

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

An ACI Standard

Reported by ACI Committee 211

Donald E. Dixon,
Chairman

Jack R. Prestrera,
Secretary

George R. U. Burg,*
Chairman, Subcommittee A

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Milton H. Willis, Jr.
Francis C. Wilson
Robert Yuan

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Gary R. Mass†
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Chairman, Subcommittee A

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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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† Members of Subcommittee A who prepared the 1991 revision.

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. Adaptation 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 concern about generation of an excessive amount of heat in concrete is not confined to