



## Concrete Craftsman Series

# Concrete Fundamentals



CCS-0(16)



American Concrete Institute  
*Always advancing*



Concrete Craftsman Series

# Concrete Fundamentals

CCS-0 Concrete Fundamentals was originally written by ACI Committee E703, Concrete Construction Practices.

The 2016 edition of CCS-0 was reviewed and approved by an Education Task Group including: William Nash, William Palmer, Michael Pedraza, David Suchorski, and Scott Tarr. Thank you to the Task Group members for their thoughtful and thorough review of the fundamental material.

CCS-0(16)



American Concrete Institute  
*Always advancing*

Concrete Craftsman Series:  
CCS-0 Concrete Fundamentals  
ISBN 978-1-942727-63-7  
Copyright © 2016 American Concrete Institute

ACI Committee Reports, Guides, and Commentaries are intended for guidance in planning, designing, executing, and inspecting construction. This document is intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. The American Concrete Institute disclaims any and all responsibility for the stated principles. The Institute shall not be liable for any loss or damage arising therefrom.

Reference to this document shall not be made in contract documents. If items found in this document are desired by the Architect/Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer.

Managing Editor: Katie A. Amelio, P.E.  
Art Program: Claire Hiltz  
Engineering Editors: Michael Tholen, Ph.D., P.E.  
Jerzy Zemajtis, Ph. D., P.E.  
Professional Development Specialist: Tiffany Vojnovski  
Technical Editors: Emily Bush, Cherrie Fergusson  
Manager, Publishing Services: Barry M. Bergin  
Production Editors: Carl Bischof, Kelli Slayden,  
Kaitlyn Hinman, Tiesha Elam  
Page Design & Composition: Ryan Jay  
Manufacturing: Marie Fuller

First Printing: December 2015  
Printed in Ann Arbor, Michigan.

American Concrete Institute  
38800 Country Club Drive  
Farmington Hills, MI 48331  
USA  
[www.concrete.org](http://www.concrete.org)  
+1.248.848.3700

# CONTENTS

<b>PREFACE</b>	<b>7</b>
<b>VOCABULARY</b>	<b>9</b>
<b>CHAPTER 1—INTRODUCTION</b>	
What is concrete?	17
Importance of concrete	19
Importance of the craftsman	21
Adding water to concrete	21
Handling concrete safely	24
<b>CHAPTER 2—CONCRETE MATERIALS</b>	
Portland cements	27
Types of portland cement	28
White and colored portland cement	30
Special types of cement	30
Aggregates	32
Nominal maximum size of aggregate	34
Aggregate grading	34
Harmful materials in aggregate	36
Handling aggregates	36
Mixing water	37
Admixtures	38
Supplementary cementitious materials	41
<b>CHAPTER 3—MIXTURE PROPORTIONING</b>	
Properties of the unhardened concrete	43
Properties of hardened concrete	45
Control of shrinkage and cracking	46
Effects of temperature	47
Proportioning example	48
Values needed to choose mixture proportions	49
A summary of concrete mixture proportioning by weight method according to ACI 211.1	49
Concrete for the small job	55

## **CHAPTER 4—BATCHING AND MIXING CONCRETE**

Batching	57
Mixing concrete	58
Stationary mixers: central or on site	58
Ready mixed concrete	60
Mobile batcher mixer	62
High-energy mixers	62
Remixing concrete	63
Maintenance of mixing equipment	64

## **CHAPTER 5—HANDLING, PLACING, AND CONSOLIDATING CONCRETE**

Handling and placing methods	66
Depositing concrete from the truck mixer	66
Wheelbarrows and buggies	67
Belt conveyors	68
Buckets and hoppers	69
Pumping concrete	69
Pneumatic or air gun placing	71
Shotcrete	71
Other placing equipment and methods	72
Depositing the concrete	73
Consolidation	74
Hand methods	74
Mechanical vibration	75
Internal vibration	75
Form vibration	77
Surface vibration	77
Roller compacted concrete	78
Benefits of consolidation	78
Self-consolidating concrete	79

## CHAPTER 6—CURING AND PROTECTION

Rain damage	81
Curing time and temperature	82
Accelerating admixtures	83
Keeping moisture in the concrete	84
Membrane-forming curing compounds	84
Waterproof paper or plastic film	85
Water spray or soaker hose	86
Wet burlap or mats	87
Other methods	87
Cold weather precautions	88
Protection against freezing	89
Hot weather precautions	91
Keeping cool	92
Avoiding delays	92
Plastic shrinkage cracking	93

## CHAPTER 7—FIELD TESTING AND CONTROL OF CONCRETE QUALITY

Sampling fresh concrete (ASTM C172/C172M)	95
Slump test (ASTM C143/C143M)	98
Air content tests	100
Air content by the pressure method (ASTM C231/C231M)	100
Air content by the volumetric method (ASTM C173/C173M)	101
Air content estimated with an air indicator	103
Density (unit weight) and yield (ASTM C138/C138M)	104
Temperature (ASTM C1064/C1064M)	106
Making test cylinders (ASTM C31/C31M)	106
Curing and protecting test cylinders	108
Cylinders for design strength check	109
Cylinders made for construction site control	110

## **CHAPTER 8—EVALUATING CONCRETE STRENGTH**

Core and Cylinder Strength Tests of Hardened Concrete	111
ACI 318 requirements	111
Cylinder compressive strength tests (ASTM C39/C39M)	112
Core tests (ASTM C42/C42M)	114
Nondestructive and in-place testing methods	115
Rebound hammer test (ASTM C805)	115
Penetration resistance method (ASTM C803/C803M)	117
Pullout tests (ASTM C900)	118
Pulse velocity test (ASTM C597)	118
Concrete maturity method (ASTM C1074)	119
Load testing concrete structures	119

## **APPENDIX A—REFERENCES**

Referenced standards and committee reports	121
American Concrete Institute	122
ASTM International	122



## PREFACE

This is one of six books in the Concrete Craftsman Series published by the American Concrete Institute. This book is intended for anyone who wants an introduction to concrete and concrete construction. Craftsmen in the concrete field may find it particularly useful as a guide for good practice.

Two other books in this series cover common concrete topics. “CCS-1 Slabs-on-Ground” covers good construction practices for slabs and is the basis for the ACI Flatwork Finisher Certification exam. “CCS-4 Shotcrete for the Craftsman” covers shotcrete construction practices and is the basis for the ACI Shotcrete Nozzleman Certification exam. CCS-4 is also available in a Spanish language edition.

Decorative concrete topics are covered in “CCS-5 Placing and Finishing Decorative Concrete Flatwork.” This book provides details about the materials, equipment, and techniques required to successfully install decorative concrete flatwork.

Two other books that are part of this series are no longer in publication. “CCS-2 Cast-in-Place Walls,” described formwork, reinforcement, placing of concrete, curing, and wall finishes. “CCS-3 Supported Beams and Slabs,” provided technical background on such subjects as shoring, reshoring, form removal, reinforcement placement, and concrete placing, finishing, and curing.

Because this book went back to cover the fundamentals, it is numbered accordingly. “CCS-0 Concrete Fundamentals,” starts with the most basic question of all, “What is concrete?” Other sections cover materials, basic construction practices, and testing. This book is a good starting point for someone in the concrete industry, whether they are an apprentice, a journeyman, a foreman, a material supplier, or even a young engineer without field experience. This book is not a design aid but rather a guide to good practice.

The design of concrete structures is the responsibility of a professional engineer. Designs are usually reviewed and approved by local building authorities and are governed by codes such as the International Building Code (IBC), or other local building codes that usually reference “Building Code Requirements for Structural Concrete (ACI 318) and Commentary.” This book is not a replacement for these documents. Plans and specifications for a specific project, and local building code requirements are required to be followed, even if they differ from the information in this book.



*Fig. 0.1—Project plans and specifications should be followed. Practices described in this book are not a replacement for project plans*

## VOCABULARY

If you are using this book as an introduction to concrete, you will soon notice that a lot of ordinary words like accelerator, bleeding, blistering, honeycomb, slump, and many others have their own very special meaning when applied to concrete. To help with these meanings, listed are some of the terms that appear in this book, along with brief definitions. For longer definitions and for other words not included here, refer to “ACI Concrete Terminology (CT-13),” published by the American Concrete Institute.

**Accelerator** — an admixture that causes an increase in the rate of hydration of the hydraulic cement and thus shortens the time of setting, increases the rate of strength development, or both.

**Admixture** — a material other than water, aggregates, cementitious materials, and fiber reinforcement, used as an ingredient of a cementitious mixture to modify its freshly mixed, setting, or hardened properties and that is added to the batch before or during its mixing.

**Aggregate** — granular material, such as sand, gravel, crushed stone, crushed hydraulic cement concrete, or iron blast-furnace slag used with a cementing medium to produce either concrete or mortar.

**Air-entraining agent** — an admixture for concrete that develops a system of microscopic bubbles of air in cement paste, mortar, or concrete during mixing.

**Air entrainment** — the incorporation of air in the form of microscopic bubbles (typically smaller than 0.04 in. [1 mm]) during the mixing of either concrete or mortar.

**Bleeding** — the autogenous flow of mixing water within, or its emergence from, a newly placed cementitious mixture caused by the settlement of solid materials within the mass.

**Blistering** — the irregular raising of a thin layer at the surface of a placed cementitious mixture during or soon after the completion of the finishing operation (Fig. 0.2).

**Bug holes** — common term used to describe surface air voids. Small regular or irregular cavities, usually not exceeding 5/8 in. (15 mm) in diameter, resulting from entrapment of air bubbles in the surface of formed concrete during placement and consolidation.

**Cement** — any of a number of materials that are capable of binding aggregate particles together. (See also hydraulic cement.)

**Cement paste** — binder of concrete and mortar consisting essentially of cement, water, hydration products, and any

admixtures together with very finely divided materials included in the aggregates.

**Cementitious materials** — pozzolans and hydraulic cements. (See also fly ash, silica fume, and slag cement.)

**Clinker** — a partially fused product of a kiln that is ground to make cement.

**Coarse aggregate** — aggregate predominantly retained on the No. 4 (4.75 mm) sieve or that portion retained on the No. 4 (4.75 mm) sieve (Fig. 0.3).

**Concrete compressive strength** — measured maximum resistance of a concrete specimen to axial compressive loading and expressed as a force per unit cross-sectional area.

**Consolidation** — the process of reducing the volume of voids, air pockets, and entrapped air in a fresh cementitious mixture, usually accomplished by inputting mechanical energy.

**Craze cracks** — fine random cracks or fissures in a surface of plaster, cement paste, mortar, or concrete.

**Crazing** — the development of craze cracks; the pattern of craze cracks existing in a surface.

**Curing** — action taken to maintain moisture and temperature conditions in a freshly placed cementitious mixture to allow hydraulic cement hydration and, if applicable, pozzo-



*Fig. 0.2—Example of concrete surface blistering (photo courtesy of Portland Cement Association (PCA))*



lanic reactions to occur so that the potential properties of the mixture may develop.

**Dropchute** — a device used to confine or direct the flow of a falling stream of fresh concrete. (1) *articulated dropchute* — a device consisting of a succession of tapered metal cylinders so designed that the lower end of each cylinder fits into the upper end of the one below; (2) *flexible dropchute* — a device consisting of a heavy rubberized canvas or plastic collapsible tube.

**Dusting** — development of a powdered material at the surface of hardened concrete.

**Final setting** — a degree of stiffening of a cementitious mixture greater than initial setting, generally stated as an empirical value indicating the time required for the cementitious mixture to stiffen sufficiently to resist, to an established degree, the penetration of a weighted test device. (See also initial setting.)

**Fine aggregate** — (1) aggregate passing the 3/8 in. (9.5 mm) sieve, almost entirely passing the No. 4 (4.75 mm) sieve, and predominantly retained on the No. 200 (75 mm) sieve; (2) that portion of aggregate passing the No. 4 (4.75 mm) sieve and predominantly retained on the No. 200 (75 mm) sieve. (See also aggregate.)



Fig. 0.3—Coarse aggregates (photo courtesy of CTLGroup)

**Fineness modulus** — a factor obtained by adding the total percentages of material in the sample that are coarser than each of the following sieves (cumulative percentages retained), and dividing the sum by 100: No. 100 (150 mm), No. 50 (300 mm), No. 30 (600 mm), No. 16 (1.18 mm), No. 8 (2.36 mm), No.4 (4.75 mm), 3/8 in. (9.5 mm), 3/4 in. (19.0 mm), 1-1/2 in. (37.5 mm), 3 in. (75 mm), and 6 in. (150 mm)

**Fly ash** — the finely divided residue that results from the combustion of ground or powdered coal and that is transported by flue gases from the combustion zone to the particle removal system.

**Grout** — mixture of cementitious materials and water, or other binding medium, with fine aggregate.

**High-range water-reducing admixture** — a water-reducing admixture capable of producing large water reduction or great flowability without causing undue set retardation or entrainment of air in mortar or concrete.

**Honeycomb** — voids left in concrete between coarse aggregates due to inadequate consolidation.

**Hydration** — the chemical reaction between hydraulic cement and water.

**Hydraulic cement** — a binding material that sets and hardens by chemical reaction with water and is capable of doing so underwater. For example, portland cement and slag cement are hydraulic cements.

**Initial setting** — a degree of stiffening of a cementitious mixture less than final set, generally stated as an empirical value indicating the time required for the cementitious mixture to stiffen sufficiently to resist, to an established degree, the penetration of a weighted test device. (See also final setting.)

**Mortar** — a mixture of cement paste and fine aggregate; in fresh concrete, the material occupying the interstices among particles of coarse aggregate; in masonry construction, joint mortar may contain masonry cement, or may contain hydraulic cement with lime (and possibly other admixtures) to afford greater plasticity and workability than are attainable with standard portland cement mortar.

**Paste** — see **Cement paste**.

**Plastic shrinkage cracking** — surface cracking that occurs in concrete before initial set.

**Plasticity** — property of freshly mixed cement paste, concrete, or mortar that determines its resistance to deformation or ease of molding.

**Portland cement** — a hydraulic cement made by pulverizing portland-cement clinker and usually with addition of calcium sulfate to control setting.

**Pozzolans** — a siliceous or silico-aluminous material that will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds having cementitious properties (there are both natural and artificial pozzolans).

**Prestressed concrete** — structural concrete in which internal stresses have been introduced to reduce potential tensile stresses in concrete resulting from loads.



*Fig. 0.4—Rodding is performed using a tamping rod, the length and diameter of the rod may vary based on the size of the sample being consolidated (photo courtesy of PCA)*



**Retarder** — an admixture that delays the setting of a cementitious mixture.

**Rock pocket** — a porous, mortar-deficient portion of hardened concrete consisting of coarse aggregate and voids. (See also honeycomb.)

**Rodding** — consolidation of concrete by means of a tamping rod (Fig. 0.4). (See also tamping.)

**Scaling** — local flaking or peeling away of the near-surface portion of hardened concrete or mortar (Fig. 0.5).

**Segregation** — the separation of coarse aggregate from the sand-cement mortar portion of the concrete mixture.

**Setting** — a chemical process that results in a gradual development of rigidity of a cementitious mixture, adhesive, or resin.



*Fig. 0.5—Scaling removes the top layer of paste from the concrete (photo courtesy of PCA)*



**Sieve** — a metallic plate or sheet, woven-wire cloth, or other similar device with regularly spaced apertures of uniform size mounted in a suitable frame or holder for use in separating granular material according to size.

**Silica fume** — very fine noncrystalline silica produced in electric arc furnaces as a byproduct of the production of elemental silicon or alloys containing silicon.

**Slag cement** — granulated blast-furnace slag that has been finely ground and that is hydraulic cement.

**Slump** — a measure of the consistency of freshly mixed concrete, equal to the subsidence of a molded specimen immediately after removal of the slump cone.

**Specified compressive strength** — compressive strength of concrete used in design.

**Superplasticizer** — See **High-range water-reducing admixture**.

**Supplementary cementitious material** — inorganic material such as fly ash, silica fume, metakaolin, or slag cement that reacts pozzolanically or hydraulically.

**Tamping** — the operation of consolidating freshly placed concrete by repeated blows or penetrations with a tamper. (See also consolidation and rodding.)

**Tensile strength** — maximum stress that a material is capable of resisting under axial tensile loading based on the cross-sectional area of the specimen before loading.

**Tremie** — a pipe or tube through which concrete is deposited under water, having at its upper end a hopper for filling and a bail for moving the assemblage.

**Vibration** — energetic agitation of freshly mixed concrete during placement by mechanical devices, either pneumatic or electric, that create vibratory impulses of moderately high frequency to assist in consolidating the concrete in the form or mold.

1. *External vibration* — employs vibrating devices attached at strategic positions on the forms and is particularly applicable to manufacture of precast items and for vibration of tunnel-lining forms; in manufacture of concrete products, external vibration or impact may be applied to a casting table.

2. *Internal vibration* — employs one or more vibrating elements that can be inserted into the fresh concrete at selected locations, and is more generally applicable to in-place construction.

3. *Surface vibration* — employs a portable horizontal platform on which a vibrating element is mounted.

**Water-cement ratio ( $w/c$ )** — the ratio of the mass of water, exclusive only of that absorbed by the aggregates, to the mass of portland cement in a cementitious mixture, stated as a decimal and abbreviated as  $w/c$ .

**Water-cementitious materials ratio ( $w/cm$ )** — the ratio of the mass of water, excluding that absorbed by the aggregate, to the mass of cementitious material in a mixture, stated as a decimal and abbreviated  $w/cm$ . (See also water-cement ratio.)

**Workability** — the property of freshly mixed concrete or mortar that determines the ease with which it can be mixed, placed, consolidated, and finished to a homogenous condition.

**Yield** — (1) the volume of freshly mixed concrete produced from a known quantity of ingredients; (2) the total mass of ingredients divided by the density mass of the freshly mixed concrete; (3) the number of units produced per bag of cement or per batch of concrete.