Concrete Testing *or* The Life of a Concrete Test Cylinder

By Brent J. Bandy

A good testing program is key to the success of any concrete construction. Fortunately, there are many standards and common practices that reinforce the quality of concrete construction. And quality control is much more than the ubiquitous test cylinders. It consists of a whole quality program including planning, design, specifications, choosing a qualified ready-mix supplier and testing laboratory, and following through on the program.

Who Wants to Test Concrete?

Engineers are always concerned about the quality of the concrete, but today's knowledgeable owners and architects are interested, too. Owners want the assurance that their buildings will be durable and as maintenance-free as possible. Architects want to know that mixes are consistent and will achieve the most uniform appearance for exposed concrete surfaces. Engineers want to know that strength and other structural goals are met.

To meet these goals, the first step is defining the concrete properties. Just as important, however, is the testing specification, which outlines many of the quality control procedures. A solid specification should eliminate ambiguities about who is responsible for certain testing and what type of coordination is expected between the testing lab and the contractor.

At the Batch Plant

Trucks full of stone and sand make their way to the batch plant from local quarries and rivers. Cement and admixtures arrive from elsewhere in the country. The aggregates can be exposed to wet and dry conditions, sunny or shady. There can be significant variability in the properties of these natural and manufactured materials. Moreover, some industrial byproducts such as fly ash and slag cement are being successfully substituted for part of the cement in a concrete mix. All these contribute to the complexity of designing mixes and batching consistent, high-quality concrete. Testing helps to regulate this process.

Quality control should start at the source: cement, aggregates, and admixtures can be tested by the owner's testing laboratory or certified by the supplier's testing laboratory.

The Right Recipe

Just as cooking is an art, concrete mix designs are more than a science. A good concrete specification will allow the local supplier to design a mix to meet the structural and architectural requirements while using local materials and meeting the scheduling, placing, and finishing requirements of the general contractor.

If project specifications require mix designs that are out of the ordinary, such as high-strength concrete, use of new admixtures, or special architectural concrete, early testing of mix designs helps to assure the team that the mix will perform. Admixture suppliers can use their knowledge at this stage to assist in integrating their admixtures into the mix design.

A preconstruction/preconcrete conference is an invaluable communication and coordination tool for any project. Any questions about the mix design or special requirements can be discussed. The testing laboratory should be present to hear the concerns of each party and prepare to deal with them in the field.

The Daily Routine

At last! After all the designing and planning, the concrete is mixed in the truck and makes its way to the site. What happens next?

Getting to the Job Site

How long will the concrete be in the truck? Does it get stuck in traffic? The testing laboratory should note the age of the concrete and reject concrete older than 90 minutes. The truck tickets should be checked to ensure that the right truck is in the right place at the right time.

The question of where to sample often comes up. ASTM C 172 notes that "sampling should normally be performed as the concrete is delivered from the mixer to the conveying vehicle used to transport the concrete to the forms; however, specifications may require other points of sampling, such as the discharge of a concrete pump." ACI Committee 304 agrees that "it may be desirable to sample at both the point of delivery to the pump and the point of discharge from the line to perform comparative testing to determine if any significant changes in slump, air content, and other mix characteristics occur." Pumped concrete can lose some of its entrained air and slump. Comparative testing can help the mix designer make adjustments to provide a more workable mix for the placers and finishers while still meeting the requirements of the specifications.

By the way, who's testing the concrete? The testing specification should call for the lab to meet ASTM E 329, which discusses the certification and experience of the testing laboratory and its personnel. The owner should choose the most reputable and experienced company, and hopefully one with whom the whole team has developed a relationship of trust and respect. A good testing laboratory will not only perform its contractual duties well but can use its experience to help the team deal with problems and unforeseen conditions in the field.

Testing Plastic Properties

Testing for entrained air—Too much air can reduce durability in traffic surfaces, and too little can reduce freezing-and-thawing durability. Also, air affects the finishability of concrete. So, everybody has an interest in air content. The testing company should notify the contractor immediately if the air requirements are not met.

Testing for temperature—The temperature of concrete is crucial not only to the workability and finishing life of the concrete but also to the long-term strength of the concrete. A simple thermometer will measure the temperature in fresh concrete. Concrete outside the temperature limits can be immediately identified. Cooler concrete may take longer to set but can reach higher long-term strengths. Concrete that is too cold may never react enough to reach the 28-day strength. Hot concrete can look great at 7 days but fall short at 28 days and beyond because the mix burns itself out early. This can also be a concern with mass concrete pours; a special monitoring system can be established to make sure this concrete meets the specifications. Procedures for cold-weather and hot-weather concreting should be outlined in the specification. Adjusting the

Figure 1: Testing for air content using a pressure meter

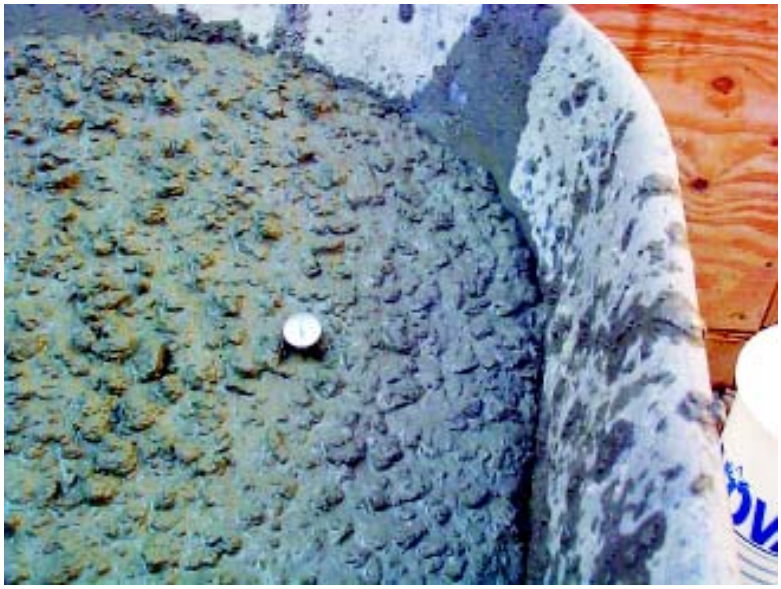

Figure 2: A basic concrete thermometer

Figure 3: Measuring slump

Figure 4: Rodding the cylinders in the mold

temperature of the materials, especially the mix water, can help offset the effects of weather or the fact that materials have been exposed to extreme temperatures.

Testing for slump—Because of the tension between the placers and finishers, who usually want more water, and the engineer, who wants less water for higher strength and less shrinkage, the addition of water at the site and limits of slump should be agreed upon early. The batch plant will often leave out some water at the plant and add some in the field up to the amount in the mix design. This is one way to adjust for vicissitudes of time in truck, temperature, moisture variations in aggregates, and pumping/conveying changes. The testing laboratory will monitor these adjustments relative to the specifications.

The Famous Cylinder

The life of the concrete test cylinder now begins to take shape. While other methods of concrete testing have been used with success, making and breaking test cylinders remains the most common method in the U.S. Concrete is placed in the cylinder form and consolidated according to ASTM C 31. The cylinders are carried to the field storage box. Transporting and storage of the cylinders from the beginning is of the utmost importance because vibration after concrete starts to set up can weaken the concrete's internal structure and reduce cylinder strength. The storage box should be sturdily built in a location convenient for the testing laboratory and out of the way of vibrations and construction traffic. The box may be moved occasionally to allow for staging of construction activities but should not be moved while cylinders are inside. The box should be well insulated. Placing an active light bulb inside during cold weather can provide extra heat to simulate the warmer environment in the forms. For hot-weather conditions, ACI 305 provides recommendations for protecting cylinders from evaporation and excess heat, such as covering with damp sand or wet burlap.

Finally, the outdoor life of the cylinders is over. The next day they leave the job site and are treated with the utmost respect: They are carefully secured in the vehicle, transported to the lab, and placed in a steam room to cure. The cylinders are typically tested as follows: one at 7 days and two at 28 days, with reserves to test later if the 28-day results are low strength or otherwise questionable. While the reserve cylinders can provide an indication of additional strength gain or problems with the previously tested cylinders, ACI 318 does not recognize them as appropriate statistical indicators for acceptance of concrete.

If early breaks are requested by the contractor for early form stripping or post-tensioning, extra cylinders can be made with test results reported to the contractor immediately. For high-strength or high fly ash/slag cement concrete, the strength may be specified at 56 or 90 days rather than the typical 28 days.

What Happens to All the Data?

The data from the testing is published by the testing laboratory according to ASTM C 39 and distributed. The location placed should be included on each report in case remedial work or further testing is required. The reports will be reviewed to determine whether the concrete has met the specifications. Some companies will highlight nonconforming tests by printing them on colored paper.

The concrete properties should be within tolerances set forth in the specifications and ACI 318. According to ASTM C 39, "care must

be exercised in the interpretation of the significance of compressive strength determinations by this test method since strength is not a fundamental or intrinsic property of concrete made from given materials." Nonetheless, "the results of this method are used as a basis for quality control of proportioning, mixing, and placing operations." Because the overall design methodology anticipates some statistical variation in test cylinder strength, low breaks within the ACI limits may be acceptable, even if the numbers are a little low.

Low Strength Results

On most projects, some cylinders will not achieve the specified strength. Maybe the cylinders weren't properly prepared or stored. Maybe the mix was batched improperly. Whatever the case, testing the in-place concrete is usually the next step in resolving low strength test results.

While coring is expensive and destructive, it produces the most reliable results; and it is the only ACI 318 approved method other than load testing. At least three cores should be taken and prepared per ACI 318 section 5.6.4. The average of the three core strengths should equal or exceed 85% f_c', with no core less than 75% f_c'. Experience has shown that most cores will exceed the test cylinder strength and will often provide the needed confirmation of the adequacy of the concrete unless strength is especially low.

Swiss Hammer tests are much less expensive and easier to perform than coring, but troweled surfaces can skew results because they may be locally harder than the underlying concrete. Windsor Probe tests are also fairly simple to perform, but the results can be skewed when the pins strike the coarse aggregate. Both of these tests are great for comparing large areas of concrete against one another, but for actual strength values they require calibration with core samples.

Figure 5 and 6: Cylinders in an insulated storage box

So, Why Do We Test Concrete?

From the conceptual stage of the project to the topping-out party, a concrete quality program is of paramount importance. The owner and design team work hard to design and specify a top-notch building, and the contractors work hard to turn the designs into reality. The testing laboratory helps to bring the groups together and provide the quality assurance in the field for which all parties are aiming. So that little test cylinder goes through a lot, but the peace of mind it gives is valuable to the entire project team.

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