Standard Practice for Selecting Proportions for Structural Lightweight Concrete (ACI 211.2-98)

Reported by ACI Committee 211

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This standard describes, with examples, two methods for proportioning and adjusting proportions of structural grade concrete containing lightweight aggregates. The weight (pycnometer) method uses a specific gravity factor determined by a displacement pycnometer test on the aggregates (Method 1). The weight method also employs the specific gravity factor to estimate the weight per yd^3 of the fresh concrete. The damp, loose volume method uses the cement content-strength relationship for the design of all lightweight and sand lightweight concrete (Method 2). Examples are given for systematic calculation of batch weights; effective displaced volumes; and adjustment to compensate for changes in aggregate moisture content; aggregate proportions; cement content; slump, air content, or both

Keywords: absorption; **adsorption**; air content; air entrainment; cement content; coarse aggregate; fine aggregate; fineness modulus; grading; lightweight aggregate; **mixture proportioning**; moisture; slump test; specific gravity factor.

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CHAPTER 1—INTRODUCTION

1.1—Purpose

The purpose of this standard is to provide generally applicable methods for selecting and adjusting mixture proportions for structural lightweight concrete. These methods are also applicable to concrete containing a combination of lightweight and normalweight aggregate.

1.2—Scope

Discussion in this standard is limited to structural grade, lightweight aggregates, and structural lightweight-aggregate concrete. Structural lightweight-aggregate concrete is defined as concrete which: (a) is made with lightweight aggregates conforming to ASTM C 330, (b) has a compressive strength in excess of 2500 psi (17.2 MPa) at 28 days of age when tested in accordance with methods stated in ASTM C 330, and (c) has an equilibrium weight not exceeding 115 lb/ft^3 (1842 kg/m^3) as determined by ASTM C 567. Concrete in which a portion of the lightweight aggregate is replaced by normalweight aggregate is within the scope of this standard. When normalweight fine aggregate is used, it should conform to the requirements of ASTM C 33. The use of pozzolanic and chemical admixtures is not covered in this standard.

CHAPTER 2—FACTORS AFFECTING PROPORTIONING OF LIGHTWEIGHT AGGREGATE CONCRETE

2.1—Aggregates (absorption and moisture content)

2.1.1 The principal factors necessitating modification of proportioning and control procedures for lightweight-aggregate concrete, compared with normalweight concrete, are the greater absorptions and the higher rates of absorption of most lightweight aggregates.

2.1.2 Damp aggregates are preferable to dry aggregates at time of mixing, as they tend to absorb less water during mixing and therefore reduce the possibility of loss of slump as the concrete is being mixed, transported, and placed. Damp aggregates have less tendency to segregate in storage. Absorbed water is accounted for in the mixture-proportioning procedure.

2.1.3 When concrete is made with lightweight aggregates that have low initial moisture contents (usually less than 8 to 10%) and relatively high rates of absorption, it may be desirable to mix the aggregates with one-half to two-thirds of the mixing water for a short period before adding cement, admixtures, and air-entraining admixture to minimize slump loss. The supplier of the particular aggregate should be consulted regarding the necessity for such predampening and for mixing procedure.

2.1.4 Concrete made with saturated lightweight aggregates may be more vulnerable to freezing and thawing than concrete made with damp or dry lightweight aggregates, unless the concrete is allowed to lose its excess moisture after curing, before such exposure, and has developed adequate strength to resist freezing.

2.1.5 When producing trial batches in the laboratory using the specific gravity method, the specific gravity of the lightweight aggregate should be determined at the moisture content anticipated before use.

2.1.6 For most concrete mixture proportions to be practical, aggregate proportions should be listed at a moisture condition readily attainable in the laboratory and in the field. In structural lightweight concrete, the main problem is accounting properly for the moisture in (absorbed), and on (adsorbed), the lightweight aggregate particles as well as for the effects of absorption for a specific application. Traditionally, concrete technologists have assumed, for aggregate moisture content correction purposes, that aggregates are in one of the four conditions at the time of use. These four conditions are shown in Fig. 2.1.

Most concrete mixture proportions are reported with aggregates in either saturated surface-dry (SSD) condition or oven-dry (OD) condition. In the field, aggregates are usually in the air-dry (AD) or wet condition. Lightweight aggregate, however, usually presents a unique situation. Most structural lightweight-aggregate concrete mixture proportions are reported in the OD condition; however, in the field they are not SSD, but in a damp or wet condition. This condition is usually achieved by sprinkling, soaking, thermal quenching, or vacuum saturation. The result is sometimes referred to as the "as-is" condition (Fig. 2.2).

Table 2.1—Comparison of fineness modulus by weight and volume for typical lightweight aggregate

Sieve size, no.	Opening, in. (mm)	Percent retained by weight	Cumulative percent retained by weight	Bulk specific gravity, SSD basis	Percent retained by volume	Cumulative percent retained by volume
4	0.187 (4.75)	0	0	—	0	0
8	0.0937 (2.38)	22	22	1.55	26	26
16	0.0469 (1.19)	24	46	1.78	25	51
30	0.0234 (0.59)	19	65	1.90	19	70
50	0.0117 (0.30)	14	79	2.01	13	83
100	0.0059 (0.15)	12	91	2.16	10	93
Pan	—	9	100	2.40	7	100

Note: Fineness modulus (by weight) = 3.03; fineness modulus (by volume) = 3.23.

The main problem for the concrete technologist is to have an easy method of using field data to convert the oven-dry laboratory trial proportions to proportions in the "as-is" moisture condition.

2.2—Aggregates (gradation)

2.2.1 Grading of the fine and coarse aggregates and the proportions used have an important effect on the concrete. A well-graded aggregate will have a continuous distribution of particle sizes, producing a minimum void content and will require a minimum amount of cement paste to fill the voids. This will result in the most economical use of cement and will provide maximum strength with minimum volume change due to drying shrinkage.

2.2.2 In general, the largest total volume of aggregate in the concrete is achieved:

(a) when the coarse aggregate is well graded from the largest to the smallest sizes;

(b) when the particle is rounded to cubical in shape; and

(c) when the surface texture is least porous.

Conversely, concrete containing coarse aggregates that tend to be angular in shape, more porous in surface texture, and possibly deficient in one or more particle sizes, will require a smaller volume of aggregates.

These same factors of grading, particle shape, and texture also affect the percentage of fine aggregate required with a minimum percentage of fine aggregate being associated with a rounded or cubical shape and smooth texture. It is common that when a well-graded, normalweight sand is used to replace lightweight fine aggregate, the proportion of coarse lightweight aggregate may be increased. The proportion of coarse aggregate should approach the maximum consistent with workability and placeability, unless tests indicated that a lesser proportion provides optimum characteristics.

In some cases, strength may be increased by reducing the nominal maximum size of the aggregate without increasing the cement content.

2.2.3 For normalweight aggregates, the bulk specific gravities of fractions retained on the different sieve sizes are nearly equal. Percentages retained on each size indicated by weight give a true indication of percentages by volume. The bulk specific gravity of the various size fractions of lightweight aggregate, however, usually increases as the particle size decreases. Some coarse aggregate particles may float on water, whereas material passing a No. 100 sieve (0.15 mm) may have a specific gravity approaching that of normalweight sand. It is the volume occupied by each fraction, and not the weight of material retained on each sieve, that determines the void content and paste content, and influences workability of the concrete. For a fine aggregate with a specific gravity of 1.89, the percentages retained on each sieve and fineness modulus, by weight and by volume, are computed for comparison in the example illustrated in Table 2.1.

A fineness modulus of 3.23 by volume in the example indicates a considerably coarser grading than that normally associated with the fineness modulus of 3.03 by weight. Therefore, lightweight aggregates require a larger percentage of material retained on the finer sieve sizes on a weight basis than do normalweight aggregates to provide an equal size distribution by volume.

2.2.4 As indicated in Section 1.2, concrete containing some normalweight aggregates, such as normalweight sand, is classified as lightweight concrete, provided the strength and unit weight requirements are met. The use of normalweight sand usually results in some increase in strength and modulus of elasticity. These increases, however, are made at the sacrifice of increased weight. The mixture proportions

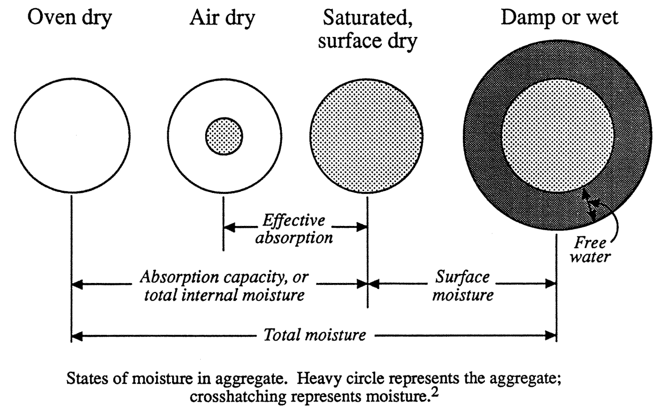

Fig. 2.1—States of moisture in aggregate.

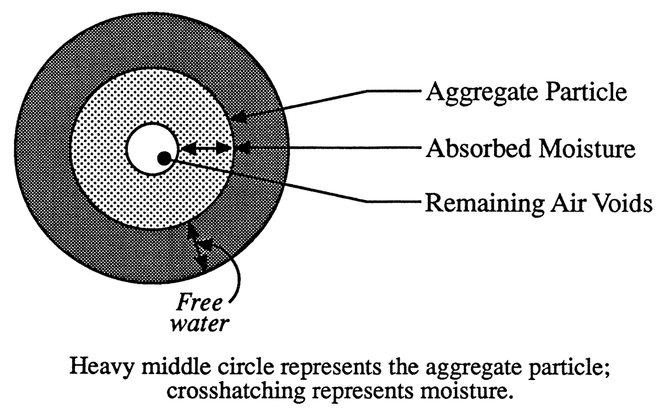

Fig. 2.2—"As-is" condition.

selected, therefore, should consider these properties in conjunction with the corresponding effects on the overall economy of the structure.

2.3—Water-cementitious material ratio

2.3.1 *Method 1*—Lightweight-aggregate concrete may be proportioned by Method 1 (weight method, specific gravity pycnometer) on the basis of an approximate water-cementitious material ratio (*w/cm*) relationship when the absorption of the lightweight aggregate is known or determined, as described later in Appendix A. This method utilizes the fact that the sum of the weights per unit volume of all ingredients in a mixture is equal to the total weight of the same mixture. If the weight of the particular concrete per unit volume, which contains a particular aggregate, is known or can be estimated from the specific gravity factor of the aggregate, the weight of the lightweight aggregates in that volume of concrete can be determined.

2.3.2 *Method 2*—When trial mixtures are proportioned by procedures other than the weight method (Method 1—specific gravity pycnometer), the net water-cement ratio of most lightweight concrete mixtures cannot be established with sufficient accuracy to be used as a basis for mixture proportioning. This is due to the difficulty of determining how much of the total water is absorbed in the aggregate and thus is not available for reaction with the cement, versus the amount of water that is absorbed in open surface pores or cells of the aggregate particles, which usually remains there after surface drying and is available to react with the cement. The amount of free water in the surface pores or open cells varies according to the size and number of pores or open cells in the lightweight-aggregate particles. Lightweight-aggregate concrete mixtures are usually established by trial mixtures proportioned on a cement air content basis at the required consistency rather than on a water-cement ratio-strength basis when the weight method is not employed.

2.4—Air entrainment

2.4.1 Air entrainment is recommended in most lightweight-aggregate concrete as it is in most normalweight concrete (ACI 201.2R and 213R). It enhances workability, improves resistance to freezing-and-thawing cycles and deicer chemicals, decreases bleeding, and tends to obscure minor grading deficiencies. When severe exposure is not anticipated, its use may be waived, but the beneficial effects of air entrainment on concrete workability and cohesiveness are desirable and can be achieved at air contents of not less than 4.0%. Entrained air also lowers the unit weight of the concrete by several percentage points.

2.4.2 The amount of entrained air recommended for lightweight-aggregate concrete that may be subjected to freezing-and-thawing or to deicer salts is 4 to 6% air when maximum aggregate size is 3/4 in. (19.0 mm), and 4.5 to 7.5% when maximum aggregate size is 3/8 in. (9.5 mm).

2.4.3 The strength of lightweight concrete may be reduced by high air contents. At normal air contents (4 to 6%), the reduction is small if slumps are 5 in. (125 mm) or less and cement contents are used as recommended.

2.4.4 The volumetric method of measuring air, as described in ASTM C 173/C 173M, is the most reliable method of measuring air in either air-entrained concrete or non-air-entrained, structural lightweight concrete and is recommended.

CHAPTER 3—ESTIMATING FIRST TRIAL MIXTURE PROPORTIONS

3.1—General

The best approach to making a first trial mixture of lightweight concrete, which has given properties and uses a particular aggregate from a lightweight-aggregate source, is to use proportions previously established for a similar concrete using aggregate from the same aggregate source. Such proportions may be obtained from the aggregate supplier and may be the result of either laboratory mixtures or of actual mixtures supplied to jobs. These mixtures may then be adjusted as necessary to change the properties or proportions using the methods described in Chapter 4.

Chapter 3 provides a guide to proportioning a first trial mixture where such prior information is not available, following which, the adjustment procedures of Chapter 4 may be used. Trial mixtures can be proportioned by either:

1. *Method 1 (weight method, specific gravity pycnometer)*—Lightweight coarse aggregate and normalweight fine aggregate; or
2. *Method 2 (volumetric method)*—All lightweight and combinations of lightweight and normalweight aggregates.

Method 1 (the weight method) is described in detail in Section 3.2, and the volumetric method is described in Section 3.3.

3.2—Method 1: Weight method (specific gravity pycnometer)

For use with lightweight coarse aggregate and normalweight fine aggregate.

3.2.1 This procedure is applicable to sand-lightweight concrete comprised of lightweight coarse aggregate and normalweight fine aggregate. Estimating the required batch weights for the lightweight concrete involves determining the specific gravity factor of lightweight coarse aggregate, as discussed in Appendix A, from which the first estimate of the weight of fresh lightweight concrete can be made. Additionally, the absorption of lightweight coarse aggregate may be measured by the method described in ASTM C 127 or by the spin-dry procedure discussed in Appendix B, which permits the calculation of effective mixing water.

3.2.2 The proportioning follows the sequence of straightforward steps that, in effect, fit the characteristics of the available materials into a mixture suitable for the work. The question of suitability is frequently not left to the individual who selects the proportions. The job specifications may dictate some or all of the following:

1. Minimum cement or cementitious materials content;
2. Air content;
3. Slump;
4. Nominal maximum size of aggregate;
5. Strength;

Table 3.1—Recommended slumps for various types of construction

Types of construction	Slump, in. (mm)*	
	Maximum†	Minimum†
Beams and reinforced walls	4 (100)	1 (25)
Building columns	4 (100)	1 (25)
Floor slabs	3 (75)	1 (25)

*Slump may be increased when chemical admixtures are used, provided that the admixture-treated concrete has the same or lower *w/c* or *w/cm* and does not exhibit segregation potential or excessive bleeding.

†May be increased 1 in. for methods of consolidation other than vibration.

6. Unit weight;

7. Type of placement (such as pump, bucket, belt conveyor); and

8. Other requirements (such as strength overdesign, admixtures, and special types of cement and aggregate).

Regardless of whether the concrete characteristics are prescribed by the specifications or are left to the individual selecting the proportions, establishment of batch weights per unit volume of concrete can be best accomplished in the following sequence:

Step 1: *Choice of slump*—If slump is not specified, a value appropriate for the work can be selected from Table 3.1. The slump ranges shown apply when vibration is used to consolidate the concrete. Mixtures of the stiffest consistency that can be placed efficiently should be used.

Step 2: *Choice of nominal maximum size of lightweight aggregate*—The largest nominal maximum size of well-graded aggregates has fewer voids than smaller sizes. Hence, concrete with large-sized aggregates require less mortar per unit volume of concrete. Generally, the nominal maximum size of aggregate should be the largest that is economically available and consistent with the dimensions of the structure. In no event should the nominal maximum size exceed one-fifth of the narrowest dimension between sides of forms, one-third the depth of slabs, nor three-quarters of the minimum clear spacing between individual reinforcing bars, bundles of bars, or pretensioning strands. These limitations are sometimes waived by the engineer if workability and methods of consolidation are such that the concrete can be placed without honeycombing or voids. When high-strength concrete is desired, better results may be obtained with reduced nominal maximum sizes of aggregate because these can produce higher strengths at a given *w/c* or *w/cm.*

Step 3: *Estimation of mixing water and air content*—The quantity of water per unit volume of concrete required to produce a given slump is dependent on the nominal maximum size, particle shape and grading of the aggregates, amount of entrained air, and inclusion of chemical admixtures. It is not greatly affected by the quantity of cement or cementitious materials. Table 3.2 provides estimates of required mixing water for concrete made with various nominal maximum sizes of aggregate, with and without air entrainment. Depending on aggregate texture and shape, mixing water requirements may be somewhat above or below the tabulated values, but they are sufficiently accurate for the first estimate. Such differences in water demand are not necessarily reflected in strength because other compensating factors may be involved.

Table 3.2—Approximate mixing water and air content requirements for different slumps and nominal maximum sizes of aggregates*

Aggregate size	3/8 in. (9.5 mm)	1/2 in. (12. 7 mm)	3/4 in. (19.0 mm)
Air-entrained concrete			
	Water, lb/yd^3 (kg/m^3) of concrete		
Slump, 1 to 2 in. (25 to 50 mm)	305 (181)	295 (175)	280 (166)
Slump, 3 to 4 in. (75 to 100 mm)	340 (202)	325 (193)	305 (181)
Slump, 5 to 6 in. (125 to 150 mm)	355 (211)	335 (199)	315 (187)
	Recommended average† total air content, %, for level of exposure		
Mild exposure	4.5	4.0	4.0
Moderate exposure	6.0	5.5	5.0
Extreme exposure‡	7.5	7.0	6.0
Nonair-entrained concrete			
	Water, lb/yd^3 (kg/m^3) of concrete		
Slump, 1 to 2 in. (25 to 50 mm)	350 (208)	335 (199)	315 (187)
Slump, 3 to 4 in. (75 to 100 mm)	385 (228)	365 (217)	340 (202)
Slump, 5 to 6 in. (125 to 150 mm)	400 (237)	375 (222)	350 (208)
	Approximate amount of entrapped air in nonair-entrained concrete, %		
	3	2.5	2

*Quantities of mixing water given for air-entrained concrete are based on typical total contents requirements as shown for "moderate exposure" in the table above. These quantities of mixing water are for use in computing cement or cementitious materials content for trial batches at 68 to 77 °F (20 to 25 °C). They are maximum for reasonably well-shaped angular aggregates graded within limits of accepted specifications. The use of water-reducing chemical admixtures (ASTM C 494) may also reduce mixing water by 5% or more. The volume of the liquid admixtures is included as part of the total volume of the mixing water. The slump values of 7 to 11 in. (175 to 275 mm) are only obtained through the use of water-reducing chemical admixture; they are for concrete containing nominal maximum size aggregate not longer than 1 in. (25 mm).

†Additional recommendations for air content and necessary tolerances on air content for control in the field are given in a number of ACI documents, including ACI 201.2R, 345R, 318, 301, and 302.1R. ASTM C 94 for ready-mixed concrete also gives air content limits. The requirements in other documents may not always agree exactly, so in proportioning concrete, consideration should be given to selecting an air content that will meet the needs of the job and also meet the applicable specifications.

‡These values are based on the criteria that 9% air is needed in the mortar phase of the concrete. If the mortar volume will be substantially different from that determined in this recommended practice, it may be desirable to calculate the needed air content by taking 9% of the actual mortar value.

Table 3.2 indicates the approximate amount of entrapped air to be expected in non-air-entrained concrete, and shows the recommended levels of average air content for concrete in which air is to be purposely entrained for durability, workability, and reduced in weight.

When trial batches are used to establish strength relationships or verify strength-producing capability of a mixture, the least-favorable combination of mixing water and air content should be used. That is, the air content should be the maximum permitted or likely to occur, and the concrete should be gaged to the highest permissible slump. This will avoid developing an overly optimistic estimate of strength on the assumption that average rather than extreme conditions will prevail in the field. For additional information on air content recommendations, see ACI 201.2R, 213R, 302.1R, and 345R.

Step 4: *Selection of approximate* w/c—The required *w/c* or *w/cm* is determined not only by strength requirements but also by such factors as durability and finishing properties. Because different aggregates and cements generally produce

Table 3.3—Relationships between *w/c* and compressive strength of concrete*

Compressive strength at 28 days, psi (MPa)	Approximate water-cement ratio, by weight	
	Nonair-entrained concrete	Air-entrained concrete
6000 (41.4)	0.41	—
5000 (34.5)	0.48	0.40
4000 (27.6)	0.57	0.48
3000 (20.7)	0.68	0.59
2000 (13.8)	0.82	0.74

*Values are estimated average strengths for concrete containing not more than 2% air for non-air-entrained concrete and 6% total air content for air-entrained concrete. For a constant *w/c* or *w/cm*, the strength of concrete is reduced as the air content is increased. Twenty-eight-day strength values may be conservative and may change when various cementitious materials are used. The rate at which the 28-day strength is developed may also change.

Strength is based on 6 x 12 in. (150 x 300 mm) cylinders moist cured for 28 days in accordance with the sections on "Initial Curing" and "Curing of Cylinders for Checking the Adequacy of Laboratory Mixture Proportions for Strength or as the Basis for Acceptance or for Quality Control" of ASTM C 31 of *Making and Curing Concrete Specimens in the Field*. These are cylinders moist cured at 73.4 ± 3 °F (23 ± 2 °C) before testing.

The relationship in this table assumes a nominal maximum aggregate size of about 3/4 to 1 in. (19 to 25 mm) For a given source of aggregate, strength produced at a given *w/c* or *w/cm* will increase as nominal maximum size of aggregate decreases. See Section 2.3.

Table 3.4—Maximum permissible water-cement ratios for concrete in severe exposures*

Type of structure	Structure wet continuously or frequently; exposed to freezing and thawing†	Structure exposed to sea water or sulfates
Thin sections (railings, curbs, sills, ledges, ornamental work) and sections with less than 1 in. (25 mm) cover over steel	0.45	0.40‡
All other structures	0.50	0.45‡

*Based on ACI 201.2R.

†Concrete should also be air entrained.

‡If sulfate-resisting cement (Type II or Type V of ASTM C 150) is used, permissible *w/c* or *w/cm* may be increased by 0.05.

Table 3.5—Volume of coarse aggregate per unit of volume of concrete*

Maximum size of aggregate, in. (mm)	Volume of oven-dry loose coarse aggregates* per unit volume of concrete for different fineness moduli of sand			
	2.40	2.60	2.80	3.00
3/8 (9.5)	0.58	0.56	0.54	0.52
1/2 (12.7)	0.67	0.65	0.63	0.61
3/4 (19.0)	0.74	0.72	0.70	0.68

*Volumes are based on aggregates in oven-dry loose condition as described in ASTM C 29/C 29M for unit weight of aggregate. These volumes are selected from empirical relationships to produce concrete with a degree of workability suitable for usual reinforced construction. For more workable concrete, such as may sometimes be required when placement is to be by pumping, they may be reduced up to 10%.

different strengths at the same *w/c* or *w/cm*, it is highly desirable to have or develop the relationship between strength and *w/c* or *w/cm* for the materials actually to be used. In the absence of such data, approximate and relatively conservative values for concrete containing Type I portland cement can be taken from Table 3.3. With typical materials, the tabulated *w/c* or *w/cm* should produce the strengths shown, based on 28 day tests of specimens cured under standard laboratory conditions. The average strength selected must exceed the specified strength by a sufficient margin to keep the number of low tests within specified limits. For severe conditions of exposure, the *w/c* or *w/cm* should be kept low even though strength requirements may be met with a higher value. Table 3.4 gives limiting values.

Step 5: *Calculation of cement content*—The amount of cement per unit volume of concrete is determined in Steps 3 and 4. The required cement is equal to the estimated mixing water content (Step 3) divided by the *w/c* (Step 4). If, however, the specification includes a separate minimum limit on cement in addition to requirements for strength and durability, the mixture must be based on whichever criterion leads to the larger amount of cement. The use of other cementitious materials or chemical admixtures will affect properties of both the fresh and hardened concrete. The use of various combinations of cementitious material, use of chemical admixtures, or both, is beyond the scope of this document, but may be found in ACI 212.1R, 212.2R, 226.1R, and 226.3R.

Step 6: *Estimation of lightweight coarse aggregate content*—Aggregates of essentially the same nominal maximum size and grading will produce concrete of satisfactory workability when a given volume of coarse aggregate, on a dry, loose basis, is used per unit volume of concrete. Appropriate values for this aggregate volume are given in Table 3.5. For equal workability, the volume of coarse aggregate in a unit volume of concrete depends only on its nominal maximum size and fineness modulus of the normal-weight fine aggregate. Differences in the amount of mortar required for workability with different aggregates, due to differences in particle shape and grading, are compensated for automatically by differences in dry loose unit weight.

The volume of aggregate, in ft^3 (m^3), on an oven-dry loose basis, for a unit volume of concrete is equal to the value from Table 3.5 multiplied by 27 for a yd^3 (1 for a m^3). This volume is converted to dry weight of coarse aggregate required in a unit volume of concrete by multiplying it by the oven-dry loose weight per ft^3 (m^3)of the lightweight coarse aggregate.

Step 7: *Estimation of fine aggregate content*—At completion of Step 6, all ingredients of the concrete have been estimated except the fine aggregate. Its quantity is determined by difference.

If the weight of the concrete per unit volume is estimated from experience, the required weight of fine aggregate is the difference between the weight of fresh concrete and the total weight of the other ingredients.

Often the unit weight of concrete is known with reasonable accuracy from previous experience with the materials. In the absence of such information, Table 3.6 can be used to make a first estimate based on the specific gravity factor of the lightweight coarse aggregate and the air content of the concrete. Even if the estimate of concrete weight per yd^3 (m^3) is approximate, mixture proportions will be sufficiently accurate to permit easy adjustment on the basis of trial batches, as will be shown in the examples.

The aggregate quantities to be weighed out for the concrete must allow for moisture in the aggregates. Generally, the aggregates will be moist and their dry weights should be increased by the percentage of water they contain, both absorbed and surface. The mixing water added to the bath must be reduced by an amount equal to the free moisture contributed by the aggregate (such as total moisture minus absorption).

3.2.3 *Sample computations—Method 1: weight method (specific gravity pycnometer)*—A sample problem in inch-pound units (Example A—inch-pound units) will be used to illustrate application of the proportioning procedures. The following conditions are assumed:

3.2.3.1 Type I non-air-entrained cement will be used.

3.2.3.2 Lightweight coarse aggregate and normalweight fine aggregate are of satisfactory quality and are graded within limits of generally accepted specifications, such as ASTM C 330 and C 33.

3.2.3.3 The coarse aggregate has a specific gravity factor of 1.50 and an absorption of 11.0%.

3.2.3.4 The fine aggregate has an absorption of 1.0%, and a fineness modulus of 2.80.

Lightweight concrete is required for a floor slab of a multistory structure subjected to freezing and thawing during construction. Structural design considerations require a 28-day compressive strength of 3500 psi. On the basis of information in Table 3.1 and previous experience, under the conditions of placement to be used, a slump of 3 to 4 in. should be used and that the available 3/4 in.to No. 4 lightweight coarse aggregate will be suitable.

The oven-dry loose weight of coarse aggregate is found to be 47 lb/ft^3. Employing the sequence outlined in Section 3.2.2, the quantities of ingredients per yd^3 of concrete are calculated as follows:

Step 1—As indicated previously, the desired slump is 3 to 4 in.

Step 2—The locally available lightweight aggregate, graded from 3/4 in. to No. 4, has been indicated as suitable.

Step 3—Because the structure will be exposed to severe weathering during construction, air-entrained concrete will be used. The approximate amount of mixing water to produce a 3 to 4 in. slump in air-entrained concrete with 3/4 in. nominal maximum-size aggregate is found from Table 3.2 to be 305 lb/yd^3. Estimated total air content is shown as 6.0%.

Step 4—From Table 3.3, the *w/c* needed to produce a strength of 3500 psi in air-entrained concrete is found to be approximately 0.54. In consideration of the severe exposure during construction, the maximum permissible *w/c* or *w/cm* from Table 3.4 is 0.50.

Step 5—From the information derived in Steps 3 and 4, the required cement content is found to be 305/0.50 = 610 lb/yd^3.

Step 6—The quantity of lightweight coarse aggregate is estimated from Table 3.5. For a fine aggregate having fineness modulus of 2.80 and 3/4 in. nominal maximum size of coarse aggregate, the table indicates that 0.70 yd^3 of coarse aggregate, on a dry-loose basis, may be used in each yd^3 of concrete. Therefore, for a unit volume, the coarse aggregate will be 1 × 0.70 = 0.70 yd^3. Because it weighs 47 lb/ft^3, the dry weight of coarse aggregate is 0.70 × 47 × 27 = 888 lb. Because the coarse aggregate has an absorption of 11.0%, the saturated weight is 1.11 × 888 = 986 lb.

Table 3.6—First estimate of weight of fresh lightweight concrete comprised of lightweight coarse aggregate and normalweight fine aggregate

Specific gravity factor	First estimate of lightweight concrete weight, lb/yd^3(kg/m^3)*		
	Air-entrained concrete		
	4%	6%	8%
1.00	2690 (1596)	2630 (1561)	2560 (1519)
1.20	2830 (1680)	2770 (1644)	2710 (1608)
1.40	2980 (1769)	2910 (1727)	2850 (1691)
1.60	3120 (1852)	3050 (1810)	2990 (1775)
1.80	3260 (1935)	3200 (1899)	3130 (1858)
2.00	3410 (2024)	3340 (1982)	3270 (1941)

*Values for concrete of medium richness (550 lb of cement per yd^3 [326 kg/m^3]) and medium slump with water requirements based on values for 3 to 4 in. (75 to 100 mm) slump in Table 3.2. If desired, the estimated weight may be refined as follows, if necessary information is available: for each 10 lb (5.9 kg) difference in mixing water from Table 3.2, correct the weight per yd^3 15 lb in the opposite direction (8.9 kg per m^3); for each 100 lb (59.3 kg^3) difference in cement content from 550 lb (326 kg), correct the weight per yd^3 15 lb in the same direction (8.9 kg per m^3).

Step 7—With the quantities of water, cement, and coarse aggregate established, the remaining material comprising the yd^3 of concrete must consist of sand and the total air used. The required sand is determined on the weight basis by difference. From Table 3.6, the weight of a yd^3 of air-entrained concrete made with lightweight aggregate having a specific gravity factor of 1.50 is estimated to be 2980 lb. (For a first trial batch, exact adjustments of this value for usual differences in slump, cement factor, and aggregate specific-gravity factor are not critical.) Weights already known are

	Per yd^3
Water (net mixing)	305 lb
Cement	610 lb
Coarse aggregate	986 lb (saturated)
Total	1901 lb

The saturated surface dry (SSD) weight of sand, therefore, is estimated to be 2980 – 1901 = 1079 lb. Oven-dry weight of sand is 1079/1.01 = 1068 lb.

Step 8—For the laboratory trial batch, it is convenient to scale the weights down to produce at least 1.0 ft^3 of concrete. The batch weights for a 1.0 ft^3 batch are calculated as follows

Cement	610/27 =	22.59 lb
Fine aggregate (SSD)	1079/27 =	39.96 lb
Coarse aggregate (SSD)	986/27 =	36.52 lb
Water (net mixing)	305/27 =	11.30 lb
Total		110.37 lb

Tests indicate total moisture content of 15.0% for the lightweight coarse aggregate and 6.0% for the fine aggregate. Absorbed water does not become part of the mixing water and must be excluded from the adjustment of added water. Thus, surface water contributed by the lightweight coarse aggregate amounts to 15.0 – 11.0 = 4.0% and by the fine aggregate 6.0 – 1.0 = 5.0%. The adjustments to the aggregates for this free moisture are calculated as follows

Fine aggregate (39.96/1.01) × 1.06 = 41.94 lb
Coarse aggregate (36.52/1.11) × 1.15 = 37.84 lb

The adjustment of the added water to account for the moisture added with the aggregates is as follows

Water from fine aggregate = 41.96 – 39.96 = 1.98 lb
Water from coarse aggregate = 37.84 – 36.52 = 1.32 lb

Therefore, water to be added to the batch is

$$11.30 - 1.98 - 1.32 = 8.00 \text{ lb}$$

The weights to be used for the 1.0 ft^3 trial batch are

Cement	22.59 lb
Fine aggregate (wet)	41.94 lb
Coarse aggregate (wet)	37.84 lb
Water (added)	8.00 lb
Total	110.37 lb

Step 9—Although the calculated quantity of water to be added was 8.00 lb, the amount actually used in an attempt to obtain the desired 3 to 4 in. slump was 8.64 lb. The as-mixed batch, therefore, consists of

Cement	22.59 lb
Fine aggregate (wet)	41.94 lb
Coarse aggregate (wet)	37.84 lb
Water (added)	8.64 lb
Total	111.01 lb

The concrete mixture is judged to be satisfactory as to workability and finishing properties; however, the concrete had a measured slump of only 2 in. and a unit weight of 108.0 lb/yd^3. To provide the proper yield for future trial batches, the following adjustments are made.

Because the yield of the trial batch was 111.01/108.0 = 1.028 ft^3 and the mixing water actually used was 8.64 (added) + 1.98 (from fine aggregate) + 1.32 (from coarse aggregate) = 11.94 lb, the mixing water required for 1 yd^3 of concrete with the same 2 in. slump as the trial batch should be approximately

$$(11.94/1.028) \times 27 = 314 \text{ lb}$$

As indicated in Section 4.4.2.3, this amount must be increased by about 15 lb/yd^3 to raise the slump from the measured 2 in. to the desired 3 to 4 in. range, bringing the net mixing water to 329 lb. With the increased mixing water, additional cement will be required to maintain the desired *w/c* of 0.50. The new cement content per yd^3 becomes

$$329/0.50 = 658 \text{ lb}$$

Because workability was found to be satisfactory, the quantity of lightweight coarse aggregate per unit volume of concrete will be maintained the same as in the trial batch. The amount of coarse aggregate per yd^3 becomes

$$(37.84/1.028) \times 27 = 994 \text{ lb (wet)}$$

which is

$$994/1.15 = 864 \text{ lb (dry)}$$

or

$$864 \times 1.11 = 959 \text{ lb (SSD)}$$

The new estimate for the weight (Fig. 4.1) of a unit volume of concrete is 108.0 × 27 = 2916 lb/yd^3. Therefore, the amount of fine aggregate per yd^3 required is

$$2916 - (329 + 658 + 959) = 970 \text{ lb (SSD)}$$

or

$$970/1.01 = 960 \text{ lb (dry)}$$

The adjusted batch weights per yd^3 are

Cement	658 lb
Fine aggregate (dry)	960 lb
Coarse aggregate (dry)	864 lb
Water (total*)	434 lb
Total	2916 lb

or on a SSD condition

Cement	658 lb
Fine aggregate (SSD)	970 lb
Coarse aggregate (SSD)	959 lb
Water (net mixing)	329 lb
Total	2916 lb

A verification laboratory trial batch of concrete using the adjusted weights should be made to determine if the desired properties have been achieved.

3.2.6 *Sample computations—Method 1: weight method (specific gravity pycnometer)*—A second sample problem in inch-pound units. (Example B—inch-pound units) will be used to illustrate application of the proportioning procedures where several of the specific mixture requirements are specified. Examples B and D (volumetric method—damp, loose volume method, Section 3.3.4) are similar for direct comparison of both methods.

Requirements

- 3500 psi specified compressive strength at 28 days;
- 1200 psi required over-design (per ACI 318, Section 5.3.2.2, no prior history);
- Required average strength of concrete f'_{cr} : 4700 psi;
- Lightweight aggregate: ASTM C 330, 3/4 in. to No. 4;
- Concrete sand: ASTM C 33, No. 4 to 0;

- Air-entraining admixture (AEA) for 6 ± 1%: ASTM C 260;
- Water-reducing admixture (WRA) use permitted: ASTM C 494, Type A or D; and
- Slump: 4 ± 1 in.; conventional placement.

Background information

From the lightweight-aggregate manufacturer:

- Specific gravity factor—1.48 at a 15% moisture content (ACI 211.2, Appendix A); and
- Suggested coarse aggregate factor (CAF) is 870 lb/yd^3 at a 15% moisture content (“as-is” condition).

From the sand supplier:

- Specific gravity = 2.60, fineness modulus = 2.80.

From the cement supplier:

- Specific gravity = 3.14;

General information

- Moisture content at time of use = 15%; and
- Unit weight of water = 62.4 lb/ft^3.

Proportioning design

Step 1: Establish *w/c* required for 4700 psi air-entrained concrete = 0.42 (Table 3.4, interpolated value).

Step 2: Establish water required per yd^3 (SSD basis), 3 to 4 in. slump, air-entrained, 3/4 in. aggregate = 305 lb less 11% for WRA = 271 lb (Table 3.2).

Step 3: Calculate cement content = 271 lb/0.42 = 645 lb.

Step 4: Calculate air content = 27.00 ft^3/yd^3 × 0.06 = 1.62 ft^3.

Step 5: Calculate lightweight aggregate absolute volume 870 lb/1.48 × 62.4 lb/ft^3 = 9.42 ft^3.

Step 6: Calculate absolute volume of sand by totaling absolute volumes of all other materials and subtracting from 27 ft^3.

<u>Item A</u>: Cement absolute volume = 645/3.14 × 6.24 = 3.29 ft^3

<u>Item B</u>: Water absolute volume = 271 lb/1 × 62.4 = 4.34 ft^3

<u>Item C</u>: Air volume (from Step 4) = 1.62 ft^3

<u>Item D</u>: Lightweight aggregate absolute volume (from Step 5) = <u>9.42 ft^3</u>

Total of absolute volumes + volume of air 18.67 ft^3

<u>Item E</u>: Sand absolute volume = 27.00 – 18.67 = 8.33 ft^3

Sand weight = 8.33 × 2.60 × 62.4 = 1351 lb

Step 7: Calculate theoretical plastic unit weight by adding all batch weights and dividing by 27.

Weights: 1 yd^3

Cement	645 lb
LWA (as is)	870 lb
Sand (dry)	1351 lb
Water (total)	<u>271 lb</u>
Total	**3137 lb/yd^3**
	or 116.2 lb/ft^3 plastic

Mixtures must be monitored and adjusted in the field to maintain yield.

3.25 *Sample computations—Method 1: weight method (specific gravity pycnometer)*—A sample problem in SI units (Example A—SI units) will be used to illustrate application of the proportioning procedures. The following conditions are assumed:

3.2.5.1 Type I non-air-entrained cement will be used.

3.2.5.2 Lightweight coarse aggregate and normalweight fine aggregate are of satisfactory quality and are graded within limits of generally accepted specifications, such as ASTM C 330 and C 33.

3.2.5.3 The coarse aggregate has a specific gravity factor of 1.50 and an absorption of 11.0%.

3.2.5.4 The fine aggregate has an absorption of 1.0%, and a fineness modulus of 2.80.

Lightweight concrete is required for a floor slab of a multistory structure subjected to freezing and thawing during construction. Structural design considerations require a 28-day compressive strength of 24 MPa. On the basis of information in Table 3.1 and previous experience, under the conditions of placement to be used, a slump of 75 to 100 mm should be used, and the available 19 to 5 mm lightweight coarse aggregate will be suitable.

The oven-dry loose weight of coarse aggregate is found to be 47 lb/ft^3. Employing the sequence outlined in Section 3.2.2, the quantities of ingredients per yd^3 of concrete are calculated as follows:

Step 1—As indicated previously, the desired slump is 75 to 100 mm.

Step 2—The locally available lightweight aggregate, graded from 19 to 5 mm, has been indicated as suitable.

Step 3—Because the structure will be exposed to severe weathering during construction, air-entrained concrete will be used. The approximate amount of mixing water to produce a 75 to 100 mm slump in air-entrained concrete with 19 mm nominal maximum-size aggregate is found from Table 3.2 to be 181 kg/m^3. Estimated total air content is shown as 6.0%.

Step 4—From Table 3.3, the *w/c* needed to produce a strength of 24 MPa in air-entrained concrete is found to be approximately 0.54. In consideration of the severe exposure during construction, the maximum permissible *w/c* or *w/cm* from Table 3.4 is 0.50.

Step 5—From the information derived in Steps 3 and 4, the required cement content is found to be 181/0.50 = 362 kg/m^3.

Step 6—The quantity of lightweight coarse aggregate is estimated from Table 3.5. For a fine aggregate having fineness modulus of 2.80 and 19 mm nominal maximum size of coarse aggregate, the table indicates that 0.70 m^3 of coarse aggregate, on a dry-loose basis, may be used in each m^3 of concrete. Therefore, for a unit volume, the coarse aggregate will be 1 × 0.70 = 0.70 m^3. Because it weighs 753 kg/m^3, the dry weight of coarse aggregate is 0.70 × 753 = 527 kg. Because the coarse aggregate has an absorption of 11.0%, the saturated weight is 1.11 × 527 = 585 lb.

Step 7—With the quantities of water, cement, and coarse aggregate established, the remaining material comprising the m^3 of concrete must consist of sand and the total air used. The required sand is determined on the weight basis by difference. From Table 3.6, the weight of a m^3 of air-entrained concrete made with lightweight aggregate having a specific gravity factor of 1.50 is estimated to be 1768 kg. (For a first trial batch, exact adjustments of this value for usual differences in slump, cement factor, and aggregate specific-gravity factor are not critical.) Weights already known are

	Per m^3
Water (net mixing)	181 kg
Cement	362 kg
Coarse aggregate	585 kg (saturated)
Total	1128 kg

Therefore, the saturated surface dry (SSD) weight of sand is estimated to be 1768 – 1128 = 640 kg. Oven-dry weight of sand is 640/1.01 = 634 kg.

Step 8—For the laboratory trial batch, it is convenient to scale the weights down to produce at least 0.028 m^3 of concrete. The batch weights for a 0.028 m^3 batch are calculated as follows

Cement	362 × 0.028 =	10.14 kg
Fine aggregate (SSD)	640 × 0.028 =	17.92 kg
Coarse aggregate (SSD)	585 × 0.028 =	16.38 kg
Water (net mixing)	181 × 0.028 =	5.07 kg
Total		49.51 kg

Tests indicate total moisture content of 15.0% for the lightweight coarse aggregate and 6.0% for the fine aggregate. Absorbed water does not become part of the mixing water and must be excluded from the adjustment of added water. Thus, surface water contributed by the lightweight coarse aggregate amounts to 15.0 – 11.0 = 4.0% and by the fine aggregate 6.0 – 1.0 = 5.0%. The adjustments to the aggregates for this free moisture are calculated as follows

Fine aggregate (17.92/1.01) × 1.06 = 18.81 kg
Coarse aggregate (16.38/1.11) × 1.15 = 16.97 lb

The adjustment of the added water to account for the moisture added with the aggregates is as follows

Water from fine aggregate = 18.81 – 17.92 = 0.89 kg
Water from coarse aggregate = 16.97 – 16.38 = 0.59 kg

Therefore, water to be added to the batch is

$$5.07 - (0.89 + 0.59) = 3.59 \text{ kg}$$

The weights to be used for the 0.028 m^3 trial batch are

Cement	10.14 kg
Fine aggregate (wet)	18.81 kg
Coarse aggregate (wet)	16.97 kg
Water (added)	3.59 kg
Total	49.51 kg

Step 9—Although the calculated quantity of water to be added was 3.59 kg, the amount actually used in an attempt to obtain the desired 50 mm slump was 3.88 kg. Therefore, the as-mixed batch consists of:

Cement	10.14 kg
Fine aggregate (wet)	18.81 kg
Coarse aggregate (wet)	16.97 kg
Water (added)	3.88 kg
Total	49.80 kg

The concrete mixture is judged to be satisfactory as to workability and finishing properties; however, the concrete had a measured slump of only 50 mm and a unit weight of 1730 kg/m^3. To provide the proper yield for future trial batches, the following adjustments are made.

Because the yield of the trial batch was 49.80/1730 = 0.0288 m^3 and the mixing water actually used was 3.88 (added) + 0.89 (from fine aggregate) + 0.59 (from coarse aggregate) = 5.36 kg, the mixing water required for 1 m^3 of concrete with the same 50 mm slump as the trial batch should be approximately

$$(5.36/0.0288) = 186 \text{ kg}$$

As indicated in Section 4.4.2.3, this amount must be increased by about 9 kg/m^3 to raise the slump from the measured 50 mm to the desired 75 to 100 mm range, bringing the net mixing water to 195 kg. With the increased mixing water, additional cement will be required to maintain the desired *w/c* of 0.50. The new cement content per m^3 becomes

$$195/0.50 = 390 \text{ kg/m}^3$$

Because workability was found to be satisfactory, the quantity of lightweight coarse aggregate per unit volume of concrete will be maintained the same as in the trial batch. The amount of coarse aggregate per m^3 becomes

$$(16.97/0.0288) = 589 \text{ kg (wet)}$$

which is

$$589/1.15 = 512 \text{ kg (dry)}$$

or

$$512 \times 1.11 = 569 \text{ kg (SSD)}$$

The new estimate for the weight (Fig. 4.1) of a unit volume of concrete is 1730 kg/m^3. Therefore, the amount of fine aggregate per yd^3 required is

$$1730 - (195 + 390 + 569) = 576 \text{ kg (SSD)}$$

or

$$576/1.01 = 570 \text{ kg (dry)}$$

The adjusted batch weights per m^3 are

Cement	390 kg
Fine aggregate (dry)	570 kg
Coarse aggregate (dry)	512 kg
Water (total*)	258 kg
Total	1730 kg

or on a SSD condition

Cement	390 kg
Fine aggregate (SSD)	576 kg
Coarse aggregate (SSD)	568 kg
Water (net mixing)	196 kg
Total	1730 kg

A verification laboratory trial batch of concrete using the adjusted weights should be made to determine if the desired properties have been achieved.

3.2.6 *Sample computations—Method 1: weight method (specific gravity pycnometer)*—A second sample problem in SI units. (Example B-SI units) will be used to illustrate application of the proportioning procedures where several of the specific mixture requirements are specified. Examples B and D (volumetric method—damp, loose volume method, Section 3.3.4) are similar for direct comparison of both methods.

Requirements

- 24 MPa specified compressive strength at 28 days;
- 8 MPa required over-design (per ACI 318, Section 5.3.2.2, no prior history);
- Required average strength of concrete f'_{cr} : 32 MPa;
- Lightweight aggregate: ASTM C 330, 19 to 5 mm;
- Concrete sand: ASTM C 33, 5 to 0 mm;
- Air-entraining admixture (AEA) for 6 ± 1%: ASTM C 260;
- Water-reducing admixture (WRA) use permitted: ASTM C 494, Type A or D; and
- Slump: 100 ± 25 mm.; conventional placement.

Background information

From the lightweight-aggregate manufacturer:

- Specific gravity factor—1.48 at a 15% moisture content (ACI 211.2, Appendix A); and
- Suggested coarse aggregate factor (CAF) is 516 kg/m^3 at a 15% moisture content (“as-is” condition).

From the sand supplier:

- Specific gravity = 2.60, fineness modulus = 2.80.

From the cement supplier:

- Specific gravity = 3.14.

General information:

- Moisture content at time of use = 15%; and
- Unit weight of water = 1000 kg/m^3.

Proportioning design

Step 1: Establish *w/c* required for 32 MPa air-entrained concrete = 0.42 (Table 3.4, interpolated value).

Step 2: Establish water required per yd^3 (SSD basis), 75 to 100 mm slump, air-entrained, 19 mm aggregate = 181 kg less 11% for WRA = 161 kg (Table 3.2).

Step 3: Calculate cement content = 161 kg/0.42 = 383 kg.

Step 4: Calculate air content = 0.06 m^3.

Step 5: Calculate lightweight aggregate absolute volume 516/(1.48 × 1000) = 03.49 m^3.

Step 6: Calculate absolute volume of sand by totaling absolute volumes of all other materials and subtracting from 1 m^3.

Item A: Cement absolute volume = 383/(3.14 × 1000) = 0.122 m^3

Item B: Water absolute volume = 161/(1.00 × 1000) = 0.161 m^3

Item C: Air volume (from Step 4) = 0.060 m^3

Item D: Lightweight aggregate absolute volume (from Step 5) = 0.349 m^3

Total of absolute volumes + volume of air = 0.692 m^3

Item E: Sand absolute volume = 1.000 – 0.692 = 0.308 m^3

Sand weight = 0.308 × 2.60 × 1000 = 800 kg

Step 7: Calculate theoretical plastic unit weight by adding all batch weights.

Weights: 1 m^3

Cement	383 kg
LWA (as is)	516 kg
Sand (dry)	800 kg
Water (total)	161 kg
Total	**1860 kg/m^3**

Mixtures must be monitored and adjusted in the field to maintain yield.

3.3—Method 2: Volumetric method (damp, loose volume)

For use with all lightweight aggregate or a combination of lightweight and normalweight aggregates.

3.3.1 Some lightweight aggregate producers recommend trial mixture proportions based on damp, loose volumes converted to batch weights. This procedure is applicable to all lightweight or to sand lightweight concrete comprised of various combinations of lightweight aggregate and normal-weight aggregate. The total volume of aggregates required, measured as the sum of the uncombined volumes on a damp, loose basis, will usually be from 28 to 34 ft^3/yd^3 (1.04 to 1.26 m^3/m^3). Of this amount, the loose volume of the fine aggregate may be from 40 to 60% of the total loose volume. Both the total loose volume of aggregate required and the proportions of fine and coarse aggregates are dependent on several variables; these variables relate to both the nature of the aggregates and to the properties of the concrete to be produced. Estimating the required batch weights for the lightweight concrete involves estimating cement content to produce a required compressive strength level. The aggregate producer should be consulted to obtain a closer approximation of cement content and aggregate propor-

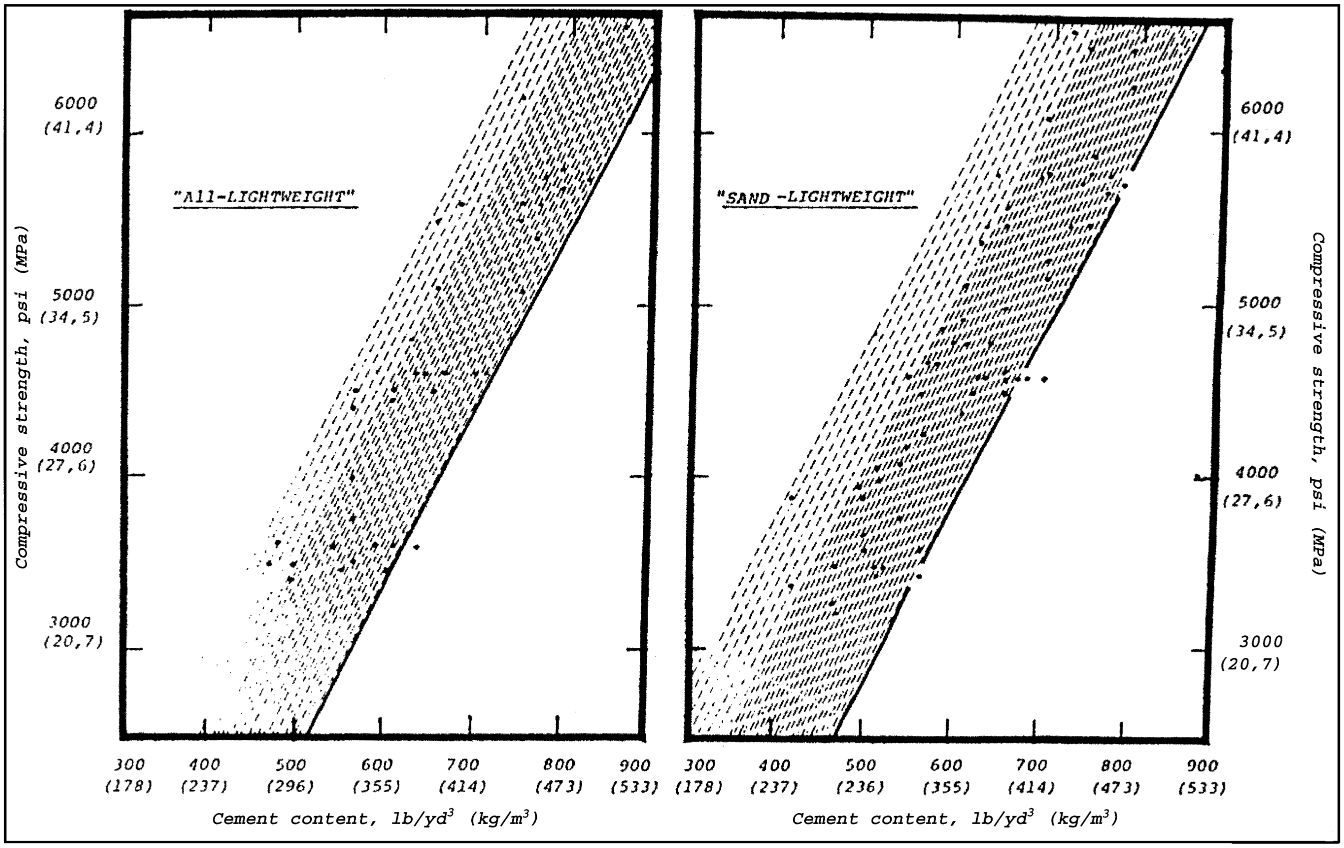

Fig. 3.1—Relationship of compressive strength and cement content of field concrete for lightweight fine aggregate and coarse aggregate, or lightweight coarse aggregate and normalweight fine aggregate (data points represent actual project strength results using a number of cement and aggregate sources).

tions required to achieve desired strength and unit weight with the specific aggregate. When this information is not available, the only alternative is to make a sufficient number of trial mixtures with varying cement contents to achieve a range of compressive strengths, including the compressive strength desired.

3.3.2 *Estimation of cement content*—The cement content-strength relationship is similar for a given source of lightweight aggregate but varies widely between sources. Therefore, the aggregate producer should be consulted for a close approximation of cement content necessary to achieve the desired strength. When this information is not available, the cement content can be estimated from the data in Fig. 3.1

3.3.3 *Sample computations*—A sample problem (Example C) will be used to illustrate application of the proportioning procedure. Assume that a sand lightweight concrete with 4000 psi (27.6 MPa) compressive strength weighing no more than 105 lb/ft^3 (1682 kg/m^3), air dry (as in ASTM C 567), is required and will be placed by bucket at a 4 in. (100 mm) slump. The damp, loose unit weights for the coarse and fine lightweight aggregates have been determined as 47 and 55 lb/ft^3 (753 and 881 kg/m^3). The normalweight fine aggregate has been determined to weigh 100 or 102 lb/ft^3 (1602 or 1634 kg/m^3) in a SSD condition with 2% absorption.

Bulking caused by moisture on the aggregate surface, while of little significance with coarse aggregate, must be taken into account with fine aggregate when using the damp, loose volume method. This is accomplished by increasing the volume of lightweight fine aggregate, usually in the range of 2 to 3%, depending on the typical condition of the aggregate as shipped. Normalweight fine aggregates can vary appreciably from different sources in the same general area and are best handled on the basis of dry, loose volumes plus moisture. The local lightweight-aggregate producer has been consulted and has recommended 580 lb (344 kg) of cement per yd^3 (m^3)with 17 ft^3 (0.63 m^3) if coarse lightweight aggregate, 5 ft^3 (0.18 m^3) of lightweight fine aggregate, and 9-1/2 ft^3 (0.35 m^3) if normalweight fine aggregates per yd^3 (m^3). A trial batch of 1 ft^3 (0.028 m^3) will be made. The tabulated computations are as follows

	First trial batch weights, damp, loose, lb	Adjusted weights, yd^3 damp, loose, lb
Cement	$\frac{580}{27} = 21.5$	$\frac{27}{1.011} \times 21.5 = 574$
Coarse lightweight aggregate	$\frac{17 \times 47}{27} = 29.6$	$\frac{27}{1.011} \times 29.6 = 791$
Fine lightweight aggregate	$\frac{5 \times 55}{27} = 10.2$	$\frac{27}{1.011} \times 10.2 = 272$
Fine normalweight aggregate	$\frac{9.5 \times 102}{27} = 35.9$	$\frac{27}{1.011} \times 35.9 = 959$

Added water (4-in. slump)	11.2	$\frac{27}{1.011} \times 11.2 = 299$
Total weight	108.4	2895

Fresh unit weight, ASTM C 138 = 107.2 lb/ft^3

Yield: 108.4 lb/ft^3/107.2 lb/ft^3 = 1.011 lb/ft^3

Air content, ASTM C 173 = 6.3%

A trial batch of 0.028 m^3 will next be made using metric units. The tabulated computations are as follows

	First trial batch weights, damp, loose, kg	Adjusted weights, m^3 damp, loose, kg
Cement	344 × 0.028 = 9.63	$\frac{9.63}{0.0282} = 341$
Coarse lightweight aggregate	0.028 × 0.63 × 753 = 13.28	$\frac{13.28}{0.0282} = 471$
Fine lightweight aggregate	0.028 × 0.18 × 881 = 4.44	$\frac{4.44}{0.0282} = 157$
Fine normalweight aggregate	0.028 × 0.35 × 1634 = 16.01	$\frac{16.01}{0.0282} = 568$
Added water (100 mm slump)	5.08	$\frac{5.08}{0.0282} = 180$
Total weight	48.44	1717

Fresh unit weight, ASTM C 138 = 1717 kg/m^3

Yield: 48.44 kg/107.2 kg/m^3 = 0.0282 kg/m^3

Air content, ASTM C 173 = 6.3%

3.3.4 *Sample computations*—A second sample problem (Example D) will be used to illustrate application of the proportioning procedure where several of the specific mixture requirements are specified. Also the derivation of the volumetric, damp loose method is discussed and utilized in preparing a laboratory trial mixture and the method's subsequent use in field moisture adjustment. Examples B (weight method—specific gravity pycnometer, Section 3.2.4) and D are similar for direct comparison of both methods.

Because of the variations in the amount and rate of absorption of most lightweight aggregates, the true *w/c* cannot always be determined accurately enough to be of practical value. It is usually more practical to establish proportions by a series of trial mixtures proportioned on a cement content basis (water held constant for the desired slump) for the required degree of workability. Specimens from each acceptable trial mixture are tested at the specified ages to establish the cement content strength relationship in the series. From this information the cement content for the desired strength can be selected. (Acceptable trial mixtures are those with the

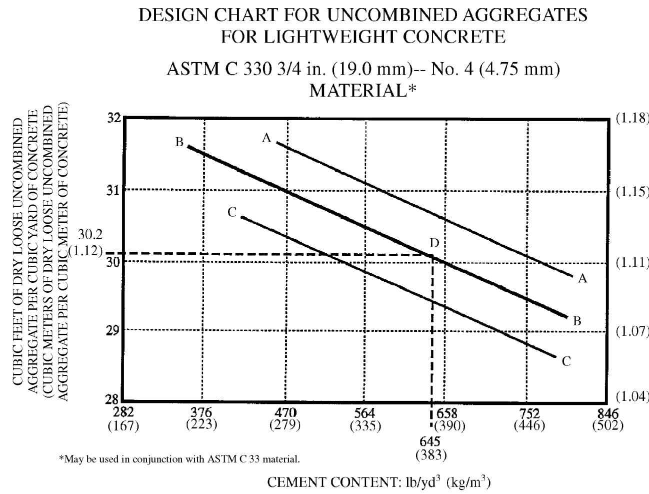

Fig. 3.2—Design chart for uncombined aggregates for lightweight concrete.

properties of workability, yield, slump, strength, and air content similar to those desired in the target mixture.)

The usual approach to estimating concrete trial mixtures is to use proportions from previously established mixtures having the same materials sources and other similar properties. Producers supplying lightweight aggregate for structural lightweight concrete can usually supply data on mixture proportions for various applications. Their information is usually quite useful as a starting point in estimating trial mixtures for specific materials. Trial mixtures should be prepared in the absence of previously established data, with the same materials as will be used on the project. Trial mixtures should be made with at least three different cement contents and should have the desired degree of workability and adequate entrained air to ensure the durability and workability of the concrete for the intended application.

One procedure for estimating concrete trial mixture proportions in the absence of satisfactory historical data is to use, develop, or obtain from a lightweight aggregate producer a graph like Fig. 3.2.

This graph was developed by batching several mixtures of varying cement contents, similar air contents, (4 to 6%), and a constant slump of 5 ± 1 in. (125 ± 25 mm), then plotting the volumes of dry loose uncombined materials (3/4 in. to No. 4 [19 to 5 mm] lightweight aggregate and No. 4 to 0 [5 to 0 mm] natural concrete sand) for those mixtures having good workability and proper yield. This method is similar to the one used to develop the original coarse aggregate factor values used in conjunction with the fineness modulus to estimate normalweight concrete mixtures.

The graph was also developed to minimize or eliminate the need for "extra" trial mixtures to establish approximate proportions of materials needed to determine: proper yield, workability, combining losses, and strength. This enables the technologist to proceed directly with three trial mixtures, or perhaps one mixture, for verification of specific materials for specific mixture design criteria. After trial mixture proportions selected with this method are tested, it will become

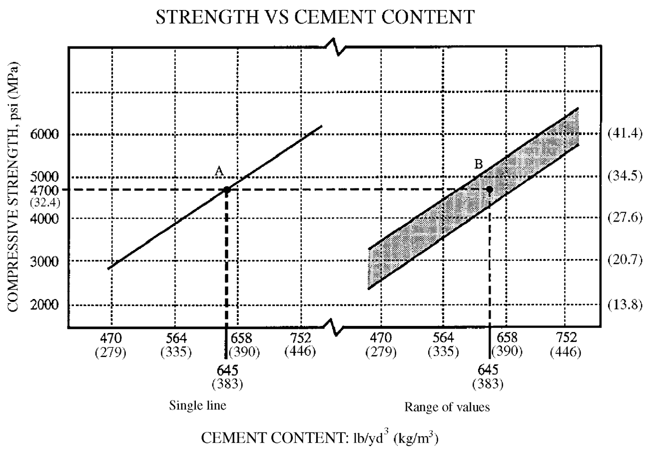

Fig. 3.3—Strength versus cement content.

apparent that the line B-B in Fig. 3.2 can move in the direction of either line A-A or line C-C at the same slope. The movement of the line B-B in either direction is caused by changes in the aggregate grading, changing from one aggregate size to another, adjustments for texture or workability, or for pump or conventional placement, (that is, if a change was made to go from ASTM C 330 3/4 in. to No. 4 [19 to 5 mm] to 3/8 in. to No. 8 [9.5 to 2.38 mm], the Line B-B would shift downward toward Line C-C due to a reduction in voids, causing a reduction in combining loss). The slope of Line B-B (and therefore Lines A-A and C-C) relates the volume of aggregate to the volume of cement. For example, decreasing the cement content from 658 to 564 lb/yd^3 (390 to 355 kg/m^3) on Fig. 3.2, Line B-B, increases the design volume from 30 to 30.5 ft^3/yd^3 (1.11 to 1.13 m^3/m^3).

An additional advantage of this development procedure is that when the test specimens from the trial mixtures are tested, a strength-versus-cement content curve (or range) for historical information can be plotted similar to Fig. 3.3.

Sample calculations (inch-pounds)

From the lightweight aggregate manufacturer:

- Oven-dry loose unit weight is 43 lb/ft^3, and the total water will be about 420 lb/yd^3.
- Forty-eight-hour laboratory soaked absorption is approximately 23%.
- Suggested coarse aggregate factor is 16.7 ft^3/yd^3.

From the sand supplier:

- Sand dry loose unit weight is approximately 100 lb/ft^3.

Step One: Estimate 1 yd^3 trial batch weights on an oven-dry basis.

- 645 lb cement from Fig. 3.3 (Point A)
- 718 lb 3/4-in. lightweight aggregate from background information: (16.7 ft^3/yd^3)(43 lb/ft^3) = 718 lb/yd^3
- 1350 lb concrete sand from Fig. 3.2: 30.2 ft^3/yd^3 – 16.7 ft^3/yd^3 = 13.50 ft^3/yd^3 and (13.50 ft^3) (100 lb/ft^3) = 1350 lb/yd^3
- 420 lb water from background information; can also be estimated from water Table 3.2 and adding the amount of water equal to the 48 h laboratory-soaked absorption.

3133 lb/yd^3(plastic) or 116.0 lb/ft^3 plastic

Step Two: Approximate air-dry weight.

(This is the plastic weight minus the oven-dry hydrated weight and corrected for the retained moisture.)

(645 lb cement) + [(0.20 water of hydration per ASTM C 567-91, Section 9.4) (645 lb cement)] is equal to the hydrated cement weight = 774 lb

plus the oven-dry lightweight aggregate weight = 718 lb
plus the oven-dry natural concrete sand weight = <u>1350 lb</u>
equals the oven-dry weight 2842 lb/yd^3
or 105.3 lb/ft^3

The plastic unit weight minus the oven-dry hydrated weight is 116.0 lb/ft^3 – 105.3 lb/ft^3 = 10.7 lb/ft^3 and (10.7 lb/ft^3) (75% retained moisture factor per ASTM C 567-91, Section 9.7) = 8.0 lb/ft^3 and (8.0 lb/ft^3 retained moisture) + (105.3 lb/ft^3 oven-dry) = 113.3 lb/ft^3, which is the approximate air-dry weight.

Step Three: Convert oven-dry proportions to "as-is" proportions. Assume that the oven-dry concrete mixture design used previously is to be implemented in the field for a ready-mix concrete project and placed via truck chute. To minimize slump loss caused by absorption, the lightweight aggregate has been *sprinkled* for the past 48 h and the sprinkler has been turned off about 1 h before batch time to allow the aggregate's excess surface water to drain and the stockpile's overall moisture condition to stabilize.

The field technician's first activity is to obtain at least three representative loose unit weights of the wet or "as-is" (sprinkled or soaked) aggregate. The numerical values for the weights should have a narrow range (see ASTM C 330). A wide range could indicate variations in aggregate grading, moisture content, or careless loose unit weight measurement.

Loose unit field weights are

$$\frac{51\ \text{lb/ft}^3 + 52\ \text{lb/ft}^3 + 53\ \text{lb/ft}^3}{3} = 52\ \text{lb/ft}^3\ \text{“as-is” loose}$$

Multiply the "as-is" loose unit weight by the design coarse aggregate factor: (52 lb/ft^3) (16.7 ft^3/yd^3) = 868 lb/ft^3

From this information the field batch water, or added water, can be estimated

868 lb/yd^3 LWA ("as-is" loose)
– <u>718 lb/yd^3</u> <u>LWA</u> (dry loose)
150 lb/yd^3 Water <u>IN</u>, (absorbed) and <u>ON</u>, (adsorbed) the LWA

If the 48 h sprinkled field absorption is 18% then:

(718 lb/yd^3) (0.18 absorption) = 129 lb/yd^3 absorbed water and the free, surface, or adsorbed water is 150 lb/yd^3 – 129 lb/yd^3 = 21 lb/yd^3

Next, adjustments for sand surface moisture should be made; assume 3% surface moisture

$$1.000 + \frac{0.03}{1.000} + \frac{0.005}{1.000} = 1.035\text{, and}$$

(1350 lb/ft^3 oven-dry sand) (1.035 for the total moisture content) = 1397 lb/yd^3

The field batch water is

420 lb/yd^3 – 150 lb/yd^3 = 270 lb/yd^3 or

420 lb/yd^3 – 129 lb/yd^3 absorbed water – 21 lb/yd^3 surface water = 270 lb/yd^3, and

270 lb/yd^3 – sand moisture correction of 47 lb/yd^3 = 223 lb/yd^3

This information provides the field mixture design as follows:

Field weights: 1 yd^3 – "as-is" basis
645 lb cement
870 lb 3/4-in. LWA ("as-is")
1397 lb sand (wet)
223 lb batch water
3135 lb/yd^3 or 116.1 lb/yd^3 plastic

After batching, this mixture should be tested in the plastic state for yield, slump, and air content.

Appropriate corrections should be made if necessary to provide within tolerance concrete.

Mixtures must be adjusted in the field to maintain yield.

Sample calculations (metric units)

From the lightweight aggregate manufacturer:

- Oven-dry loose unit weight is 689 kg/m^3, and the total water will be about 249 kg/m^3.
- Forty-eight-hour laboratory soaked absorption is approximately 23%.
- Suggested coarse aggregate factor is 0.618 m^3/m^3.

From the sand supplier:

- Sand dry loose unit weight is approximately 100 lb/ft^3.

Step One: Estimate 1 yd^3 trial batch weights on an oven-dry basis.

- 338 kg cement from Fig. 3.3 (Point A)
- 426 kg 19 mm lightweight aggregate from background information: (0.618)(689 kg/m^3) = 426 kg/m^3
- 801 kg concrete sand from Fig. 3.2: (1.118 – 0.618)1602 kg/m^3 = 801 kg/m^3
- 249 kg water from background information; can also be estimated from water Table 3.2 and adding the amount of water equal to the 48 h laboratory-soaked absorption.

1859 kg/m^3(plastic)

Step Two: Approximate air-dry weight.

(This is the plastic weight minus the oven-dry hydrated weight and corrected for the retained moisture.)

(386 kg cement) + [(0.20 water of hydration per ASTM C 567, Section 9.4)(386 kg cement)] is equal to the hydrated cement weight = 463 kg

plus the oven-dry lightweight aggregate weight = 463 kg
plus the oven-dry natural concrete sand weight = 802 kg
equals the oven-dry weight 1690 kg/m^3

The plastic unit weight minus the oven-dry hydrated weight is 1859 kg/m^3 – 1690 kg/m^3 = 169 kg/m^3 and (169 kg/m^3) (75% retained moisture factor per ASTM C 567, Section 9.7) = 127 kg/m^3 and (127 kg/m^3 retained moisture) + (1690 kg/m^3 oven-dry) = 1817 kg/m^3, which is the approximate air-dry weight.

Step Three: Convert oven-dry proportions to "as-is" proportions. Assume that the oven-dry concrete mixture design used previously is to be implemented in the field for a ready-mix concrete project and placed via truck chute. To minimize slump loss caused by absorption, the lightweight aggregate has been sprinkled for the past 48 h and the sprinkler has been turned off about 1 h before batch time to allow the aggregate's excess surface water to drain and the stockpile's overall moisture condition to stabilize.

The field technician's first activity is to obtain at least three representative loose unit weights of the wet or "as-is" (sprinkled or soaked) aggregate. The numerical values for the weights should have a narrow range (see ASTM C 330). A wide range could indicate variations in aggregate grading, moisture content, or careless loose unit weight measurement.

Loose unit field weights are

$$\frac{817\ \text{kg/m}^3 + 833\ \text{kg/m}^3 + 849\ \text{kg/m}^3}{3} = 833\ \text{kg/m}^3$$

"as-is" loose

Multiply the "as-is" loose unit weight by the design coarse aggregate factor: (833 kg/m^3)(0.618 m^3/m^3) = 515 kg/m^3

From this information the field batch water, or added water, can be estimated

515 kg/m^3 LWA ("as-is" loose)
– 426 kg/m^3 LWA (dry loose)
89 kg/m^3 Water IN, (absorbed) and ON, (adsorbed) the LWA

If the 48 h sprinkled field absorption is 18% then:

(426 kg/m^3) (0.18 absorption) = 77 kg/m^3 absorbed water and the free, surface, or adsorbed water is 89 kg/m^3 – 77 kg/m^3 = 12 kg/m^3

Next, adjustments for sand surface moisture should be made; assume 3% surface moisture

$$1.000 + \frac{0.03}{1.000} + \frac{0.005}{1.000} = 1.035 \text{, and}$$

(801 kg/m^3 oven-dry sand)(1.035 for the total moisture content) = 829 kg/m^3

The field batch water is

249 kg/m^3 – 89 kg/m^3 = 160 kg/m^3 or

249 kg/m^3 – 77 kg/m^3 absorbed water – 12 kg/m^3 surface water = 160 kg/m^3, and

160 kg/m^3 – sand moisture correction of 28 kg/m^3 = 132 kg/m^3

This information provides the field mixture design as follows:

Field weights: 1 m^3 – "as-is" basis
383 kg cement
515 kg 19 mm LWA ("as-is")
829 kg sand (wet)
132 kg batch water
1859 kg/m^3

After batching, this mixture should be tested in the plastic state for yield, slump, and air content.

Appropriate corrections should be made if necessary to provide within tolerance concrete.

Mixtures must be adjusted in the field to maintain yield.

CHAPTER 4—ADJUSTING MIXTURE PROPORTIONS

4.1—General

In proportioning normalweight concrete (ACI 211.1), the volume displaced or absolute volume occupied by each ingredient of the mixture (except entrained air) is calculated as the weight in lb (kg) of that ingredient divided by the product of 62.4 lb/ft^3 (1000 kg/m^3) and the specific gravity of that ingredient. Total volume of the mixture is the sum of the displaced or absolute volume of each ingredient thus calculated plus the volume of entrained and entrapped air determined by direct test. Calculation of the absolute volume of cement, based on dry weight of cement in the mixture, and calculation of air as the percentage of air determined by test multiplied by total volume, are the same for both lightweight concrete and normalweight concrete mixtures. The volume displaced by normalweight aggregates is calculated on the basis of the SSD weights of aggregates and the bulk specific gravities (SSD basis) as determined by ASTM C 127 and C 128. Volume displaced by water in normalweight concrete mixtures is therefore on the basis of "net" mixture water. Net mixture water is the water added at the mixer plus any surface water on the aggregates or minus any water absorbed by aggregates that are less than saturated.

The effective volume displaced by lightweight aggregates in concrete is calculated on the basis of weights of aggregates with a known moisture content as used, and on a specific gravity factor that is a function of the moisture content of the aggregate, and that is determined in Appendix A. Effective displaced volume of water in lightweight concrete mixtures is then based on the actual water added at the mixer. The relationship of weight to displaced volume for lightweight aggregates, as determined by the method of Appendix A, is termed a specific gravity factor. It is the ratio of the weight of the aggregates as introduced into the mixer, to the effective volume displaced by the aggregates. The weight of aggregates as introduced into the mixer includes any moisture absorbed in the aggregate and any free water on the aggregates.

4.2—Method 1: Weight method (specific gravity pycnometer)

4.2.1 Specific gravity factors generally vary with moisture content of aggregates. For each aggregate type and gradation, therefore, it is necessary to determine by the method of Appendix A the specific gravity factors over the full range of moisture conditions likely to be encountered in service. The variation is usually approximately linear in the lower range of moisture contents, but may digress from linearity at higher moisture contents. Therefore, the full curve should be established and extrapolation should be avoided. (See example curve in Fig. A.1 of Appendix A.)

4.2.2 Indicated specific gravity factors of coarse aggregates generally increase slightly with time of immersion in the pycnometer because of continued aggregate absorption. The rate of increase becomes smaller with longer immersion periods. The increase with time of immersion generally is greatest when the aggregate is tested in the dry condition and will become smaller as the moisture content of the aggregate before immersion increases. Pycnometer specific gravity factors obtained after 10 min immersion of aggregates should normally be suitable for mixture proportioning and adjustment procedures. Where some loss of slump is anticipated in long-haul ready-mixed concrete operations due to continued absorption of water into the aggregates, additional water is required to offset the resultant loss of yield. The mixture proportions should be determined on the basis of the 10 min specific gravity factor. A calculation of the lower effective displaced volumes of aggregates, however, based on the longer time specific gravity factor, should provide guidance to the anticipated loss of yield to be compensated for by additional water.

4.2.3 *Trial batch adjustments*—Mixture proportions calculated by the weight method should be checked by means of trial batches prepared and tested in accordance with ASTM C 192 or by full-sized batches. Only sufficient water should be used to produce the required slump regardless of the amount assumed in selecting the trial proportions. The concrete should be checked for unit weight and yield (ASTM C 138) and for air content (ASTM C 173). It should also be carefully observed for proper workability, freedom from segregation, and finishing properties. Appropriate adjustments should be made in the proportions for subsequent batches in accordance with the following procedure.

4.2.3.1 Reestimate the required mixing water per unit volume of concrete by multiplying the net mixing water per unit volume of concrete by the net mixing water content of the trial batch by 27 for a yd^3 (for inch-pound units only) and dividing the product by the yield of the trial batch in ft^3 (m^3). If the slump of the trial batch is not correct, increase or decrease the reestimated amount of water by 10 lb/yd^3 (5.9 m^3) for each required increase or decrease of 1 in. (25 mm) in slump.

4.2.3.2 If the desired air content (for air-entrained concrete) was not achieved, re-estimate the admixture content and decrease or increase the mixing water content stated in Step 3 of Section 3.2.2 by 5 lb/yd^3 (3.0 kg/m^3)for each 1% by which the air content is to be increased from that of the previous trial batch.

4.2.3.3 Reestimate the weight per unit volume of fresh concrete by multiplying the unit weight in lb/ft^3 (kg/m^3) of the trial batch by 27 (for inch-pound units only) and decreasing or increasing the result by the anticipated percentage increase or decrease in air content of the adjusted batch from the first trial batch.

4.2.3.4 Calculate new batch weights starting with Step 5 of Section 3.2.2, modifying the volume of coarse aggregate from Table 3.5, if necessary, to provide proper workability.

4.3—Method 2: Volumetric method (damp, loose volume)

4.3.1 Trial batch adjustments to mixtures designed by the damp, loose volume method should be checked by means of trial batches prepared and tested in accordance with ASTM C 192 or full-sized batches. Only sufficient water should be used to produce the desired slump regardless of the amount assumed in the trial proportions. The concrete should be checked for unit weight and yield (ASTM C 138) and for air content (ASTM C 173). It should be carefully observed for workability and finishing properties. Appropriate adjustments should be made.

4.4—Adjustment procedures

4.4.1 Both field mixtures and laboratory mixtures may require adjustment from time to time to compensate for some unintentional change in the characteristics of the concrete or to make a planned change in the characteristics. Adjustment may be required, for example, to compensate for a change in moisture content of the aggregates; it may be desired to proportion a mixture for greater or lesser cement content, or use of chemical admixtures; or other cementitious material, or perhaps, a change in slump or air content may be necessary. These adjustments can be made with considerable confidence based on either a first trial mixture or on previous field or laboratory mixtures with similar aggregates. Small mixtures of perhaps 1.0 to 2.0 ft^3 (0.028 or 0.056 m^3) total volume that are made and adjusted in the laboratory will require some further adjustments when extrapolated to field mixtures of possibly 100 to 300 times the laboratory volume. Tests of fresh unit weight, air content, and slump should be made on the initial field mixtures, and any necessary adjustments should be made on the field batch quantities.

4.4.2 *Guides for adjusting mixtures*—When it is desirable to change the amount of cement, the volume of air, or the percentage of fine aggregate in a mixture, or when it is desirable to change the slump of the concrete, it is necessary to offset such changes with adjustments in one or more other factors if yield and other characteristics of the concrete are to remain constant. The following paragraphs indicate some of the compensating adjustments, show the usual direction of adjustments necessary, and give a rough approximation of the amount of the adjustments per yd^3 (m^3) of concrete. Note that the numerical values given are intended for guidance only, they are approximations, and more accurate values obtained by observation and experience with particular materials should be used whenever possible.

4.4.2.1 *Proportion of fine aggregate*—An increase in the percentage of fine to total aggregates generally requires an increase in water content. For each percent increase in fine aggregate, increase water by approximately 3 lb/yd^3 (1.8 kg/m^3). An increase in water content will require an increase in cement content to maintain strength. For each 3 lb/yd^3 (1.8 kg/m^3) increase in water, increase cement by approximately 1%. Coarse and fine aggregate weights should be adjusted as necessary to obtain desired proportions of each, and to maintain required total effective displaced volume.

4.4.2.2 *Air content*—An increase in air content will be accompanied by an increase in slump unless water is reduced to compensate. For each percent increase in air content, water should be decreased by approximately 5 lb/yd^3 (3.0 kg/m^3). An increase in air content may be accompanied by a decrease in strength unless compensated for by additional cement (see Section 2.4.3). Fine aggregate weight should be adjusted as necessary to maintain required total effective displaced volume.

4.4.2.3 *Slump*—An increase in slump may be obtained by increasing water content. For each desired 1 in. (25 mm) increase in slump, water should be increased approximately 10 lb/yd^3 (5.9 kg/m^3) when initial slump is about 3 in. (75 mm); it is somewhat less when initial slump is higher. Increase in water content will be accompanied by a decrease in strength unless compensated for by an increase in cement content. For each 10 lb/yd^3 (5.9 kg/m^3) increase in water, increase cement content approximately 3%. Adjustment should be made in fine aggregate weight as necessary to maintain required total effective displaced volume.

4.4.3 *Adjustment for changes in aggregate moisture condition*—Procedure to adjust for changes in moisture content of aggregates is as follows:

a. Maintain constant the weight of cement and the effective displaced volumes of cement and air.

b. Calculate new weights of both coarse and fine aggregates, using the appropriate value for total moisture content, so that oven-dry weights of both coarse and fine aggregates remain constant.

c. Calculate effective displaced volumes of both coarse and fine aggregates using weights of the aggregates in the appropriate moisture condition or the specific gravity factor corresponding to that moisture condition.

d. Calculate the required effective displaced volume of added water as the difference between the required 27 ft^3 (1 m^3) and the total of the effective displaced volumes of the cement, air, and coarse and fine aggregates.

e. Calculate required weight of added water as 62.4 lb/ft^3 (1000 kg/m^3) multiplied by the required effective displaced volume of added water determined in (d).

4.5—Controlling proportions in the field

Proportions that have been established for given conditions may require adjustment from time to time to maintain the planned proportions in the field. Knowledge that proportions are remaining essentially constant, or that they may vary beyond acceptable limits, can be obtained by conducting tests for fresh unit weight of concrete (ASTM C 138), air content (ASTM C 173), and slump (ASTM C 143). These tests should be made not only at such uniform frequency as may be specified (a given number of tests per stated quantity of concrete, per stated time period, or per stated section of structure), but should also be made when observation indicates some change in the ingredients of the concrete or in the physical characteristics of the concrete. These tests should be made, for example, when moisture contents of the aggregates may have changed appreciably, when the concrete shows change in slump or workability characteristics, or when there is an appreciable change in added water requirements.

A change in fresh unit weight of concrete, with batch weights and air content remaining constant, shows that the batch is overyielding (with lower unit weight) or underyielding (with higher unit weight) (Fig. 4.1). The overyielding batch will have lower than planned cement content, and the underyielding batch will have a higher than planned cement content.

A change in the aggregate specific gravity factor may be the result of:

a. A change in the moisture content of the aggregate; or

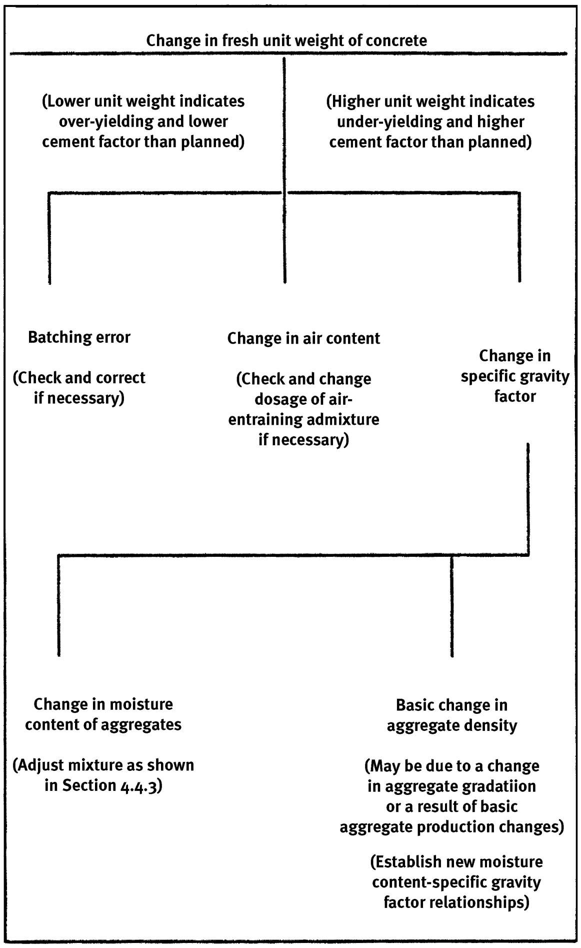

Fig. 4.1—Controlling proportions.

b. A basic change in aggregate density.

If a moisture test indicates moisture changes, the mixture should be adjusted, as shown in Section 4.4.3. If the basic aggregate density has changed, determination of new moisture content-specific gravity factor relationships are indicated (Aggregate density changes may be a result of changes in raw material, processing, or both). A change in slump may indicate:

a. A change in air content;

b. A change in moisture content of aggregate without corresponding change in batching; or

c. A change in aggregate gradation or density.

Each of these factors is also indicated by the fresh unit weight test.

Note: Controlling concrete mixtures in the field also requires recognizing possible changes due to variations in ambient temperature of ingredients, length of mixing and agitating time, and other causes. Discussion of such factors is beyond the scope of this standard.

Summary

The examples of the two methods of proportioning structural lightweight concrete mixtures are intended to provide guidance to the user. Each lightweight aggregate has its own particular characteristics that influence the mixture proportioning. Therefore, the user can only develop proficiency in proportioning and controlling structural lightweight concrete by practice. This proficiency is further increased with laboratory and field experience that can be gained from actual concrete production with each specific lightweight aggregate and selected mixture proportions.

CHAPTER 5—REFERENCES

5.1—Referenced standards and reports

The standards and reports listed below were the latest editions at the time this document was prepared. Because these documents are revised frequently, the reader is advised to contact the proper sponsoring group if it desired to refer to the latest version.

American Concrete Institute (ACI)

201.2R Guide to Durable Concrete
211.1 Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete
212.1R Admixtures for Concrete
212.2R Guide for Use of Admixtures in Concrete
213R Guide for Structural Lightweight-Aggregate Concrete
226.1R Ground Granulated Blast-Furnace Slag as a Cementitious Constituent in Concrete
226.3R Use of Fly Ash in Concrete
301 Standard Specifications for Structural Concrete
302.1R Guide for Concrete Floor and Slab Construction
318 Building Code Requirements for Structural Concrete
345 Standard Practice for Concrete Highway Bridge Deck Construction

ASTM International

C 29/C 29M Standard Test Method for Bulk Density (Unit Weight) and Voids in Aggregate
C 31/C 31M Standard Practice for Making and Curing Concrete Test Specimens in the Field
C 33 Standard Specification for Concrete Aggregates
C 94/ C 94M Standard Specification for Ready-Mixed Concrete
C 127 Standard Test Method for Density, Relative Density (Specific Gravity) and Absorption of Coarse Aggregate
C 128 Standard Test Method for Density, Relative Density (Specific Gravity) and Absorption of Fine Aggregate
C 138/ C 138M Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
C 143/C 143M Standard Test Method for Slump of Hydraulic Cement Concrete
C 150 Standard Specification for Portland Cement
C 173/C 173M Standard Test Method for Air Content of Freshly Mixed Concrete by Volumetric Method
C 192/C 192M Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory

C 330	Standard Specification for Lightweight Aggregates for Structural Concrete
C 494/C 494M	Standard Specification for Chemical Admixtures for Concrete
C 566	Standard Test Method for Total Moisture Content of Aggregate by Drying
C 567	Standard Test Method for Determining Density of Structural Lightweight Concrete

These publications may be obtained from the following organizations:

American Concrete Institute
P.O. Box 9094
Farmington Hills, MI 48333-9094

ASTM International
100 Barr Harbor Dr.
West Conshohocken, PA 19428

APPENDIX A—DETERMINATION OF SPECIFIC GRAVITY FACTORS OF STRUCTURAL LIGHTWEIGHT AGGREGATE

Methods presented herein describe procedures for determining the specific gravity factors of lightweight aggregates, either dry or moist.

Pycnometer method for fine and coarse lightweight aggregates:

a. A pycnometer consisting of a narrow-mouthed 2 qt (2 L) mason jar with a pycnometer top (Soiltest G-335, Humboldt H-3380, or equivalent).

b. A balance or scale having a capacity of at least 11 lb (5 kg) and a sensitivity of 0.035 oz. (1 g).

c. A water storage jar (about 5 gal. [20 L] capacity) for maintaining water at room temperature.

d. Isopropyl (rubbing) alcohol and a medicine dropper.

Calibration of pycnometer

The pycnometer is filled with water and agitated to remove any entrapped air and adding water to "top off" the jar. The filled pycnometer is dried and weighed and the weight (weight B in grams) is recorded. (A review of ASTM C 128 may be helpful regarding this method.)

Sampling procedure

Representative samples of about 2 to 3 ft^3 (0.057 to 0.085 m^3) of each size of aggregate should be obtained from the stockpile and put through a sample splitter or quartered until the correct size of the sample desired has been obtained. During this operation with damp aggregates, extreme care is necessary to prevent the aggregates from drying. The aggregate sample should occupy 1/2 to 2/3 the volume of the 2 qt (2 L) pycnometer.

Test procedure

Two representative samples should be obtained of each size of lightweight aggregate to be tested.

The first is weighed, placed in an oven at 221 to 230 °F (105 to 110 °C) and dried to constant weight. "Frying pan drying" to constant weight is an acceptable field expedient. The dry aggregate weight is recorded, and the aggregate moisture content (percentage of aggregate dry weight) is calculated.

The second aggregate sample is weighted (weight C in grams). The sample is then placed in the empty pycnometer and water is added until the jar is three-quarters full. The time of water addition should be noted.

The air entrapped between the aggregate particles is removed by rolling and shaking the jar. During agitation, the hole in the pycnometer top is covered with the operator's finger. The jar is then filled and agitated again to eliminate any additional entrapped air. If foam appears during the agitation and prevents the complete filling of the pycnometer with water at this stage, a minimum amount of isopropyl alcohol should be added with the medicine dropper to eliminate the foam. The water level in the pycnometer must be adjusted to full capacity and the exterior surfaces of the jar must be dried before weighing.

The pycnometer, thus filled with the sample and water, is weighed (weight A in grams) after 5, 10, and 30 min of sample immersion to obtain complete data, and the weights at these times are recorded after each "topping-off." Fig. A.1 shows a typical plot of such determinations. The variation is usually approximately linear in the lower range of moisture contents, but may digress from linearity at higher moisture contents. The full curve, therefore, should be established and extrapolation should be avoided.

Calculation

The pycnometer specific gravity factor S, after any particular immersion time, is calculated by the following formula.

$$S = \frac{C}{C + B - A}$$

where

A = weight of pycnometer charged with aggregate and then filled with water, g;
B = weight of pycnometer filled with water, g; and
C = weight of aggregate tested, moist or dry, g.

Buoyancy methods for coarse aggregates

If larger test samples of coarse aggregate than can be evaluated in the pycnometer are desired, coarse aggregate gravity factors may be determined by the wholly equivalent weight-in-air-and-water procedures described in ASTM C 127. The top of the container used for weighing the aggregates under water must be closed with a screen to prevent light particles from floating away from the sample.

Specific gravity factors by this method are calculated by the equation

$$\text{Specific gravity factor } S = \frac{C}{C - E}$$

where

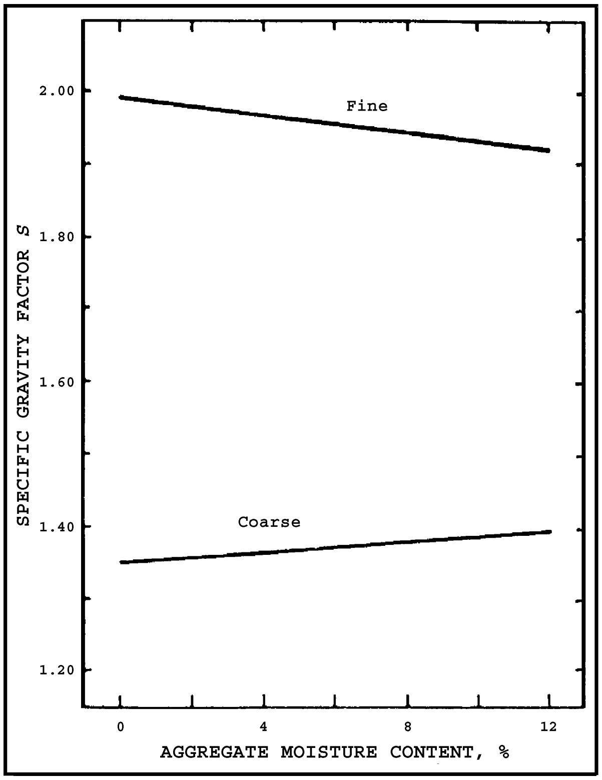

Fig. A.1—Example of relationship between pycnometer specific gravity factor and moisture content for lightweight aggregate.

C = same as above (the weight in air);
E = weight of coarse aggregate sample under water, g; and
S = specific gravity factor, equal (by the theory of the method) to the pycnometer specific gravity factor.

APPENDIX B—DETERMINATION OF STRUCTURAL LIGHTWEIGHT COARSE AGGREGATE ABSORPTION

The method presented hereafter describes a procedure for determining the absorption of lightweight coarse aggregate by spin-drying in a centrifuge to produce an SDD condition following 24 h of immersion in water.

Apparatus

a. A bench-top centrifuge with a speed control capable of spinning a 0.67 to 0.88 lb (300 to 400 g) sample of graded coarse aggregate at 500 rpm. A centrifuge similar to an International Model HN or a centrifugal extraction apparatus similar to a Soiltest Model AP 179-B are satisfactory.

b. A bowl or colander approximately 8-1/2 in. (216 mm) in diameter and 3-in. (75 mm) deep mounted on the axis of the centrifuge and fitted with a lid to prevent loss of the aggregate when spun. Centrifugal extractors are manufactured with such bowls; therefore, this requirement does not apply to them.

c. A balance having a capacity of at least 2.2 lb (1000 g) and a sensitivity of 0.0035 oz. (0.1 g).

Sampling procedure

Representative samples of about 44 to 66 lb (20 to 30 kg) of graded aggregate should be taken from the stockpile and reduced with a sample splitter or quartered until a 0.67 to 0.88 lb (300 to 400 g) sample is obtained. During this operation, definite precautions should be taken to prevent segregation of the coarser particles from those smaller in size. Two or more representative samples should be taken.

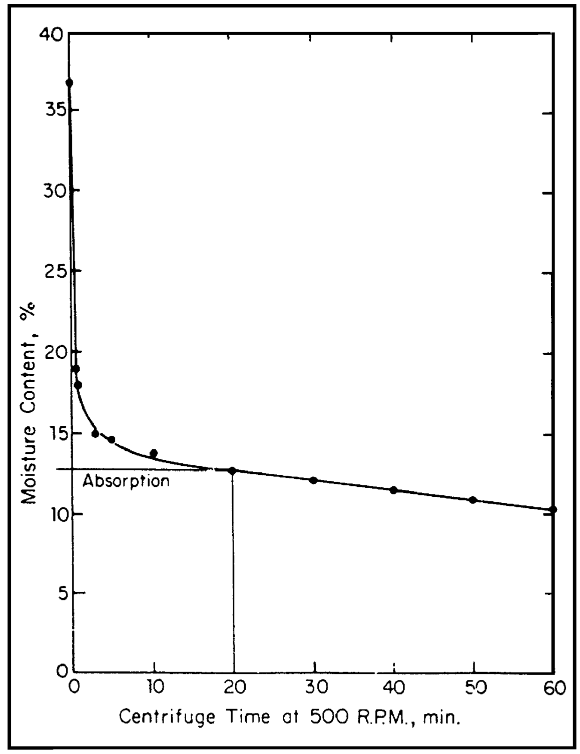

Fig. B.1—Typical relationship illustrating measurement of lightweight aggregate absorption.

Test procedure

Immerse the samples of graded, lightweight coarse aggregate for approximately 24 h in tap water at room temperature. After that period, decant the excess water and transfer the sample into the bowl or colander and secure the lid. Activate the centrifuge and spin the sample at 500 rpm for 20 min. Remove the sample and measure its SSD weight. Dry the sample to constant weight by any of the procedures described in ASTM C 566—electric or gas hot plate, electric heat lamps, or a ventilated oven capable of maintaining the temperature surrounding the sample at 221 to 239 °F (105 to 115 °C). Figure B.1 shows a typical plot of determining lightweight coarse aggregate absorption.

Calculation

After measuring the dry weight, the absorption of the lightweight coarse aggregate is calculated in the following manner

$$A, \% = 100\,(W - D)/D$$

where
W = saturated surface dry weight, g; and
D = dry weight, g.

A satisfactory test on two samples by the same technician should not differ by more than 0.67% in one test out of 20.