"During the initial 24+/-8 hours after molding the temperature immediately adjacent to the specimens shall be maintained in the range of 60 to 80 degrees F (16 to 27 C), loss of moisture shall be prevented. "

from A.S.T.M. standard C31-84
"Making and Curing Concrete Test Specimens in the Field"

We asked concrete contractors, suppliers and DOT officials the following question:

"What do *you* do with *your* test cylinders for the first 24 hours?"

Here are some of the responses we received:

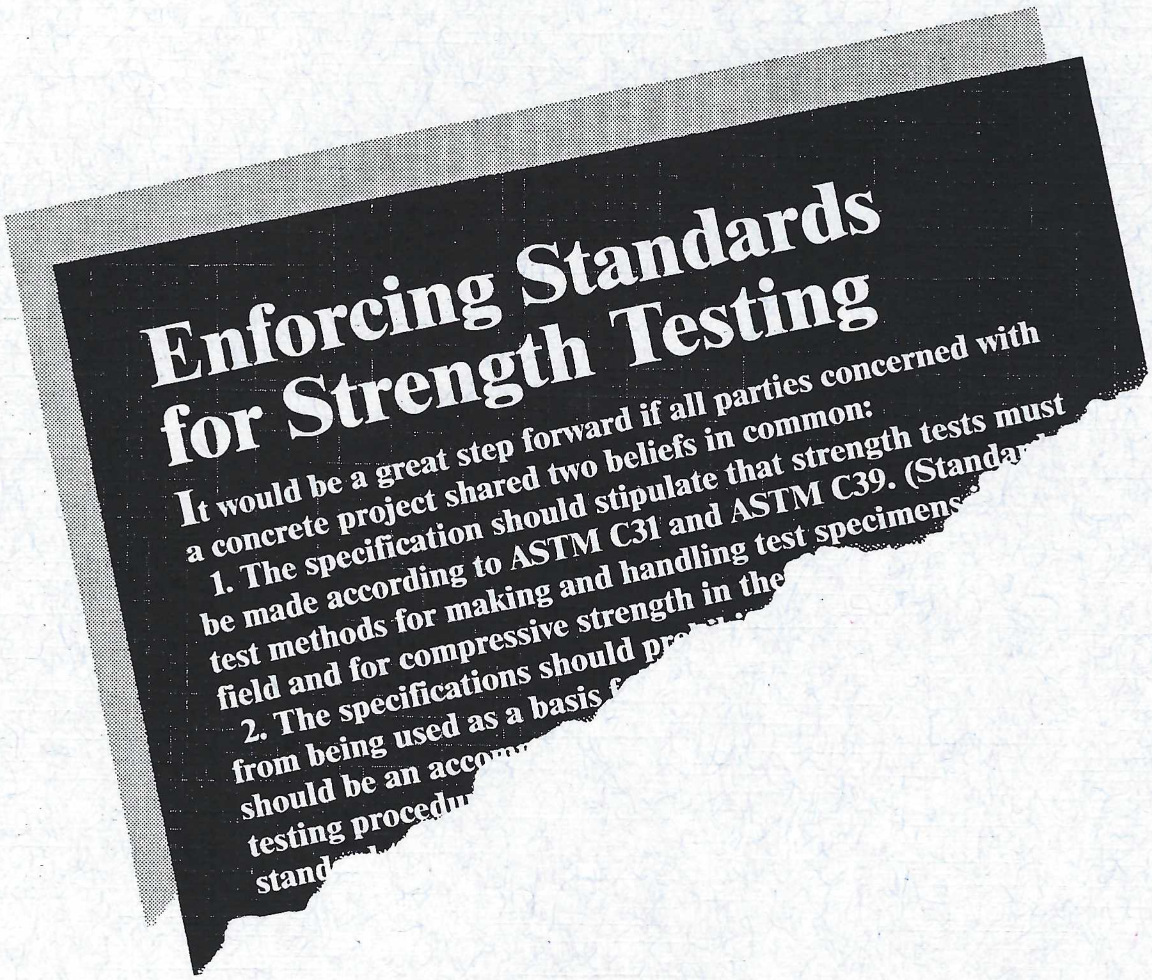
1. Leave them on our pick-up truck.
2. Bury them in the sand.
3. Place them in "cool" water.
4. Place them in "warm" water.
5. Cover them with wet burlap.
6. Cover them with polyethylene
7. Put them in the jobsite trailer.
8. Place them in zonolite or vermiculite insulation.
9. Put them in water and add ice.
10. We build our own curing box.
    (Out of what?)
    a. galvanized sheet metal.
    b. plywood.
    c. styrofoam.

Do these methods *really* satisfy the standard? Can any of these methods actually control the temperature of the cylinders? What happens if the temperatures are not in spec?...So what?...Isn't the structure strong enough anyway?...

Please read on!

Amid great fanfare, the project is nearing completion. The publicity has been great for the community, the owner, contractor and concrete supplier alike. But now, the cylinder tests are coming in low, or worse yet, there's failure in the structure. The owner blames the contractor, the contractor blames the supplier, no one is getting paid, and lawsuits are looming on the horizon.

Who's at fault? Were the cylinders handled properly?
Where is the control?



Enforcing Standards for Strength Testing

It would be a great step forward if all parties concerned with a concrete project shared two beliefs in common:

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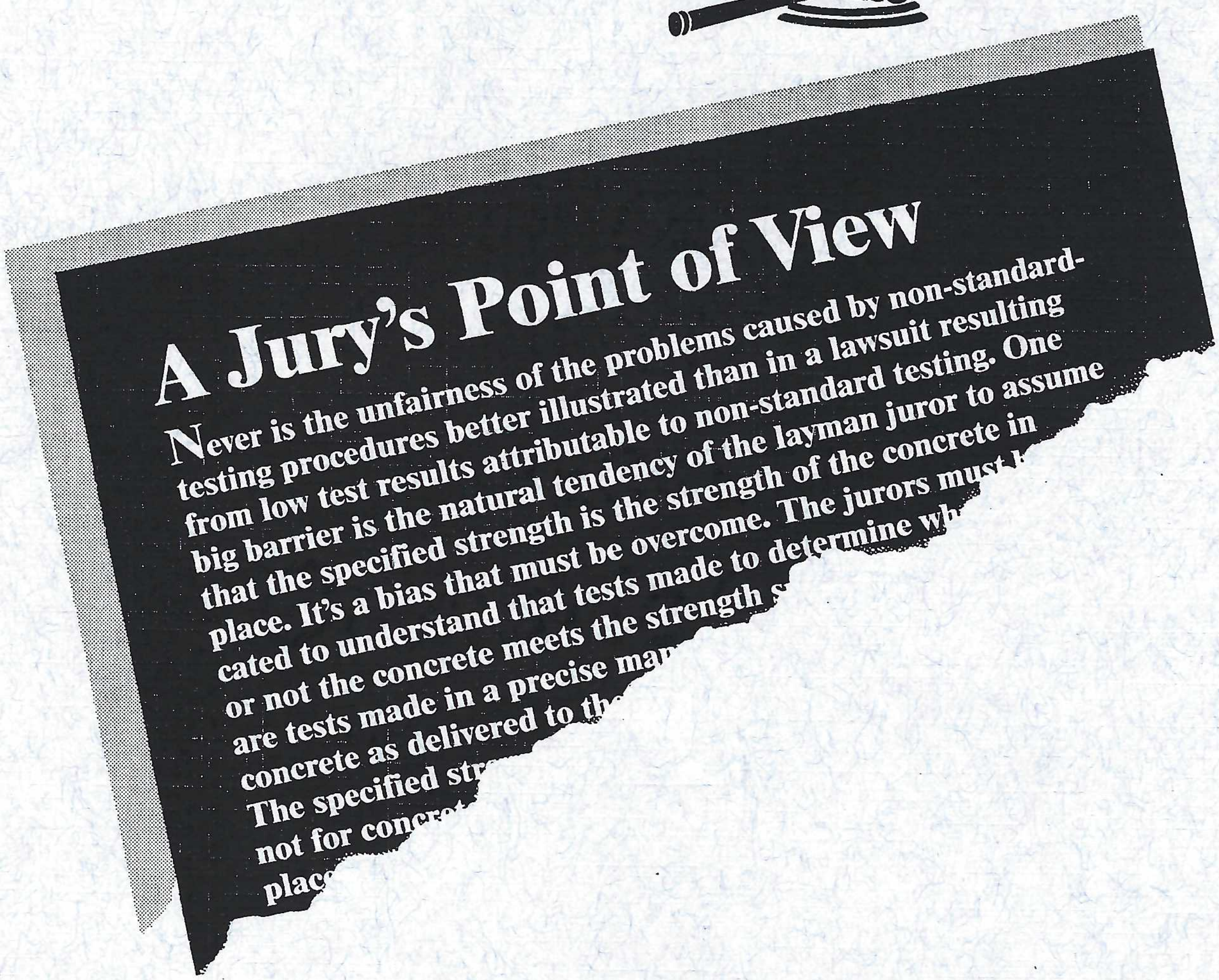
One contractor told us he recently paid over $500,000 in fines because of mishandling of the specimens. A.S.T.M. standards dictate procedures for making and curing of test cylinders in the field. Proper casting and curing can provide peace of mind and even a legal safety net for contractor, owner, supplier and testing lab. Non-standard testing procedures may not hold up in court!



A Jury's Point of View

Never is the unfairness of the problems caused by non-standard-
testing procedures better illustrated than in a lawsuit resulting
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Why Low Cylinder Tests In Hot Weather?

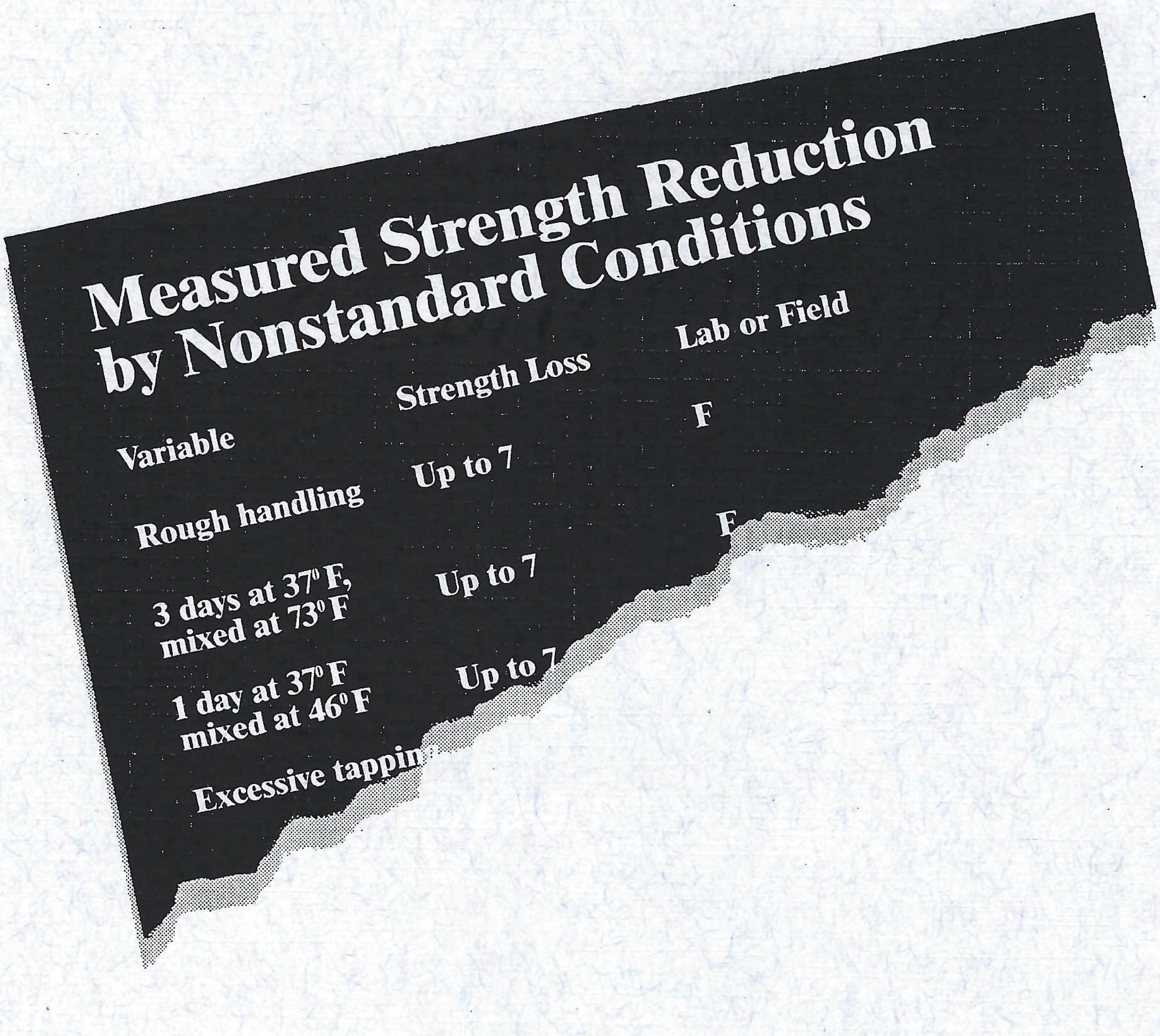
Of Several Causes, Testing Procedure May Be Number One!

"The loss of strength caused by early exposure of cylinders to the 100 degree F temperature averaged 10 percent of the 28-day strength for all mixes tested."

Concrete Journal, Jan. 1986

"With low temperature curing for 3 to 7 days the strength loss could be as much as 7%. Severe consequences can occur from actual freezing of the concrete. One day of freezing followed by standard curing can result in 28-day strength losses of as much as 56%."

From a report by the American Society of Civil Engineers, May, 1991



Measured Strength Reduction by Nonstandard Conditions

Variable	Strength Loss	Lab or Field
Rough handling	Up to 7	F
3 days at 37°F, mixed at 73°F	Up to 7	F
1 day at 37°F mixed at 46°F	Up to 7	
Excessive tappin		

The preceding pages represent only a fraction of the myriad of things that can go wrong when A.S.T.M. standards are not followed carefully in the field. While the importance of strength and durability of *in-place* concrete is more universally understood, we must be equally vigilant in pursuing a benchmark or *control* for the quality assurance of the concrete *delivered.* These standards exist, but are too often ignored or misunderstood. (See Specifications section.)

When standard test specimens are made, the owner and contractor will know exactly what concrete they had to work with, the supplier can cover himself, and the lab can perform tests that are reliable and reputable, and the state is not bogged down with delays and lawsuits. *And money can be saved all around.* In one area, we found redi-mix suppliers spending huge amounts of money adding extra portland cement to their batches in order for their cylinder tests to hold up. All that was really needed was to maintain the cylinders according to A.S.T.M. Standards.

In the next section, we will walk through the standard procedures for handling cylinders, including immersion in our thermostatically-controlled concrete cylinder curing box, Thermocure™. This is the only product on the market that will keep the cylinders in the required condition at the required temperature regardless of outside temperatures, or the more vexing problem of the heat natuarally produced by the cylinders themselves during the curing process.

by Eugene O. Goeb, P.E.

New strength test research

Several years ago in Albuquerque, N.M., a jury rendered a typically terrible decision in a dispute over responsibility for low cylinder strengths tests. The jury ruled out any consideration for the manner in which cylinders had been cured on the job by stating "... established local testing procedures, which do not address temperature or water loss (from test cylinders while stored on the job) were adequate since they were representative of in-place concrete." This court decision was cited by local specifiers as justification for not requiring standard jobsite curing for test cylinders. If non-standard curing really is the norm, it tells us that the specifiers and laboratory personnel make it so, because they don't recognize the difference between cylinder tests made to determine compliance with the strength specification and those which represent strength of in-place concrete. The New Mexico Ready Mix Concrete and Aggregate Association (NMRMCAA) recognized the need for an educational program backed by substantial test data.

As a start, NMRMCAA organized an ACI chapter and initiated an ACI certification program for concrete technicians. That was not enough, however, to gain the cooperation of key specifiers in requiring standard curing practices for test cylinders. The association has now completed an outstanding research program, comparing various methods of curing cylinders stored on the job. Worthy of national attention, it is described as "The NMRMCAA Hot Weather Comparison Program." Not only are the results of interest to every segment of the concrete industry, but the approach to the research was somewhat unique.

The association set up the program. Technicians from three commercial laboratories, city, county and state agencies, and three ready-mix producers made up teams which participated in slump and air content tests and in molding and handling test cylinders. All cylinders were tested for compressive strength by the New Mexico DOT district laboratory. Standard procedures were used throughout the tests with one exception — the method of curing the test cylinders for the first 24 hours. Five methods were used, two of which were standard curing (60 to 80 degrees F) and three of which were not.

The standard curing procedures entailed:

1. Immersion in saturated lime water in which the temperature of the water was 73 degrees F, increasing to 82 degrees F.
2. Use of a commercially available curing box in which the cylinders are immersed in water at a controlled temperature of 71 degrees F to 76 degrees F.

The non-standard curing procedures were:

1. Cylinders were wrapped in wet burlap and then carefully wrapped and sealed in plastic sheeting. They were stored in the sun. The temperature in the air space under the plastic rose to 135 degrees F. This should not be confused with covering cylinders with wet burlap and keeping the burlap wet to assure continuous evaporation and cooling. Wrapped in plastic, there was no evaporation, and therefore no cooling — just the opposite of the desired effect.
2. Cylinders openly exposed to the sun. The actual thermometer reading in the air space between the cylinders was 107 degrees F. That was measured by a shaded thermometer. It's likely that the temperature with the thermometer directly exposed to the sun would have read much higher.
3. Cylinders stored unprotected (no moist curing) on a garage floor in a structure with controlled temperature of 78 to 82 degrees F, but in a "dry environment."

Control for comparisons

The saturated lime water curing was treated as the "control" curing procedure. In effect, there were eight tests for each of the other four curing methods which were compared to the "control" for 7-day and 28-day compressive strengths. The following table shows the comparison of 28 day strengths. The saturated lime water and the curing box produced almost duplicate results. The other methods are shown as a percentage of those two.

Curing method	28-day strength psi	percent
Immersion in lime water	4,850	100
Curing box	4,860	100
Wet burlap (wrapped)	4,040	83
Unprotected in sun	4,110	85
Unprotected inside storage	4,270	88

In these tests, the 28 day strength loss is 12 percent to 17 percent when the cylinders are not cured according to ASTM C31, the standard required in almost every major project specification. These tests were well planned and carried out and can be used most authoritatively.

The percent loss in strength in the cylinders exposed to drying in the first 24 hours but stored at a moderate 80 to 82 degrees may seem surprising. Humidity in New Mexico's climate can be 10 percent or less, so early drying could be severe. There is research (and experience) that indicates a sharp reduction in rate of strength gain at the point moist curing is disrupted, even though re-started later. That, at least, is a logical explanation and is one more reason for using standard curing procedures. A "cold weather" program currently underway shows similar results.

In validating these tests, there are at least two other test programs that can be used for comparison. They are cited in the National Ready Mixed Concrete Association research paper entitled "Effect of Temperature and Delivery Time on Concrete Proportions" and a Portland Cement Association research bulletin, "Effect of Mixing and Curing Temperature on Concrete Strength."The NRMCA research confirms a loss of strength of 9 to 12 percent when first day curing is 100 degrees F. The PCA bulletin shows reductions of strength of 15 percent at 105 degrees F and 25 percent at 120 degrees F. The NMRMCAA data is consistent with these other respected research programs.

The quality of the New Mexico program provides one more solid reference to cite in promoting the enforcement of standard curing procedures for test cylinders. In New Mexico, the next step is educating laboratory personnel, specifiers and others of the need for using standard test procedures.

A Wheaton, Ill.-based consultant, Gene Goeb is a veteran of concrete production, testing and practice. He is a member of American Concrete Institute, American Society for Testing and Materials and American Society of Civil Engineers.

by Eugene O. Goeb, P.E.

Enforcing Standards for Strength Testing

It would be a great step forward if all parties concerned with a concrete project shared two beliefs in common:

1. The specification should stipulate that strength tests must be made according to ASTM C31 and ASTM C39. (Standard test methods for making and handling test specimens in the field and for testing for compressive strength in the laboratory).

2. The specification should prohibit non-standard tests from being used as a basis for acceptance evaluation.

(There should be an accompanying recognition that non-standard testing procedures usually produce lower strengths than standard tests. Therefore, non-standard test results that meet the specified strength in all likelihood confirm that the strength specification has been met. Low non-standard test results do not confirm the specification has not been met and are not a basis for rejection).

Non-Standard Procedures Produce Lower Strength Tests

Anyone who has experience in investigating "low" strength tests could cite case history after case history showing non-standard testing procedures as a common cause. Exposure of cylinders or beams to high temperatures during early storage on the job would be No. 1. The evidence includes published research (Portland Cement Association, National Ready Mixed Concrete Association and others), and the experiences of any engineer who has had the responsibility of investigating the reason for low strength test results. There can be no doubt that exposure to high temperatures in the field at a very early stage will reduce the compressive strength of cylinders by 10 percent to 15 percent in comparison with standard cured cylinders.

Why, then, can't we eliminate the use of non-standard tests in evaluating cylinders or beams for acceptance? A large part of the answer is the fact that the adverse effect of non-standard test procedures isn't felt in the same way by the owner-specifier, the testing laboratory, the contractor and the ready mix producer, so each views the seriousness of the problem quite differently.

A Jury's Point of View

Never is the unfairness of the problems caused by non-standard testing procedures better illustrated than in a lawsuit resulting from low test results attributable to non-standard testing. One big barrier is the natural tendency of the layman juror to assume that the specified strength is the strength of the concrete in place. It's a bias that must be overcome. The jurors must be educated to understand that tests made to determine whether or not the concrete meets the strength specification are tests made in a precise manner on the concrete as delivered to the job. <u>The specified strength is not for concrete in place.</u> That concept is foreign to the layman and may seem illogical to them, putting the target of the lawsuit, the contractor and/or ready-mix producer, at a disadvantage.

The jury must be educated to the fact that non-standard tests are invalid tests for evaluating strength. If the results of an invalid test fall below the specified strength, you do not have a "low test." Only if a valid test falls below the specified strength do you have a low test. This may seem to be a fine point, but it's important to any controversy over whether or not the strength specification has been met. Low test results from non-standard tests have no status.

The Specifier's Viewpoint

The specifier is affected quite differently from the contractor or ready mix producer by non-standard tests. Since non-standard testing procedures for cylinders and beams can be expected to reduce the reported strength, he might view non-standard testing procedures as an added safety factor rather than a penalty. It would not cause him to accept concrete of inadequate strength, but it could cause him to reject concrete that was actually acceptable and to force the ready mix producer to furnish higher strength concrete than specified.

Although they will specify tests to be made according to ASTM C31 and ASTM C39, some specifiers continue to believe that it is strength in place that really counts (much like the juror). On occasion, you will find the standard testing procedures specified, but non-standard curing procedures being used and tolerated by the specifier because they better represent the exposure of the concrete in place. These are the kind of projects that lead us into court before a naively biased jury.

Ready Mix Producer and Contractor Responsibility

Getting the specifier to enforce his own specification is step one in correcting the problem. He will often consider actual enforcement of testing according to ASTM C31 and ASTM C39 (which would prohibit use of results from non-standard tests) as a "concession" to the contractor or ready mix producer. He should, in fact, accept enforcement as a taken-for-granted obligation. Approached properly, that can be a primary subject to be settled, preferably in written minutes, at a pre-job conference or in a follow-up letter. If there is no conference, the ready mix producer and contractor, from the first pour, should watch for discrepancies in molding and handling cylinders on the job. When discrepancies occur, a polite letter, or call backed up by a letter, should go to the specifier documenting the discrepancies and pointing out that test results from non-standard tests may not be used as a basis for acceptance or rejection of concrete.

Another step that can be taken is to strengthen the language in ASTM and American Concrete Institute standards and specifications. In specific language, carrying this meaning, there should be a section that says:

For strength test results to be used in acceptance evaluation a certifying statement that the tests were performed in accordance with ASTM C31 and ASTM C39 must be on the test report. Test reports that are not so certified are prohibited from use for acceptance evaluation.

That is fair and enforceable and is consistent with the purpose of the standards as presently written. It leaves no doubt that use of standard test procedures is more than just a recommendation as some specifiers now treat it. As you may have read in earlier Technical Talk articles, a specification should not be treated as a one-way street.

A Wheaton, Ill.-based consultant, Gene Goeb is a veteran of concrete production, testing and practice. He is a member of American Concrete Institute, American Society for Testing and Materials and American Society of Civil Engineers.

by Eugene O. Goeb, P.E.

An expensive comedy of errors

A recent personal experience involving a project constructed several years ago presents a graphic picture of the penalty to be paid for misunderstood, incomplete specifications and non-standard testing in our litigation-prone world.

The concrete specification

The specifier made a verbal request for "3000 psi concrete" for a 4-in. slab for a new building that would accommodate a light industrial operation. The ready-mix producer submitted a standard 3000 psi mix on which 28 day laboratory tests of 4600 psi had been obtained. It was designed for a 5-in. slump and 4 to 5 percent entrained air.

Lacking a real concrete specification, there was no provision for any concrete testing during or after construction, nor was there any specification for construction practices such as joint spacing, surface finishing or curing. Joints were spaced at least three times farther apart than any standard recommendation for control joints. No curing was provided during hot summer construction exposed to the sun. There were no references to ASTM or ACI or any other body that would provide guidelines or specifications for construction practices or testing.

The art of placing the blame

The construction practices that were used all but guaranteed there would be some problems. Shrinkage cracks, fewer than might have been expected, were caused by excessive joint spacing and lack of curing. Cracking around a column base was an obvious product of poor jointing practices. The curling of slab corners was thoroughly predictable in a thin slab with wide joint spacing and subject to rapid drying. Some minor surface wear, restricted to a small area, was not surprising considering the hot summer exposure for finishing and lack of curing. Even without repair, however, the slab was completely serviceable.

There was nothing in the performance of the concrete slab to suggest that the concrete furnished to the job did not meet the 3000 psi specification. The "problems" were all thoroughly explainable outside of any consideration for concrete strength. Nonetheless, six months after construction, the owner decided to core the concrete to check for strength. Based on some standard core tests, some non-standard core tests and a misinterpretation of every core test result, a lawsuit was initiated against the ready-mix producer for not having met the strength specification.

Creating a problem

In reviewing the case, it appeared that the owner had been unaware of the existence of standard test procedures and of proper evaluation of test results. He expected cores to test 3000 psi plus a factor for a strength gain after 28 days when the cores were tested. Anything less than that was a failure. He was actually demanding core strengths that might have been expected of a 3500 to 4000 psi concrete mix, not the 3000 psi he had specified.

Initially, three standard core tests were made. The locations were widely spaced, with each test being the average of three cores at one location as per ASTM C42, ACI 301, and ACI 318. Based on those results, the testing laboratory recommended rebound hammer readings over the entire slab to locate areas that should be cored. Ten locations were selected from those readings as being areas of "lowest strength". They were cored and tested using standard procedures. Five tests were over 3000 psi and five were less for an average of 3010 psi. Accepting concrete when cores test at 85 percent of the specified strength (2550 psi for a 3000 psi spec) as directed in ACI 318 was never considered, and the test results were misinterpreted as "failure". In order to confirm this "failure", eleven more individual cores were drilled at various locations. Each individual core was erroneously treated as a test. In addition, contrary to the curing conditions required for cores in ACI 301 and ACI 318, the testing laboratory was directed to test the cores the same day they were drilled (no 7 days of laboratory drying). The laboratory, quite properly, did not certify these cores as having been tested according to any standard, as had been done for the earlier cores.

The strengths of these non-standard single cores were then reduced by about 20 percent to account for strength gain after 28 days, and used for considering whether or not the concrete had met the specified strength. At that point the concrete strength was undervalued by about 35 percent.

The response to the charges of low strength

The ludicrous nature of the situation was self-evident. The ready-mix producer had furnished a mix which when tested according to ASTM C31 and ASTM C39 would meet the requirements of a 3000 psi specification, but no standard cylinder tests were ever made to confirm compliance with the specification. Instead, six months later the owner decided to test for concrete strength in place by coring, accumulating test results from both standard and non-standard core tests. He then misinterpreted the results of all of the tests, clearly contrary to the purposes and interpretation of core tests as defined in ACI 301 and ACI 318. Six months after the last load of concrete had been delivered to the job he had, in effect, increased the specified strength, (in comparison to standard cylinder tests), by as much as 500 to 1000 psi! The standard core tests when properly interpreted provided no evidence of low strength concrete. The lack of control joints and lack of curing were clear-cut reasons for any performance problems. The 4-in. slab thickness and 3000 psi concrete were minimal standards at best for light industrial use. Facing very strong documentation, the owner reduced his demands dramatically at the 11th hour before going into court; and a settlement satisfactory to the ready-mix producer was reached—almost four years after construction.

The lesson to be learned

The ready-mix producer should never fail to make certain that all parties to the contract understand what the strength specification means, what tests must be performed for acceptance, how the tests are performed, how the tests are evaluated, what follow-up tests may be used if needed, and what their limitations are. Don't take for granted that the specifier or owner knows and understands these things. Many thousands of dollars wasted on lawsuits could be saved if mutual understanding is reached before the job starts—and if we're well informed and ready to face the problem when it arises.

A Wheaton, Ill.-based consultant, Gene Goeb is a veteran of concrete production, testing and practice. He is a member of American Concrete Institute, American Society for Testing and Materials and American Society of Civil Engineers.

by Eugene O. Goeb, P.E.

Evaluating concrete cylinder test results

Previous *Technical Talk* articles have paid considerable attention to problems created by non-standard concrete cylinder testing procedures. The greatest emphasis has been on the adverse effect of the exposure of the freshly made cylinders to high temperatures while stored on the job with a resulting loss in compressive strength of 10 to 15 percent. Acceptance evaluation is a most important second part of this equation. The fact that these non-standard tests are commonly used by the specifier for evaluating the cylinder test results for acceptance of the concrete is a blatant violation of the standard specifications and is extremely costly to the concrete industry. It may well be that specifiers don't enforce the standards for molding, curing and testing cylinders for acceptance testing because they don't appreciate or understand fully the basis for acceptance evaluation in the first place. Major documents that relate to these procedures and which appear in project specifications are:

- ASTM C31—Standard Practice for Making and Curing Test Specimens in the Field.
- ASTM C94—Standard Specification for Ready Mixed Concrete.
- ACI 301—Specifications for Structural Concrete.
- ACI 318—Building Code Requirements for Reinforced Concrete.

Evaluating test results for acceptance of concrete

All three of the specifications—ACI 301, ACI 318 and ASTM C94—have the same strength requirements for cylinders that are to be used for acceptance evaluation:

1. A cylinder test is an average of two cylinders
2. The average of any three successive tests must equal or exceed the specified strength (f'c).
3. No single test may be more than 500 psi below the specified strength.

For example, following is an excerpt from a "Moving Average of Three" tabulation for a project with a 4,000 psi f'c.

Sample	Cyl. 1	Cyl. 2	Test Avg.	Moving Avg. of three
1	4530	4500	4515	–
2	4570	4510	4540	–
3	3850	3870	3865	4310 (1+2+3)
4	4110	4150	4130	4180 (2+3+4)
5	4300	4190	4240	4080 (3+4+5)

The important point the specifier must learn is that the 3865 psi test meets the specification. It is not more than 500 psi less than 4000 psi and all three moving averages of which it is a part are more than 4000 psi.

Some testing laboratories call attention in the test report to every test result that falls below f'c, such as the 3865 psi test. That should not be done. It can mislead the specifier into thinking it is a "low test", which in this case it isn't. In fact, at one time the standard specifications were stated in terms that allowed "one test in ten" to fall below the specified strength as long as it was within 500 psi of the specified strength. Those words were eliminated in favor of a statistical formula based on the "standard deviation", which accomplishes the same thing.

If the concrete mix has been designed without wasteful overdesign, and if standard testing procedures are used, the average cylinder strength required may easily be 400 psi to 800 psi over the specified strength. About 1 out of 10 or 1 out of 11 tests may fall below the specified strength in a series of 30 or more tests in which the concrete strength meets the specified strength. Be careful that the term "specified strength" is never confused with "minimum strength." They are not the same thing at all.

Standard deviation

The standard deviation as applied to a number of cylinder tests is simply a measure of the spread of the test results–that is how much the individual tests vary (deviate) from the average of all of the tests. The more closely bunched the tests are, the smaller the standard deviation will be. When the test results are spread farther between the highest and lowest, the standard deviation is greater.

The significance of the standard deviation is that it controls the average cylinder strength required to meet the specification. A higher standard deviation increases the overdesign required for the concrete mix. That can be seen in the formulas that are contained in ACI 318:

The average cylinder test must exceed the specified strength by 1.34 x standard deviation. If the standard deviation is more than 500 psi, the average strength must exceed the specified strength by (2.33 x standard deviation)-500 psi.

Examples for 4000 psi f'c

Standard Deviation - 450 psi	Standard Deviation - 600 psi
Average strength required:	Average strength required:
4000 + (1.34 x 450) = 4600 psi	4000 + (2.33 x 600) - 500 = 4900 psi

The effect of testing practices on standard deviation

We have placed great emphasis on the fact that non-standard curing or lack of curing of test cylinders in the field can reduce cylinder strength by 10 to 15 percent. But non-standard testing procedures, by their very nature, don't produce consistent results. Not only is strength reduced, but it's reduced inconsistently. That produces a wider spread of test results, increases the standard deviation, and further increases the overdesign of the concrete mix needed to meet the specification. **Non-standard test procedures reduce cylinder strengths at the same time they increase the average strength required to meet the specified strength!**

The evaluation of cylinder tests is based on a sophisticated statistical procedure. Toleration of non-standard testing which can only feed false information into that procedure seems senseless. Yet, it's done quite commonly. A better understanding of that procedure, especially on the part of the specifier, is needed if we are to improve enforcement of standard testing procedures as presented in ACI 318.

Note: The computation for determining standard deviation shown in ACI 318 is not easy to grasp. A convenient step-by-step "crib sheet" is illustrated in an out-of-print PCA publication, "Statistical Product Control." You may obtain a copy of the computation by writing or calling the Portland Cement Association, c/o Robert Shuldes, Construction Information Services, 5420 Old Orchard Road, Skokie, IL. 60077-1083, phone (708) 966-6200.

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