Acceptance Testing of Field-Cured Cylinders

Q. *We are a large concrete contractor specializing in multi-story concrete construction. The owner's testing agency makes and tests field-cured cylinders prior to post-tensioning or removal of forms and shoring. On past projects, the average value of the field-cured cylinder tests was used to confirm compliance with the required in-place compressive strength. This has been acceptable to the engineer of record, but now the testing agency is saying that it is not the average that applies, but the lowest individual cylinder strength value. We asked the testing agency where they are getting this requirement, and they say it is from ACI CODE-318-25.[1] Can you explain?*

A. The testing agency is referring to new compliance requirements for acceptance criteria of field-cured specimens in ACI CODE-318-25: Building Code for Structural Concrete—Code Requirements and Commentary. This was published in January 2025 and has not been cited in the International Building Code (IBC) yet. Thus, we are surprised that this is applicable to your current project, but that is a contract documents issue to consider.

The 2024 IBC, Chapter 17: Special Inspections and Tests, Table 1705.3: Required Special Inspections and Tests of Concrete Construction, item 13, states, "Verify in-situ concrete strength, prior to stressing of tendons in post-tensioned concrete and prior to removal of shores and forms from beams and structural slabs."[2] The IBC notes this is periodic special inspection and references Section 26.11.2 in ACI 318-19.[3] Note that Section 26.11.2 provides compliance requirements for removal of formwork; however, the 2024 IBC indicates that the compliance requirements for formwork are also applicable to stressing tendons in post-tensioned concrete. ACI CODE-318-25, Section 26.10.2(j), provides compliance requirements for post-tensioned concrete: "The estimate of in-place concrete strength shall be based on tests of field-cured cylinders prepared in accordance with 26.5.3.2(d). Alternatively, it may be based on other procedures approved by the licensed design professional."[1] The next version of the IBC is expected to reference both Section 26.11.2 for formwork removal and Section 26.10.2 for post-tensioned concrete.

ACI CODE-318-25, Commentary Section R26.12.4.1, provides the rationale for the new compliance requirements for field-cured specimens, stating "Typically, the required in-place compressive strengths at designated construction stages are minimum values. Therefore, the strengths of all field-cured cylinders made from the same concrete sample must be at or above the required strength, rather than using the average strength."[1] Section 26.12.4.1(a) further states, "Before application of prestressing forces or removal of shoring and formwork supporting beams and slabs, the compressive strength of field-cured cylinders shall be acceptable if the strengths of all cylinders made from the same sample and tested in accordance with ASTM C39[4] equal or exceed the strength required for that stage of construction, unless otherwise approved by the licensed design professional."[1]

ACI CODE-318-25, Section 26.12.3.1(a) provides acceptance criteria for standard-cured specimens as "(1) Every average of any three consecutive strength tests equals or exceeds f'_c," and "(2) No strength test falls below f'_c by more than 500 psi if f'_c is 5000 psi or less; or by more than $0.10f'_c$ if f'_c exceeds 5000 psi."[1] The Commentary, however, cautions that these provisions for standard-cured specimens are not applicable to field-cured cylinders. Commentary Section R26.12.1.1(a) states, "the term 'strength test' does not apply to results on cylinders field cured in or on the structure."[1]

Field-Cured Specimens versus In-Place Concrete Strength

ACI CODE-318-25 recognizes that field-cured specimens may not be the most reliable indicator of in-place concrete strength due to differences in temperature history. Commentary Section R26.5.3(d) on curing notes, "In evaluating test results of field-cured cylinders, it should be recognized that even if cylinders are protected in the same manner as the structure, they may not experience the same

temperature history as the concrete in the structure. Heat of hydration may be dissipated differently in the cylinders than in the structural member."[1]

Another ACI document also questions the reliability of field-cured specimens for evaluating in-place concrete strength. ACI 306R-16: Guide to Cold Weather Concreting, Section 8.2, on field-cured cylinders states, "Field-cured cylinders intended to be cured with the structure were once widely accepted to represent the lowest likely strength of the concrete. Field-cured cylinders can cause confusion and unnecessary delay in construction. The use of field-cured cylinders is inappropriate and should not be allowed in cold weather concreting. This is mainly related to the difficulty in maintaining the cylinders in any approximation of the condition of the structure. In-place testing, maturity testing, or both, should be used instead."[5]

ACI 228.1R-19: Report on Methods for Estimating In-Place Concrete Strength, Section 1.2, indicates that a measure of the strength of the concrete in the structure has traditionally been obtained using field-cured cylinders, but that these measured strengths "may be significantly different from in-place concrete strengths."[6] ACI 228.1R-19, ACI 301-20,[7] and ACI 325.11R-19[8] provide guidance when using methods other than field-cured specimens to evaluate the in-place strength of concrete. ACI 228.1R-19, Section 8.2.3, recommends the requirements for judging the acceptability of in-place concrete to be "(1) the estimated average, in-place, compressive strength based on an ASTM standard in-place test procedure equals at least 85% of f'_c; and (2) no test result estimates the compressive strength to be less than 75% of f'_c."[6] Thus, standard industry practice for evaluating in-place concrete strength by "alternative procedures" is based on the average.

Table 1:
Comparison of compressive strength of match- and field-cured cubes (from Reference 10)

Time, hours	Match, psi	Field, psi	Difference, psi	Field/match, %
19	522	232	290	44
26	1030	566	464	55
67	2437	1929	508	79

Match- and Field-Cured Test Results

ACI CODE-318-25, Section R26.11.2.1(e), on removal of formwork permits temperature-match curing of cylinders per AASHTO R 72-22[9] as an alternative procedure to using field-cured specimens. Temperature-match cured specimens are not subjected to the same acceptance criteria as field-cured specimens. AASHTO R 72-22 covers procedures for making and curing concrete specimens at the same temperature as that measured in a concrete member. The "match curing" test results are considered a more reliable indicator of in-place concrete strength than both field-cured cube and cylinder specimens. Test data from Williams[10] and Roller et al.[11] are shown in Tables 1 and 2.

Williams' tests illustrate strength differences in early-age concrete strength of about 500 psi between match- and field-cured cubes.[10] Roller et al.[11] showed a strength difference of more than 1000 psi between match- and field-cured cylinders.

Some licensed design professionals use the "average field-cured specimen test results," inherently acknowledging that field-cured strengths are typically artificially low due to temperature history differences.

Impact of ACI CODE-318-25 Acceptance Criteria for Field-Cured Specimens

Figure 1 illustrates the ACI CODE-318-25 acceptance criteria and impact on the required concrete compressive strength to begin tensioning or remove formwork. These operations typically occur at 3 days to meet the owner's schedule. On many projects, the specified f'_c of 5000 psi is

Table 2:
Comparison of compressive strength of match- and field-cured cylinders (from Reference 11)

	Release			7-day		
Post-tensioned girder	Match, psi	Field, psi	Difference, psi	Match, psi	Field, psi	Difference, psi
A	9110	6470	2640	8910	8360	550
B	8210	6840	1370	9850	8590	1260
C	8510	7790	720	9100	8000	1100
D	7630	7000	630	9140	8140	1000
Average	8360	7020	1340	9250	8270	980

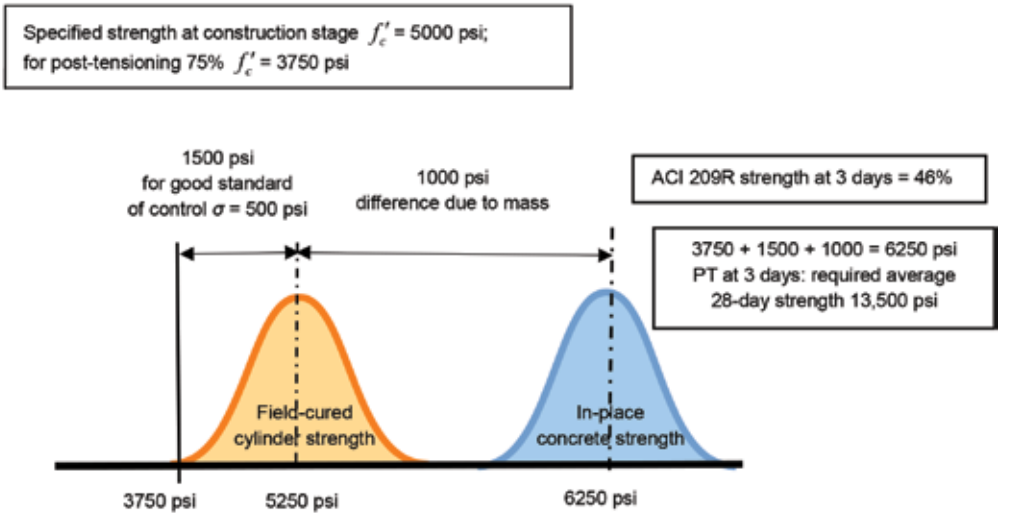

Fig. 1: Illustrating the average 28-day compressive strength required to begin tensioning or remove formwork at 3 days based on ACI CODE-318-25 acceptance criteria for field-cured specimens. The specified strength f'_c of 5000 psi with a required construction strength of 75% of f'_c to begin tensioning or remove formwork increases to an f'_c of about 12,000 psi to ensure no delay in schedule

used for suspended slabs with a common requirement permitting stressing or form removal at 75% of f'_c or 3750 psi. ACI 214R-11, Section 4.5,[12] recommends standard deviations for construction testing based on standards of control; for this example, consider a "good" standard of control with a standard deviation of 500 psi. Because no individual field-cured specimen can be below 3750 psi, adding 1500 psi (three times the standard deviation) to prevent any delay at 3 days provides an average compressive strength of field-cured specimens of 5250 psi. However, as previously acknowledged, the field-cured specimen is less than the actual in-place strength, and for this example, we are using 1000 psi as the strength difference. This means the concrete strength needs to average 6250 psi at 3 days. ACI 209R-92, Table 2.2.1,[13] indicates that the strength at 3 days is about 46% of the 28-day strength. Thus, avoiding low field-cured specimen test results that would delay the schedule requires an average 28-day compressive strength of about 13,500 psi, which represents an f'_c of about 12,000 psi. Traditionally, concrete contractors use a concrete strength of about 7000 psi to provide 3-day strengths that meet strength requirements for construction stages. ACI CODE-318-25 acceptance criteria for field-cured specimens increases the required strength for construction operations.

Other Procedures Approved by the Licensed Design Professional

Other procedures can be used in lieu of field-cured specimens. ACI CODE-318-25, Section 26.11.2.1(e), provides compliance requirements stating, "The estimate of in-place concrete strength shall be based on tests of field-cured cylinders or on other procedures to evaluate concrete strength approved by the licensed design professional and, when requested, approved by the building official."

Alternative procedures to estimate in-place compressive strength per Commentary Section R26.11.2.1(e) include (a) through (e):

(a) Tests of cast-in-place cylinders in accordance with ASTM C873/C873M[14];

(b) Penetration resistance in accordance with ASTM C803/C803M[15];

(c) Pullout strength in accordance with ASTM C900[16];

(d) Maturity index measurements and correlation in accordance with ASTM C1074[17]; and

(e) Temperature-match curing of cylinders in accordance with AASHTO R 72.

Procedures (b), (c), and (d) require sufficient data on the materials used in the work to demonstrate the correlation between measurements on the structure and the compressive strength of molded cylinders or drilled cores. Procedure (e), temperature-match curing of cylinders in accordance with AASHTO R 72, may be used to more closely represent the temperature within the concrete member during curing. And, because temperature-match curing is considered an "alternative procedure," the ACI CODE-318-25 acceptance criteria for field-cured specimens do not seem to apply. However, the licensed design professional needs to provide the acceptance criteria for temperature-match curing of specimens.

A common alternative method used on many construction projects is the maturity method, in accordance with ASTM C1074. This ASTM International standard requires other testing to be used to verify the maturity index before "performing critical operations, such as formwork removal or

post-tensioning."[17] One other testing option includes early-age tests of field-molded cylinders instrumented with maturity sensors. The measured strengths are compared with the strengths estimated from the established strength-maturity relationship and the maturity index of the test cylinders. If the difference consistently exceeds 10%, a new strength-maturity relationship must be developed. We do not believe that these cylinder tests are required to be evaluated based on the acceptance criteria for field-cured specimens because the maturity method is an alternative procedure.

Testing Frequency

The compliance requirements in ACI CODE-318-25, Section 26.12.2.1, on testing frequency are only "For concrete evaluated and accepted based upon standard-cured cylinders."[1] What is the frequency of testing for field-cured specimens? Typically, field-cured specimens are made at the same time and on the same sample of concrete as standard-cured specimens. For a suspended slab concrete placement of 350 yd^3, ACI CODE-318-25, Section 26.12.2.1, requires concrete samples from at least three trucks—at least once for every 150 yd^3 of concrete. This provides three sets of standard-cured and field-cured specimens. The number of field-cured specimens from each concrete sample is determined at the concrete preconstruction conference.

Section 26.5.3.1 requires that for field-cured specimens used to verify adequacy of curing and protection, and that "the number and size of test specimens and frequency of testing"[1] be provided as design information in the contract documents. This should also apply to field-cured specimens used to verify concrete strength for post-tensioning and form removal.

Number of Specimens to Test

ACI CODE-318-25, Section 26.12.1.1(a), states that the evaluation of hardened concrete is to be based on strength tests defined as the average of the compressive strengths of at least two 4 x 8 in. or two 6 x 12 in. cylinders made from the same concrete sample standard-cured in accordance with ASTM C31/C31M[18] and tested in accordance with ASTM C39/C39M at 28 days or at test age designated for f'_c. Based on this, the evaluation of hardened concrete at construction stages is not a "strength test" as defined by ACI CODE-318-25. Commentary Section R26.12.1.1(a) states that "the term 'strength test' does not apply to results on cylinders field cured in or on the structure."[1]

Thus, the licensed design professional must determine and specify how many field-cured specimens need to be made and tested. Commentary Section R26.12.4.1 states, "all field-cured cylinders made from the same concrete sample must be at or above the required strength."[1] Does this require all field-cured specimens to be tested or only some of them? If one cylinder is tested and exceeds the required strength, is it necessary to test other specimens? If the first field-cured specimen tests below the required strength, should any other field-cured specimens be tested? If the first field-cured specimen tests low, what is the appropriate waiting time to test another field-cured specimen to take advantage of additional curing superseding the previous test result? If there are three sets of field-cured specimens, each from a different concrete sample, should there be a test specimen from each set? The licensed design professional must provide direction, preferably in the contract documents, but at least at the concrete preconstruction meeting.

Core Testing

On some occasions, field-cured cylinders are not available for testing. Sometimes the cylinders are damaged, not made, or not made or cured properly. In these extreme situations, core testing may be performed to determine if the in-place concrete strength meets that specified for the construction stage. ACI CODE-318-25, Section 26.12.7.1(d), states that the concrete in the area represented by the core tests shall be considered structurally adequate if "(1) The average of three cores is equal to at least 85% of f'_c," and "(2) No single core is less than 75% of f'_c." ACI CODE-318-25 states that cores can be used for investigating low strength-test results when the acceptance criteria of standard-cured concrete specimens and shotcrete are not met (Section 26.12.3.1(c) and 26.12.5.1(d), respectively). The Code does not state that option when the acceptance criteria for field-cured specimens are not met. If cores were to be used, does the average of three cores apply, or would the requirement be for the lowest core value?

Concrete Preconstruction Conference

If not stated in the contract documents, a mandatory concrete preconstruction conference must be held to discuss:

- Acceptance criteria for field-cured specimens—ACI CODE-318 or unless otherwise permitted by the licensed design professional;
- Testing frequency for field-cured specimens;
- Number of field-cured specimens to make;
- Number of specimens to test;
- Selection of field-cured specimens from each concrete sample to test;
- Time between testing when the next field-cured test makes previous test results invalid, such as 2, 4, 12, or 24 hours;
- Alternative procedures that may be used in lieu of field-cured specimens;
- Permitting temperature-match curing that includes acceptance criteria; and

- Applicability of core tests and their acceptance criteria in place of field-cured specimens.

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17. ASTM C1074-19, "Standard Practice for Estimating Concrete Strength by the Maturity Method," ASTM International, West Conshohocken, PA, 2019, 11 pp.

18. ASTM C31/C31M-25, "Standard Practice for Making and Curing Concrete Test Specimens in the Field," ASTM International, West Conshohocken, PA, 2025, 7 pp.

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Questions in this column were asked by users of ACI documents and have been answered by ACI staff or by a member or members of ACI technical committees. The answers do not represent the official position of an ACI committee. Comments should be sent to lacey.stachel@concrete.org.