These 1 Exam Prep Tabs are based on the *15th Edition of the Design and Control of Concrete Mixtures, Kosmatka and Panarese, Portland Cement Association copyright 2011.*

Each 1 Exam Prep tabs sheet has five rows of tabs. Start with the first tab at the first row at the top of the page; proceed down that row placing the tabs at the locations listed below. Place each tab in your book setting it down one notch until you get to the last tab (usually the index or glossary). Then start with the highlights.

**Special Note to our Students:** If you are a 1 Exam Prep student, here is how to really get the most from these 1 Exam Prep Tabs. Follow the above instructions, but before placing the tab, find the tab’s topic in the outline of your appropriate module. Now locate and highlight several items listed in the outline just before the topic, and just after. See how the topic fits in the outline and how it relates as a concept to the broader concept spelled out in the outline. If you take a few minutes to do this, when you take the test key words in the test questions will remind you of where the information is in the manual!

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<td><strong>Bridges:</strong> More than 70% of the bridges throughout the U.S. are constructed of concrete.&quot;</td>
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<td>Figure 1-12. Range in proportions of materials used in concrete, by absolute volume. (Notice the proportions of the various elements.)</td>
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<td>&quot;Aggregates are generally divided into two groups: fine and coarse. Fine aggregates consist of natural or manufactured sand with particle sizes ranging up to 9.5 mm (3/8 in.); coarse aggregates are particles retained on the 1.18 mm (No. 16) sieve and ranging up to 150 mm (6 in.) in size.&quot;</td>
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<td>&quot;Since aggregates make up about 60% to 75% of the total volume of concrete, their selection is important.&quot;</td>
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<td>&quot;Some advantages of reducing water content include: (6 bullets.)</td>
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<td><strong>Transporting:</strong> 'ASTM C 94, Standard Specification for Ready-Mixed Concrete (AASHTO M 157)*, requires that the concrete be delivered and placed within 90 minutes after the addition of water to the mixture ... 300 revolutions of the mixing drum ..&quot;</td>
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Hydration and Curing: "Hydration begins as soon as cement comes in contact with water."

"Hydration continues as long as favorable moisture and temperature conditions exist and space for hydration products is available. As hydration continues, concrete becomes harder and stronger. Most of the hydration and strength development take place within the first month but then continues slowly for a long time with adequate moisture and temperature. Continuous strength increase exceeding 30 years have been recorded."

The primary driving factors are generally recognized as: Note each of the following sections: Energy Conservation and Atmosphere; Water Management and Resources; Site Selection and Development; Indoor Environmental Quality; Material Quality and Resources; Functional Resilience.

Rating Systems: Concrete and LEED: "Concrete use can contribute credit in fifteen categories in the LEED for New Construction and Major Renovations (NC) 2009 system as summarized in Table 2-1."

Table 2-1. Potential Contributions by Concrete to LEED® 2009 for New Construction and Major Renovations (NC) v3.

Concrete Sustainability: "The following sections elaborate on the characteristics of concrete structures that contribute to innovative sustainable designs." Note each of the following sections: Durability; Safety; Disaster Resistance; Blast Resistance.

Energy Performance: Thermal Mass: "Thermal mass is the property that enables building materials to absorb store, and later release significant amounts of heat."

Heat-Island Reduction: "Heat islands are areas that have higher ambient air temperatures as compared to their surrounding areas."

Highlight only the headings of the following sections: Lighting Efficiency; Indoor Air Quality; Acoustics; Storm water Management; Pervious Concrete; and Permeable Grid Paver Systems.

Recycling. Post-consumer and Pre-consumer.

Life-Cycle Analysis. A life-cycle-cost analysis (LCCA) is the practice of accounting for all expenditures incurred over the service-life of a particular structure."

"Hydraulic cements set and harden by reacting chemically with water and maintain their stability underwater."

"The clinker is rapidly cooled and then pulverized into a fine material. During this operation, small amounts of gypsum (Figure 3-10) are added to regulate the setting time of the cement and to improve shrinkage and strength development properties. Limestone and inorganic processing additions may also be added, each in amounts up to 5% by mass."
Types of Portland Cement: Types I - V (Note the definition which follows of each of the types.)

Blended Hydraulic Cements: Type IS; Type IP; and Type IT. (Note the definition of each type.)

Masonry and Mortar Cements: "Masonry cements and mortar cements are hydraulic cements designed for use in mortar for masonry construction (Figures 3-22). They consist of a mixture of portland cement or blended hydraulic cement and plastizing materials (such as limestone or hydrated or hydraulic lime), together with other materials introduced to enhance one or more properties ..."

Table 3-3. Applications for Hydraulic Cements Used in Concrete Construction*

Table 3-4 Applications. Applications for Special Cements

Plastic Cements: "Plastic cement is a hydraulic cement that meets the requirements of ASTM C1328, Standard Specification for Plastic (Stucco) Cement. It is used to produce portland cement-based plaster or stucco (ASTM C926). These cements are popular throughout the southwest and west coast of the United States (Figure 3-23)."

Finely-Ground Cements (Ultrafine Cements): Finely-ground cements, also referred to as ultrafine cements, are hydraulic cements, that are ground very fine for use in grouting into fine soil or thin rock fissures (Figure 3-24).

Expansive Cements: "Expansive cement is a hydraulic cement that expands slightly during the early hardening period."

Oil-Well Cements: "Oil-well cements are used for oil-well grouting. (This procedure is often called oil well cementing). Oil-well cements are usually made from Portland cement clinker or from blended hydraulic cements."

Rapid Hardening Cements: "Rapid hardening, high early strength, hydraulic cement is used in construction applications, such as fast-track paving, where fast strength development is required ..."

Cements with Functional Additions: "Functional additions can be interground with cement clinker to beneficially change the properties of hydraulic cement."

Water-Repellent Cements: "Water-repellent cements, sometimes called waterproofed cements, are usually made by adding a small amount of water repellent additive such as stearate (sodium, aluminum, or other) to cement clinker during final grading."
Regulated-Set Cements: "Regulated-set cement is a calcium fluoroaluminate hydraulic cement that can be formulated and controlled by produce concrete with setting times ranging from a few minutes to one hour."

Geopolymer Cements: Geopolymer cements are inorganic hydraulic cements that are based on the polymerization of minerals. "The term more specifically refers to alkali-activated alumino-silicate cements, also called zeolitic or polysialate cements."

Ettringite Cements: "Ettringite cements are calcium sulfoaluminate cements that are specially formulated for particular uses, such as the stabilization of waste materials."

Calcium Aluminate Cements: "Calcium aluminate cement is not Portland cement based. It is used in special applications for early strength gain (for example, to achieve design strength in one day), resistance to high temperatures, and resistance to sulfates, weak acids, and seawater."

Magnesium Phosphate Cements: "Magnesium phosphate cement is a rapid setting, early strength gain cement. It is usually used for special applications, such as repair of pavements and concrete structures or for resistance to certain aggressive chemicals."

Sulfur Cements: "Sulfur cement is used with conventional aggregates to make sulfur cement concrete for repairs and chemically resistant applications. Sulfur cement melts at temperatures between 113°C and 121°C (235°F and 250°F)."

Selecting and Specifying Cements: "If no special properties, (such as low-heat generation or sulfate resistance) are required, all general use cements should be permitted."

Availability of Cements: "Some types of cement may not be readily available in all areas of the United States. ATM C150 (AASHTO M 85) Type I portland cement is usually carried in stock and is furnished when no other type of cement is specified."

Canadian and European Cement Specifications: "In some instances, projects in the United States designed by engineering firms from other countries refer to cement standards other than those in ASTM or AASHTO."

"Water is observed in cementitious materials in different forms." Note the definitions of each: free water; bound water; evaporable water; and non-evaporable water. "For complete hydration of portland cement to occur, only about 40% water (a water-cement ratio of 0.40) is required. If a water cement ratio greater than about 0.40 is used, the excess water not needed for cement hydration remains in the capillary pores or evaporates."

Physical Properties of Cement: Note the definitions of each: Compressive Strength; Setting Time; Early Stiffening; Particle Size and Fineness; Soundness; Consistency; and Heat of Hydration.
"In calorimetry testing, the first heat measurements are typically obtained 5 to 7 minutes after mixing the paste; as a result, often only the downward slope of the first peak is observed."

**Loss on Ignition:** "Loss on ignition (L01) of portland cement is determined by heating a cement sample of known weight up to a temperature between 900°C and 1000°C until a constant weight is obtained."

**Thermal analysis:** "Typical uses for thermal analysis include: (8 bullets)" Note the definitions of each: Thermogravimetric Analysis (TGA); Differential Thermal Analysis (DTA); and Differential Scanning Calorimetry (DSC).

**Virtual Cement Testing.** Testing cement by simulating hydration on a computer.

**Transportation and Packaging:** "Traditionally a U.S. bag contained 94 lb (42.6 kg) and had a volume of 28 L (one cubic foot)"

"The mass of masonry cement and mortar cement by the bag is 36 kg for Type M, 34 kg for Type S, and 32 kg for Type N. Plastic cement has a mass of 42 kg for Type M and 35 kg for Type S…"

**Storage of Cement:** "Cement bags should not be stored on damp floors but should rest on pallets..."

"A pozzolan is a siliceous or aluminosiliceous material…"

**Fly Ash:** "Fly ash. the most widely used SCM in concrete, is a byproduct of the combustion of pulverized coal in electric power generating plants." "In the process, the fused material cools and solidifies into glassy particles called fly ash."

**Slag Cement:** "Slag cement, previously known as ground, granulated blast-furnace slag (GGBF), is the glassy material formed from molten slag produced in blast furnaces as a byproduct from the production of iron used in steel making."

"In order to transform the molten slag into a cementitious material ... to form a glassy, sand-like, granulated material, then dried and ground into a fine powder."

"Slag cement, when used in general purpose concrete in North America, commonly constitutes between 30% and 50% of the cementitious material in the mixture."

**Silica Fume:** "Silica fume is the ultrafine noncrystalline silica produced in electric-arc furnaces as an industrial byproduct of the production of silicon metals and ferrosilicon alloys. Silica fume is also known as condensed silica fume, or micro-silica."
Natural Pozzolans: "Natural pozzolans are produced from natural mineral deposits. Some of these materials require heat treatment known as calcining, to make them pozzolanic. Others, such as volcanic ash, can be used with only minimal processing (such as drying and grinding)."

Effects on Freshly Mixed Concrete: Water Demand: "Concrete mixtures containing fly ash generally require less water (about 1% to 10% less at normal dosages) for a given slump than concrete containing only portland cement."

"In general, water demand for a given slump in concrete mixtures with slag cement will be 3% to 5% lower than ordinary portland cement concrete."

Workability. "Generally, the use of fly ash, slag cement, and calcined clay and shale increase workability. ..." "Concrete containing SCMs will generally have equal or improved finishability compared to similar concrete mixtures without them."

Bleeding and Segregation. "Concretes using fly ash generally exhibit less bleeding and segregation."

Setting Time. "The use of SCMs will generally retard the setting time of concrete ..." Note and highlight the other additives that will delay setting time.

Air Content. "For fly ash concrete mixtures, the amount of air-entraining admixture required to achieve a certain air content in the concrete is primarily a function of the carboi content."

Heat of Hydration. "The majority of supplementary cementing materials (fly ash, natural pozzolans, and slag cement) typically have a lower heat of hydration than portland cement."

Effects on Hardened Concrete: Strength: "In general, supplementary cementing materials (fly ash, slag cement, silica fume, calcined shale, and calcined clay (including Metakaolin)) all contribute to the longterm strength gain of concrete."

"However, the strength of concrete containing these materials can be either higher or lower than the strength of concrete using only Portland cement ... Figure 4-12."

"As with portland cement concrete, low curing temperatures can reduce early strength gain (Gebler and Klieger 1986)."

Impact and Abrasion Resistance: "Supplementary cementing materials generally do not affect these properties beyond their influence on strength."

Permeability and Absorption: "With appropriate design of the concrete mixture, control of w/cm, and adequate curing; fly ash, slag cement, and natural pozzolans generally reduce the permeability and absorption of concrete."
Corrosion Resistance: When concrete is properly cured, SCMs can help reduce reinforcing steel corrosion by reducing the permeability of concrete to water, air, and chloride ions.

Alkali-Silica Reactivity: "Alkali-silica reactivity (ASR) can be controlled through the use of SCMs (Figures 4-15 and 4-16)."

Sulfate Resistance: "With proper proportioning and material selection, most supplementary cementing materials can improve the resistance of concrete to sulfate or seawater attack."

Chemical Resistance: "Supplementary cementitious materials often reduce chemical attack by reducing the permeability of concrete."

Freeze-Thaw Resistance: "... the freeze-thaw resistance of concrete is dependent on the air void system of the paste, the strength of the concrete, the water-to-cementitious materials ratio, and the quality of aggregate relative to its freeze-thaw resistance."

Deicer-Scaling Resistance: "Decades of field experience have demonstrated that air-entrained concretes containing normal dosages of fly ash, slag cement, silica fume, calcined clay, or calcined shale are resistant to the scaling caused by the application of deicing salts in a freeze-thaw environment ..."

"Scaling resistance can decrease as the amount of SCMs increases ..."

"The importance of using a low water-cement ratio for scaling resistance is demonstrated in Figure 4-19."

"The ACI 318 building code ... Total SCM content should not exceed 50% of the cementitious material"

Aesthetics: "Supplementary cementitious materials may slightly alter the color of hardened concrete."

Concrete Mixture Proportions: "The optimum amounts of SCMs used with portland cement or blended cement are determined by testing, taking into account the relative cost and availability of the materials, and the specified properties of the concrete."

"Typical practice in the United States uses fly ash, slag, silica fume, calcined clay, or calcined shale ..."

Availability: "All SCMs may not be available in all areas. Consult local material appliciers on availability."

Storage: "In some cases, moisture will not affect the physical performance of SCMs. In general these materials should be kept dry to avoid difficulties in handling and discharge."
"Water of questionable suitability, including nonpotable water or water from concrete production operations, can be used in concrete if it is qualified for use ..."

"The 7-day strength of concrete cylinders ...must achieve at least 90% of the strength of the control batch."

Seawater: "Seawater containing up to 35,000 ppm of dissolved salts is generally suitable as mixing water for concrete not containing reinforcing steel. About 78% of the salt is sodium chloride, and 15% is chloride and sulfate of magnesium"

"Seawater is not suitable for use in production of concrete with steel reinforcement and likewise, it should not be used in pre-stressed concrete due to the risk of corrosion of the reinforcement."

Effects of Impurities in Mixing Water on Concrete Properties: "Water containing less than 2000 parts per million (ppm) of total dissolved solids is generally satisfactory for use in concrete."

Alkali Carbonate and Bicarbonate: "Carbonates and bicarbonates of sodium and potassium have varying effects on the setting times of different cements. Sodium carbonate can cause very rapid setting, bicarbonates can either accelerate or retard the set depending on the chemistry of the cement used in the concrete. In large concentrations, these salts can materially reduce concrete strength. When the sum of the dissolved salts exceeds 1000 ppm, tests for their effect on setting time and 28-day strength should be made."

Chloride: "The ACI 318 building code and CSA Standard A23.1 limit water soluble chloride ion content in reinforced concrete to the following percentages by mass of cement (CSA's limit is based on mass of cementitious materials): (Note the percentage.)" "ACI 318 and CSA Standard A23.1 do not limit the amount of chlorides in plain (unreinforced) concrete."

Sulfate: "Although mixing waters containing 10,000 ppm of sodium sulfate have been used satisfactorily, the limit in Table 5-2 should be considered ...

Other common salts: "Carbonates of calcium and magnesium are not very soluble in water and are seldom found in sufficient concentration to affect the strength of concrete."

Iron Salts: "Natural ground waters seldom contain more than 20 ppm to 30 ppm of iron; however, acid mine waters may carry rather large quantities."

Miscellaneous Inorganic Salts: "Salts of manganese, tin, zinc, copper, arid lead in mixing water can cause a significant reduction in strength and large variations in setting time."
Sugar: "Small amounts of sucrose, as little as 0.03% to 0.15% by mass of cement, usually retard the setting of cement." "The 7-day strength may be reduced while the 28-day strength may be improved. Sugar in quantities of 0.25% or more by mass of cement may cause rapid setting and a substation reduction in 28-day strength."

"Fine aggregates (Figure 6-1) generally consist of natural sand or crushed stone with most particles smaller than 5 mm (0.2 in.). Coarse aggregates (Figure 6-2) typically consist of gravels, crushed stone, or a combination of both, with particles predominantly larger than 5 mm (0.2 in.) and generally between 9.5 mm and 37.5 (3/8 in. and 1 ½ in.)."

Table 6-2. Characteristics and Tests of Aggregate.

Table 6-3. Fine-Aggregate Grading Limits

Figure 6-11. Cement and water contents in relation to maximum size of aggregate for air-entrained and non-air-entrained concrete.

Coarse Aggregate Grading: "The terminology used to specify size of coarse aggregate must be chosen carefully. Particle size is determined by size of sieve and applies to the aggregate passing that sieve and retained on the next smaller sieve."

Maximum Size vs. Nominal Maximum Size Aggregate: "The maximum size of aggregate that can be sued generally depends on the size and shape of the concrete member and on the amount and distribution of reinforcing steel (Figure 6-12). Requirements for limits on nominal maximum size of aggregate particles are covered by ACI 318 (ACI 318-08). The nominal maximum size of aggregate should not exceed 1-3."

Combined Aggregate Grading: "In reality, the amount of cement paste required is greater than the volume of voids between the aggregates."

Particle Shape and Surface Texture: "Flat and elongated aggregate particles should be avoided or at least limited to about 15% by mass of the total aggregate."

Figure 6-17. Moisture conditions of aggregate.

Resistance to Freezing and Thawing: "The frost resistance of an aggregate is related to its porosity, absorption, permeability, and pore structure. An aggregate particle with high absorption may not accommodate the expansion that occurs during the freezing of water if that particle becomes critically saturated."

Figure 6-20. A popout is the breaking away of a small fragment of concrete surface due to internal pressure that leaves a shallow, typically conical depression.

Figure 6-21. D-cracking along a transverse joint caused by failure of carbonate coarse aggregate.
"The cracking of concrete pavements caused by freeze-thaw deterioration of the aggregate is called D-cracking. D-cracks are closely spaced crack formation oriented parallel to transverse and longitudinal joints that later multiply outward from the joints toward the center of the pavement panel (Figure 6-21). ...

**Figure 6-22.** Fractured aggregate particle as a source of distress in D-cracking.

**Figure 6-23.** Concretes containing sandstone or slate produce a high shrinkage concrete. Granite, limestone, and quartz, are low shrinkage-producing aggregates."

**Potentially Harmful Materials:** Table 6-6. Harmful Materials in Aggregates.

Alkali-Aggregate Reactivity: Alkali-Silica Reaction:

**Handling and Storing Aggregates:** "Aggregates should be handled and stored in a way that minimizes segregation (separation of aggregates by size) and degradation and that prevents contamination by deleterious substances."

"Washed aggregates should be stockpiled well before use so that they can drain to a uniform moisture content. Damp fine material has less tendency to segregate than dry material. When dry fine aggregate is dropped from buckets or conveyors, wind can blow away the fines; this should be avoided if possible."

"Chemical admixtures can be classified by function as follows: 1 - 13." "The major reasons for using chemical admixtures in concrete mixtures are: 1-4."

**Table 7-1.** Concrete Admixtures by Classification

**Air-Entraining Materials:** "Most air-entraining admixtures consist of one or more of the following materials: wood resin (Vinsol resin), sulfonated hydrocarbons, fatty and resinous acids, and synthetic materials."

**Impact of Air Content on Properties of Concrete:** "Improvements in the performance of hardened concrete obviously include improved resistance to freezing and thawing, and deice-salt scaling."

**Normal (Conventional) Water Reducers:** "When used as a water reducer, normal range, or conventional water reducers can reduce the water content by approximately 5% to 10%."

**Impact of Water Reducers on Properties of Concrete:** "An increase in strength is generally obtained with water-reducing admixtures as the water-cement ratio is reduced."

**Set Retarding Admixtures:** "Set retarding admixtures are used to delay the rate of setting of concrete. Retarders are sometimes used to: 1-3"
Set Accelerating Admixtures: Types of Set Accelerating Admixtures: "Calcium chloride (CaCl2) is the most common material used in set accelerating admixtures, especially for non-reinforced concrete." "The amount of calcium chloride added to concrete should be no more than is necessary to produce the desired results and in no case should be permitted to exceed 2% by mass of cementing material."

Effects of Set Accelerators on Concrete Properties: "Applications where calcium chloride should be used with caution: 1-5." "Calcium chloride or admixtures containing soluble chlorides should not be used in the following: 1-8"

Corrosion Inhibitors: "Commercially available corrosion inhibitors include: calcium nitrate, sodium nitrite, dimethyl ethanolamine, amines, phosphates, and ester amines as listed in Table 7-1."

Shrinkage-Reducing Admixtures: "Shrinkage reducing admixtures (SRAs), introduced in the 1980s, have potential uses in bridge decks, critical floor slabs, and buildings where cracks, curling, and warping must be minimized for durability or aesthetic reasons (Figure 7-18)."

Alkali-Aggregate Reactivity Inhibitors: "In the 1950s, McCoy and Caldwell discovered that lithium based compounds when used in sufficient quantity were capable of inhibiting damage due to alkali-silica reactivity (ASR). The use of lithium nitrate, lithium carbonate, lithium hydroxide, lithium aluminum silicate (decrepitated spodumene), and barium salts have shown reductions of alkali-silica reactions (ASR) in laboratory tests (Figure 7-19)."

Bonding Admixtures and Bonding Agents: "Bonding admixtures are usually water emulsions of organic materials including rubber, polyvinyl chloride, polyvinyl acetate, acrylics, styrene butadiene copolymers, and other polymers."

"They are added in proportions equivalent to 5% to 20% by mass of the cementing materials ..."

"Bonding agents should be confused with bonding admixtures. Admixtures are an ingredient in the concrete; bonding agents are applied to existing concrete surfaces immediately before the new concrete is placed."

Why Use Reinforcement in Concrete: "In addition to resisting tensile forces in structural members, reinforcement is also used in concrete construction for the following reasons: (5 bullets)."

Reinforcing Bars: "...steel reinforcing bars are generally about 15 times stronger than conventional concrete ...

Grades: "Reinforcing bar is specified by ASTM A615, Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement. The most common form is grade 60 ..."
Table 8-1. Summary of ASTM Strength Requirements for Reinforcements

Table 8-2. ASTM Standard Reinforcing Bars (Size and weight)

Prestressing Steel: "Prestressing steel comes in three standard types: wires, tendons composed of several strands of wires, and high strength alloy steel bars."

Fibers: "The main factors that control the performance of the composite material are: 1-2;" Although the basic governing principles are the same, there are several characteristic differences between conventional reinforcement and fiber systems: 1-3."

Advantages and Disadvantages of Using Fibers: "Typically, the spray up fabrication method has a 2-D random fiber orientation while the premix (or batch) fabrication method typically has a 3-D random fiber orientation."

"Fiber concretes are best suited for thin section shapes where correct placement of conventional reinforcement would be extremely difficult."

Steel Fibers: "Steel-fiber volumes used in concrete typically range from 0.25% to 2%."
"Steel fibers delay the fracture of restrained concrete during shrinkage and they improve stress relaxation induced by creep mechanisms."

"Steel fibers are most commonly used in airport pavements and runway/taxi overlays. They are also used in bridge decks (Figure 8-15), industrial floors, and highway pavements."

Table 8-5. Properties of Selected Fiber Types.

Glass Fibers

Synthetic Fibers: "Acrylic fibers are generally considered the most promising replacement for asbestos fibers. They are used in cement board and roof-shingle production, where fiber volumes of up to 3% can produce a composite with mechanical properties similar to that of an asbestos-cement composite."

Natural Fibers: Unprocessed Natural Fibers: "Products were made using portland cement and unprocessed natural fibers such as coconut coir, sisal, bamboo, jute, wood, and vegetable fibers."

Wood Fibers (Processed Natural Fibers): "The process by which wood is reduced to a fibrous mass is called pulping."

Multiple Fiber Systems: "For a multiple fiber system, two or more fibers are blended into one system."
"Quality concrete possesses well defined and accepted principal requirements. For freshly mixed concrete, those requirements in Jude: Consistency, Stability, Uniformity, Workability and Finishability. For hardened concrete, they include: Strength, Durability, Appearance, and Economy."

**Freshly Mixed Concrete:** "While a plastic mixture with a slump ranging from 75 mm to 150 mm (3 in. to 6 in.) is suitable for most concrete work, plasticizing admixtures may be used to make concrete more flowable in thin or heavily reinforced concrete members."

**Bleeding and Settlement:** "Bleeding is the development of a layer of water at the top or surface of freshly placed concrete."

"Excessive bleeding increases the water-cement ratio near the top surface which creates a weak top layer with poor durability, particularly if finishing operations take place while bleed water is present."

The most effective means of reducing bleeding in concrete include: 1 - 8"

**Air Content:** "Air entrainment is recommended for nearly all exterior concretes, principally to improve freeze-thaw resistance when exposed to freezing water and deicing chemicals (see Chapter 11)."

**Table 9-1.** Effect of Concrete Constituents on Control of Air Content in Concrete.

"A low-alkali cement may require 20% to 40% (occasionally up to 70%) more air-entraining admixture than a high-alkali cement to achieve an equivalent air content." "Water-reducing and set-retarding admixtures generally increase the efficiency of air-entraining admixtures by 50% to 100%.

**Mixture Design:** "An increase in the mixing water makes more water available for the generation of air bubbles, thereby increasing the air content as slumps increase up to 150 mm or 175 mm (6in. or 7in.)."

**Table 9-2.** Effect of Concrete Mixture Design on Control of Air Content in Concrete.

**Transportation and Delivery:** "Generally, some air, approximately 1 % to 2%, is lost during transportation of concrete from the mixer to the jobsite."

**Placement and Consolidation:** "At all slumps, however, even 15 seconds of vibration (ACI 309) will cause a considerable reduction in air content. Prolonged vibration of concrete should be avoided."
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| 166    | **Curing:** "Increase in strength with age continues provided (1) un-hydrated cement is still present, (2) concrete remains moist or has a relative humidity above approximately 80% (Powers 1948), (3) the concrete temperature remains favorable, and (4) sufficient space is available for hydration products to form."
| 167    | **Figure 9-22.** Concrete strength gain versus time for concrete exposed to outdoor conditions. |
| 168    | **Drying Rate of Concrete:** "Concrete elements with large surface area in relation to volume (such as floor slabs) dry faster than large volume concrete members with relatively small surface areas (such as bridge piers)."
| 172    | **Volume Stability and Crack Control:** "Two basic causes of cracks in concrete are: (1) stress due to applied loads and (2) stress due to drying shrinkage, temperature changes, durability related distress, and restraint."
|        | **Joints:** "Joints are the most effective method of controlling unsightly cracking." Note the three joint definitions: Contraction joints; Isolation joints; and construction joints. |
| 172-173| **Durability:** Note the six causes for deterioration: Freeze thaw and deicer salts; corrosion; carbonation; alkali-silica reactivity; abrasion; and sulfate attack. |
| 177    | **Figure 10-1.** Chemical shrinkage and autogenous shrinkage volume changes of fresh and hardened paste. |
| 178    | **Autogenous Shrinkage:** "Autogenous shrinkage is the macroscopic volume reduction (visible dimensional change) of cement past, mortar, or concrete caused by cement hydration and is measured in accordance with ASTM C1698, Standard Test Method for Autogenous Strain of Cement Paste and Mortar."
|        | Figure 10-5. Volumetric relationship between subsidence, bleed, water, chemical shrinkage, and autogenous shrinkage. |
| 179    | **Subsidence:** "Subsidence refers to the vertical shrinkage of fresh cementitious materials before initial set." Swelling: "Concrete, mortar, and cement paste swell in the presence of external water."
| 180    | **Moisture Changes (Drying Shrinkage) of Hardened Concrete:** "Hardened concrete expands slightly with a gain in moisture aid contracts with a loss in moisture."
| 182    | **Effect of Concrete Ingredients on Drying Shrinkage:** The most important controllable factor affecting drying shrinkage is the amount of water per unit volume of concrete."
|        | "Shrinkage can be minimized by keeping the water content of concrete as low as possible." |
"Aggregates in concrete, especially coarse aggregate physically restrain the shrinkage of hydrating and drying cement paste. Paste content affects the drying shrinkage of mortar more than that of concrete. Drying shrinkage is also highly dependent on the type of aggregate."

Curling and Warping: "In addition to horizontal movement caused by changes in moisture and temperature, curling and warping of slabs on ground can be a problem. This is caused by differenced in moisture content and temperature between the top and bottom of slabs."

Elastic and Inelastic Deformation: Note definitions for: Deflection; Poisson's Ratio; Shear Strain; Torsional Strain; and Creep.

"... the resistance of concrete to the ingress of fluids (that is, low permeability) is fundamental to durability."

Permeability and Diffusion: "Permeability refers to the ease of fluid migration through concrete when the fluid is under pressure or to the ability of concrete to resist penetration by water or other substances (liquid, gas, or ions) as discussed in Chapter 9. Diffusivity refers to the ease with which dissolved ions move through concrete."

Table 11-2. Test Methods Used to Determine various Permeability-Related Properties.

Table 11-3. Exposure Categories for Durable Concrete.

Abrasion and Erosion: "Wear on concrete surfaces can occur in the following situations: 6 bullets."

Freezing and Thawing: This section begins a discussion of concrete exposed to weathering in colder climates. Deicing chemicals increases the effects and deterioration.

Mechanism of Freeze-Thaw Damage: "Hydraulic pressures are caused by the 9% expansion of water upon freezing; in this process growing ice crystals displace unfrozen water."

Table 11-5. Snow and Ice Control Materials.

Table 11-15. Effect of entrained air on the resistance of concrete to freezing and thawing in laboratory tests.

Materials and Methods to Control Freeze-Thaw and Deicer Damage: "The air content of concrete with 19-mm (3/4-in.) maximum-size aggregate would be about 6% for effective freeze-thaw resistance."

"When concrete in service will be exposed to cycles of freezing and thawing or deicing chemicals, consult local guidelines on allowable practices and use the following guidelines to ensure adequate concrete performance: 1 - 9"
Corrosion (Section)

Materials and Methods to Control Corrosion: "ACI committee 201 (ACI 201.2R-08) recommends a minimum cover of 40 mm (1 1/2 in.) and preferably at least 50 mm (2 in.) for concrete in moderate-to-severe corrosion environments."

"There are three phases in the development of a concrete mixture for a particular project; specifying, designing, and proportioning."

Strength: "Differences in concrete strength for a given water cementing material; ratio may result from: 1-5"

Table 12-1. Maximum Water-Cementitious Material Ratios and Minimum Design Strengths for Various Exposure Conditions.

Figure 12-3. Approximate relationship between compressive strength and water to cementing materials ratio for concrete using 19-mm to 25-mm 3/4 -in. to 1-in.).

Table 12-3 (Inch-Pound Units). Relationship between Water to Cementitious Material Ratio and Compressive Strength of Concrete.

Aggregates: "Requirements for limits on nominal maximum size of aggregate particles are covered by ACI 318 (ACI 318-08). The nominal maximum size of aggregate should not exceed: 1-3"

Air Content: Note the four exposure levels: Mild Exposure, FO; Moderate Exposure, Fl; Severe Exposure, F2; and Very Severe Exposure, F3.

Table 12-5 (Inch-Pound Units). Approximate Mixing Water and Target Air Content Requirements for Different Slumps and Nominal Maximum Sizes of Aggregate.

Slump: "The slump test is used to measure concrete consistency. For a given proportion of cement and aggregate without admixtures, the higher the slump, the wetter the mixture. Slump is indicative of workability when assessing similar mixtures."

"Different slumps are needed for various types of concrete construction. Slump is usually indicated in the job specifications as a range, such as 50 mm to 100 mm (2 in. to 4 in), or as a maximum value not to be exceeded. Slump should be specified based on the method of placement. Slumps vary by application."

"For minor batch adjustments, the slump can be increased by about 10 mm by adding 2 kilograms of water per cubic meter of concrete (1 in. by adding 10 lb of water per cubic yard of concrete)."
Chemical Admixtures: "High-range water reducers (plasticizers) reduce water contents between 12% and 30% and some can simultaneously increase the air content up to 1 percentage point; others can reduce or have no affect the air content."

Proportioning: "The design and proportioning of concrete mixtures involves: 1-2"

Proportioning by Trial Mixtures: "A number of different methods of proportioning concrete ingredients have been used including: Arbitrary assignment (1:2:3), volumetric Void ratio; Fineness modulus; Surface area of aggregates; Cement content."

Figure 12-8. Relationship between strength and water to cement ratio based on field and laboratory data for specific concrete ingredients.

Ordering Concrete: "ATM C94 provides three options for ordering concrete: 1-3"

Batching: "Specifications generally require that materials be measured for individual batches within the following percentages of accuracy: ...

Mixing Concrete: "Mixers should not be loaded above their rated mixing capacities and should be operated at the mixing speed and for the period, either based on revolutions or time, recommended by the manufacturer."

Stationary Mixing: "Concrete may be mixed at the jobsite in a stationary mixer or a paving mixer (Figure 13-2). Stationary mixers include both onsite mixers and central mixers in ready mix plants. They are available in sizes up to 9.0 m³ (12 yd³) ..."

"Many specifications require a minimum mixing time of one minute plus 15 seconds from every cubic meter (yard)...

"Under usual conditions, most of the mixing water should be charged in the drum before the sold materials are added."

Ready Mixed Concrete: ASTM C94 (AASHTO M 157) notes that when a truck mixer is used for complete mixing, 70 to 100 revolutions of the drum or blades at mixing speed are usually required ...

"Agitating speed is usually about 2 rpm to 6 rpm, and mixing speed is generally at 12 rpm to 18 rpm. Mixing at high speeds for long periods (one or more hours), along with the addition of water to maintain slump, can result in concrete strength loss, ...

"When truck mixers are used ASTM C94 (AASHTO M 157) also limits the time between batching and complete discharge of the concrete at the job site to 1 ½ hours."
Retempering (Remixing) Concrete: ASTM C94 (AASHTO M 157) allows water to be added to the concrete when the truck arrives on the jobsite and the slump is less than specified providing the following conditions are met: 1 - 4".

Table 13-1. Methods and Equipment for Transporting and Handling Concrete.

Work At and Below Ground Level: "The concrete may be chuted directly from the truck mixer to the point needed. They must not slope greater than 1 vertical to 2 horizontal or less than 1 vertical to 3 horizontal. Long chutes, over 6 meters (20 ft.), or those not meeting slope standards must discharge into a hopper before distribution to point of need."

Work Above Ground Level: "The tower crane and pumping boom (Figure 13-19) are the right tools for tall buildings."

Subgrade Preparation: "The three major causes of nonuniform support are: 1 - 3"

Moisture Control and Vapor Retarders: "Many of moisture problems associated with enclosed slabs on ground (floors) can be minimized or eliminated by: 1 - 5."

"If concrete is placed directly on a vapor retarder, the water-cementitious materials ratio should be kept low (0.45 or less) because excess mix water can only escape to the surface as bleed water."

Formwork: "Slab edge forms are usually metal or wood braced firmly with wood or steel stakes to keep them in horizontal and vertical alignment."

Reinforcement: "Reinforcing steel should be clean and free of excessive rust or mill scale when concrete is placed."

Depositing the Concrete: "Concrete should be deposited continuously as near as possible to its final position without objectionable segregation (Figures 14-8 and 14-9)."

"In general, concrete should be placed in walls, thick slabs, or foundations in layers of uniform thickness and thoroughly consolidated before the next layer is placed."

"In general, layers should be about 150 mm to 500 mm (6 in. to 20 in.) deep for reinforced members and 375 mm to 500 mm (15 in. to 20 in.) thick for mass work using large aggregates or stiff consistency concrete mixtures."

"Where standing water is present, concrete should be placed in a manner that displaces the water - ahead of the concrete and does not allow the water to be mixed into the concrete."
"Dropchutes are used to move concrete to lower elevations (usually in wall forms) without segregation and spattering of mortar on reinforcement and forms (Figure 14-11). Field studies indicate that free fall of concrete from heights of up to 46 m (150 ft) directly over reinforcing steel or at a high slump, so long as the material is confined, does not result in segregation of the concrete ingredients nor reduce compressive strength."

"Concrete is sometimes placed through openings (called windows) in the sides of tall, narrow forms."

"In monolithic placement of deep beams, walls, or columns, to avoid cracks between structural elements, concrete placement should pause (about 1 hr) to allow settlement of the deep element before concreting is continued in any slabs, beams, or girders framing into them."

**Placing Concrete Underwater:** "Methods for placing concrete underwater include the following: tremie, concrete pump, bottom-dump buckets, grouting preplaced aggregate, toggle bags, bagwork, and the diving bell. A tremie is a smooth, straight pipe long enough to reach the lowest point to be concreted from a working platform above the water (Figure 14-12). The diameter of the tremie pipe should be a least 8 times the diameter of the maximum size of aggregate."

"The current in the water through which the concrete is deposited should not exceed 3m (10 ft.) per minute."

**Placing on Hardened Concrete:** "A bonded construction joint is required between two structural concrete placements."

"Poorly bonded construction joints are usually the result of: 1 - 2."

**Preparing Hardened Concrete:** "Partially set or hardened concrete may only require stiff wire brushing. In some types of construction such as dams, the surface of each concrete lift is cut with a high-velocity air-water jet to expose clean, sound concrete just before final set. This is usually done 4 to 12 hours after placing."

**Vibration:** "Vibration, either internal or external, is the most widely used method for consolidating concrete. When concrete is vibrated, the internal friction between the aggregate particles is temporarily disrupted and the concrete behaves like a liquid; ..."

"The vibrating head is usually cylindrical with a diameter ranging from 19 to 175 mm (1/4 to 7 in.). Some vibrators have an electric motor built directly into the head, which is generally at least 50 mm (2 in.) in diameter."

"Vibrators with a diameter of 19 mm to 38 mm (3/4 in. to 1 1/2 in.) have a radius of action ..."
"Vibrators should not be used to move concrete horizontally since this causes segregation. Whenever possible, the vibrator should be lowered vertically into the concrete at regularly spaced intervals and allowed to descend by gravity. It should penetrate to the bottom of the layer being placed and at least 150 mm (6 in.) into any previously placed layer."

"The distance between insertions should be about 1 ½ times the radius of action so that the area visibly affected by the vibrator overlaps the adjacent previously vibrated area by a few centimeters (inches)."

"An insertion time of 5 to 15 seconds will usually provide adequate consolidation."

"Allowing a vibrator to remain immersed in, concrete after paste accumulates over the head can result in non-uniformity."

External Vibration: "Form vibrators, designed to be securely attached to the outside of the forms, are especially useful for the following: 1-3."

"Attaching a form vibrator directly to the concrete form generally is unsatisfactory."
"Vibratory screeds give positive control of the strikeoff operation and save a great deal of labor. When using this equipment, concrete should not have slumps in excess of 75 mm (3 in.)..." "Vibratory screeds are used for consolidating slabs up to 250 mm (10 in.) thick ..."

Consequences of Improper Vibration: "Undervibration may cause honeycombing; excessive amount of entrapped air voids, often called bugholes; sand streaks, cold joints; placement lines; and subsidence cracking." Note the definitions of each consequence.

Screeding (Strikeoff): "Screeding or strikeoff is the process of cutting off excess concrete to bring the top surface of a slab to proper grade."

"There should be a surplus (surcharge) of concrete against the front face of the straightedge to fill in low areas as the straightedge passes over the slab."

Bullfloating or Darbying: "To eliminate high and low spots and to embed large aggregate particles, a bullfloat or darby (Figure 14-22 top) should be used immediately after strikeoff."

"When the bleed water sheen has evaporated the concrete may then receive additional finishing passes."

"When the concrete will sustain foot pressure with only about 6-mm (14 in.) indentation, the surface is ready for continued finishing operations using mechanical means ..."

"Warning: One of the principal causes of surface defects in concrete slabs is finishing while bleed water is present on the surface. If bleed water is worked into the surface, the water-cement ratio is significantly increased. ..."
**Highlight**

**Edging and Jointing:** "First pass edging operations should be completed before the onset of bleeding; otherwise, the concrete should be cut away from the forms to a depth of 25 mm (1 in.) using appointed mason trowel or a margin trowel ..."

"Proper jointing practices can eliminate unsightly random cracks. Contraction joints, sometimes called control joints, can be formed with a hand groover ...

"For these slabs, contraction joints should be sawn into hardened concrete."

**Floating:** "The purpose of floating is to embed aggregate particles just beneath the surface; remove slight imperfections, humps, and voids; compact the mortar at the surface in preparation for additional finishing operations; and reestablish the moisture content of the paste at the near surface where evaporation has its greatest impact." "The hand float should be held flat on the concrete surface and moved with a slight sawing motion in a sweeping arc to fill in holes, cut off lumps, and smooth ridges."

**Troweling:** "Where a smooth, hard, dense surface is desired, floating should be followed by steel troweling (Figure 14-25)."

**Brooming:** "Brooming or tining should be performed before the concrete has thoroughly hardened, but it should be sufficiently hard to retain the scoring impression to produce a slip-resistant surface (Figure 14-26 and 14-27)."

**Exposed-Aggregate Concrete** "Other methods for obtaining an exposed aggregate surface include: 1 -2."

**Curing and Protection:** "Initial curing should begin immediately after strike-off operations and continue until finishing operations are complete (Figure 14-29). Final curing is needed to ensure continued hydration of the cement, assure proper strength gain and durability of the concrete, and to minimize early drying shrinkage."

**Rain Protection:** "Protective coverings such as polyethylene sheets or tarpaulins should be available and onsite at all times."

**Jointing Concrete: Isolation Joints:** "Isolation joints permit both horizontal and vertical differential movements at adjoining parts of a structure (Figure 14-30)."

"Isolation-joint material (often called expansion-joint material) can be as thin as 6 mm (¼ in.) or less, but 13-mm ( 1/2 in.) material is commonly used."
"Columns on separate footings are isolated from the floor slab either with a circular or square shaped isolation joint."

**Contraction Joints:** "Contraction joints provide for movement in the plane of a slab or wall. Joints induce controlled cracking caused by drying and thermal shrinkage at preselected locations (Figure 14-31). Contraction joints (also sometimes called control joints) should be constructed to permit transfer of loads perpendicular to the plane of a slab or wall."

"Sawing must be coordinated with the setting time of the concrete. It should be started as soon as the concrete has hardened sufficiently to prevent aggregates from being dislodged by the saw (usually within 4 to 12 hours after the concrete hardens.) Sawing should be completed before drying shrinkage stresses become large ..."

"Contraction joints, whether sawed, grooved, or preformed, should extend vertically into the slab to a depth of at least one-fourth the slab thickness or a minimum of 25 mm (1 in.) deep." "The thickness of the wall at a contraction joint should be reduced by a minimum of 25%, preferably 30%." "In addition, contraction joints should be placed where abrupt changes in wall thickness or height occur, and near corners – if possible, within 3 meters to 4 meters (10 ft to 15 ft)."

"The spacing of contraction joints in floors on ground depends on: 1 - 5"

**Construction Joints:** "Construction joints (Figure 14-33) are stopping places in the process of construction. In structural building systems, a true construction joint should bond new concrete to existing concrete and permit no movement. Deformed tie bars are often used in construction joints to restrict movement."

**Joint Layout for Floors:** "Construction joints should be planned to provide long-strips for each placement rather than a checker-board pattern. Contraction joints are then placed to divide the long strips into relatively square panels, with panel length not exceeding 1.5 times the width."

**Filling Floor Joints:** "There are three options for treating joints: they can be filled, sealed, or left open. The movement at contraction joints in a floor is generally very small."

"The difference between a filler and a sealer is the hardness of the material. Fillers are more rigid than sealers and provide support to joint edges."

**Unjointed Floors:** "2. Large areas - a single day of slab placement, usually 800 m2 to 1000 m2 (8000 ft2 to 10,000 ft2 ) - can be cast without contraction joints..."

**Removing Forms:** "In general for concrete temperatures above 10'C (50°F), the side forms of reasonably thick, supported sections can usually be removed 24 hrs after concreting. Beam and floor slab forms and supports (shoring) may be removed between 3 and 21 days ..."
Holes, Defects, and Overlays: "The mortar should be mixed as stiff as is practical: use 1 part cement, 2 1/2 parts sand passing a 1.25 mm (No. 16) sieve, and just enough water to form a ball when the mortar is squeezed gently in the hand."

"Concrete used to fill large patches and thin-bonded overlays should have a low water-cement ration ..." 'Before the patching concrete is applied, the surrounding concrete should be clean and sound (Figure 14-37). Abrasive methods of cleaning (sandblasting, hydrojetting, waterblasting, scarification, or shotblasting) are usually required. ..."

Figure 14-38. Concrete patch installation.

"Shallow patches can be filled with a drypack mortar as described earlier."

Cleaning Concrete Surfaces: "There are three techniques for cleaning concrete surfaces: water, chemical, and mechanical (abrasion)." Note the definition for each of the three techniques.

Precautions: Concrete specific precautions including: Protect Your Head and Eyes; Protect Your Back; and Working Safely with Concrete.

"Curing is the maintenance of a satisfactory moisture content and temperature in concrete for a sufficient period of time during and immediately following placing so that the desired properties may develop (Figure 15-1). The need to adequate curing of concrete cannot be overemphasized. Curing has a strong influence on the properties of hardened concrete. ..."

"When moist curing is interrupted, the development of strength continues for a short period and then stops after the concrete's internal relative humidity drops to about 80%."

"Hydration proceeds at a much slower rate when the concrete temperature is low. Temperatures below 10°C (50°F) are unfavorable for the development of early strength ..."

"Maturity is the cumulative product of the age of the concrete and its average curing temperature above a certain base temperature."

Curing Methods and Materials: "Concrete can be kept moist (and in some cases at a favorable temperature) by three curing methods: Supplying additional moisture; Sealing in the mix water; and accelerated curing." Note definitions for each of the three curing methods.

Fogging and Sprinkling: "Fogging (Figure 15-4) and sprinkling with water are excellent methods of curing when the ambient temperature is well above freezing and the humidity is low."

"The cost of sprinkling may be a disadvantage."
**Wet Coverings:** "Fabric coverings saturated with water, such as burlap, cotton mats, rugs, or other moisture-retaining fabrics, are commonly used for curing (Figure 15-5)."

**Impervious Paper:** "Impervious paper for curing concrete consists of two sheets of kraft paper cemented together by a bituminous adhesive with fiber reinforcement."

**Plastic Sheets:** "Plastic sheet materials, such as polyethylene film, can be used to cure concrete (Figure 15-7)."

"Polyethylene film should conform to ASTM C171 (AASHTO M 171), which specifies a 0.10-mm (4-mil) thickness for curing concrete ...

**Membrane-Forming Curing Compounds:** "Membrane-forming curing compounds are of two general types; clear, or translucent; and white pigmented. Clear or translucent compounds may contain a fugitive dye that makes it easier to check visually ...

**Internal Curing:** "Internal curing refers to the process by which hydration of cement and pozzolanic reactions can continue because of an internal water supply that is available ...

**Forms Left in Place:** Forms provide satisfactory protection against loss of moisture if the top exposed concrete surfaces are kept wet. A soaker hose is excellent for this. The forms should be left on the concrete as long as practical."

**Steam Curing:** "Steam curing is advantageous where early strength gain in concrete is important or where additional heat is required to accomplish hydration, as in cold weather."

"Two methods of steam curing are used: live steam at atmospheric pressure (for enclosed cast-in-place structures and large precast concrete units) and high-pressure steam in autoclaves (for small manufactured units)."

**Insulating Blankets or Covers:** "Layers of dry, porous material such as straw or hay can be used to provide insulation against freezing of concrete when temperatures fall below 0°C (32°F)."

**Electrical, Oil, Microwave, and Infrared Curing Methods:** "Electrical, hot oil, microwave, and infrared curing methods have been available for accelerated and normal curing of concrete for many years."

**Curing Period and Temperature:** "The curing period may be 3 weeks or longer for lean concrete mixtures used in massive structures such as dams; conversely, it may be only a few days for rich mixtures, especially if Type II or HE cement is used. Steam-curing periods are normally much shorter, ranging from a few hours to 3 days; but generally 24-hour cycles are used."
"For concrete slabs on ground (floors, pavements, canal linings, parking lots, driveways, sidewalks) and for structural concrete (cast-in-place walls, columns, slabs, beams, small footings, piers, retaining walls, bridge decks), the length of the curing period for ambient temperatures above 5°C (40°F) should be a minimum of 7 days (ACI 301)."

**Sealing Compounds:** "Sealing compounds (sealers) are liquids applied to the surface of hardened concrete to reduce the penetration of liquids or gases such as water, deicing solutions, and carbon dioxide to protect concrete from freeze-thaw damage, corrosion of reinforcing steel, and acid attack."

"The penetrating sealer used most extensively historically is a mixture of 50 percent boiled linseed oil and 50 percent mineral spirits (AASHTO M 233, Standard Specification for Boiled Linseed Oil Mixture for Treatment of Portland Cement Concrete). Although this mixture is an effective sealer, it has two main disadvantages; it darkens the concrete, and periodic reapplication is necessary for long-term protection."

"Hot weather conditions can adversely influence concrete quality primarily by accelerating the rate of evaporation/moisture loss and rate of cement hydration." "Hot weather conditions can create difficulties in fresh concrete, such as: 8 bullets."

"Adding water to the concrete at the jobsite can adversely affect properties and serviceability of the hardened concrete, resulting in: 6 bullets."

**Effects of High Concrete Temperatures:** "At higher temperatures a greater amount of water is required to hold slump constant than is needed at lower temperatures. The addition of water results in a higher water-cement ratio, thereby lowering the strength at all ages and adversely affecting other desirable properties of the hardened concrete."

"This shows that the setting time can be reduced by 2 or more hours with a 10°C (18°F) increase in concrete temperature."

**Aggregates:** "Aggregates have a pronounced effect on the fresh concrete temperature because they represent 70% to 85% of the total mass of concrete. To lower the temperature of concrete 0.5 °C (1°F) requires only a 0.8°C to 1.1°C (1.5°F to 2°F) reduction in the temperature of the coarse aggregate."

"There are several simple methods of keeping aggregates cool. Cooling effects are realized when stockpiles are shaded from the sun and kept moist by sprinkling. Since evaporation is a cooling process, sprinkling provides effective cooling, especially when the relative humidity is low."
Transporting, Placing, and Finishing: "ASTM C94 (AASHTO M 157) requires that discharge of concrete be completed within 90 minutes or before the drum has completed 300 revolutions, whichever occurs first. However, these restrictions may be extended under certain conditions (ACI 301-10). During hot weather the time limit may be reduced to 60 minutes or even 45 minutes."

Plastic Shrinkage Cracking: 'Plastic shrinkage cracking is usually associated with hot-weather concrete in however, it can occur any time ambient conditions produce rapid evaporation of moisture from the concrete surface. These cracks occur when water evaporates from the surface faster than it can travel to the surface during the blooding process. ... The following conditions, individually or collectively, increase evaporation of surface moisture and also increase the possibility of plastic shrinkage cracking: 1 - 6''

Heat of Hydration: As a general rule a total temperature rise of 2°C to 9°C (5°F to 15°F) per 45 kg (100 lb) of portland cement can be expected for thinner slab-type placements from the heat of hydration."

"Cold weather is defined by ACI Committee 306 as existing when the air temperature has fallen to, or is expected to fall below 4°C (40°F) during the protection period."

Effect of Freezing on Fresh Concrete: "Concrete gains very little strength at low temperatures. Freshly mixed concrete must be protected against the disruptive effects of freezing ..." "Significant ultimate strength reductions, up to about 50%, can occur if concrete is frozen ..."

Special Concrete Mixtures: "High strength at an early age is desirable in cold weather construction to reduce the length of time temporary protection required."

"High-early-strength concrete can be obtained by using one or a combination of the following: 1 - 3"

Table 17-1. Recommended Concrete Temperature for Cold-Weather Construction - Air Entrained Concrete

Heaters: Three types of heaters are used in cold weather concrete construction: direct fired, indirect fired, and hydronic systems (Figures 17-22 to 17-25)."

Moist Curing: "Strength gain stops when moisture required for curing is no longer available."

Form Removal and Reshoring: "It is good practice in cold weather to leave forms in place as long as possible. Even within heated enclosures, forms serve to distribute heat more evenly and help prevent drying and local overheating."
"Slump, air content, density (unit weight), and temperature tests should be made for the first batch of concrete each day ..." "The number of strength tests will depend on the job specifications and the occurrence of variations in the concrete mixture. The ACI 318 building code and ASTM C94 require that strength tests for each class of concrete placed each day ..."

**Sampling Aggregates:** "Methods for obtaining representative samples of aggregates are given in ASTM D75, *Standard Practice for Sampling Aggregates* (or AASHTO T 2)."

**Organic Impurities:** "Organic impurities in fine aggregate should be determined in accordance with ASTM C40, *Standard Test Method for Organic Impurities in Fine Aggregates for Concrete* (or AASHTO T 21)."

**Objectionable Fine Material:** 'Large amounts of clay and silt in aggregates can adversely affect durability, increase water requirements, and increase shrinkage.'

**Grading:** "The particle size distribution, or grading, of an aggregate significantly affects concrete mixture proportioning and workability and are an important element in the assurance of concrete quality."

**Moisture Content of Aggregates:** "Several methods are used for determining the amount of moisture in aggregate samples. The total moisture content for fin or coarse aggregate can be measured in accordance with ASTM C566, *Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying*, (AASHTO T 255)."

**Sampling Freshly Mixed Concrete:** "Except for routine slump and air-content tests performed for process control, ASTM C172 (AASHTO T 141) requires that sample size used for acceptance purposes be at least 28 L (1ft³) end be obtained within 15 minutes between the first and final portions of the sample. The composite sample, made of two or more portions, should not be taken from the very first or last portion of the batch discharge."

**Consistency:** "The slump test described by ASTM C143, *Standard Test Method for Slump of Hydraulic- Cement Concrete* (AASHTO T 119), is the most generally accepted method used to measure the consistency of concrete (Figure 18-2)."

**Temperature Measurement:** "The thermometer should be accurate to plus or minus 0.5°C (±1°F) and should remain in a representative sample of concrete for a minimum of 2 minutes or until the reading stabilizes."

**Strength Specimens:** "The length of beams should be at least three times the depth of the beam plus 50 mm (2 in.), or a total length of at least 500 mm (20 in.) for a 150-mm x 150-mm (6-in. x 6-in.) beam." "Beams up to 200 mm (8 in.) deep are molded using two layers of consolidated by rodding and using one layer if consolidated by vibration."
"For beams wider than 150 mm (6 in.), alternate insertions of the vibrator should be along two lines." "The strength of a test specimen can be greatly affected by jostling, changes in temperature, and exposure to drying, particularly within the first 24 hours after casting. Thus, test specimens should be cast ..."

356 Bleeding of Concrete: "The bleeding tendency of fresh concrete can be determined by two methods described in ASTM C232, Standard Test Methods for Bleeding of Concrete (or AASHTO T 158). One method ...; the other method

357-371 Testing Hardened Concrete: Review all of the various items and methods of testing; highlight each paragraph heading.

366 Table 18-3. Nondestructive Test Methods for Concrete.

375-376 "High-performance concrete (HPC) exceeds the properties and constructability of normal concrete."

"High-performance concrete characteristics are defined, categorized, or developed for particular applications and environments (Goodspeed, Vanikar, and Cook 1996 and Russell and Ozyildirim 2006); some of the characteristics that may be required include: Enhanced Durability (5 bullets); Enhanced Engineering Properties (5 bullets); Other Enhanced Properties (4 bullets)."

"High-performance concrete almost always has greater durability than normal concrete. This greater durability may be accompanied by normal strength or it may be partnered with high strength. Note that strength is not always the primary required property."

376 Table 19-1: Materials Used in High-Performance Concrete.

380 High Durability. Note the following properties: Abrasion Resistance; Blast Resistance; Permeability; Diffusion; Carbonation; Freeze-Thaw Resistance; Chemical Attack; Alkali-Silica Reactivity; and Resistivity.

382 High-Early-Strength Concrete: "High-early-strength concrete, also called fast-track concrete, achieves its specified strength at an earlier age than normal concrete."

"High-early-strength- can be obtained using one or a combination of the following: 1 - 10"

"High early- strength concrete is used for prestressed concrete to allow for early stressing, precast concrete for rapid production of elements, high-speed cast-inplace construction, rapid form reuse, cold-weather construction, rapid repair of pavements (to reduce traffic downtime), fast-track paving, and several other uses."
High-Strength Concrete: "The definition of high strength changes over the years as concrete strength used in the field increases. This publication considers high-strength concrete (HSC) as a strength significantly beyond what is used in normal practice. About 90% of ready mixed concrete has a 28-day specified compressive strength ranging from 20 MPa (3000 psi) to 40 MPa (6000 psi), with most of it between 20 MPa (3000 psi) and 35 MPa (5000 psi).

Table 19-5 (Metric). Mixture Proportions and Properties of Commercially Available High-Strength Concrete.

Table 19-5 (Inch-Pound Units). Mixture Proportions and Properties of Commercially Available High-Strength Concrete.

Supplementary Cementing Materials: "Fly ash, silica fume, or slag cement are frequently used and are sometimes mandatory in the production of high performance concrete. The strength gain obtained with these supplementary cementing materials cannot be attained by using additional cement alone."

Aggregates: "Tests have shown that crushed-stone aggregates produce higher compressive strength in concrete than gravel aggregate using the same size aggregate and the same cementing materials content. This is probably due to a superior aggregate-to-paste bond when using rough, angular, crushed material."

Mixing: "Where dry, uncompacted silica fume has been batched into a mixture, "balling" of the mixture has occurred and mixing has been incomplete. In these instances it has been necessary to experiment with the charging sequence, and the percentage of each material added at each step in the batching procedure."

Self-Consolidating Concrete: "Self-consolidating concrete (SCC), also referred to as self-compacting concrete, is able to flow and consolidate under its own weight. At the same time it is cohesive enough to fill spaces of almost any size and shape without segregation or bleeding."

Ultra-High Performance Concrete: "Ultra-high performance concrete (UHPC) is also known as reactive powder concrete. Reactive-powder concrete was first patented by a French construction company in 1994. It is characterized by high strength and very low permeability, obtained by optimized particle packing and by a low water content."

Structural Lightweight Aggregate Concrete: "Structural lightweight aggregate concrete is similar to normal-weight concrete except that it has a lower density. It is made with lightweight aggregates or with a combination of lightweight and normal-weight aggregates. The term "sand lightweight" refers to concrete made with coarse lightweight aggregate and natural sand."

Table 20-1. Some Special Types of Concrete.
Slump: "Due to lower aggregate density, structural lightweight concrete does not slump as much as normal weight concrete with the same work ability. A lightweight air-entrained mixture with a slump of 50 mm to 75 mm (2 in. to 3 in.) can be placed under conditions that would require a slump of 75 mm to 125 mm (3 in. to in.) for normal weight concrete."

Insulating and Moderate-Strength Lightweight Concretes: "Insulating concrete is a lightweight concrete with an oven-dry density of 800 kg/m³ (50 lb/ft³) or less. It is made with cementing materials, water, air, and with or without aggregate and chemical admixtures."

"Cast-in-place insulating concrete is used primarily for thermal and sound insulation, roofdecks, fill for slab-on-grade sub-bases, leveling courses for floors or roofs, firewalls, and underground thermal conduit linings."

Table 20-2. Examples of Lightweight Insulating Concrete Mixtures.

Autoclaved Cellular Concrete: "Autoclaved cellular concrete (also called autoclaved aerated concrete or AAC) is a special type of lightweight building material. It is typically manufactured from a mortar consisting of pulverized siliceous material (sand, slag, or fly ash), cement or lime, and water. A gas forming admixture, for example aluminum powder, is added to the mixture."

High-Density Concrete: "High-density (heavyweight) concrete has a density of up to about 6400 kg/m³ (400 lb/ft³). Heavyweight concrete is used principally for radiation shielding but is also used for counterweights and other applications where high density is important. As a shielding material, heavyweight concrete protects against the harmful effects of X-rays, gamma rays, and neutron radiation."

Mass Concrete: "Mass concrete is defined by ACI Committee 207 as "any volume of concrete in which a combination of dimensions of the member being cast, the boundary conditions, the characteristics of the concrete mixture, and the ambient conditions can lead to undesirable thermal stresses, cracking, deleterious chemical reactions, or reduction in the long-term strength as a result of elevated concrete temperature due to heat from hydration."

Preplaced Aggregate Concrete: "Preplaced aggregate concrete is produced by first placing coarse aggregate in a form and later injecting a cement-sand grout, usually with admixtures, to fill the voids."

No-Slump Concrete: "No-Slump concrete is defined as concrete with a consistency corresponding to a slump of 6 mm (1/4 in.) or less. Such concrete, while very dry, must be sufficiently workable to be placed and consolidated with the equipment to be used on the job."

Roller-Compacted Concrete: "Roller-compacted concrete (RCC) is a stiff, no-slump, nearly dry concrete that is compacted in place by vibratory roller or pneumatic tire rollers (Figure 20-11)."
408 **Shotcrete:** "Shotcrete is mortar or small-aggregate concrete pneumatically projected onto a surface at height velocity (Figure 20-13). Also known as gunite and sprayed concrete, shotcrete was developed in 1911 and its concept is essentially unchanged even in today's use."

409 **Shrinkage-Compensating Concrete:** "Shrinkage compensating concrete is concrete containing expansive cement or an expansive admixture. The concrete produces expansion during hardening and thereby offsets the contraction occurring during drying (drying shrinkage). Shrinkage-compensating concrete is used in concrete slabs, pavements, structures, and repair work to minimize drying shrinkage cracks."

409 **Pervious Concrete:** "Pervious (porous or no-fines) concrete contains a narrowly graded coarse aggregate, little to no fine aggregate, and insufficient cement paste to fill voids in the coarse-aggregate. This low water-cement ratio, low-slump concrete resembling popcorn is primarily held together by cement paste at the contact points of the coarse aggregate particles. This produces a concrete with a high volume of voids (15% to 35%) and a high permeability that allows water to flow through it ..."

410 **Colored Concrete:** "Colored concrete can be produced using colored aggregates or by adding color pigments (ASTM C979, Standard specification for Pigments for Integrally Colored Concrete) or both. When colored aggregates are used, they should be exposed at the surface of the concrete."

412 **Polymer-Portland Cement Concrete:** "Polymer portland cement concrete (PPCC), also called polymer-modified concrete, is essentially normal portland cement concrete to which a polymer or monomer has been added during mixing to improve durability and adhesion."

**Ferrocement:** "Ferrocement is a special type of reinforced concrete composed of closely spaced layers of continuous relatively thin metallic or nonmetallic mesh or wire embedded in mortar. It is constructed by hand plaster, shotcreting, laminating (forcing the mesh into fresh mortar), or a combination of these methods."