Portland Cement and Concrete

Lesson 3

This lesson focuses on the most consumed construction material, *Portland cement*–based concrete. It's consumed for pavement, dams, bridges, floors, walls, columns, and even pre-stressed modular components.

The lesson begins by describing concretes chief ingredient, Portland cement. You'll learn how Portland is produced from just a few raw materials, its physical properties, and how a chemical reaction occurs when water is added. This lesson continues the discussion of aggregates, explaining why they make up the highest volume of concrete and how their role in the recipe is critical to the performance of the product.

The lesson's second assignment introduces the techniques to estimate and place concrete. These topics relate to how concrete consistency is controlled and specified. Because concrete serves as a critical structural element, its failure would likely affect every other system in the building and often the building's ability to stand. For this reason, concrete is highly tested and stringently specified. A substantial part of this lesson deals with testing methods.

This lesson closes with a quick look at precast concrete. Precast concrete is closely related to structural steel framing. Members are fabricated offsite to the designer's specifications, shipped to the job site, and put in place with cranes.

When you complete this lesson, you'll be able to

- Explain the difference between *tensile* and *compressive* strength
- Define the role of aggregates in concrete design
- Name and explain the purpose of each raw material required to produce Portland cement
- Explain the process of *hydration*
- Calculate the number of cubic yards of concrete required to fill a form

- Predict the degrading effects of common chemical contact with concrete
- Explain how to investigate the causes for concrete failure and whether they're installation or manufacturing related
- Explain the process for determining the consistency of concrete mixes

ASSIGNMENT 5

Read this introduction to Assignment 5. Then study the first half of Chapter 4, "Portland Cement Concrete," on pages 88–106 in the textbook.

Cement is an *adhesive*, a material that bonds two or more other materials. While you'll encounter plastic cements or rubber cements, for instance, the most common use of the word has to do with concrete. In fact, people often use the word *cement* interchangeably with the term *concrete* when they refer to cement sidewalks or cement block. *Portland cement* is an adhesive used in the production of concrete. While Portland cement is the smallest ingredient in concrete, it's the most important and most expensive. Other components of concrete like water, sand, and gravel are raw materials found in nature. Portland cement, on the other hand, is something we manufacture. The raw materials required to produce Portland cement can be obtained from various substances found in many locations. Most are the obtained from mining operations while others are byproducts of other industrial processes.

When water is mixed with Portland cement, a paste is formed. Often, water-based adhesives bond when they dry. When the water evaporates from the liquid adhesive, the dry bonding agent remains between the materials as a joint. However, the bonding process of Portland paste isn't a drying process at all. Instead of drying, Portland cement *sets*. Setting results from a chemical reaction known as *hydration,* which occurs when Portland cement and water mix, forming a third substance. And because the chemical reaction creates a completely different third substance, Portland cement that has set is no longer soluble by water.

The setting time of Portland cement paste has less to do with water volume than it does with the proportions and ingredients in the dry cement. The different types of Portland cement are designed for different installation environments and applications. Weather conditions at the time of concrete placement can greatly affect the time before setting occurs, or *working time.* This is the time period during which the poured concrete is finished. By adjusting the raw materials, we can control to some degree the amount of time that concrete will remain workable or *plastic*. When working in hot weather, it might be advantageous to extend the working time, while a reduction in working time is preferable during slip-form roadway construction where the concrete must become self-supporting almost immediately. The agents used to control the working time and other properties of Portland cement are called *admixtures*.

Portland cement is the basic ingredient in many building products. It's found in various types of mortars for stone, brick, and block that contain sand as their only aggregate. Grouts and plaster as well as floor patching compounds rely on Portland cement as a bonding agent. Lightweight concrete, used as an insulator or fire retarder over other construction materials like iron and wood, includes Portland cement and lightweight aggregates like vermiculite and gypsum. Self-leveling Portland-based topping compounds pour with nearly the consistency of water and leave a perfectly smooth and level floor substrate with concrete-like compressive strength.

Water contains various minerals, silts and sediments, and even chemicals used for treatment. For the most part, the water used to mix construction concrete is specified as *potable,* the formal name given to drinking water. Impurities in water can alter both setting characteristics and bonding strength of the aggregates. However, chlorine levels, salt levels, iron content, and other variations in the water's makeup considerably impact the Portland-cement hydration process. When white Portland is used in plaster and tile grouts, water quality may be critical to the appearance of the finished product. Many manufacturers of finish-grade Portland-based products specify water quality that's superior to simply potable water. Some manufactures recommend only the use of distilled water. One could imagine a time when construction concrete specifications require water testing.

Concrete contains a mixture of coarse and fine aggregates. The maximum size of coarse aggregates is dictated by the available space around each piece. This ensures each piece of aggregate is adequately covered with cement paste. The available space depends most often on the thickness of planned project. Thickness is the shortest distance between forms. If the project requires the addition of reinforcing steel in the concrete, then the space between the forms is reduced and so may be the maximum allowable aggregate size. The most successful concrete projects are carefully planned to include varying aggregate sizes. These aggregates arrange in the plastic mix to interlock with each other as well as any reinforcing materials. Concrete mixes with excessively large aggregates are difficult to work and finish.

Concrete's workability depends on the ratios of its components. More than any other relationship between the raw materials, the proportion of water to cement is critical in achieving a desired strength and density. You'll quickly learn to avoid the temptation to make the mix more workable by increasing its water volume. On the other hand, concrete mixes that are too stiff to work lead to voids, particularly around forms and reinforcing. Similarly, a surface that can't be properly *floated* and *troweled* (as the finishing techniques are known) leads to reduced durability and weather resistance, not to mention less-than-desirable appearance.

After you've read pages 88–106 in the textbook carefully and completed question 1–11 from the "Review Questions" on page 137, check your answers against those provided in the back of this study guide. When you're sure you completely understand the material from Assignment 5, move on to Assignment 6.

ASSIGNMENT 6

Read this introduction to Assignment 6. Then study the second half of Chapter 4, "Portland Cement Concrete," on pages 107–136.

Concrete is sold by the cubic yard or meter. When pouring concrete into well-constructed formwork and properly graded sub-bases, only simple calculations are necessary to determine the needed volume of concrete. Concrete estimating problems arise with variances in forms or grading. One of the most troublesome concrete calculations involves determining the volume required to fill a trenched footer where the excavation walls will serve as the footer's form. Even the most experienced excavator won't create a perfectly uniform trench for the entire perimeter of a structure. While the contractor may plan to absorb the cost of the additional concrete required to fill the oversized footer in exchange for the labor and material saved by eliminating forms, the risk of underestimating the concrete required is rarely worth any savings on the formwork. Similarly, pouring a large slab over an irregularly graded sub-base can wildly impact the volume required. A slab that specified as six inches thick shouldn't measure seven in some locations and five at others. Precise formwork and grading are keys to accurate concrete estimation and effective installations.

There's no question that concrete is a heavy construction material. Any cast-in-place project involving forms demands that they sufficiently support the concrete's weight until it sets and becomes self-supporting. A thin slab might not exert much pressure on its containment compared to the base of a tall poured wall. While this lesson doesn't concern itself with the design of concrete forms, it's important that you recognize that one of the most significant characteristics of plastic concrete is that it's a very heavy fluid. Significant consequences come from a containment failure, including lost time, additional expense, and personal injury.

Installing, or as it's more commonly known, *placing*, concrete involves careful orchestration of equipment and manpower. After completing site preparations and estimating the required amount of concrete, the materials must be mixed, delivered, placed, and finished in an organized timely fashion. Unlike other building materials, plastic concrete is workable and thus usable for a very limited time.

The first phase of concrete placing is mixing. A particular recipe begins with the combination of dry raw materials in the correct ratios. Because concrete begins the process of setting the moment water is added, addition of water occurs just before placing. The vast majority of dry material mixing is performed in rotating-drum mixing trucks on the way to the job site.

With the truck at the site and positioned to place the mix, water is added and the mix agitated at relatively high speeds for a short duration. A traditional concrete truck has paddles or blades mounted inside of a drum pitched to throw the materials to the top of the drum. The mixing process is much like a kitchen blender where material in the bottom is continuously fanned to the top. When sufficiently mixed, the drum reverses direction and a port opens at its rear. It takes only a very slow rotation to feed the concrete out of the drum. Normally a chute attaches to the drum's opening and directs the flow of concrete to a placement position. However, the concrete must flow down the chute only a limited distance. Similarly, the distance the concrete falls vertically from the chute must also be controlled. These limitations prevent segregation of aggregates from one another as well as from the cement paste. If traditionally mixed concrete must travel more than a few yards on a chute or fall vertically more than a few feet, other means of transportation including carts, wheelbarrows, dump trucks, and loaders must move the concrete from the mixing truck to its final placement location.

Once concrete in placed there's no way to change its workability. "Workable" can be a relative term. Depending on the application, the finished concrete product requires a particular amount and type of work. A concrete footer may need to be leveled at the top of the forms and left with a very rough finish to help lock in the foundation wall that's later placed on top of it. A slab that will receive resilient floorcovering requires trowelling to a very level and smooth finish. A sidewalk might require floating, but only to a "broom" finish to leave a nonslip surface. Aggregate shape, size, and quantity affect the workability of a mix, as do many additives. The most obvious factor affecting workability is water content. The final consistency of a mix depends most on the water-to-cement ratio. An experienced delivery technician adjusts the final water to achieve the specified mix consistency very well just by visually observing how the mix tumbles in the drum. Concrete contractors can tell a lot about the mix consistency by observing how it rolls down a chute. Still, to create a specifiable standard, define the stiffness and workability of a particular mix by observing how well a sample of the mix retains a shape and stands on its own without support. This simple and quick observation ensures that a particular mix meets the designer's specification as well as controls consistency when a project requires delivery of more than one mix.

In this assignment, you'll learn that the strength and durability of concrete depends on many variables. Unfortunately, it's impossible to visually recognize the quality of concrete. We can see failure and realize that something wasn't correct after the fact, but for the most part weak cast-in-place concrete can look exactly like quality concrete. Quality control must include testing. A very large percentage of concrete testing is a result of research and development. As the concrete industry evolves to meet environmental concerns and energy-use limitations, new methods emerge for concrete manufacturing and placement. This testing is to predict how a given product will perform in place. Workability, durability, strength, and cost are all characteristics we predict as a result of concrete research.

Another form of testing occurs to prove that a given mix is installed as specified. As we've have seen, there's quite a journey from raw material to finished product, and no matter how specific and accurate a particular application is prepared on paper, things can go wrong. Cast-in-place concrete is the only construction material where the manufacturing process ends just minutes before installation. On top of that, the installation time is finite and not easily interrupted. When we consider the consequences of structural failure in concrete structures, site testing is more than justified.

Like all other construction materials, concrete degrades. There's a lifespan to concrete. It may be hundreds or even thousands of years, or relatively few as in road surface construction. Many times, structures are altered to suit the needs of a new owner. Existing structural concrete is often reevaluated for renovation purposes. A bridge designed for a specific traffic rate and weight load 20 years ago may need to be tested for its current level of use. Even if we were to stop using concrete as a construction material today, concrete testing would go on for a long time.

After you've read pages 107–136 in the textbook carefully and completed questions 12–28 from the "Review Questions" on pages 137 and 138, check your answers against those provided in the back of this study guide. When you're sure you completely understand the material from this lesson, complete the Lesson 3 Examination.