3000 and 0.40 is Not 3000!

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This is a case where ingrained habits die hard. Concrete producers probably still receive orders and project specifications for a 3000 psi — 0.40 w/cm concrete mixture today. A rationale for this can probably be traced to the 1989 (and prior) ACI 318 Building Code that included a table of w/c and strength that really did not match up. It was there as a conservative provision to permit a project to start if field or lab trial batch strength data was not available. Due to its misuse in concrete specifications, the table was removed in the 95 code.

Anyone familiar with concrete understands that a concrete mixture at a w/cm of 0.40 will result in strength much higher than 3000 psi. The mix that complies with the w/cm requirement, being the more critical controlling factor, will cost more than a mix that complies with a specified strength of 3000 psi. It is also important to recognize that w/cm is not necessarily an antidote to all durability aspects and may result in other problems. It should not be included in a specification if it's not necessary. For example, concrete at a low w/cm for a floor may have an increased paste content rich in cementitious materials that can result in increased cracking and curling due to higher shrinkage and temperature rise.

A specification that has a strength requirement that is not consistent with a specified w/cm poses two problems: In a competitive bidding situation, there could be confusion as to whether the basis of the bid is strength or w/cm. Secondly, since w/cm is not verifiable, the acceptance basis for concrete during the project is on the specified strength set at 3000 psi. So individual strength test results can bounce around anywhere between 2500 psi to 8000 psi (or higher) and the concrete still "meets spec" and no one is worried. However, it does not serve the owner well to have concrete that is highly variable. There is no incentive for the supplier, whose goal is to meet the strength spec, to maintain good quality control. Delivering a product with a high variability does not serve the supplier well because it's a waste of costly ingredients that are in short supply.

The argument from the design professional writing the concrete specification is — I only need 3000 psi for design loads but I need the low w/cm for durability. The problem here is that the contractor who often orders the concrete is tuned in to a price based on the concrete strength. Frequently, the concrete supplier may not see the project specification to realize that there is a w/cm requirement.

The provisions for durability in the ACI 318 Code emphasize the use of a lower w/cm. The code, however, does not have any "required average w/cm" or acceptance criteria for w/cm, like it does for strength. It relies on strength tests and for that reason includes a minimum specified strength, f'_c, along with the limit for maximum w/cm. In the commentary the code states:

Since it is difficult to accurately determine the water-cementitious material ratio of concrete during production, the f'_c specified should be reasonably consistent with the water-cementitious material ratio required for durability.

The producer that chooses to optimize concrete mixtures and exercise better control is more likely to win the bid and actually make a small profit on the job.

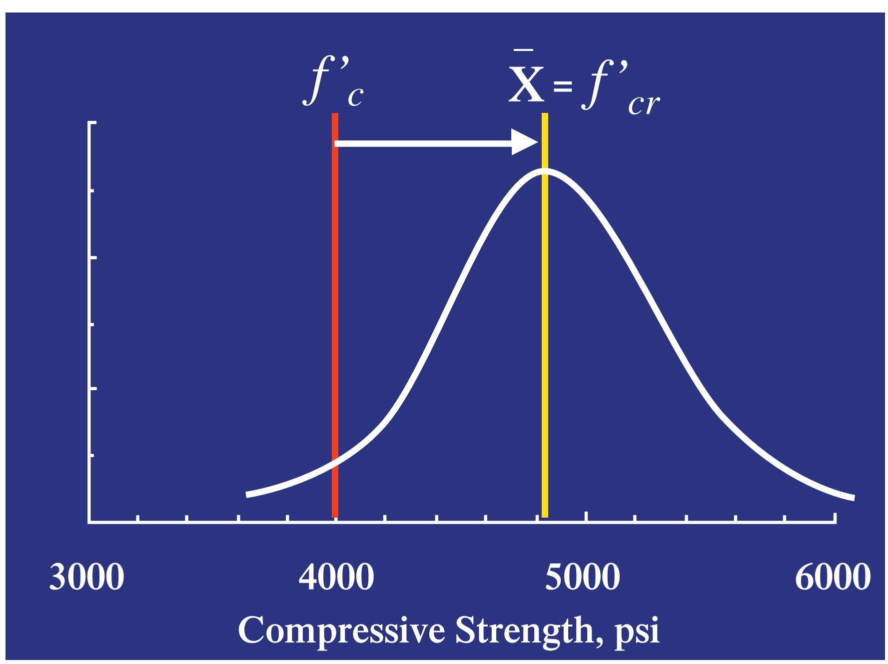

Figure 1. Required average strength, f'_{cr}, of concrete is higher than the specified strength, f'_c, to ensure a small probability "failing" tests.

Selection of an f'_c that is consistent with the water-cementitious material ratio selected for durability will help ensure that the required water-cementitious material ratio is actually obtained in the field. Because the usual emphasis on inspection is for strength, test results substantially higher than the specified strength may lead to a lack of concern for quality and production of concrete that exceeds the maximum water-cementitious material ratio.

Consider the situation where the emphasis for concrete on a project is for a low w/cm for durability and the strength required for designed loads is not consistent with the required w/cm. There is no reliable means of enforcing/verifying the w/cm requirement during construction. One option is to use a minimum specified strength, f'_c, that is consistent with the w/cm with the local materials, similar to recommendations in the code. Alternatively, one might establish a process in the specification for acceptance of concrete during the project based on strength tests more in line with what the concrete mixture will achieve. This process should assure the owner that he gets what he wants and set acceptance criteria and expectations for concrete are clear to all other parties.

An attempt to do this alternative would be to *reverse-engineer* the current strength provisions to establish the acceptance criteria, which are tied to a specified strength, f'_c. As illustrated in Figure 1, ACI provisions establish that the required average strength for the proposed mixture, f'_{cr}, should be higher than the specified strength, f'_c, such that there is less than a 1% probability of failing both of the following strength acceptance criteria:

- Average of 3 consecutive tests should be greater than f'_c
- Each individual test should be greater than (f'_c - 500) psi

If the actual average strength (similar to f'_{cr}) of a proposed concrete mixture at the w/cm required in the specification can be documented in a submittal, the value of f'_c for the above acceptance criteria can be set by back-calculating from the average strength. If the average is derived from lab trial batches, it might be appropriate to reduce this average strength by 10% to account for translating from lab to production batches and jobsite testing.

As an example, if the w/cm requirement for a job is 0.40, the proposed mixture results in an average strength of 6400 psi from field tests, and the producer's standard deviation for producing that class of concrete is 400 psi; the value of f'_c can be back-calculated using the ACI equation:

$f'_c = f'_{cr}$ - 1.34 s = 6400 – (1.34 ? 400) = 5800 psi

If the average strength is obtained from laboratory trial batches use (0.9 ? 6400) as the value for f'_{cr}

This illustrates the point that "3000 and 0.40 is not 3000." There are a few problems with this proposed scenario but none that are not insurmountable. The concept ensures that acceptance provisions are more likely to achieve the desired w/cm and hence durable concrete. The producer that chooses to optimize concrete mixtures and exercise better control is more likely to win the bid and actually make a small profit on the job. ■