervision at the jobsite. It should not be expected that field results will be an exact duplicate of laboratory trial batches. An adjustment of the selected trial mixture is usually necessary on the job.

The mixture design and proportioning procedures presented here and summarized in Fig. 9-10 are applicable to normal-weight concrete. For concrete requiring some special property, using special admixtures or materials—lightweight aggregates, for example—different proportioning principles may be involved.

Internet web sites also provide assistance with designing and proportioning concrete mixtures (Bentz 2001). Many of these web sites are internationally oriented and assume principles not used in North America. Therefore, appropriate cautions should be taken when using the internet to design concrete mixtures.

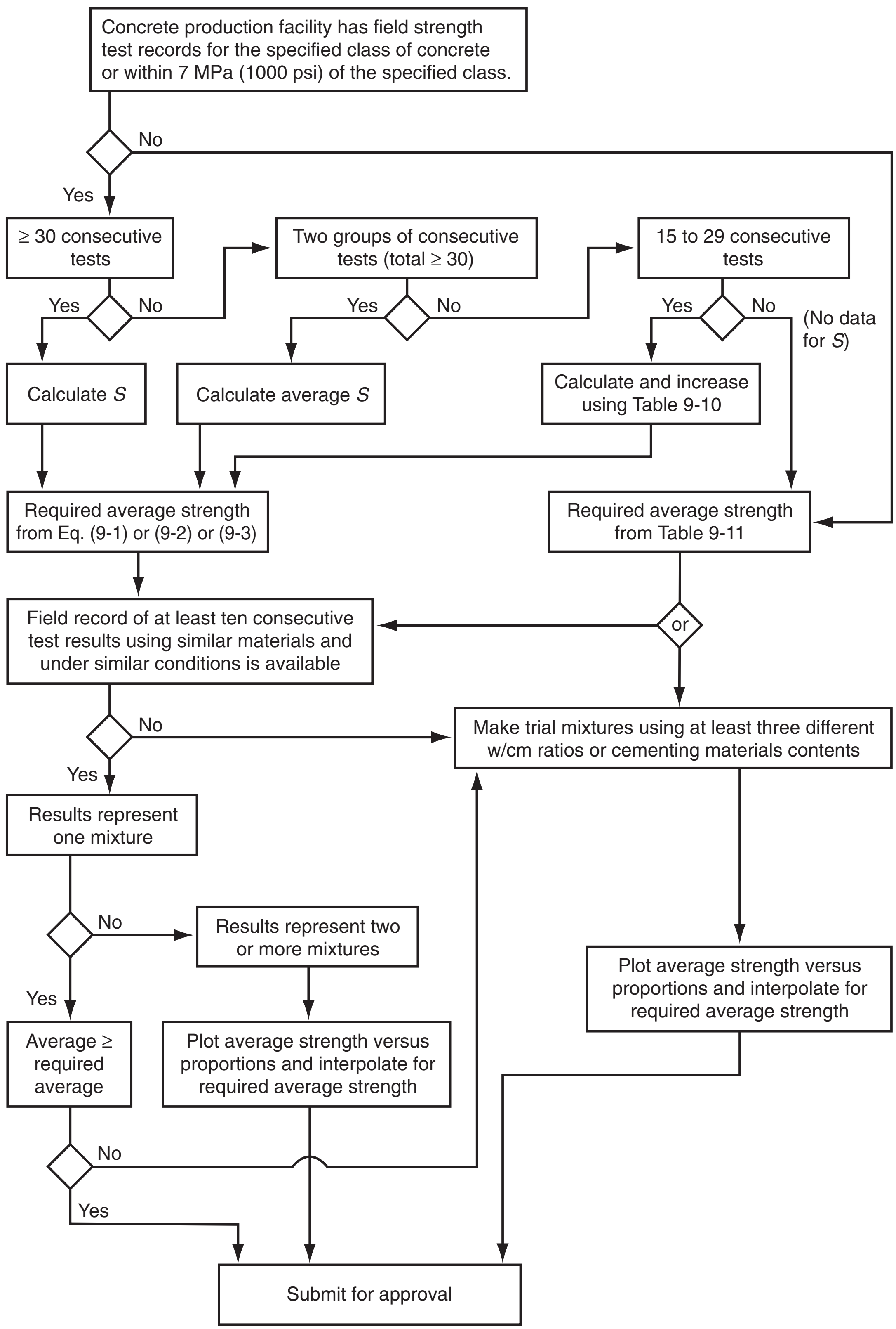

Fig. 9-10. Flowchart for selection and documentation of concrete proportions.

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