

Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete

An ACI Standard

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Describes, with examples, two methods for selecting and adjusting proportions for normal weight concrete, both with and without chemical admixtures, pozzolanic, and slag materials. One method is based on an estimated weight of the concrete per unit volume; the other is based on calculations of the absolute volume occupied by the concrete ingredients. The procedures take into consideration the requirements for placeability, consistency, strength, and durability. Example calculations are shown for both methods, including adjustments based on the characteristics of the first trial batch.

The proportioning of heavyweight concrete for such purposes as radiation shielding and bridge counterweight structures is described in an appendix. This appendix uses the absolute volume method, which is generally accepted and is more convenient for heavyweight concrete.

There is also an appendix that provides information on the proportioning of mass concrete. The absolute volume method is used because of its general acceptance.

Keywords: absorption; admixtures; aggregates; blast-furnace slag; cementitious materials; concrete durability; concretes; consistency; durability; exposure; fine aggregates; fly ash; heavyweight aggregates; heavyweight concretes; mass concrete; mix proportioning; pozzolans; quality control; radiation shielding; silica fume; slump tests; volume; water-cement ratio; water-cementitious ratio; workability.

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This standard supersedes ACI 211.1-89. It was revised by the Expedited Standardization procedure, effective Nov. 1, 1991. This revision incorporates provisions related to the use of the mineral admixture silica fume in concrete. Chapter 4 has been expanded to cover in detail the effects of the use of silica fume on the proportions of concrete mixtures. Editorial changes have also been made in Chapters 2 through 4, and Chapters 6 through 8.

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CHAPTER 1 - SCOPE

1.1 This Standard Practice describes methods for selecting proportions for hydraulic cement concrete made with and without other cementitious materials and chemical admixtures. This concrete consists of normal and/or high-density aggregates (as distinguished from lightweight aggregates) with a workability suitable for usual cast-in-place construction (as distinguished from special mixtures for concrete products manufacture). Also included is a description of methods used for selecting proportions for mass concrete. Hydraulic cements referred to in this Standard Practice are portland cement (ASTM C 150) and blended cement (ASTM C 595). The Standard does not include proportioning with condensed silica fume.

1.2 The methods provide a first approximation of proportions intended to be checked by trial batches in the laboratory or field and adjusted, as necessary, to produce the desired characteristics of the concrete.

1.3 U.S. customary units are used in the main body of the text. Adaption for the metric system is provided in Appendix 1 and demonstrated in an example problem in Appendix 2.

1.4 Test methods mentioned in the text are listed in Appendix 3.

CHAPTER 2 -- INTRODUCTION

2.1 Concrete is composed principally of aggregates, a portland or blended cement, and water, and may contain other cementitious materials and/or chemical admixtures. It will contain some amount of entrapped air and may also contain purposely entrained air obtained by use of an admixture or air-entraining cement. Chemical admixtures are frequently used to accelerate, retard, improve workability, reduce mixing water requirements, increase strength, or alter other properties of the concrete (see ACI 212.3R). De-

pending upon the type and amount, certain cementitious materials such as fly ash, (see ACI 226.3R) natural pozzolans, ground granulated blast-furnace (GGBF) slag (see ACI 226.1R) and silica fume may be used in conjunction with portland or blended cement for economy or to provide specific properties such as reduced early heat of hydration, improved late-age strength development, or increased resistance to alkali-aggregate reaction and sulfate attack, decreased permeability, and resistance to the intrusion of aggressive solutions (See ACI 225R and ACI 226.1R).

2.2 The selection of concrete proportions involves a balance between economy and requirements for placeability, strength, durability, density, and appearance. The required characteristics are governed by the use to which the concrete will be put and by conditions expected to be encountered at the time of placement. These characteristics should be listed in the job specifications.

2.3 The ability to tailor concrete properties to job needs reflects technological developments that have taken place, for the most part, since the early 1900s. The use of water-cement ratio as a tool for estimating strength was recognized about 1918. The remarkable improvement in durability resulting from the entrainment of air was recognized in the early 1940s. These two significant developments in concrete technology have been augmented by extensive research and development in many related areas, including the use of admixtures to counteract possible deficiencies, develop special properties, or achieve economy (ACI 212.2R). It is beyond the scope of this discussion to review the theories of concrete proportioning that have provided the background and sound technical basis for the relatively simple methods of this Standard Practice. More detailed information can be obtained from the list of references in Chapter 8.

2.4 Proportions calculated by any method must always be considered subject to revision on the basis of experience with trial batches. Depending on the circumstances, the trial mixtures may be prepared in a laboratory, or, perhaps preferably, as full-size field batches. The latter procedure, when feasible, avoids possible pitfalls of assuming that data from small batches mixed in a laboratory environment will predict performance under field conditions. When using maximum-size aggregates larger than 2 in., laboratory trial batches should be verified and adjusted in the field using mixes of the size and type to be used during construction. Trial batch procedures and background testing are described in Appendix 3.

2.5 Frequently, existing concrete proportions not containing chemical admixtures and/or materials other than hydraulic cement are reportioned to include these materials or a different cement. The performance of the reportioned concrete should be verified by trial batches in the laboratory or field.

CHAPTER 3 -- BASIC RELATIONSHIP

3.1 Concrete proportions must be selected to provide

necessary placeability, density, strength, and durability for the particular application. In addition, when mass concrete is being proportioned, consideration must be given to generation of heat. Well-established relationships governing these properties are discussed next.

3.2 Placeability -- Placeability (including satisfactory finishing properties) encompasses traits loosely accumulated in the terms “workability” and “consistency.” For the purpose of this discussion, workability is considered to be that property of concrete that determines its capacity to be placed and consolidated properly and to be finished without harmful segregation. It embodies such concepts as moldability, cohesiveness, and compactability. Workability is affected by: the grading, particle shape, and proportions of aggregate; the amount and qualities of cement and other cementitious materials; the presence of entrained air and chemical admixtures; and the consistency of the mixture. Procedures in this Standard Practice permit these factors to be taken into account to achieve satisfactory placeability economically.

3.3 Consistency -- Loosely defined, consistency is the relative mobility of the concrete mixture. It is measured in terms of slump -- the higher the slump the more mobile the mixture -- and it affects the ease with which the concrete will flow during placement. It is related to but not synonymous with workability. In properly proportioned concrete, the unit water content required to produce a given slump will depend on several factors. Water requirement increases as aggregates become more angular and rough textured (but this disadvantage may be offset by improvements in other characteristics such as bond to cement paste). Required mixing water decreases as the maximum size of well-graded aggregate is increased. It also decreases with the entrainment of air. Mixing water requirements usually are reduced significantly by certain chemical water-reducing admixtures.

3.4 Strength -- Although strength is an important characteristic of concrete, other characteristics such as durability, permeability, and wear resistance are often equally or more important. Strength at the age of 28 days is frequently used as a parameter for the structural design, concrete proportioning, and evaluation of concrete. These may be related to strength in a general way, but are also affected by factors not significantly associated with strength. In mass concrete, mixtures are generally proportioned to provide the design strength at an age greater than 28 days. However, proportioning of mass concrete should also provide for adequate early strength as may be necessary for form removal and form anchorage.

3.5 Water-cement or water-cementitious ratio [w/c or $w/(c + p)$] -- For a given set of materials and conditions, concrete strength is determined by the net quantity of water used per unit quantity of cement or total cementitious materials. The net water content excludes water absorbed by the aggregates. Differences in strength for a given water-cement ratio w/c or water-cementitious materials ratio $w/(c + p)$ may result from changes in: maximum size of aggregate; grading, surface texture, shape, strength, and

stiffness of aggregate particles; differences in cement types and sources; air content; and the use of chemical admixtures that affect the cement hydration process or develop cementitious properties themselves. To the extent that these effects are predictable in the general sense, they are taken into account in this Standard Practice. In view of their number and complexity, it should be obvious that accurate predictions of strength must be based on trial batches or experience with the materials to be used.

3.6 Durability -- Concrete must be able to endure those exposures that may deprive it of its serviceability -- freezing and thawing, wetting and drying, heating and cooling, chemicals, deicing agents, and the like. Resistance to some of these may be enhanced by use of special ingredients: low-alkali cement, pozzolans, GGBF slag, silica fume, or aggregate selected to prevent harmful expansion to the alkali-aggregate reaction that occurs in some areas when concrete is exposed in a moist environment; sulfate-resisting cement, GGBF slag, silica fume, or other pozzolans for concrete exposed to seawater or sulfate-bearing soils; or aggregate composed of hard minerals and free of excessive soft particles where resistance to surface abrasion is required. Use of low water-cement or cementitious materials ratio [w/c or $w/(c + p)$] will prolong the life of concrete by reducing the penetration of aggressive liquids. Resistance to severe weathering, particularly freezing and thawing, and to salts used for ice removal is greatly improved by incorporation of a proper distribution of entrained air. Entrained air should be used in all exposed concrete in climates where freezing occurs. (See ACI 201.2R for further details).

3.7 Density -- For certain applications, concrete may be used primarily for its weight characteristic. Examples of applications are counterweights on lift bridges, weights for sinking oil pipelines under water, shielding from radiation, and insulation from sound. By using special aggregates, placeable concrete of densities as high as 350 lb/ft³ can be obtained--see Appendix 4.

3.8 Generation of heat -- A major concern in proportioning mass concrete is the size and shape of the completed structure or portion thereof. Concrete placements large enough to require that measures be taken to control the generation of heat and resultant volume change within the mass will require consideration of temperature control measures. As a rough guide, hydration of cement will generate a concrete temperature rise of 10 to 15 F per 100 lb of portland cement/yd³ in 18 to 72 hours. If the temperature rise of the concrete mass is not held to a minimum and the heat is allowed to dissipate at a reasonable rate, or if the concrete is subjected to severe temperature differential or thermal gradient, cracking is likely to occur. Temperature control measures can include a relatively low initial placing temperature, reduced quantities of cementitious materials, circulation of chilled water, and, at times, insulation of concrete surfaces as may be required to adjust for these various concrete conditions and exposures. It should be emphasized that mass concrete is not necessarily large-aggregate concrete and that concrete with generation of an excessive amount of heat in concrete is not confined to

massive dam or foundation structures. Many large structural elements may be massive enough that heat generation should be considered, particularly when the minimum cross-sectional dimensions of a solid concrete member approach or exceed 2 to 3 ft or when cement contents above 600 lb/yd³ are being used.

CHAPTER 4--EFFECTS OF CHEMICAL ADMIXTURES, POZZOLANIC, AND OTHER MATERIALS ON CONCRETE PROPORTIONS

4.1 Admixtures -- By definition (ACI 116R), an admixture is "a material other than water, aggregates, hydraulic cement, and fiber reinforcement used as an ingredient of concrete or mortar and added to the batch immediately before or during its mixing." Consequently, the term embraces an extremely broad field of materials and products, some of which are widely used while others have limited application. Because of this, this Standard Practice is restricted to the effects on concrete proportioning of air-entraining admixtures, chemical admixtures, fly ashes, natural pozzolans, and ground granulated blast-furnace slags (GGBF slag).

4.2 Air-entraining admixture -- Air-entrained concrete is almost always achieved through the use of an air-entraining admixture, ASTM C 260, as opposed to the earlier practice in which an air-entraining additive is interground with the cement. The use of an air-entraining admixture gives the concrete producer the flexibility to adjust the entrained air content to compensate for the many conditions affecting the amount of air entrained in concrete, such as: characteristics of aggregates, nature and proportions of constituents of the concrete admixtures, type and duration of mixing, consistency, temperature, cement fineness and chemistry, use of other cementitious materials or chemical admixtures, etc. Because of the lubrication effect of the entrained air bubbles on the mixture and because of the size and grading of the air voids, air-entrained concrete usually contains up to 10 percent less water than non-air-entrained concrete of equal slump. This reduction in the volume of mixing water as well as the volume of entrained and entrapped air must be considered in proportioning.

4.3 Chemical admixtures -- Since strength and other important concrete qualities such as durability, shrinkage, and cracking are related to the total water content and the w/c or $w/(c + p)$, water-reducing admixtures are often used to improve concrete quality. Further, since less cement can be used with reduced water content to achieve the same w/c or $w/(c + p)$ or strength, water-reducing and set-controlling admixtures are used widely for reasons of economy (ACI 212.2R).

Chemical admixtures conforming to ASTM C 494, Types A through G, are of many formulations and their purpose purposes for use in concrete are as follows:

- Type A -- Water-reducing
- Type B -- Retarding
- Type C -- Accelerating

- Type D -- Water-reducing and retarding
- Type E -- Water-reducing, and accelerating
- Type F -- Water-reducing, high-range
- Type G -- Water-reducing, high-range, and retarding

The manufacturer or manufacturer's literature should be consulted to determine the required dosage rate for each specific chemical admixture or combination of admixtures. Chemical admixtures have tendencies, when used in large doses, to induce strong side-effects such as excessive retardation and, possibly, increased air entrainment, in accordance with ASTM C 1017. Types A, B, and D, when used by themselves, are generally used in small doses (2 to 7 oz/100 lb of cementitious materials), so the water added to the mixture in the form of the admixture itself can be ignored. Types C, E, F, and G are most often used in large quantities (10 to 90 oz/100 lb of cementitious materials) so their water content should be taken into account when calculating the total unit water content and the w/c or $w/(c + p)$. When Types A, B, and D admixtures are used at higher than normal dosage rates in combination or in an admixture system with an accelerating admixture (Type C or E), their water content should also be taken into account.

Although chemical admixtures are of many formulations, their effect on water demand at recommended dosages is governed by the requirements of ASTM C 494. Recommended dosage rates are normally established by the manufacturer of the admixture or by the user after extensive tests. When used at normal dosage rates, Type A water-reducing, Type D water-reducing and retarding, and Type E water-reducing and accelerating admixtures ordinarily reduce mixing-water requirements 5 to 8 percent, while Type F water-reducing, high-range, and Type G water-reducing, high-range, and retarding admixtures reduce water requirements 12 to 25 percent or more. Types F and G water-reducing, high-range admixtures (HRWR) are often called "superplasticizers."

High-range, water-reducing admixtures are often used to produce flowing concrete with slumps between about 7½ or more with no increase in water demand other than that contained in the admixture itself. Types A, B, or D admixtures at high dosage rates, in combination with Types C or E (for acceleration), may also be used to produce the same effect. When flowing concrete is so produced, it is sometimes possible to increase the amount of coarse aggregate to take advantage of the fluidity of the concrete to flow into place in constricted areas of heavy reinforcement. Flowing concrete has a tendency to segregate; therefore, care must be taken to achieve a proper volume of mortar in the concrete required for cohesion without making the concrete undesirably sticky.

ASTM C 494 lists seven types of chemical admixtures as to their expected performance in concrete. It does not classify chemical admixtures as to their composition. ACI 212.2R lists five general classes of materials used to formulate most water-reducing, set-controlling chemical admixtures. This report, as well as ACI 212.2R, should be reviewed to determine when restrictions should be

placed upon the use of certain admixtures for a given class of concrete. For example, admixtures containing purposely added calcium chloride have been found to accelerate the potential for stress-corrosion of tensioned cables imbedded in concrete when moisture and oxygen are available.

4.4 Other cementitious materials -- Cementitious materials other than hydraulic cement are often used in concrete in combination with portland or blended cement for economy, reduction of heat of hydration, improved workability, improved strength and/or improved durability under the anticipated service environment. These materials include fly ash, natural pozzolans (ASTM C 618), GGBF slag (ASTM C 989), and silica fume. Not all of these materials will provide all of the benefits listed.

As defined in ASTM C 618, pozzolans are: "Siliceous or siliceous and aluminous materials which in themselves possess little or no cementitious value, but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties . . . " Fly ash is the "finely divided residue that results from the combustion of ground or powdered coal . . . " Fly ash used in concrete is classified into two categories: Class F, which has pozzolanic properties, and Class C, which, in addition to having pozzolanic properties, also has some cementitious properties in that this material may be self-setting when mixed with water. Class C fly ash may contain lime (CaO) amounts higher than 10 percent. The use of fly ash in concrete is more fully described and discussed in ACI 226.3R.

Blast-furnace slag is a by-product of the production of pig iron. When this slag is rapidly quenched and ground, it will possess latent cementitious properties. After processing, the material is known as GGBF slag, whose hydraulic properties may vary and can be separated into grades noted in ASTM C 989. The grade classification gives guidance on the relative strength potential of 50 percent GGBF slag mortars to the reference portland cement at 7 and 28 days. GGBF slag grades are 80, 100, and 120, in order of increasing strength potential.

Silica fume,* as used in concrete, is a by-product resulting from the reduction of high-purity quartz with coal and wood chips in an electric arc furnace during the production of silicon metal or ferrosilicon alloys. The silica fume, which condenses from the gases escaping from the furnaces, has a very high content of amorphous silicon dioxide and consists of very fine spherical particles.

Uses of silica fume in concrete fall into three general categories:

- Production of low permeability concrete with enhanced durability.
- Production of high-strength concrete.
- As a cement replacement (The current economics of cement costs versus silica fume costs do not usually

make this a viable use for silica fume in the U.S.).

Silica fume typically has a specific gravity of about 2.2. The lower specific gravity of silica fume compared with that of portland cement means that when replacement is based on weight (mass), a larger volume of silica fume is added than the volume of cement removed. Thus, the volume of cementitious paste increases and there is actually a lowering of the water-cementitious materials ratio on a volume basis.

The particle-size distribution of a typical silica fume shows that most particles are smaller than one micrometer (1 μm with an average diameter of about 0.1 μm , which is approximately one hundred times smaller than the average size cement particle).

The extreme fineness and high silica content of silica fume make it a highly effective pozzolanic material. The silica fume reacts pozzolanically with the calcium hydroxide produced during the hydration of cement to form the stable cementitious compound, calcium silicate hydrate (CSH).

Silica fume has been successfully used to produce very high strength (over 18,000 psi), low permeability, and chemically resistant concretes. Such concretes contain up to 25 percent silica fume by weight (mass) of cement. The use of this high amount of silica fume generally makes the concrete difficult to work. The mixing water demand of a given concrete mixture incorporating silica fume increases with increasing amounts of silica fume.

To maximize the full strength-producing potential of silica fume in concrete, it should always be used with a water-reducing admixture, preferably a high-range, water-reducing (HRWR) admixture. the dosage of the HRWR will depend on the percentages of silica fume and the type of HRWR used.

When proportioning concrete containing silica fume, the following should be considered:

- Mixing -- The amount of mixing will depend on the percentage of silica fume used and the mixing conditions. Mixing time may need to be increased to achieve thorough distribution when using large quantities of silica fume with low water content concrete. The use of HRWR assists greatly in achieving uniform dispersion.
- Air-entrainment -- The amount of air-entraining admixture to produce a required volume of air in concrete may increase with increasing amounts of silica fume due to the very high surface area of the silica fume and the presence of any carbon within the silica fume. Air entrainment is not usually used in high strength concretes unless they are expected to be exposed to freezing and thawing when saturated with water or to deicing salts.
- Workability -- Fresh concrete containing silica fume is generally more cohesive and less prone to segregation than concrete without silica fume. This increase in cohesiveness and reduction to bleeding can provide improved pumping properties. Concrete containing silica fume in excess of 10 percent by

* Other names that have been used include silica dust, condensed or pre-compacted silica fume and micro silica; the most appropriate is silica fume.

weight (mass) of the cementitious materials may become sticky. It may be necessary to increase the slump 2 to 5 in. to maintain the same workability for a given length of time.

- d. Bleeding -- Concrete containing silica fume exhibits reduced bleeding. This reduced bleeding is primarily caused by the high surface area of the silica fume particles, resulting in very little water being left in the mixture for bleeding. As the result of reduced bleeding of concrete containing silica fume, there is a greater tendency for plastic shrinkage cracking to occur.

Typically, the materials listed previously are introduced into the concrete mixer separately. In some cases, however, these same materials may be blended with portland cement in fixed proportions to produce a blended cement, ASTM C 595. Like air-entraining admixtures added to the concrete at the time of batching, the addition of GGBF slag also gives the producer flexibility to achieve desired concrete performance.

When proportioning concrete containing a separately batched, cementitious material such as fly ash, natural pozzolan, GGBF slag, or silica fume, a number of factors must be considered. These include:

- a. Chemical activity of the cementitious material and its effect on concrete strength at various ages.
- b. Effect on the mixing-water demand needed for workability and placeability.
- c. Density (or specific gravity) of the material and its effect on the volume of concrete produced in the batch.
- d. Effect on the dosage rate of chemical admixtures and/or air-entraining admixtures used in the mixture.
- e. Effect of combinations of materials on other critical properties of the concrete, such as time of set under ambient temperature conditions, heat of hydration, rate of strength development, and durability.
- f. Amount of cementitious materials and cement needed to meet the requirements for the particular concrete.

4.4.1 Methods for proportioning and evaluating concrete mixtures containing these supplementary cementitious materials must be based on trial mixtures using a range of ingredient proportions. By evaluating their effect on strength, water requirement, time of set, and other important properties, the optimum amount of cementitious materials can be determined. In the absence of prior information and in the interest of preparing estimated proportions for a first trial batch or a series of trial batches in accordance with ASTM C 192, the following general ranges are given based on the percentage of the ingredients by the total weight of cementitious material used in the batch for structural concrete:

Class F fly ash -- 15 to 25 percent

Class C fly ash -- 15 to 35 percent

Natural pozzolans -- 10 to 20 percent

Ground granulated blast-furnace slag -- 25 to 70 percent

Silica fume -- 5 to 15 percent

For special projects, or to provide certain special required properties, the quantity of the materials used per yd^3 of concrete may be different from that shown above.

In cases where high early strengths are required, the total weight of cementitious material may be greater than would be needed if portland cement were the only cementitious material. Where high early strength is not required higher percentages of fly ash are frequently used.

Often, it is found that with the use of fly ash and GGBF slag, the amount of mixing water required to obtain the desired slump and workability of concrete may be lower than that used in a portland cement mixture using only portland cement. When silica fume is used, more mixing water is usually required than when using only portland cement. In calculating the amount of chemical admixtures to dispense for a given batch of concrete, the dosage should generally be applied to the total amount of cementitious material. Under these conditions the reduction in mixing water for conventional water-reducing admixtures (Types A, D, and E) should be at least 5 percent, and for water-reducing, high-range admixtures at least 12 percent. When GGBF slag is used in concrete mixtures containing some high-range water-reducing admixtures, the admixture dosage may be reduced by approximately 25 percent compared to mixtures containing only portland cement.

4.4.2 Due to differences in their specific gravities, a given weight of a supplementary cementitious material will not occupy the same volume as an equal weight of portland cement. The specific gravity of blended cements will be less than that of portland cement. Thus, when using either blended cements or supplementary cementitious materials, the yield of the concrete mixture should be adjusted using the actual specific gravities of the materials used.

4.4.3 Class C fly ash, normally of extremely low carbon content, usually has little or no effect on entrained air or on the air-entraining admixture dosage rate. Many Class F fly ashes may require a higher dosage of air-entraining admixture to obtain specified air contents; if carbon content is high, the dosage rate may be several times that of non-fly ash concrete. The dosage required may also be quite variable. The entrained air content of concrete containing high carbon-content fly ash may be difficult to obtain and maintain. Other cementitious materials may be treated the same as cement in determining the proper quantity of air-entraining admixtures per yd^3 of concrete or per 100 lb of cementitious material used.

4.4.4 Concrete containing a proposed blend of cement, other cementitious materials, and admixtures should be tested to determine the time required for setting at various temperatures. The use of most supplementary cementitious materials generally slows the time-of-set of the concrete, and this period may be prolonged by higher percentages of these materials in the cementitious blend.

cold weather, and the presence of chemical admixtures not formulated especially for acceleration.

Because of the possible adverse effects on finishing time and consequent labor costs, in some cold climates the proportion of other cementitious materials in the blend may have to be reduced below the optimum amount for strength considerations. Some Class C fly ashes may affect setting time while some other cementitious materials may have little effect on setting time. Any reduction in cement content will reduce heat generation and normally prolong the setting time.

CHAPTER 5 -- BACKGROUND DATA

5.1 To the extent possible, selection of concrete proportions should be based on test data or experience with the materials actually to be used. Where such background is limited or not available, estimates given in this recommended practice may be employed.

5.2 The following information for available materials will be useful:

5.2.1 Sieve analyses of fine and coarse aggregates.

5.2.2 Unit weight of coarse aggregate.

5.2.3 Bulk specific gravities and absorptions of aggregates.

5.2.4 Mixing-water requirements of concrete developed from experience with available aggregates.

5.2.5 Relationships between strength and water-cement ratio or ratio of water-to-cement plus other cementitious materials, for available combinations of cements, other cementitious materials if considered, and aggregates.

5.2.6 Specific gravities of portland cement and other cementitious materials, if used.

5.2.7 Optimum combination of coarse aggregates to meet the maximum density gradings for mass concrete as discussed in Section 5.3.2.1 of Appendix 5.

5.3 Estimates from Tables 6.3.3 and 6.3.4, respectively, may be used when items in Section 5.2.4 and Section 6.3.5 are not available. As will be shown, proportions can be estimated without the knowledge of aggregate-specific gravity and absorption, Section 5.2.3.

CHAPTER 6 -- PROCEDURE

6.1 The procedure for selection of mix proportions given in this section is applicable to normal weight concrete. Although the same basic data and procedures can be used in proportioning heavyweight and mass concretes, additional information and sample computations for these types of concrete are given in Appendixes 4 and 5, respectively.

6.2 Estimating the required batch weights for the concrete involves a sequence of logical, straightforward steps which, 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 selecting

the proportions. The job specifications may dictate some or all of the following:

6.2.1 Maximum water-cement or water-cementitious material ratio.

6.2.2 Minimum cement content.

6.2.3 Air content.

6.2.4 Slump.

6.2.5 Maximum size of aggregate.

6.2.6 Strength.

6.2.7 Other requirements relating to such things as strength overdesign, admixtures, and special types of cement, other cementitious materials, or aggregate.

6.3 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 yd³ of concrete can be best accomplished in the following sequence:

6.3.1 Step 1. Choice of slump -- If slump is not specified, a value appropriate for the work can be selected from Table 6.3.1. The slump ranges shown apply when vibration is used to consolidate the concrete. Mixes of the stiffest consistency that can be placed efficiently should be used.

Table 6.3.1 -- Recommended slumps for various types of construction*

Types of construction	Slump, in.	
	Maximum+	Minimum
Reinforced foundation walls and footings	3	1
Plain footings, caissons, and substructure walls	3	1
Beams and reinforced walls	4	1
Building columns	4	1
Pavements and slabs	3	1
Mass concrete	2	1

*Slump may be increased when chemical admixtures are used, provided that the admixture-treated concrete has the same or lower water-cement or water-cementitious material ratio and does not exhibit segregation potential or excessive bleeding.

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

6.3.2 Step 2. Choice of maximum size of aggregate -- Large nominal maximum sizes of well graded aggregates have less voids than smaller sizes. Hence, concretes with the larger-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 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-fourths of the minimum clear spacing between individual reinforcing bars, bundles of bars, or pretensioning strands. These limitations are sometimes waived if workability and methods of consolidation are such that the concrete can be placed without honeycomb or void. In areas congested with reinforcing steel, post-tension ducts or conduits, the proportioner should select a nominal maximum size of the aggregate so concrete can be placed without excessive segregation, pockets, or voids. When high strength concrete is desired, best results may be obtained with reduced nominal maximum size of aggregate since these produce higher strength at a given water-cement ratio.

Table 6.3.3 — Approximate mixing water and air content requirements for different slumps and nominal maximum sizes of aggregates

Water, lb/yd ³ of concrete for indicated nominal maximum sizes of aggregate								
Slump, in.	¾ in.*	½ in.*	¾ in.*	1 in.*	1-½ in.*	2 in.*†	3 in.†‡	6 in.†‡
Non-air-entrained concrete								
1 to 2	350	335	315	300	275	260	220	190
3 to 4	385	365	340	325	300	285	245	210
6 to 7	410	385	360	340	315	300	270	—
More than 7*	—	—	—	—	—	—	—	—
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-entrained concrete								
1 to 2	305	295	280	270	250	240	205	180
3 to 4	340	325	305	295	275	265	225	200
6 to 7	365	345	325	310	290	280	260	—
More than 7*	—	—	—	—	—	—	—	—
Recommended averages [§] total air content, percent for level of exposure:								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5***††	1.0***††
Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5***††	3.0***††
Severe exposure††	7.5	7.0	6.0	6.0	5.5	5.0	4.5***††	4.0***††

*The quantities of mixing water given for air-entrained concrete are based on typical total air content requirements as shown for "moderate exposure" in the table above. These quantities of mixing water are for use in computing cement contents for trial batches at 68 to 77 F. They are maximum for reasonably well-shaped angular aggregates graded within limits of accepted specifications. Rounded aggregate will generally require 30 lb less water for non-air-entrained and 25 lb less for air-entrained concretes. The use of water-reducing chemical admixtures, ASTM C 494, may also reduce mixing water by 5 percent or more. The volume of the liquid admixtures is included as part of the total volume of the mixing water. The slump values of more than 7 in. are only obtained through the use of water-reducing chemical admixture; they are for concrete containing nominal maximum size aggregate not larger than 1 in.

†The slump values for concrete containing aggregate larger than 1½ in. are based on slump tests made after removal of particles larger than 1½ in. by wet-screening.

‡These quantities of mixing water are for use in computing cement factors for trial batches when 3 in. or 6 in. nominal maximum size aggregate is used. They are average for reasonably well-shaped coarse aggregates, well-graded from coarse to fine.

§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, 345, 318, 301, and 302. 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 must be given to selecting an air content that will meet the needs of the job and also meet the applicable specifications.

**For concrete containing large aggregates that will be wet-screened over the 1½ in. sieve prior to testing for air content, the percentage of air expected in the 1½ in. minus material should be as tabulated in the 1½ in. column. However, initial proportioning calculations should include the air content as a percent of the whole.

††When using large aggregate in low cement factor concrete, air entrainment need not be detrimental to strength. In most cases mixing water requirement is reduced sufficiently to improve the water-cement ratio and to thus compensate for the strength-reducing effect of air-entrained concrete. Generally, therefore, for these large nominal maximum sizes of aggregate, air contents recommended for extreme exposure should be considered even though there may be little or no exposure to moisture and freezing.

‡‡These values are based on the criteria that 9 percent 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 percent of the actual mortar volume.

6.3.3 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; the concrete temperature; the amount of entrained air; and use of chemical admixtures. Slump is not greatly affected by the quantity of cement or cementitious materials within normal use levels (under favorable circumstances the use of some finely divided mineral admixtures may lower water requirements slightly -- see ACI 212.1R). Table 6.3.3 provides estimates of required mixing water for concrete made with various 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. The differences in water demand are not necessarily reflected in strength since other compensating factors may be involved. A rounded and an angular coarse aggregate, both well and similarly graded and of good quality, can be expected to produce concrete of about the same compressive strength for the same cement factor in spite of differences in w/c or $w/(c + p)$ resulting from the different mixing water requirements.

Particle shape is not necessarily an indicator that an aggregate will be either above or below in its strength-producing capacity.

Chemical admixtures -- Chemical admixtures are used to modify the properties of concrete to make it more workable, durable, and/or economical; increase or decrease the time of set; accelerate strength gain; and/or control temperature gain. Chemical admixtures should be used only after an appropriate evaluation has been conducted to show that the desired effects have been accomplished in the particular concrete under the conditions of intended use. Water-reducing and/or set-controlling admixtures conforming to the requirements of ASTM C 494, when used singularly or in combination with other chemical admixtures, will reduce significantly the quantity of water per unit volume of concrete. The use of some chemical admixtures, even at the same slump, will improve such qualities as workability, finishability, pumpability, durability, and compressive and flexural strength. Significant volume of liquid admixtures should be considered as part of the mixing water. The slumps shown in Table 6.3.1, "Recommended Slumps for Various Types of Construction," may be increased when chemical admixtures are used, providing the admixture-

treated concrete has the same or a lower water-cement ratio and does not exhibit segregation potential and excessive bleeding. When only used to increase slump, chemical admixtures may not improve any of the properties of the concrete.

Table 6.3.3 indicates the approximate amount of entrapped air to be expected in non-air-entrained concrete in the upper part of the table and shows the recommended average air content for air-entrained concrete in the lower part of the table. If air entrainment is needed or desired, three levels of air content are given for each aggregate size depending on the purpose of the entrained air and the severity of exposure if entrained air is needed for durability.

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

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

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

The use of normal amounts of air entrainment in concrete with a specified strength near or about 5000 psi may not be possible due to the fact that each added percent of air lowers the maximum strength obtainable with a given combination of materials.' In these cases the exposure to water, deicing salts, and freezing temperatures should be carefully evaluated. If a member is not 'continually wet and will not be exposed to deicing salts, lower air-content values such as those given in Table 6.3.3 for moderate exposure are appropriate even though the concrete is exposed to freezing and thawing temperatures. However, for an exposure condition where the member may be saturated prior to freezing, the use of air entrainment should not be sacrificed for strength. In certain applications, it may be found that the content of entrained air is lower than that specified, despite the use of usually satisfactory levels of air-entraining admixture. This happens occasionally, for example, when very high cement contents are involved. In such cases, the achievement of required durability may be demonstrated by satisfactory results of examination of air-void structure in the paste of the hardened concrete.

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. 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 over-optimistic estimate of strength on the assumption that average rather than extreme conditions will prevail in the field. If the concrete obtained in the field has a lower slump and/or air content, the proportions of ingredients should be adjusted to maintain required yield. For additional information on air content recommendations, see ACI 201.2R, 301, and 302.1R.

6.3.4 Step 4. Selection of water-cement or water-cementitious materials ratio -- The required w/c or $w/(c + p)$ is determined not only by strength requirements but also by factors such as durability. Since different aggregates, cements, and cementitious materials generally produce different strengths at the same w/c or $w/(c + p)$, it is highly desirable to have or to develop the relationship between strength and w/c or $w/(c + p)$ 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 6.3.4(a). With typical materials, the tabulated w/c or $w/(c + p)$ should produce the strengths shown, based on 28-day tests of specimens cured under standard laboratory conditions. The average strength selected must, of course, exceed the specific strength by a sufficient margin to keep the number of low tests within specific limits -- see ACI 214 and ACI 318.

Table 6.3.4(a) — Relationship between water-cement or water-cementitious materials ratio and compressive strength of concrete

Compressive strength at 28 days, psi*	Water-cement ratio, by weight	
	Non-air-entrained concrete	Air-entrained concrete
6000	0.41	—
5000	0.48	0.40
4000	0.57	0.48
3000	0.68	0.59
2000	0.82	0.74

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

Strength is based on 6 x 12 in. 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 method C 31 for Making and Curing Concrete Specimens in the Field. These are cylinders cured moist at $73.4 \pm 3^\circ\text{F}$ ($23 \pm 1.7^\circ\text{C}$) prior to testing.

The relationship in this table assumes a nominal maximum aggregate size of about 3/4 to 1 in. For a given source of aggregate, strength produced at a given w/c or $w/(c+p)$ will increase as nominal maximum size of aggregate decreases: see Sections 3.4 and 6.3.2.

For severe conditions of exposure, the w/c or $w/(c + p)$ ratio should be kept low even though strength requirements may be met with a higher value. Table 6.3.4(b) gives limiting values.

When natural pozzolans, fly ash, GGBF slag, and silica fume, hereafter referred to as pozzolanic materials, are used in concrete, a water-to-cement plus pozzolanic materials ratio (or water-to-cement plus other cementitious materials ratio) by weight must be considered in place of the traditional water-cement ratio by weight.

Table 6.3.4(b) — Maximum permissible water-cement or water-cementitious materials ratios for concrete in severe exposures*

Type of structure	Structure wet continuously or frequently and 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. cover over steel	0.45	0.40+
All other structures	0.50	0.45+

*Based on report of ACI Committee 201. Cementitious materials other than cement should conform to ASTM C 618 and C 989.

⁺Concrete should also be air-entrained.

+If sulfate resisting cement (Type II or Type V of ASTM C 150) is used, permissible water-cement or water-cementitious materials ratio may be increased by 0.05.

proaches normally used in determining the $w/(c + p)$ ratio that will be considered equivalent to the w/c of a mixture containing only portland cement: (1) equivalent weight of pozzolanic materials or (2) equivalent absolute volume of pozzolanic materials in the mixture. For the first approach, the weight equivalency, the total weight of pozzolanic materials remains the same [that is, $w/(c + p) = w/c$ directly]: but the total absolute volume of cement plus pozzolanic materials will normally be slightly greater. With the second approach, using the Eq. (6.3.4.2), a $w/(c + p)$ by weight is calculated that maintains the same absolute volume relationship but that will reduce the total weight of cementitious material since the specific gravities of pozzolanic materials are normally less than that of cement.

The equations for converting a target water-cement ratio w/c to a weight ratio of water to cement plus pozzolanic materials $w/(c + p)$ by (1) weight equivalency or (2) volume equivalency are as follows:

Eq. (6.3.4.1)—Weight equivalency

$$\frac{w}{c+p} \text{ weight ratio, weight equivalency} = \frac{w}{c}$$

where

$$\frac{w}{c+p} = \text{weight of water divided by weight of cement + pozzolanic materials}$$

$$\frac{w}{c} = \text{target water-cement ratio by weight}$$

When the weight equivalency approach is used, the percentage or fraction of pozzolanic materials used in the cementitious material is usually expressed by weight. That is, F_w , the pozzolanic materials percentage by weight of total

cement plus pozzolanic materials, expressed as a decimal factor, is

$$F_w = \frac{p}{c+p}$$

where

F_w = pozzolanic materials percentage by weight, expressed as a decimal factor

p = weight of pozzolanic materials

c = weight of cement

(Note: If only the desired pozzolanic materials percentage factor by absolute volume F_v is known, it can be converted to F_w as follows

$$F_w = \frac{1}{1 + \left(\frac{3.15}{G_p} \right) \left(\frac{1}{F_v} - 1 \right)}$$

where

F_v = pozzolanic materials percentage by absolute volume of the total absolute volume of cement plus pozzolanic materials expressed as a decimal factor

G_p = specific gravity of pozzolanic materials

3.15 = specific gravity of portland cement [use actual value if known to be different]

Example 6.3.4.1 -- Weight equivalency

If a water-cement ratio of 0.60 is required and a fly ash pozzolan is to be used as 20 percent of the cementitious material in the mixture by weight ($F_w = 0.20$), then the required water-to-cement plus pozzolanic material ratio on a weight equivalency basis is

$$\frac{w}{c+p} = \frac{w}{c} = 0.60, \text{ and}$$

$$F_w = \frac{p}{c+p} = 0.20$$

Assuming an estimated mixing-water requirement of 270 lb/yd³, then the required weight of cement + pozzolan is 270 ÷ 0.60 = 450 lb; and the weight of pozzolan is (0.20)(450) = 90 lb. The weight of cement is, therefore, 450 - 90 = 360 lb. If instead of 20 percent fly ash by weight, 20 percent by absolute volume of cement plus pozzolan was specified ($F_v = 0.20$), the corresponding weight factor is computed as follows for a fly ash with an assumed gravity of 2.40:

$$F_w = \frac{1}{1 + \left(\frac{3.15}{G_p} \right) \left(\frac{1}{F_v} - 1 \right)}$$

$$F_w = \frac{1}{1 + \left(\frac{3.15}{2.40} \right) \left(\frac{1}{0.2} - 1 \right)} = \frac{1}{1 + (1.31)(4)} = \frac{1}{1 + 5.24} = \frac{1}{6.24} = 0.16$$

In this case 20 percent by absolute volume is 16 percent by weight, and the weight of pozzolan in the batch would be $(0.16)(450) = 72$ lb, and the weight of cement $450 - 72 = 378$ lb.

Eq. (6.3.4.2) -- Absolute volume equivalency

$$\frac{W}{c+p} \text{ weight ratio, absolute volume equivalency} =$$

$$\frac{3.15 \frac{w}{c}}{3.15(1 - F_v) + G_p(F_v)}$$

where $\frac{w}{c+p}$ = weight of water divided by weight of cement + pozzolanic materials

$\frac{w}{c}$ = target water-cement ratio by weight

3.15 = specific gravity of portland cement (use actual value if known to be different)

F_v = pozzolan percentage by absolute volume of the total absolute volume of cement plus pozzolan, expressed as a decimal factor

(Note: If only the desired pozzolan percentage by weight F_w is known, it can be converted to F_v as follows

$$F_v = \frac{1}{1 + \left(\frac{G_p}{3.15} \right) \left(\frac{1}{F_w} - 1 \right)}$$

where these symbols are the same as defined previously.)

Example 6.3.4.2 -- Absolute volume equivalency

Use the same basic data as Example 6.3.4.1, but it should be specified that the equivalent water-to-cement plus

pozzolan ratio be established on the basis of absolute volume, which will maintain, in the mixture, the same ratio of volume of water to volume of cementitious material when changing from cement only to cement plus pozzolan. Again the required water-cement ratio is 0.60, and it is assumed initially that it is desired to use 20 percent by absolute volume of fly ash ($F_v = 0.20$). The specific gravity of the fly ash is assumed to be 2.40 in this example

$$\frac{w}{c+p} = \frac{3.15 \left(\frac{w}{c} \right)}{3.15(1 - F_v) + G_p(F_v)}$$

$$= \frac{(3.15)(0.60)}{(3.15)(0.80) + (2.40)(0.20)}$$

$$= \frac{1.89}{1.89 + 2.52 + 0.48} = \frac{1.89}{3.00} = 0.63$$

So the target weight ratio to maintain an absolute volume equivalency is $w/(c + p) = 0.63$. If the mixing water is again 270 lb/y₃, then the required weight of cement + pozzolan is $270 \div 0.63 = 429$ lb, and, since the corresponding weight percentage factor for $F_v = 0.20$ is $F_w = 0.16$ as calculated in Example 6.3.4.1, the weight of fly ash to be used is $(0.16)(429) = 69$ lb and the weight of cement is $429 - 69 = 360$ lb. The volume equivalency procedure provides lower weights of cementitious materials. Checking the absolute volumes

$$\text{fly ash} = \frac{69}{(2.40)(62.4)} = 0.461 \text{ ft}^3$$

$$\text{cement} = \frac{360}{(3.15)(62.4)} = 1.832 \text{ ft}^3$$

$$\text{total} = 0.461 + 1.832 = 2.293 \text{ ft}^3$$

$$\text{percent pozzolan by volume} = \frac{0.461}{2.293} \times 100 = 20 \text{ percent}$$

If, instead of 20 percent fly ash by volume ($F_v = 0.20$), a weight percentage of 20 percent was specified ($F_w = 0.20$), it could be converted to F_v using $G_p = 2.40$ and the appropriate formula

$$F_v = \frac{1}{1 + \left(\frac{G_p}{3.15} \right) \left(\frac{1}{F_w} - 1 \right)}$$

$$F_v = \frac{1}{1 + \left(\frac{2.40}{3.15} \right) \left(\frac{1}{0.2} - 1 \right)}$$

$$F_v = \frac{1}{1 + (0.762)(4)} = \frac{1}{4.048} = 0.247$$

In this case 20 percent by weight is almost 25 percent by

absolute volume. The equivalent $w/(c + p)$ ratio by volume will have to be recomputed for this condition since F_v has been changed from that originally assumed in this example

$$\begin{aligned} \frac{w}{c + p} &= \frac{3.15 \left(\frac{w}{c} \right)}{3.15(1 - F_v) + G_p(F_v)} \\ &= \frac{3.15(0.75) + 2.40(0.25)}{(3.15)(0.60)} \\ &= \frac{1.89}{2.36 + 0.60} = \frac{1.89}{2.96} = 0.64 \end{aligned}$$

Total cementitious material would be $270 \div 0.64 = 422$ lb. Of this weight 20 percent ($F_w = 0.20$) would be fly ash; $(422)(0.20) = 84$ lb of fly ash and $422 - 84 = 338$ lb of cement.

6.3.5 Step 5. Calculation of cement content -- The amount of cement per unit volume of concrete is fixed by the determinations made in Steps 3 and 4 above. The required cement is equal to the estimated mixing-water content (Step 3) divided by the water-cement ratio (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 pozzolanic or chemical admixtures will affect properties of both the fresh and hardened concrete. See ACI 212.

6.3.6 Step 6. Estimation of 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 an oven-dry-rodded basis, is used per unit volume of concrete. Appropriate values for this aggregate volume are given in Table 6.3.6. It can be seen that, for equal workability, the volume of coarse aggregate in a unit volume of concrete is dependent only on its nominal maximum size and the fine-

ness modulus of the 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 oven-dry-rodded void content.

The volume of aggregate in ft^3 , on an oven-dry-rodded basis, for a yd^3 of concrete is equal to the value from Table 6.3.6 multiplied by 27. This volume is converted to dry weight of coarse aggregate required in a yd^3 of concrete by multiplying it by the oven-dry-rodded weight per ft^3 of the coarse aggregate.

6.3.6.1 For more workable concrete, which is sometimes required when placement is by pump or when concrete must be worked around congested reinforcing steel, it may be desirable to reduce the estimated coarse aggregate content determined using Table 6.3.6 by up to 10 percent. However, caution must be exercised to assure that the resulting slump, water-cement or water-cementitious materials ratio, and strength properties of the concrete are consistent with the recommendations in Sections 6.3.1 and 6.3.4 and meet applicable project specification requirements.

6.3.7 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. Either of two procedures may be employed: the weight method (Section 6.3.7.1) or the absolute volume method (Section 6.3.7.2).

6.3.7.1 If the weight of the concrete per unit volume is assumed or can be estimated from experience, the required weight of fine aggregate is simply 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 6.3.7.1 can be used to make a first estimate. Even if the estimate of concrete weight per yd^3 is rough, mixture proportions will be sufficiently accurate to permit easy adjustment on the basis of trial batches as will be shown in the examples.

Table 6.3.6 – Volume of coarse aggregate per unit of volume of concrete

Nominal maximum size of aggregate, in.	Volume of oven-dry-rodded coarse aggregate* per unit volume of concrete for different fineness moduli of fine aggregate+			
	2.40	2.60	2.80	3.00
$\frac{3}{8}$	0.50	0.48	0.46	0.44
$\frac{1}{2}$	0.59	0.57	0.55	0.53
$\frac{3}{4}$	0.66	0.64	0.62	0.60
1	0.71	0.69	0.67	0.65
$1\frac{1}{2}$	0.75	0.73	0.71	0.69
2	0.78	0.76	0.74	0.72
3	0.82	0.80	0.78	0.76
6	0.87	0.85	0.83	0.81

*Volumes are based on aggregates in oven-dry-rodded condition as described in ASTM C 29.

These volumes are selected from empirical relationships to produce concrete with a degree of workability suitable for usual reinforced construction. For less workable concrete, such as required for concrete pavement construction, they may be increased about 10 percent. For more workable concrete see Section 6.3.6.1.

See ASTM C 136 for calculation of fineness modulus.

Table 6.3.7.1 – First estimate of weight of fresh concrete

Nominal maximum size of aggregate, in.	First estimate of concrete weight, lb/yd*	
	Non-air-entrained concrete	Air-entrained concrete
$\frac{3}{8}$	3840	3710
$\frac{1}{2}$	3890	3760
$\frac{3}{4}$	3960	3840
1	4010	3850
$1\frac{1}{2}$	4070	3910
2	4120	3950
3	4200	4040
6	4260	4110

*Values calculated by Eq. (6-1) for concrete of medium richness (550 lb of cement per yd^3) and medium slump with aggregate specific gravity of 2.7. Water requirements based on values for 3 to 4 in. slump in Table 6.3.3. If desired, the estimated weight may be refined as follows if necessary information is available: for each 10 lb difference in mixing water from the Table 6.3.3 values for 3 to 4 in. slump, correct the weight per yd^3 15 lb in the opposite direction; for each 100 lb difference in cement content from 550 lb, correct the weight per yd^3 15 lb in the same direction; for each 0.1 by which the aggregate specific gravity deviates from 2.7, correct the concrete weight 100 lb in the same direction. For air-entrained concrete the air content for 28-day exposure from Table 6.3.3 was used. The weight can be increased 1 percent for each percent reduction in air content from that amount.