CONCRETE PORTABLE HANDBOOK

R. DODGE WOODSON

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This book is dedicated to my daughter, Afton, and her new husband, Giovanni. May Mr. and Mrs. Sinclair enjoy a healthy, happy, productive marriage for their future years.

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CHAPTER

1

Basic Information

OUTLINE

Who controls the codes that you are to work with? Where are the minimum standards of good practice for concrete work found? Your local code enforcement office will mandate the code requirements in your personal jurisdiction. It is very likely that your local code requirements will be based on the recommendations and requirements set forth by the American Concrete Institute® (ACI).

I talked with people at the International Code Conference (ICC) and confirmed that the ICC codes are based around the ACI requirements for both structural concrete and reinforced concrete applications. Essentially, the ACI requirements are the foundation of most building codes.

There are some exceptions to the coverage of the ACI recommendations. For example, soil-supported slabs are often exempt from the rules of the ACI, but this is not always the case. If a slab transmits vertical loads or lateral forces from other portions of a structure to the soil, the slab requirements can be tied to the ACI regulations.

ACI regulations do not apply to the installation or design of structural concrete slabs cast on stay-in-place, composite steel form decks.

Areas subject to seismic risk levels are commonly governed by the local building code in conjunction with the ACI recommendations. Earthquake-resistance building principles are generally adopted from the ACI.

PAPERWORK

There are a host of requirements that must be met prior to the approval of a permit and these documents must bear the seal of a registered engineer or architect. Common elements required as part of an official submittal may include, but not be limited to, the following:

- Name and date of issue of the code requirements used to determine drawings and specifications
- Any supplement to the code used in the design and specifications
- Specified compressive strength of concrete at stated ages
- Each section of the structure has a compressive strength of concrete at stated stages of construction
- Specified strength or grade of reinforcement
- Size of all structural elements, reinforcement, and anchors
- Location or specified structural elements, reinforcement, and anchors
- Provision for dimensional changes that may result from creep, shrinkage, or temperature
- Magnitude of prestressing forces
- Location of prestressing forces
- Anchorage length of reinforcement
- Location and length of lap splices
- Types of mechanical and welded splices of reinforcement to be used
- Location of mechanical and welded splices of reinforcement to be used
- Details and location of all contraction or isolation joints specified for plain concrete
- Minimum compressive strength of concrete at the time of post tensioning
- Stressing sequences of post-tensioning tendons
- Statements pertaining to slabs on grade that are designed as structural diaphragms

Calculations that pertain to the design of concrete applications are filed with the drawings and specifications for a job when permit application is made. Computer-generated information is normally acceptable for calculations.

If model analysis is used, the process should be performed by an experienced engineer or architect.

INSPECTION

Code office inspections of concrete installations are required to assure that minimum standards are met. Workmanship is a key factor in the success of concrete construction. The best materials and designs will be inadequate if they are not used properly in an installation. On the rare occasions when a building code official is not available in a region, inspections may be done by qualified, registered design professionals or qualified inspectors.

Tip

Records of inspections are usually required to be kept by the inspecting engineer or architect for two years beyond the completion of construction.

When inspectors review a site location there are a number of components included in a proper inspection. The following list outlines common objectives reviewed during an official inspection:

- Quality of concrete materials
- Proportions of concrete materials
- Strength of concrete materials
- Construction methods and materials of forms
- Removal of forms and reshoring
- Placement of reinforcement and anchors
- Mixing concrete
- Placing concrete
- Curing of concrete
- Sequence of erection and connection of precast members
- Tendon tensioning
- Significant construction loadings on completed concrete structures
- General progress and workmanship

Tip

Ambient temperature changes below 40°F or above 95°F require that a record be kept of all concrete temperatures and any and all protection given to concrete during placement and curing.

SPECIAL CONSIDERATIONS

Sometimes a situation arises where a system designer wishes to stray from the traditional code requirements. When this is the case, design specifications can be brought to the attention of a local code officer. It may be necessary for special approvals to be requested from a board of examiners who are appointed by building officials. This board is typically made up of qualified engineers.

The board will consider testing procedures, load factors, deflection limits, and similar types of pertinent data.

CHAPTER

2

Concrete Materials

OUTLINE

Concrete materials are obviously a key element in concrete construction, and building officials have the power to require testing of any of these concrete materials. The purpose of this testing is to ensure that all of the materials meet the quality specified when applying for a permit. The results of these tests are generally required to be available for review for at least two years after construction is completed.

When it comes to discussing approved types of cement, specifications and standards will come from the American Standard Testing Methods (ASTM).

EXHIBIT: OVERVIEW OF PORTLAND CEMENT AND CONCRETE

Overview of Portland Cement and Concrete

Although the terms "cement" and "concrete" are often used interchangeably, cement is actually an ingredient of concrete. Cements are binding agents in concretes and mortars. Concrete is an artificial rock-like material, basically a mixture of coarse aggregate (gravel or crushed stone), fine aggregate (sand), cement, air, and water. Portland cement is a general term used to describe a variety of cements. Because they are hydraulic cements, they will set and harden by reacting chemically with water through hydration.

Current (2004) world total annual production of hydraulic cement is about 2 billion metric tons (Gt), with production spread unevenly among more than 150 countries. This quantity of cement is sufficient for about 14–18 Gt/year of concrete (including mortars), and makes concrete the most abundant of all manufactured solid materials. The current yearly output of hydraulic cement is sufficient to make about 2.5 metric tons per year (t/year) of concrete for every person worldwide (van Oss, 2005).

Cement and Cement Manufacturing

Hydraulic cements are the binding agents in concretes and most mortars and are thus common and critically important construction materials. Hydraulic cements are of two broad types: those that are inherently hydraulic (i.e., require only the addition of water to activate), and those that are pozzolanic. The term pozzolan (or pozzolanic) refers to any siliceous material that develops hydraulic cementitious properties in the presence of lime [$Ca(OH)_2$]. This includes true pozzolans and latent cements. The difference between these materials is that true pozzolans have no cementitious properties in the absence of lime, whereas latent cements already have some cementitious properties, but these properties are enhanced in the presence of lime. Pozzolanic additives or extenders can be collectively termed supplementary cementitious materials (SCM; van Oss, 2005).

Portland cement is the most commonly manufactured and used hydraulic cement in the United States (and the world). It is manufactured through the blending of mineral raw materials at high temperatures in cement rotary kilns. Rotary kilns produce an intermediate product called "clinker." Clinker is ground to produce cement. By modifying the raw material mix and, to some degree, the temperature of manufacture, slight compositional variations in the clinker can be achieved to produce Portland cements with varying properties.

Similar varieties of Portland cement are made in many parts of the world but go by different names. In the United States, the different varieties of straight Portland cement are denoted per the ASTM Standard C-150 as:

- Type I: general use Portland cement. In some countries, this type is known as ordinary Portland cement.
- Type II: General use Portland cement exhibiting moderate sulfate resistance and moderate heat of hydration.
- Type III: High-early-strength Portland cement.
- Type IV: Portland cement with low-heat hydration.
- Type V: Portland cement with high sulfate resistance.

For Types I, II, and III, the addition of the suffix A (e.g., Type IA) indicates the inclusion of an air-entraining agent. Air-entraining agents impart a myriad of tiny bubbles into the concrete containing the hydrated cement. This offers certain advantages to the concrete, such as improved resistance to freeze-thaw cracking. In practice, many companies market hybrid Portland cements; Type I/II is a common hybrid that meets the specifications of both Types I and II. Another common hybrid is Type II/V.

Blended Cements

Blended cements (called composite cements in some countries) are intimate mixes of a Portland cement base (generally Type I) with one or more SCM extenders. The SCMs make up about 5–30% by weight of the total blend, but can be higher.

In blended cements, the SCMs (or pozzolans) are activated by the high pH resulting from the hydroxide ions released during the hydration of Portland cement. The most commonly used SCMs are volcanic ashes called pozzolana, certain types of fly ash (from coal-fired power plants), ground-granulated, blast-furnace slag (GGBFS) — now increasingly being referred to as slag cement — burned clays, silica fume, and cement kiln dust (CKD). In general, incorporation of SCMs with

Portland cement improves the resistance of the concrete to chemical attack, reduces the concrete's porosity, reduces the heat of hydration of the cement (not always an advantage), potentially improves the flowability of concrete, and produces a concrete having about the same long-term strength as straight Portland cement-based concretes. However, SCMs generally reduce the early strength of the concrete, which may be detrimental to certain applications (van Oss, 2005).

Blended cements can be prepared at a cement plant for sale as a finished blended cement product or can be blended into a concrete mix. Most of the SCM consumption by U.S. concrete producers is material purchased directly for blending into the concrete mix. Concrete producers in the United States buy relatively little finished blended cement.

The designations for blended cements vary worldwide, but those currently in use in the United States meet ASTM Standard C-595, C 989, or C-l 157. ASTM Standard C-595 defines several types of blended cements. The main designations include (van Oss, 2005):

- Portland blast-furnace slag cement (IS): Contains 25–70% GGBFS.
- Portland-pozzolan cement (IP and P): Contains a base of Portland and/or IS cement and 15–40% pozzolans.
- Pozzolan-modified Portland cement (I(PM)): The base is Portland and/or Type IS cement with a pozzolan addition of less than 15%.
- Slag-modified Portland cement (I(SM)): Contains less than 25% GGBFS.
- Slag cement (S):[1] GGBFS content of 70% or more. Type S can be blended with Portland cement to make concrete or with lime for mortars; the latter combination would make the final cement a pozzolan-lime cement.

Chemical Composition of Portland Cement

Modern straight Portland cement is a very finely ground mix of Portland cement clinker and a small amount (typically 3–7%) of gypsum (calcium sulfate dihydrate) and/or anhydrite (calcium sulfate). Cement chemistry is generally denoted in simple stoichiometric shorthand terms for the major constituent oxides. Table 2.1 provides the shorthand notation for the major oxides in the cement literature. It also shows the typical chemical composition of modern Portland cement and its clinker. For clinker, the oxide compositions would generally not vary from the rough averages shown by more than 2–4%. The oxide composition of Portland cement would vary slightly depending on its actual gypsum fraction or whether any other additives are present.

Mineralogy of Portland Cement and Its Clinker

The major oxides in clinker are combined essentially into just four cement or clinker minerals, denoted in shorthand: tricalcium silicate or "alite" (C_3S), dicalcium silicate or "belite" (C_2S), tricalcium aluminate (C_3A), and tetracalcium aluminoferrite (C_4AF). These formulas represent averages, ignoring impurities commonly found in actual clinker. It is the ratios of these four minerals (and gypsum) that determine the varying properties of different types of Portland cements. Table 2.2 provides the chemical formulas and nomenclature for the major cement oxides as well as the function of each in cement mixtures.

As indicated in Table 2.2, some of the minerals in clinker serve different functions in the manufacturing process while others impart varying final properties to the cement. The proportion of C_3S, for example, determines the degree of early strength development of the cement. The "ferrite"

[1]True Type S cements are no longer commonly made in the United States. Instead, the name slag cement (but with no abbreviation) is now increasingly given to the unblended 100% GGBFS product (van Oss, 2005). ASTM C 989 now governs slag cement (GGBFS).

TABLE 2.1 Chemical Shorthand and Composition of Clinker and Portland Cement

Oxide Formula	Shorthand Notation	Percentage by Mass in Clinker	Percentage by Mass in Cement*
CaO	C	65	65.0
SiO_2	S	22	22.0
Al_2O_3	A	6	6.0
Fe_2O_3	F	3	3.0
MgO	M	2	2.0
$K_2O + Na_2O$	K + N	0.6	0.6
Other (including SO_3)	…(…$\bar{S}$)	1.4	3.6
H_2O	H	"nil"	1.0

Source: van Oss, 2005.
Based on clinker shown plus 5% addition of gypsum ($CaSO_4 \cdot 2H_2O$).

TABLE 2.2 Typical Mineralogical Composition of Modern Portland Cement

Chemical Formula	Oxide Formula	Shorthand Notation	Description	Typical Percentage	Mineral Function
Ca_3SiO_5	$(CaO)_3SiO_2$	C_3S	Tricalcium silicate (alite)	50–70	Hydrates quickly and imparts early strength and set.
Ca_2SiO_4	$(CaO)_2SiO_2$	C_2A	Dicalcium silicate	10–30	Hydrates slowly and imports long-term (ages beyond 1 week) strength.
$Ca_3A1_2O_6$	$(CaO)_3A1_2O_3$	C_4AF	Tricalcium aluminate	3–13	Hydrates almost instantaneously and very exothermically. Contributes to early strength and set.
$Ca_4A1_2Fe_2O_{10}$	$(CaO)_4A1_2O_3Fe_2O_3$	C_4AF	Tetracalcium aluminoferrite	5–15	Hydrates quickly. Acts as a flux in clinker manufacture. Imparts gray color.
$CaSO_42H_2O$	$(CaO)(SO)_3(H_2O)_2$	$C\bar{S}H_2$	Calcium sulfate dehydrate (gypsum)	3–7	Interground with clinker to make Portland cement. Can substitute anhydrite ($C\bar{S}$). Controls early set.
$CaSO_4$	$(CaO)(SO_3)$	$C\bar{S}$	Anhydrous calcium sulfate	0.2–2	

Source: van Oss, 2005.