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Changes to Concrete Mixtures and Submittals During a Project

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There are several reasons why a concrete producer may need to change concrete material ingredients or proportions during a project. Some of these situations will require a re-submittal to the engineer of record (EOR) for review and/or approval. This article addresses one such issue related to compliance with strength provisions. It stems from a clause in ACI 301-05 that is incorporated in project specifications and has been interpreted contrary to the intent.

Background

The strength provisions for concrete are established on a statistical basis with due consideration of the implication to public safety of the constructed building. These provisions are addressed in ACI 318-08, *Building Code for Structural* Concrete, and ACI 301-05, *Specifications for Structural Concrete.* The provisions require a concrete producer to develop proportions for a proposed concrete mixture at an average strength, f'_{cr}, that exceeds the specified strength, f'_c. The specified strength is used by the EOR to design the dimensions of the structural members. This is summarized below:

Acceptance Criteria for Concrete Compressive Strength

The acceptance criteria for concrete compressive strength (less than or equal to 5000 psi) are as follows:

- Average of three consecutive compressive strength test results ≥ f'_c (1)
- Individual strength test result ≥ (f'_c - 500) when f'_c is ≤ 5000 psi (2)
- Where f'_c = specified compressive strength for the project

Test cylinders should be molded and cured (standard curing) in accordance with ASTM C31/C31M.

The test result is the average of 2 or 3 cylinders tested at the same age.

Required Average Compressive Strength

To start the job, the concrete producer has to develop a proposed mixture and submit to the EOR that demonstrates that the proposed mixture has an average compressive strength (f'_{cr}).

If the concrete producer has a past test strength test record of a similar class of concrete with at least 15 tests, he calculates the standard deviation and establishes the f'_{cr} in psi as the larger of the values from the following two equations:

$$f'_{cr} = f'_c + 1.34ks \quad (3)$$

$$f'_{cr} = f'_c + 2.33ks - 500 \quad (4)$$

where k = factor to modify the standard deviation if total number of tests is between 15 and 30; and s = standard deviation

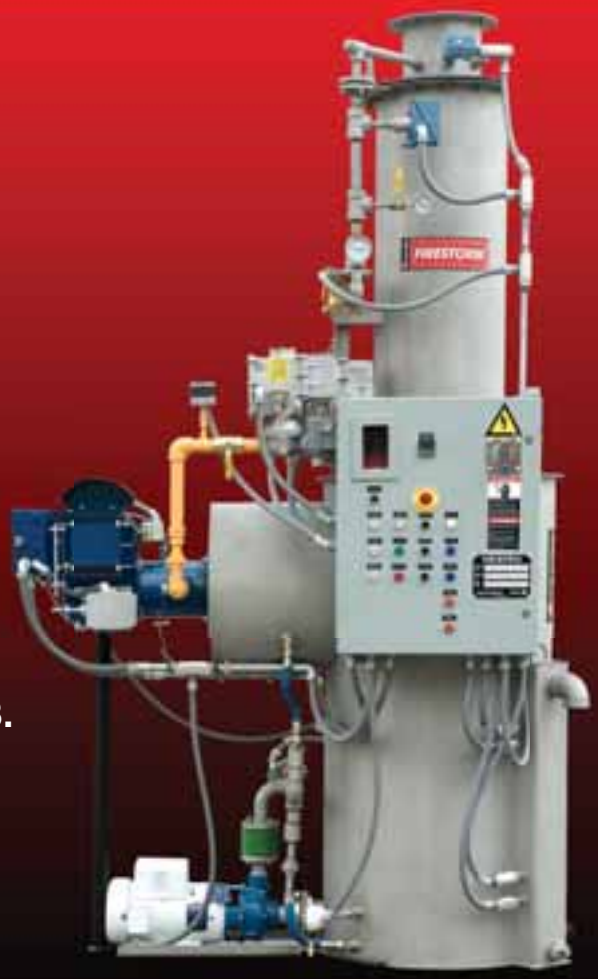
From a purely statistical consideration, if the average of the concrete strength test results during the project are at f'_{cr}, and the variability of these results is represented by the standard deviation used in equations 3 and 4, these strength provisions establish a probability of failing the acceptance criteria (Equations 1 and 2) at 1% or less. Also about 11% of the strength test results will be expected to be below f'_c. These are based on statistical concepts that assume that strength tests follow a normal probability distribution.

When the concrete producer does not have a recent field test record to establish a standard deviation, the ACI standards require the mixture be developed to achieve a higher required average compressive strength as follows:

$$f'_{cr} = f'_c + 1000 \text{ (for } f'_c < 3000 \text{ psi)} \quad (5)$$

$$f'_{cr} = f'_c + 1200 \text{ (3000} \le f'_c \le \text{5000 psi)} \quad (6)$$

It is a good idea that a concrete producer constantly monitors his strength test results and makes necessary revisions to mixtures when trending so suggests.



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Changes

Documentation that proposed concrete mixture proportions will produce required average compressive strength must be shown through field test records or lab trial batches in a pre-construction submittal.

Revisions to Concrete Mixtures

Article 4.2.3.6 in ACI 301-05 (paraphrased) states the following:

When 15 consecutive compressive strength test results become available during a project, calculate the actual average compressive strength and standard deviation from those test results. Calculate a revised value for f'_{cr} in accordance with Equations 3 and 4. Ensure that both the acceptance criteria (Equations 1 and 2) are met.

a) When the actual average compressive strength $\overline{X}$ exceeds the revised value of f'_{cr} and both the acceptance criteria are met, f'_{cr} may be decreased. This reduction in the strength of a class of concrete is permitted by the ACI 318 Code (Section 5.5). There can be some significant material cost savings on larger projects with this provision. It permits a concrete producer to reduce his level of average strength if the project was started on the basis of not having a prior test record (Equations 5 and 6) or if there is improved quality control that is translated into a reduced variability (standard deviation) of the strength test results.

b) If the actual average compressive strength $\overline{X}$ is less than the revised value of f'_{cr}, or if either of the two acceptance criteria are not met, take immediate steps to increase average compressive strength of concrete. Steps to increase the average strength is a requirement in Section 5.6.3.4 of the ACI 318 Code, but only when strength tests fail the acceptance criteria (Equations 1 and 2). There is no requirement in the ACI 318 Code to increase the average strength if $\overline{X}$ is less than the revised value of f'_{cr} and it is this part of the clause that can be misinterpreted as discussed later.

ACI 301 also requires a submittal for the revised mixture proportions for acceptance by the EOR before placing in the project.

Example

The following example illustrates some situations:

Assume that the specified strength for a project is 4000 psi.

The concrete producer has a strength test record for a similar class of concrete with a standard deviation of 550 psi.

Using equations 3 and 4, he establishes the required average strength for his proposed mixture at 4780 psi (rounded off).

During the project, the accumulation of 15 strength tests allows him to calculate his actual average strength and standard deviation. Assume that the actual average strength $\overline{X}$ is 4800 psi and that both the acceptance criteria (Equations 1, and 2) are met.

Consider the following two situations:

i. Actual standard deviation = 350 psi.

The revised value of f'cr (Equations 3 and 4) is determined to be 4470 psi. Since $\overline{X}$ > revised f'_{cr} (4800>4470) he can reduce the average strength, f'_{cr}, by about 350 psi.

ii. Actual standard deviation = 750 psi.

In this case the revised f'_{cr} is 5250 psi. Since $\overline{X}$ < revised f'_{cr} (4800<5250) he should take steps to increase his average strength and reduce his risk of "failures".

(He might also verify that the proficiency of testing is not a primary reason for his increased measure of variability).

Misinterpretation - Revisions to Concrete Mixtures

In the author's opinion, the first part of Clause (b) of article 4.2.3.6 of ACI 301-05 is subject to misinterpretation as was the case on one project.

The EOR required a calculation of the revised value of f'_{cr} when each test result was received. The concrete producer was required to make revisions to his mixture proportions whenever the actual average strength $\overline{X}$ was found to be less than the revised f'_{cr} and the revisions had to be submitted for acceptance before placement in the project. This caused needless project delays while significantly over designing the concrete (for strength) thereby resulting in higher cementitious materials content.

Effectively, on this project the EOR had imposed an additional "acceptance criteria" because the EOR assumed that the concrete "failed" the strength provisions any time the average drifted below the revised f'_{cr}, even by as much as 50 psi. To minimize these occurrences, the concrete producer had to design mixtures much higher than the traditional f'_{cr} calculated according to Equations 3 to 6. The two strength acceptance criteria (Equations 1 and 2) are based on fundamental concepts and have served the industry well. Including additional overly conservative criteria should be avoided as they detract from the project goals.

It is a good idea that a concrete producer constantly monitors his strength test results (when he can get all of them) and make necessary revisions to mixtures when trending so suggests. It is also reasonable for the EOR as the owner's representative to require this to occur so future strength problems and associated schedule problems are avoided. However, the requirement on this project was most likely not in line with the intent in ACI 301. The intent of ACI 301 Section 4.2.3.6 is to allow calculation of the revised value of f'_{cr} at the start of the project as indicated by the statement "as soon as 15 consecutive compressive strength test results become available from the field." This serves to validate the pre-construction submittal and assure the project team that strength problems will not crop up in the future. The interpretation that requires calculation of revised values of f'_{cr} on a continual basis and increase average strengths if $\overline{X}$ < revised f'_{cr} goes beyond the intent of ACI 301, in the author's opinion.

However, the clause as written in ACI 301-05 does permit this misinterpretation. Therefore it is suggested that Clause (b) of article 4.2.3.6 of ACI 301-05 be revised to provide clarity. ■

References

1. ACI Committee 301, "Specifications for Structural Concrete (ACI 301-05)," American Concrete Institute, Farmington Hills, MI, 2005, 49 pp.
2. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary," ACI American Concrete Institute, Farmington Hills, MI, 2005, 465 pp.

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