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CHAPTER TWO:

CONCRETE MATERIALS

PCCP is normally constructed with paving concrete described in Section **500**. The proportions of materials vary with different types of concrete. Admixtures that affect the air content, water requirements, and the time required for the concrete to set may be required.

Concrete Mix Design (CMD) proportions are important to know before starting the paving operation. Concrete mix designs are the responsibility of the Contractor, both for QC/QA and non-QC/QA concrete. The Specifications give broad parameters for the Contractor to design an acceptable CMD. The design is reviewed and approved by INDOT. Some specifications require the Contractor to conduct trial batch demonstrations prior to concrete pours on the contract. Mix designs for QC/QA contracts and concrete using fly ash or other pozzolans are examples of situations requiring trial batches. The Specifications should always be reviewed to determine if a trial batch is required. The PE/PS is required to have the CMD prior to placement of the concrete.

Paving concrete is composed of the following materials (Figure 2-1):

- 1) Fine aggregate, size No. 23 or gradation as identified in the QCP
- 2) Coarse aggregate, quality rating class AP, Size No. 8
- 3) Portland cement
- 4) Water

Additional materials that may be found in paving concrete are:

- 1) Fly Ash
- 2) Water-reducing admixture
- 3) Air-entraining admixture



Figure 2-1. Concrete Materials

AGGREGATES

Aggregates generally occupy approximately 75 percent of the concrete volume and strongly influence the concrete's hardened and freshly mixed properties. The properties of the aggregate have a major effect on the durability, strength, shrinkage, unit weight, and frictional properties of hardened concrete, as well as the mix proportions, slump, workability, bleeding, finishing characteristics and air content of freshly mixed concrete. The selection of the proper aggregates and control of the use of those aggregates is essential in producing quality concrete mixtures.

REQUIREMENTS

The QC/QA PCCP specifications have several restrictions on the use of aggregates in concrete. They include:

- 1) Fine aggregate is required to be natural sand.
- 2) Coarse aggregates are required to be crushed limestone or dolomite, crushed or uncrushed gravel, or air cooled blast furnace slag.
- 3) The gradation of the fine and coarse aggregates is required to be in accordance with size No. 23 and size No. 8, respectively, or a proposed alternate gradation for each.

If alternate gradations are proposed, the tolerances for each sieve are required to be as stated in the QCP

- 4) For coarse aggregates, 100 percent is required to pass the 1 in. sieve.
- 5) The combined amount of fine and coarse aggregate passing the No. 200 sieve is required to be from 0.0 to 2.0 percent for sand and gravel, and from 0.0 to 2.5 percent for sand and stone or slag.
- 6) The fine aggregate is required to be no less than 35 percent or more than 50 percent of the total volume of the aggregate in each cubic yard, based upon saturated surface dry aggregates.

Fine aggregates and coarse aggregates are defined as follows:

Fine Aggregate -- Material that is 100 percent passing the 3/8 in. sieve and a minimum of 80 percent passing the No. 4 sieve

Coarse Aggregate -- Material that has a minimum of 20 percent retained on the No. 4 sieve.

CERTIFIED AGGREGATE PRODUCER PROGRAM (CAPP)

The Certified Aggregate Producer Program is a program in which a qualified mineral aggregate Producer or Redistribution Terminal desiring to supply material to INDOT does so by assuming all of the Plant site controls and a portion of the testing responsibility that had been previously assumed by INDOT. The program focuses on production testing by the Producer and a site specific QCP that indicates how the Producer proposes to control the materials at the plant. Benefits of the program to the Producer include improved customer service, more plant control, and better documentation of test results and events at the plant.

The CAPP requires the source to conduct numerous tests as the aggregate is being produced and when the aggregate is shipped out. As a minimum, the gradation, decantation, crushed particle content, and deleterious tests are required, if applicable. Gradation, crushed particle content, and deleterious content are determined during production of the aggregate, and the gradation and decantation tests are conducted when material is shipped.

Gradation tests are required to be plotted on a control chart by the Certified Aggregate Producer. Figure 2-2 illustrates an example of a control chart for the "critical sieve" (1/2 in.) of a No. 8 aggregate. The CAPP defines what the critical sieve is for each Standard Specification coarse aggregate material and this is the only sieve required to be plotted for coarse aggregates; however, all sieves having a gradation limit designated in the specification are required to be tested. Coarse aggregates not meeting the established limits of the Standard

SOURCE #2001 - #8 STANDARD SPEC. 1/2 in. CRITICAL SIEVE

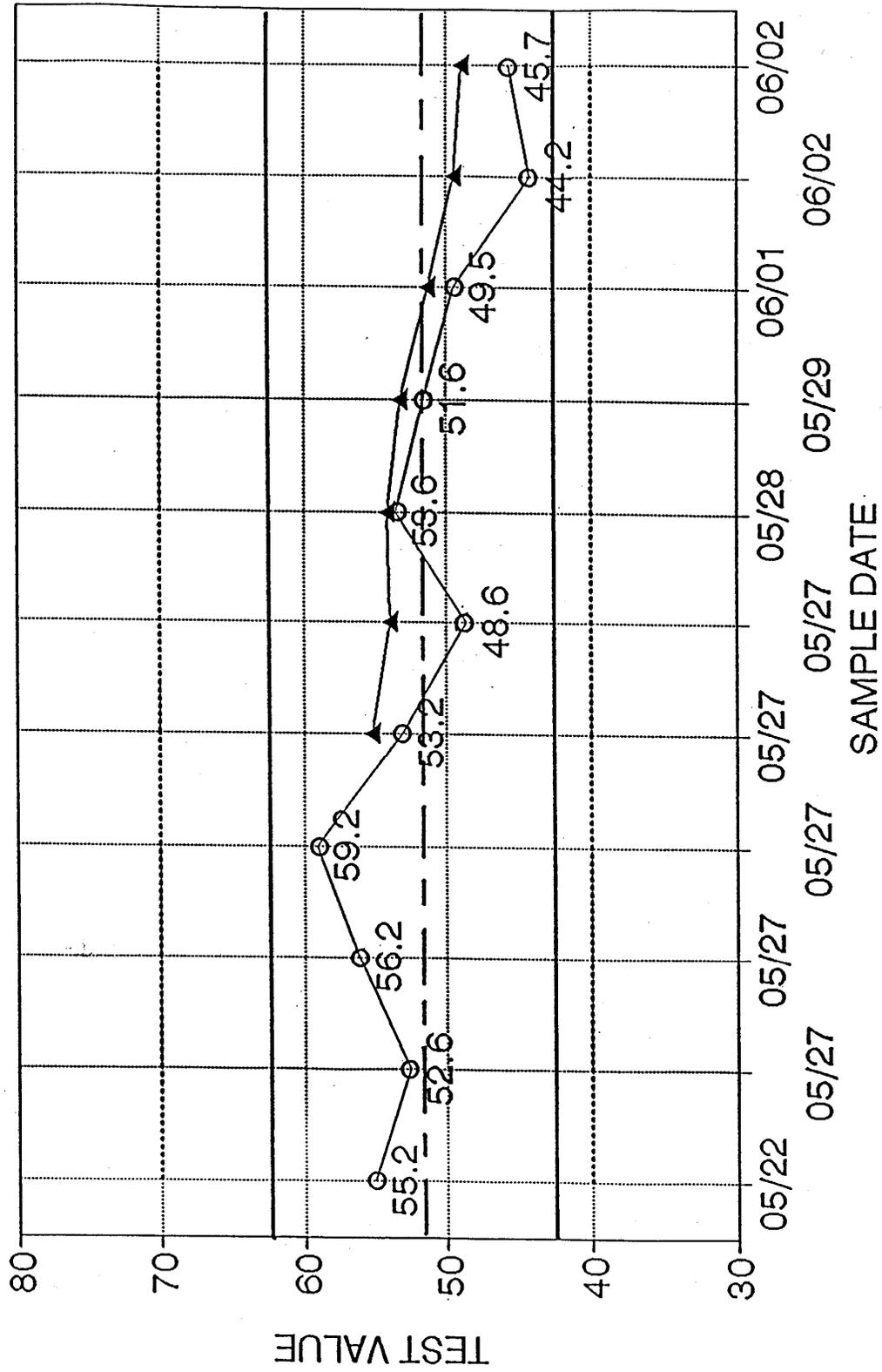


Figure 2-2. Control Chart

Specifications are classified as QA products and the Producer is required to designate the critical sieve and all the gradation limits in the QCP. Fine aggregate gradations are required to be plotted on control charts for all applicable sieves designated either in the Standard Specifications or in the QCP if the material is a QA sand.

FINE AGGREGATE GRADATION

Fine aggregate is required to be natural sand and meet the gradation requirements of No. 23 sand or a QA sand with a designated gradation from the Certified Aggregate Producer. No. 23 sand is the most common size of fine aggregate used. The gradation requirements for this material are included in the following chart:

Sieve Size	Min. % Passing	Max % Passing
3/8 in.	100	---
No. 4	95	100
No. 8	80	100
No. 16	50	85
No. 30	25	60
No. 50	5	30
No. 100	0	10
No. 200	0	3

Concrete mixtures lacking the proper amount of fine sand are harsh and difficult to finish. In particular, the amounts passing the No. 50 and No. 100 sieves affect workability, surface texture and bleeding of concrete the most.

In general, if the water/cementitious ratio is kept constant and the ratio of fine-to-coarse ratio is chosen correctly, a wide range in fine aggregate gradations may be used without a measurable effect on flexural strength.

FINENESS MODULUS

The fineness modulus is an indicator of the fineness of an aggregate and is most used for evaluating fine aggregates. The higher the number, the coarser the aggregate. The fineness modulus is computed by adding the cumulative percentages retained on the 6 in., 3 in., 1 ½ in., 3/4 in., 3/8 in., No. 4, No. 8, No. 16, No. 30, No. 50, and No. 100 sieves, and then dividing by 100. The fineness modulus of a fine aggregate is useful in estimating the proportions of fine and coarse aggregates in concrete mixtures. An example of determining the fineness modulus of a fine aggregate is as follows:

<u>Sieve Size</u>	<u>100</u>	-	<u>% Passing</u>	=	<u>% Retained</u>
3/8 in.	100	-	100	=	0.0
No. 4	100	-	100	=	0.0
No. 8	100	-	89.2	=	10.8
No. 16	100	-	68.3	=	31.7
No. 30	100	-	45.1	=	54.9
No. 50	100	-	13.8	=	86.2
No. 100	100	-	2.6	=	<u>97.4</u>
					281.0

$$\frac{281.0}{100} = 2.81 = \text{Fineness Modulus}$$

COARSE AGGREGATE GRADATION

Coarse aggregate is required to be limestone, dolomite, gravel or air cooled blast furnace slag and meet the gradation requirements of a No. 8 coarse aggregate or a QA coarse aggregate with a designated gradation from the Certified Aggregate Producer. Also, the coarse aggregate is required to have 100 percent passing the 1 in. sieve. No. 8 coarse aggregate is the most common size used in pavement concrete. The specification requires that when the material is stone or slag, the decant may be 0 to 2.5 % and when the material is gravel the decant shall be 0 to 1.5 %. The gradation requirements for No. 8 aggregate is as follows:

Sieve Size	Min. % Passing	Max % Passing
1 in.	100	---
3/4 in.	75	95
1/2 in.	40	70
3/8 in.	20	50
No. 4	0	15
No. 8	0	10
Decant *	0	1.5

* When the material is stone or slag, the decant may be 0 to 2.5

A coarse gradation is one having a percent passing each required sieve that is close to the bottom limit for that sieve (e.g., 75% passing the 3/4 in. sieve). Coarse aggregates with a coarse gradation, in general, require less water and cement than aggregates that are finer. The reason for this is that there is less surface area and therefore less cementitious paste required to adequately coat and bind the aggregate to other particles.

MIXTURE GRADATION

The combined mixture gradation affects relative aggregate proportions as well as cement and water requirements, workability, economy, porosity, shrinkage, and durability of concrete. In general, aggregates that do not have a large deficiency or excess of any size and give a smooth grading curve produce the most satisfactory results.

PARTICLE SHAPE AND SURFACE TEXTURE

Particle shape and surface texture of an aggregate predominately influence the properties of freshly mixed concrete. Rough-textured, angular, elongated particles require more water to produce workable concrete than do smooth, rounded, cubical-shaped particles. Concrete with an excess of angular particles may cause problems with workability and finishing. Irregular and angular particles that tend to interlock when consolidated will increase the strength of the mixture. Rough-textured particles give the cementing material something to grip, producing a stronger bond, and therefore also increase the strength of the mixture. Flat and elongated particles require an increase in mixing water and thus may affect the strength of concrete if the water/cementitious ratio is not maintained.

SPECIFIC GRAVITY

The specific gravity of an aggregate is the ratio of its weight to the weight of an equal volume of water. The value is used in computations for mixture proportioning and control, such as the absolute volume occupied by an aggregate. The specific gravity of an aggregate may be determined on an oven-dry basis or a saturated-surface-dry (SSD) basis. Oven-dry aggregates do not contain any absorbed or free water. Saturated-surface-dry aggregates are aggregates in which the pores in each aggregate particle are filled with water and no excess water is on the particle surface.

The bulk specific gravity is determined by first drying the test sample to a constant weight in accordance with **AASHTO T 84** and **AASHTO T 85**. Both test methods allow the elimination of this initial drying if the absorption and specific gravity values are to be used in proportioning concrete mixtures in which the aggregates are in their naturally moist condition. However, the absorption and bulk specific gravity (SSD) values may be significantly higher for aggregates that are not oven-dried

initially before soaking. This is especially true of particles with a high porosity since the water may not be able to penetrate the pores to the center of the particle in the prescribed soaking period.

Mixture design and proportioning of QC/QA PCCP are determined using bulk specific gravity (SSD) of each aggregate component. The bulk specific gravity determined on a dry basis is a common test conducted by the aggregate industry. However, using the absorption value of the aggregate, the bulk specific gravity (SSD) may be calculated in accordance with **AASHTO T 84** and **AASHTO T 85** as follows:

$$S_s = (1 + A/100) S_d$$

where:

S_s = bulk specific gravity (SSD)

S_d = bulk specific gravity (dry)

A = absorption in percent

Example: $BSG_{(dry)} = 2.615$
 Absorption = 3.21%

$$\begin{aligned} S_s &= (1 + 3.21/100) 2.615 \\ &= 1.0321 \times 2.615 \\ &= 2.699 \end{aligned}$$

The calculated bulk specific gravity (SSD) value is an estimate. QC/QA PCCP specifications require that the actual bulk specific gravity (SSD) test value be used for mixture design and proportioning of concrete.

ABSORPTION AND SURFACE MOISTURE

The absorption and surface moisture (free moisture) of aggregates are required to be determined so that the net water content of the concrete may be controlled and the correct batch weights determined. Internally, aggregate particles are made up of solid mater and voids that may or may not contain water. Definitions of absorption and surface moisture, derived from **AASHTO T 85** and **AASHTO T 255**, respectively, are as follows:

Absorption -- the increase in the weight of aggregate due to water in the pores of the material, but not including water adhering to the outside surface of the particles

Surface Moisture (Free Moisture) -- the water adhering to the outside surface of the particles

AASHTO T 255 designates the procedure for determining the total moisture content of the aggregate by drying. The surface or free moisture content of a fine or coarse aggregate may be determined by deducting the absorption from the total moisture content.

The moisture conditions of aggregates at the jobsite and their contribution to the water in the concrete include:

- 1) Oven-dry -- no contribution to the water content. Particles will absorb an amount of water equal to the water absorption of the aggregate.
- 2) Air Dry -- dry at the particle surface but containing some interior moisture. Particles have not reached full absorption and will absorb some water from the concrete mixture
- 3) Saturated Surface Dry (SSD) -- particles have obtained the full absorption that is available and will neither absorb water from nor contribute water to the concrete mixture
- 4) Damp or Wet -- particles have more moisture than the quantity needed for full absorption and will contribute water (free moisture) to the concrete mixture

The amount of water used for the concrete mixture is required to be adjusted for the moisture content of the aggregates to meet the designated water requirement. The strength, durability, workability, and other properties are affected if the water content of the concrete mixture is not kept constant.

Absorption test results for a particular size of aggregate that differ by more than 1.0 percentage points from the INDOT's source value shall be investigated. The Contractor is required to report any differences that exceed 1.0% to INDOT. The Contractor's results shall be used when calculating the water/cementitious ratio.

PORTLAND CEMENTS

Portland cements are finely ground powders that set and harden by reacting chemically with water. During this reaction, called hydration, cement combines with water to form a solid mass. When the paste (cement and water) is added to aggregates, the paste acts as an adhesive and binds the aggregates together to form concrete.

Hydration of the cement begins as soon as there is contact with water. Each cement particle forms a growth on the surface that spreads until connecting with the growth of other particles or adheres to adjacent

substances. This reaction results in progressive stiffening, hardening, and strength development. As the concrete stiffens there is a loss of workability that usually occurs within three hours of mixing; however, the composition and fineness of the cement, the mixture proportions, and temperature conditions all may have an effect on the loss of workability.

Hydration will continue as long as there is available space for the hydration products and the moisture and temperature conditions are favorable. The concrete will become stronger as the hydration continues. Most of the hydration and strength development takes place within the first month after mixing, and will continue slowly for a long time.

REQUIREMENTS

The more common types of cements allowed for QC/QA PCCP are Portland Cement (Type I), Portland Blast-Furnace Slag Cement (Type IS), or Portland-Pozzolan Cement (Type IP); however, Type I is most often used. A general description of these types of cements is as follows:

Type I

Under normal conditions, Type I portland cement is used in paving concrete where special properties, such as sulfate resistance, high early strength, or low heat of hydration, are not required. This cement is used in concrete that is not subject to aggressive exposures, such as sulfate attack from soil or water, or to an objectionable temperature rise due to heat generated by hydration. Air-entrained Portland cement, Type I-A, is cement that has been entrained with air during the manufacturing process and requires less air-entraining agent to be added to obtain the required air content.

Type IS

Type IS portland blast-furnace slag cement is used for general concrete construction applications. This cement is a blend of portland cement and granulated blast-furnace slag. These cements are produced by intergrinding the slag with the portland cement, separately grinding the slag and blending with the cement, or combining the grinding and blending of the two products.

Type IP

Portland-pozzolan cement, Type IP is similar to Type I, except that the cement also contains a pozzolan, such as fly ash, to reduce the cost. Air-entrained Portland-pozzolan cement, Type IP-A, is similar to Type I-A, except that this cement also contains a pozzolan. When Portland cement, Type IP-A is used, the fly ash specifications are also required. Type IP portland-pozzolan cement is used for general concrete construction applications. This cement is a blend of portland cement and a pozzolan

with the pozzolan content of $20 \pm 5\%$ by weight. These cements are produced by intergrinding portland cement clinker with the pozzolon, by blending portland cement and a pozzolon, or by a combination of intergrinding and blending.

Further restrictions on the use of portland cement include:

- 1) Cements are accepted from qualified manufacturers or manufacturer/distributors that are included on the INDOT approved list of Cement Sources
- 2) A means for storing and protecting the cement against dampness is required to be provided. Cement which has become partially set, contains lumps or caked cement, or is salvaged from discarded or used sacks is not allowed to be used.
- 3) Different kinds or brands, or cement of the same brand from different mills, shall not be mixed during use unless permitted, and then only as directed. They shall not be used alternately in any one pour, unless otherwise permitted.
- 4) Blended cements may only be incorporated into concrete placed between April 1 and October 15 of the same calendar year. This time period restriction does not apply if traffic is not anticipated on the concrete.
- 5) If Type IP, type IP-A, type IS or type IS-A cements are used, the minimum portland cement content is increased to 500 lb/yd^3 .

ADMIXTURES

Admixtures are those ingredients added to concrete immediately before or during mixing other than portland cement, water, and aggregates. The major reasons for using admixtures include:

- 1) To reduce the cost of concrete construction
- 2) To achieve certain properties in concrete more effectively than by other means
- 3) To insure the quality of concrete during the stages of mixing, transporting, placing, and curing in adverse weather conditions

The effectiveness of any admixture is dependent on such factors as:

- 1) Type, brand, and amount of cement
- 2) Water content
- 3) Aggregate shape, gradation, and proportions
- 4) Mixing time
- 5) Slump
- 6) Temperatures of the concrete and air

Trial batches of the contract materials and the admixtures should be made to verify the compatibility of the materials as well as the effects on the properties of the concrete. The amount of admixture recommended by the manufacturer should be used.

MINERAL ADMIXTURES

Mineral admixtures are powdered or pulverized materials added to concrete before or during mixing to improve or change some of the plastic or hardened concrete properties. The mineral admixtures allowed in QC/QA PCCP are classified as pozzolons (ground granulated blast-furnace slag and fly ash).

Ground Granulated Blast Furnace Slag

Ground granulated blast-furnace slag is a nonmetallic material that is developed in a molten condition simultaneously with iron in a blast furnace. A glassy granular material is formed when molten blast-furnace slag is rapidly chilled by immersion in water. This glassy granular material is then ground to cement fineness resulting in ground granulated blast-furnace slag. The rough and angular-shaped ground slag hydrates and sets in a manner similar to portland cement when exposed to water and portland cement.

Fly Ash

Fly ash is a finely divided residue that results from the combustion of pulverized coal in electric power generating plants. In general, class F fly ash is produced from burning anthracite or bituminous coal and class C fly ash is produced from burning lignite or subbituminous coal. During combustion, the coal's mineral impurities (such as clay, feldspar, and shale) fuse in suspension and are carried away from the combustion chamber by the exhaust gas. In the process, the fused material cools and

solidifies into spherical particles called fly ash, which is collected by electrostatic precipitators or bag filters.

The use of fly ash reduces the cost of concrete, but may extend the time needed to achieve the proper strength for opening the pavement to traffic. Class C fly ash has better structural qualities than Class F and is therefore more commonly used. The ratio of Portland cement to fly ash for use in QC/QA PCCP is required to be a minimum of 3.2 by weight.

Mineral Admixture Effect on Concrete

The effects of the ground granulated blast-furnace slag, and fly ash on the concrete are as follows:

Ground Granulated Blast Furnace Slag

- 1) Increases long-term strength
- 2) Lowers permeability
- 3) Improves sulfate resistance
- 4) Lowers heat of hydration
- 5) Reduces potential alkali-silica reaction
- 6) Improves workability

Fly Ash

- 1) Enhances workability
- 2) Lowers permeability
- 3) Lowers water demand
- 4) Slightly enhances long term strength
- 5) Reduces the heat of hydration
- 6) Retards setting time
- 7) Delays strength gain

Requirements

QC/QA PCCP has the following restrictions on the use of mineral admixtures:

- 1) Fly ash and ground granulated blast-furnace slag may only be incorporated into the concrete between April 1 and October 15 of the same calendar year.
- 2) Fly ash or ground granulated blast-furnace slag are not permitted when blended Portland cements are used

CHEMICAL ADMIXTURES

Chemical admixtures are materials added to concrete before or during mixing and are required to be included in the list of approved Admixtures for PCC. The admixtures affect the concrete as follows:

Air-Entraining Admixtures -- used to entrain microscopic air bubbles in concrete.

Water-Reducing Admixtures -- used to reduce the quantity of mixing water required to produce concrete of a certain slump, reduce water/cementitious ratio, or increase slump.

Retarding Admixtures -- used to retard the rate of setting of concrete.

Accelerating Admixtures -- used to accelerate strength development at an early age.

High-Range Water Reducers (Superplasticizers) -- added to concrete with low-to-normal slump and water-cement ratio to make high-slump flowing concrete.

Water reducing admixture Type A is not allowed to be used in conjunction with water reducing and retarding admixture Type D. in QC/QA PCCP.

WATER

When water is added to the cement, the setting process begins. In a central-mix plant this process occurs in the mixing drum, and in a transit mix this process occurs in the truck mixer. Only clean, potable water may be used. Contaminated water may contain materials which are detrimental to the concrete after placement.

After the water is added to the mix, the concrete is required to be placed within 90 minutes, if hauled in truck mixers or truck agitators. If the hauling vehicles have no agitators, this time is reduced to 30 minutes. The time the water is added to the concrete is stamped on the ticket at the concrete plant.

The amount of water added at the plant varies from day to day depending upon the moisture contents of the fine and coarse aggregates used. If an overnight rain has caused the stockpiled materials to become wetter than the day before, less water is required to be added at the plant. Materials exposed to hot, dry conditions for several days require more water to be added. The mixture is required to contain no more water than is necessary to produce a concrete that is workable, plastic, and meets the slump requirements; however, the water-cementitious ratio is required to meet the Specification limits at all times.