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ACI – An Overview

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ACI is

- A technical and educational society dedicated to improving
  - Design
  - Construction
  - Maintenance
  - Repair



- One of the world's largest sources of concrete knowledge

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- A Trade or Promotional Association
- A Government Agency
- An Educational Institution

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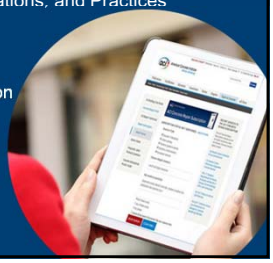
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November 11, 2026

Low Compressive Strength Test Results? What They Mean and Next Steps…

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Minnesota Concrete Council
Dedicated to Cast-in-Place Concrete

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Learning Objectives

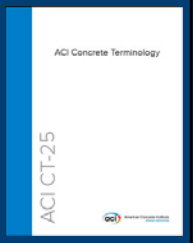
1. Understand what strength test is and is not
2. Learn proper methods of sampling, fabrication, handling and curing strength test specimens
3. Understand acceptance criteria for strength tests
4. Learn how to interpret strength tests not meeting acceptance requirements and how to investigate non-compliant concrete
5. Learn how to address low strength concrete issues in production

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1. What is a strength test and why it's needed?

specified concrete compressive strength — the specified resistance of a concrete specimen to axial compressive loading used in design calculations and as the basis for acceptance of concrete used in the work.



specified concrete compressive strength ⟺ **specified strength**

compressive strength ⟺ **strength**

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1. What is a strength test and why it's needed?

ACI 318-25: 26.12.1(a)

"Evaluation of hardened concrete shall be based on strength tests."



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1. What is a strength test and why it's needed?

ACI 318-25: 26.12.1

- "A strength test is the average of the compressive strengths of at least two 4 x 8 in. cylinders or two 6 x 12 in. cylinders from the same sample of concrete taken in accordance with ASTM C172 at the point of delivery, handled and standard-cured in accordance with ASTM C31, and tested in accordance with ASTM C39 at 28 days or at test age designated for f_c'."

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1. What is a strength test and why it's needed?

ACI 318: 26.12.1

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1. What is a strength test and why it's needed?
a. What is NOT a strength test?

ACI 318-25, R26.12.1

What is **NOT** a strength test?

- Tests on field cured cylinders
- Tests on cylinders from laboratory trial batches

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1. What is a strength test and why it's needed?
b. How to sample concrete?

Designation: C172/C172M – 17

Standard Practice for Sampling Freshly Mixed Concrete[1]

ACI 318: 26.12.1

- "…sample of concrete taken in accordance with ASTM C172 at the point of delivery…"

Stationary Mixers
Paving Mixers
Revolving Drum Truck Mixers or Agitators
Continuous Mixers
Open-Top Truck Mixers, Agitators, Nonagitating Equipment, or Other Types of Open-Top Containers







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1. What is a strength test and why it's needed?
b. How to sample concrete? – Composite sample



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1. What is a strength test and why it's needed?
b. How to sample concrete?

Designation: C172/C172M – 17

Standard Practice for Sampling Freshly Mixed Concrete[1]

ACI 318: 26.12.1

- "…sample of concrete taken in accordance with ASTM C172 at the point of delivery…"

Make composite sample

- Minimum volume
- Number of portions
- Portion of the batch

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1. What is a strength test and why it's needed?
c. How to make specimens for testing?

Designation: C31/C31M – 15

Standard Practice for Making and Curing Concrete Test Specimens in the Field[1]

ACI 318: 26.12.1

- …handled and standard-cured in accordance with ASTM C31…

Testing Requirements
- Cylinder Size

Sampling Concrete
- ASTM C 172

Molding Specimens
- Casting Cylinders
- Consolidation

Initial and Final Curing

Transportation to Laboratory



composite sample

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1. What is a strength test and why it's needed?
c. How to make specimens for testing?

ASTM C31, Standard Practice for Making and Curing Concrete Test Specimens in the Field

Slump	Consolidation
< 1 in.	Vibration
≥ 1 in.	Vibration or rodding

	Consolidation by Vibration	
Cylinder size, in.	No. of layers	No. of vibrator insertions/ layer
4 x 8	2	1
6 x 12	2	2

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1. What is a strength test and why it's needed?
c. How to make specimens for testing?

ASTM C31, Standard Practice for M… Curing Concrete Test Specimens in…

Slump	Consolidation
< 1 in.	Vibration
≥ 1 in.	Vibration or rodding

	Consolidation by Vibration		Conso… R…	
Cylinder size, in.	No. of layers	No. of vibrator insertions/ layer	No. of layers	Rod dian… in.
4 x 8	2	1	2	3/8
6 x 12	2	2	3	5/8



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1. What is a strength test and why it's needed?
c. How to make specimens for testing?

ASTM C31, Standard Practice for Making and Curing Concrete Test Specimens in the Field

Activity	Timing	f_c'	Temp.	Moisture
Initial Curing	Up to 48 h after molding	< 6000 psi	60-80°F	Store in an environment that controls the loss of moisture
		≥ 6000 psi	68-78°F	





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c. How to make specimens for testing?

ASTM C31, Standard Practice for Making and Curing Concrete Test Specimens in the Field

Activity	Timing	f_c'	Temp.	Moisture
Initial Curing	Up to 48 h after molding	< 6000 psi	60-80°F	Store in an environment that controls the loss of moisture
		≥ 6000 psi	68-78°F	
Transp.	≥ 8 h after final set; Transp. time ≤ 4 h	All	Protect from freezing	Wrap in plastic, wet burlap; caps on molds

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1. What is a strength test and why it's needed?
c. How to make specimens for testing?

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Transp.	≥ 8 h after final set; Transp. time ≤ 4 h	All	Protect from freezing	Wrap in plastic, wet burlap; caps on molds
Final Curing	Until testing	All	70-77°F	Keep in water storage tanks or moist rooms

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1. What is a strength test and why it's needed?
c. How to make specimens for testing?

ASTM C31, Standard Practice for Making and Curing Concrete Test Specimens in the Field

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		≥ 6000 psi	68-78°F	
Transp.	≥ 8 h after final set; Transp. time ≤ 4 h	All	Protect from freezing	Wrap in plastic, wet burlap; caps on molds
Final Curing	Until testing	All	70-77°F	Keep in water storage tanks or moist rooms
Test prep.	≤ 3 h prior to test	All	Ambient 68-86°F	Maintain free moisture on cylinders

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1. What is a strength test and why it's needed?
d. Factors affect strength?

- Moist curing results in higher long-term strength
- Lower temperature results in higher long-term strength

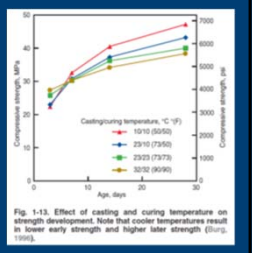


Fig. 1-13. Effect of casting and curing temperature on strength development. Note that cooler temperatures result in lower early strength and higher later strength (Burg, 1996).

Sources:
- Price, W. H., "Factors Influencing Concrete Strength," ACI Journal Proceedings, Vol. 47, American Concrete Institute, 1951, pp. 417–432.
- Kosmatka, Steven H.; Kerkhoff, Beatrix; and Panarese, William C.; Design and Control of Concrete Mixtures, EB001, 14th edition, Portland Cement Association, Skokie, Illinois, USA, 2003

1. What is a strength test and why it's needed?
f. Who can conduct the tests?

ACI 318: 26.12.1

Designation: C1077 – 17

Standard Practice for Agencies Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Testing Agency Evaluation[1]

Activity	ACI 318 Requirement
Acceptance testing	Testing agency compliant with ASTM C1077
Specimen preparation (for strength tests)	Certified field testing technicians
Laboratory testing	Certified laboratory technicians

1. What is a strength test and why it's needed?
f. Who can conduct the tests?



https://www.concrete.org/certification/
https://www.concrete.org/education/aciuniversity

1. What is a strength test and why it's needed?
g. Example

Designation: C39/C39M – 18

Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens[1]

- ASTM C39 (4 x 8 cyl.)
  - Cylinder 1: 4320 psi
  - Cylinder 2: 4420 psi

Compressive (Cylinder) Strengths

Strength Test

Average: 4370 psi

1. What is a strength test and why it's needed?
g. Example

Designation: C39/C39M – 18

Standard Test Method for
Compressive Strength of Cylindrical Concrete Specimens[1]

- ASTM C39 (4 x 8 cyl.) (6 x 12 cyl.)

	(4 x 8 cyl.)	(6 x 12 cyl.)
Cylinder 1:	4320 psi	4250 psi
Cylinder 2:	4420 psi	4150 psi

Compressive (Cylinder) Strengths

Strength Test

Average: 4370 psi

Strength Test

4200 psi

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2. How often must strength tests be conducted?

ACI 318-25, 26.12.2.1 (a)

Strength-test specimens must be made for each concrete mixture at least:
- Once a day
- Once for each 150 yd³ of concrete
- Once for each 5000 ft² of slabs or walls (governs when thickness is less than 9 ¾ in.)

26.12.2 *Frequency of testing*

26.12.2.1 Compliance requirements:

(a) Samples for preparing strength-test specimens of each concrete mixture placed each day shall be taken in accordance with (1) through (3):
(1) At least once a day.
(2) At least once for each 150 yd³ of concrete.
(3) At least once for each 5000 ft² of surface area for slabs or walls.
(b) On a given project, if total volume of concrete is such that frequency of testing would provide fewer than five strength tests for a given concrete mixture, strength test specimens shall be made from at least five randomly selected batches or from each batch if fewer than five batches are used.
(c) If the total quantity of a given concrete mixture is less than 50 yd³, strength tests are not required if evidence of satisfactory strength is submitted to and approved by the building official.

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2. How often must strength tests be conducted?

ACI 318-25, 26.12.2.1 (b)

Minimum of five strength tests must be made for each concrete mixture
- From 5 randomly selected batches
- From each batch if fewer than 5 batches are used

26.12.2 *Frequency of testing*

26.12.2.1 Compliance requirements:

(a) Samples for preparing strength-test specimens of each concrete mixture placed each day shall be taken in accordance with (1) through (3):
(1) At least once a day.
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2. How often must strength tests be conducted?

ACI 318-25, 26.12.2.1 (c)

Strength-tests NOT required:
- Total quantity < 50 yd³
- Evidence of satisfactory strength
- Approved by building official

26.12.2 *Frequency of testing*

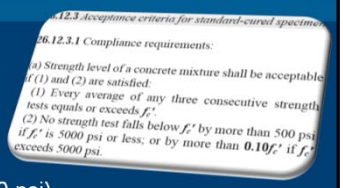
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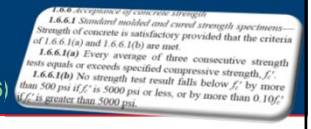
3. What are acceptance criteria for strength tests?

ACI 318-25, 26.12.3.1 (a)



Acceptable strength level:

- Each strength test:
  - ≥ f_c' - 500 psi ($f_c' \leq$ 5000 psi)
  - ≥ 0.9 f_c' ($f_c' >$ 5000 psi)
- Average of any 3 consecutive strength tests ≥ f_c'



(ACI 301-20, 1.6.6)

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3. What are accept. criteria for strength tests? a. Example

- Placement requiring 100 yd³ of concrete with f_c' = 4000 psi. Use 10 ready-mix trucks (batches) 10 yd³ each.
- Random sampling – trucks 2, 3, 5, 7, 10
- Concrete strength tests (average of two 4 x 8" cylinders):

		Average of 3 consecutive tests
Truck 2:	3950 psi	
Truck 3:	3470 psi	
Truck 5:	4150 psi	3860 psi
Truck 7:	4130 psi	3920 psi
Truck 10:	4210 psi	4160 psi

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3. What are accept. criteria for strength tests? a. Example

		Average of 3 consec. tests
Truck 2:	3950 psi	
Truck 3:	3470 psi	
Truck 5:	4150 psi	3860 psi
Truck 7:	4130 psi	3920 psi
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Truck 10:	4210 psi	4160 psi

ACI 318-25, 26.12.3.1 (a) (and 301-20, 1.6.6)

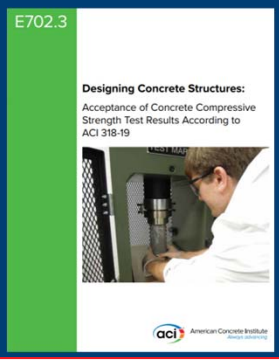
- Each strength test:
  - ≥ f_c' - 500 psi ($f_c' \leq$ 5000 psi) → f_c' = 4000 psi → 3500 psi
  - ~~≥ 0.9 f_c'~~ ~~($f_c' >$ 5000 psi)~~
- Average of any 3 consecutive strength tests ≥ f_c' → 4000 psi

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3. What are accept. criteria for strength tests?
a. Example

ACI E702.3

- Example problem with strength tests from 15 batches of concrete
- Acceptance criteria
- Recommendations for further actions
- Additional reading list



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3. What are accept. criteria for strength tests?
b. What steps are needed (by concrete supplier) if acceptance criteria are not met?

Requirement	Required Action(s) (ACI 318-25, 26.12.3.1 b)
Each strength test: • ≥ f_c' - 500 psi ($f_c' \leq$ 5000 psi) • ≥ 0.9 f_c' ($f_c' >$ 5000 psi)	• Steps shall be taken to increase subsequent strength tests
Average of any 3 consecutive strength tests ≥ f_c'	• Steps shall be taken to increase subsequent strength tests

- Increase "cm" content;
- Reduce water content;
- Use water-reducing admixture to improve dispersion of "cm"
- Make other changes in mixture proportions;
- Reduce delivery time;
- Make closer control of air content;
- Reduce conc. temperature
- Improve quality of testing, incl. strict compliance with ASTM C172, C31, & C39.

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3. What are accept. criteria for strength tests?
b. What steps are needed (by concrete supplier) if acceptance criteria are not met?



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3. What are accept. criteria for strength tests?
b. What steps are needed (by concrete supplier) if acceptance criteria are not met?

Table 3.3c (cont.)—Hardened properties issues

Issue	Area of occurrence	Possible causes	Possible adjustments
17. Low-strength concrete	Mixture	A. Changes in cementitious or other raw material production	a) New trial batches may be needed to confirm the impact on the strength and workability of the mixture. b) A temporary increase in cementitious materials may be required to maintain satisfactory results.
		B. Seasonal changes	a) Verify proper field sampling and curing conditions. b) Hotter weather can reduce later-age concrete strength. If possible, use higher volumes of alternate cementitious materials. c) Significant changes in air or concrete temperatures can affect admixture characteristics, requiring adjustment to maintain performance.
	Jobsite	Addition of water beyond that originally specified	a) Do not add water beyond the amount originally specified. b) If workability of the mixture needs to be higher, refer to Table 3.3a, Issue 2, Slump: high/low. c) Check the moisture content and absorption of the aggregates.
	Testing	Improper sampling, molding, curing, and testing procedures	a) Ensure that all tests comply with the referenced specifications for the job, such as ASTM C172/C172M, C31/C31M, C39/C39M, C143/C143M, C231/C231M, and C78/C78M. b) Ensure that all technicians are certified by ACI or an equivalent agency for the tests they are performing.

ACI 211.8R

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3. What are accept. criteria for strength tests?

b. What steps are needed (by concrete supplier) if acceptance criteria are not met?

Requirement	Required Action(s) (ACI 318-25, 26.12.3.1 b)
Each strength test: • ≥ f_c' - 500 psi ($f_c' \leq$ 5000 psi) • ≥ 0.9 f_c' ($f_c' >$ 35 MPa)	• Steps shall be taken to increase subsequent strength tests
Average of any 3 consecutive strength tests ≥ f_c'	• Steps shall be taken to increase subsequent strength tests

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4. How to investigate strength tests not meeting acceptance requirements?

Requirement	Required Action(s) (ACI 318-25, 26.12.3.1 b)
Each strength test: • ≥ f_c' - 500 psi ($f_c' \leq$ 5000 psi) • ≥ 0.9 f_c' ($f_c' >$ 5000 psi)	• Steps shall be taken to increase subsequent strength tests • Investigate strength tests → 26.12.6
Average of any 3 consecutive strength tests ≥ f_c'	• Steps shall be taken to increase subsequent strength tests

…applicable only for evaluation of in-place strength at the time of construction.

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4. How to investigate strength tests not meeting acceptance requirements?

- ACI 318-25, 26.12.7.1

"(a) If any strength test of standard-cured cylinders falls below f_c' by more than the limit allowed for acceptance, or if tests of field-cured cylinders indicate deficiencies in protection and curing, steps shall be taken to ensure that structural adequacy of the structure is not jeopardized."

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4. How to investigate strength tests not meeting….? a. What is the "limit allowed for acceptance"?

- ACI 318-25, 26.12.6.1

"(a) If any strength test of standard-cured cylinders falls below f_c' by more than the limit allowed for acceptance, or if tests of field-cured cylinders indicate deficiencies in protection and curing, steps shall be taken to ensure that structural adequacy of the structure is not jeopardized."

From acceptance criteria:

- $f_c' \leq$ 4000 psi
  f_c' - 500 psi
- $f_c' >$ 4000 psi
  0.9 f_c'

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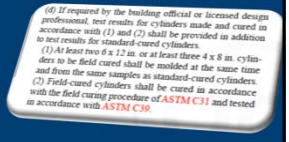
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4. How to investigate strength tests not meeting….?
b. What are field cured cylinders needed for?

- ACI 318-25, 26.12.7.1

(a) If any strength test of standard-cured cylinders falls below ***fc'*** by more than the limit allowed for acceptance, or if tests of field-cured cylinders indicate deficiencies in protection and curing, steps shall be taken to ensure that structural adequacy of the structure is not jeopardized.

318-25, 26.5.3.2 (d)
2- 4 x 8 in. or
2- 6 x 12 in. cylinders field cured
- *If req'd by building official or LDP*


(d) If required by the building official or licensed design professional, test results for cylinders made and cured in accordance with (1) and (2) shall be provided in addition to test results for standard-cured cylinders.
(1) At least two 6 x 12 in. or at least three 4 x 8 in. cylinders to be field cured shall be molded at the same time and from the same samples as standard-cured cylinders.
(2) Field-cured cylinders shall be cured in accordance with the field curing procedure of ASTM C31 and tested in accordance with ASTM C39.

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4. How to investigate strength tests not meeting….?
c. What is needed to ensure structural adequacy?

- ACI 318-25, 26.12.7.1

(a) If any strength test of standard-cured cylinders falls below ***fc'*** by more than the limit allowed for acceptance, or if tests of field-cured cylinders indicate deficiencies in protection and curing, steps shall be taken to ensure that structural adequacy of the structure is not jeopardized.

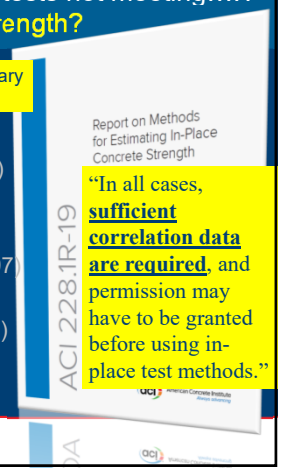
- *Structural analysis*
- *Field cured cylinders*
- *In-place tests (see ACI 228.1R, Report on Methods for Estimating In-Place Concrete Strength)*

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4. How to investigate strength tests not meeting….?
d. How to estimate in-place strength?

ACI 228.1R: In ACI 318-25 Commentary and in ACI 301-20

- Rebound number (ASTM C805)
- Penetration resistance (ASTM C803)
- Pullout test (ASTM C900)
- Pull-off test (ASTM C1583)
- Ultrasonic pulse velocity (ASTM C597)
- Maturity method (ASTM C1074)
- Cast-in-place cylinders (ASTM C873)
- Combined methods



"In all cases, **sufficient correlation data are required**, and permission may have to be granted before using in-place test methods."

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4. How to investigate strength tests not meeting acceptance requirements?

- ACI 318-25, 26.12.7.1

(a) If any strength test of standard-cured cylinders falls below f_c' by more than the limit allowed for acceptance, or if tests of field-cured cylinders indicate deficiencies in protection and curing, steps shall be taken to ensure that structural adequacy of the structure is not jeopardized.

- *Structural analysis*
- *Field cured cylinders*
- *In-place tests (see ACI 228.1R, Report on Methods for Estimating In-Place Concrete Strength)*

Low Strength Confirmed

Core Testing

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4. How to investigate strength tests not meeting….?
e. How to test cores and interpret results?

ACI 318-25, 26.12.7.1 (b)
(ACI 301-20, 1.6.4.3)

- Test in accordance with ASTM C42
- Cores drilled from area in question
- 3 cores for each failed strength test
  Each core ≥ 0.75 f_c'
  Average (3 cores) ≥ 0.85 f_c'





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5. Strength is still low – now what?

- Standard cured cylinders – failed
- Structural adequacy – in doubt
- Field cured cylinders – failed
- In-place strength evaluation – failed
- Core testing – failed

ACI 318-25, 26.12.7.1 (g)
…responsible authority shall be permitted to order a strength evaluation in accordance with Chapter 27 for the questionable portion of the structure

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6. Who pays for testing?

ACI 318-25 → SILENT
ACI 301-20, 1.6.3 and 1.6.4

Test type	Responsible for payment
Concrete strength tests (part of QA)	Owner
Additional testing of materials or concrete because of failure to meet specification requirements	Contractor
Tests to verify strength of concrete in structure	Contractor (only if subsequent testing confirms concrete does not meet acceptance criteria)

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7. How can concrete producer avoid low strengths?

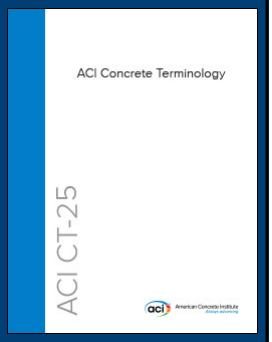
- What's the difference between specified strength and required average strength?
  - Specified strength = f_c'
  - Required average strength = f_{cr}'
- How can statistics help?

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Definitions from ACI Concrete Terminology

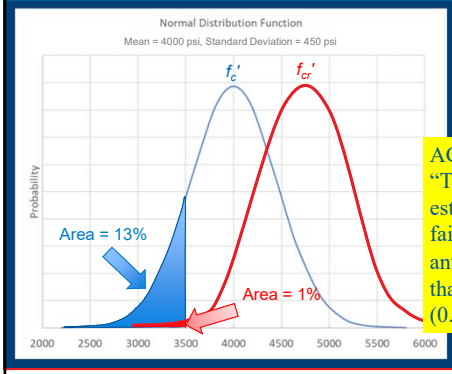
- **required average strength** — the average strength of concrete used in mixture proportioning to ensure a high likelihood that the concrete will meet specified strength acceptance criteria



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7. How can concrete producer avoid low strengths?
a. What is statistics and how can it help?



ACI 214R:
"The f_{cr}' should be established where failure to meet f_c' is anticipated at no more than 1 in 100 times (0.01)."

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7. How can concrete producer avoid low strengths?
b. What's the difference between specified strength and required average strength?

ACI 301-20, 4.2.3

- Strength test data not available

Table 4.2.3.1—Required average compressive strength f_{cr}' when data are not available to establish standard deviation.

f_c', psi	f_{cr}', psi	
Less than 3000	$f_c' + 1000$	
3000 to 5000 $f_c' = 4000$ psi	$f_c' + 1200$	$f_{cr}' = 5200$ psi
Over 5000 $f_c' = 7250$ psi	$1.1f_c' + 700$	$f_{cr}' = 8675$ psi

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7. How can concrete producer avoid low strengths?
b. What's the difference between specified strength and required average strength?

ACI 301-16, 4.2.3

- Strength test data available $f_{cr}' = 4550$ psi

$f_c' \le 5000$ psi

$f_c' > 5000$ psi

Value of k-factor depends on the total number of tests

Example in "Manual of Concrete Inspection", MNL-2

Table 4.2.3.3(a)1—Required average compressive strength f_{cr}' when data are available to establish a sample standard deviation, psi

f_c', psi	f_{cr}', psi Use the larger of:
5000 or less	$f_{cr}' = f_c' + 1.34ks_s$ $f_{cr}' = f_c' + 2.33ks_s - 500$
Over 5000	$f_{cr}' = f_c' + 1.34ks_s$ $f_{cr}' = 0.90f_c' + 2.33ks_s$

Table 4.2.3.3(a)2—*k*-factor for increasing sample standard deviation for number of tests considered in calculating standard deviation

Total number of tests considered	*k*-factor for increasing sample standard deviation
15	1.16
20	1.08
25	1.03
30 or more	1.00

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7. How can concrete producer avoid low strengths?
c. What are control charts?



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7. How can concrete producer avoid low strengths?
c. What are control charts?

Quality control charts
- Help reduce variability
- Increase production efficiency
- Identify trends

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7. How can concrete producer avoid low strengths?
c. What are control charts?

ACI 214R
- Individual strength tests
- Average of five tests
- Range of two cylinder breaks in each test

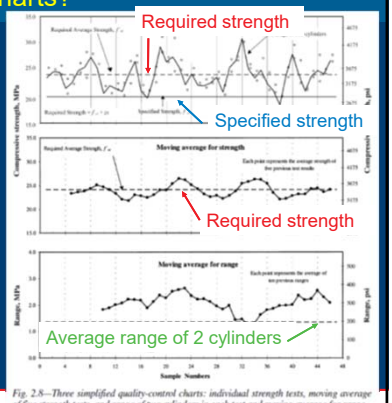


Fig. 2.8—Three simplified quality-control charts: individual strength tests, moving average of five strength tests, and range of two cylinders in each test and moving average for range.

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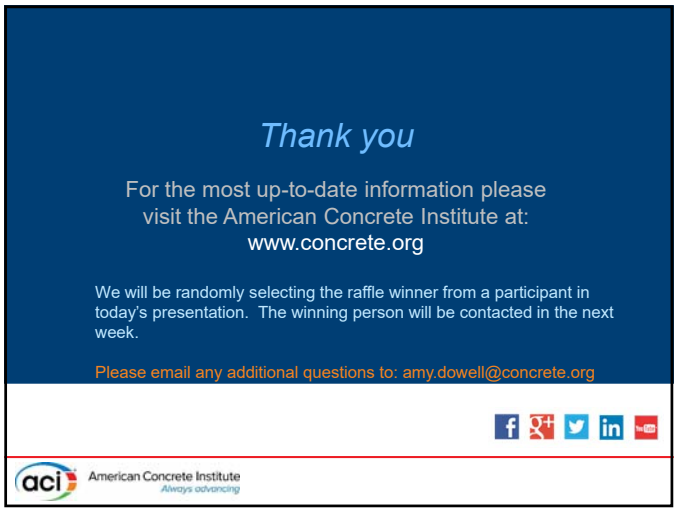
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8. Additional resources

- ACI 318, Building Code Requirements for Structural Concrete
- ACI 301, Specifications for Structural Concrete
- ACI 228.1R, Report on Methods for Estimating In-Place Concrete Strength
- ACI 214R, Guide to Evaluation of Strength Test Results of Concrete
- ACI MNL-2, Manual of Concrete Inspection
- ACI 211.8R, Guide to Troubleshooting Concrete Mixture Issues as Influenced by Constitutive Materials, Jobsite Conditions, or Testing Practices
- ACI PRC-212.3, Report on Chemical Admixtures for Concrete
- ASTM STP 169D, Significance of Tests and Properties of Concrete and Concrete-Making Materials

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We will be randomly selecting the raffle winner from a participant in today's presentation. The winning person will be contacted in the next week.
Please email any additional questions to: amy.dowell@concrete.org
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