

Expect Compressive Strength Test Results Less Than Specified Strength on Every Project!

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CONCRETE

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CONVENTION

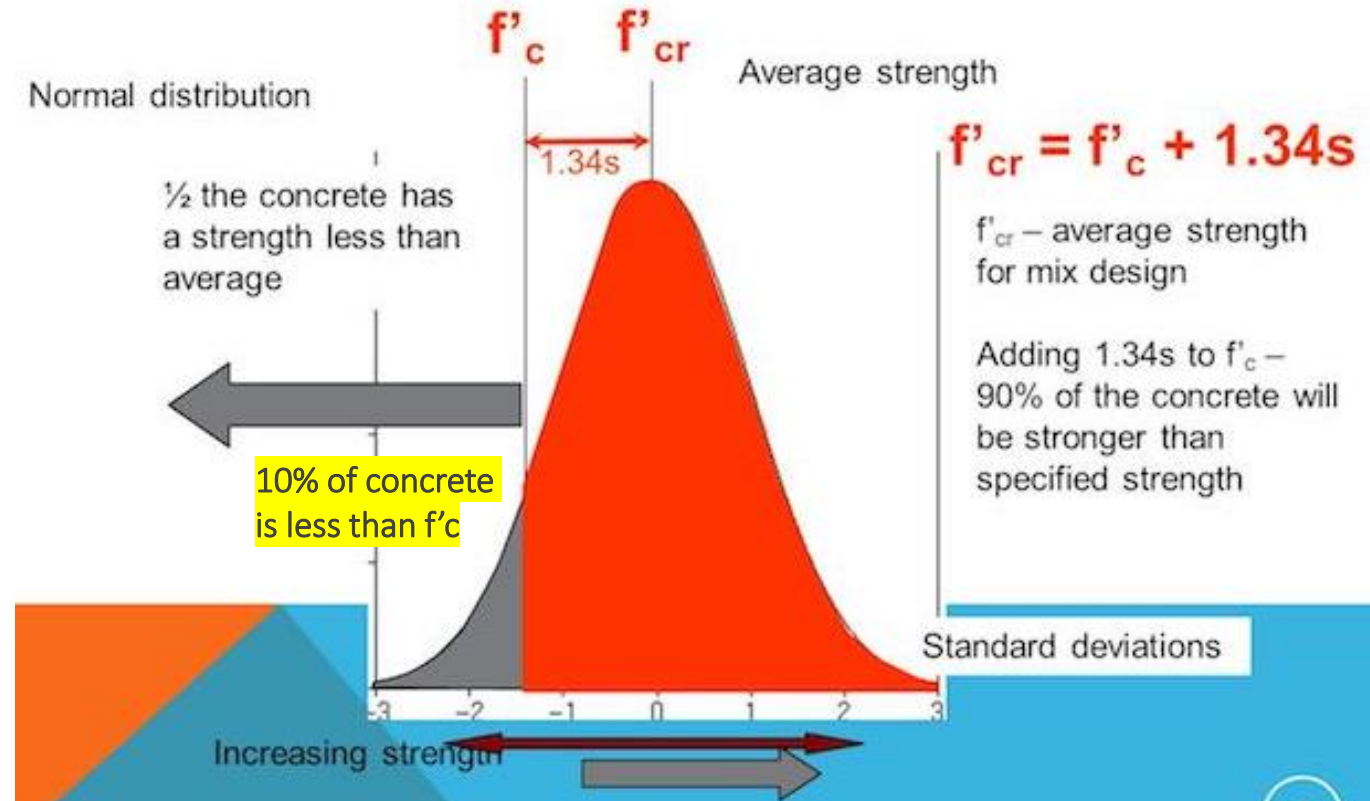


THE WORLD'S GATHERING PLACE FOR ADVANCING CONCRETE

Introduction

- Is it Normal for a Strength Test to be Less than f'_c and How Often?
- Section 26.12.3.1 of ACI 318-19 states that strength test results are acceptable if:
 - The average of three consecutive tests equals or exceeds f'_c ; and
 - Each individual test exceeds $(f'_c - 500 \text{ psi})$ or $0.9f'_c$, if f'_c exceeds 5000 psi
- ACI 301-20, Section 4.2.3.3,1 establishes the process of determining the required average strength, f'_{cr} , at a 99% probability of compliance

STRENGTH REQUIREMENTS



EXPECT LOW BREAKS

- Based upon the statistical approach that is utilized to develop the concrete mix, 10% of concrete tests should indicate strength less than f'_c

Expected number of compressive strength test results less than f'_c

Volume of placed concrete, yd ³	Minimum number of tests		Expected number of tests less than f'_c	
	One per 150 yd ³ (ACI 318-19, ACI 301-20)	One per 100 yd ³	One per 150 yd ³ (ACI 318-19, ACI 301-20)	One per 100 yd ³
1000	7	10	1	1
10,000	70	100	7	10
50,000	334	500	34	50
100,000	667	1000	67	100

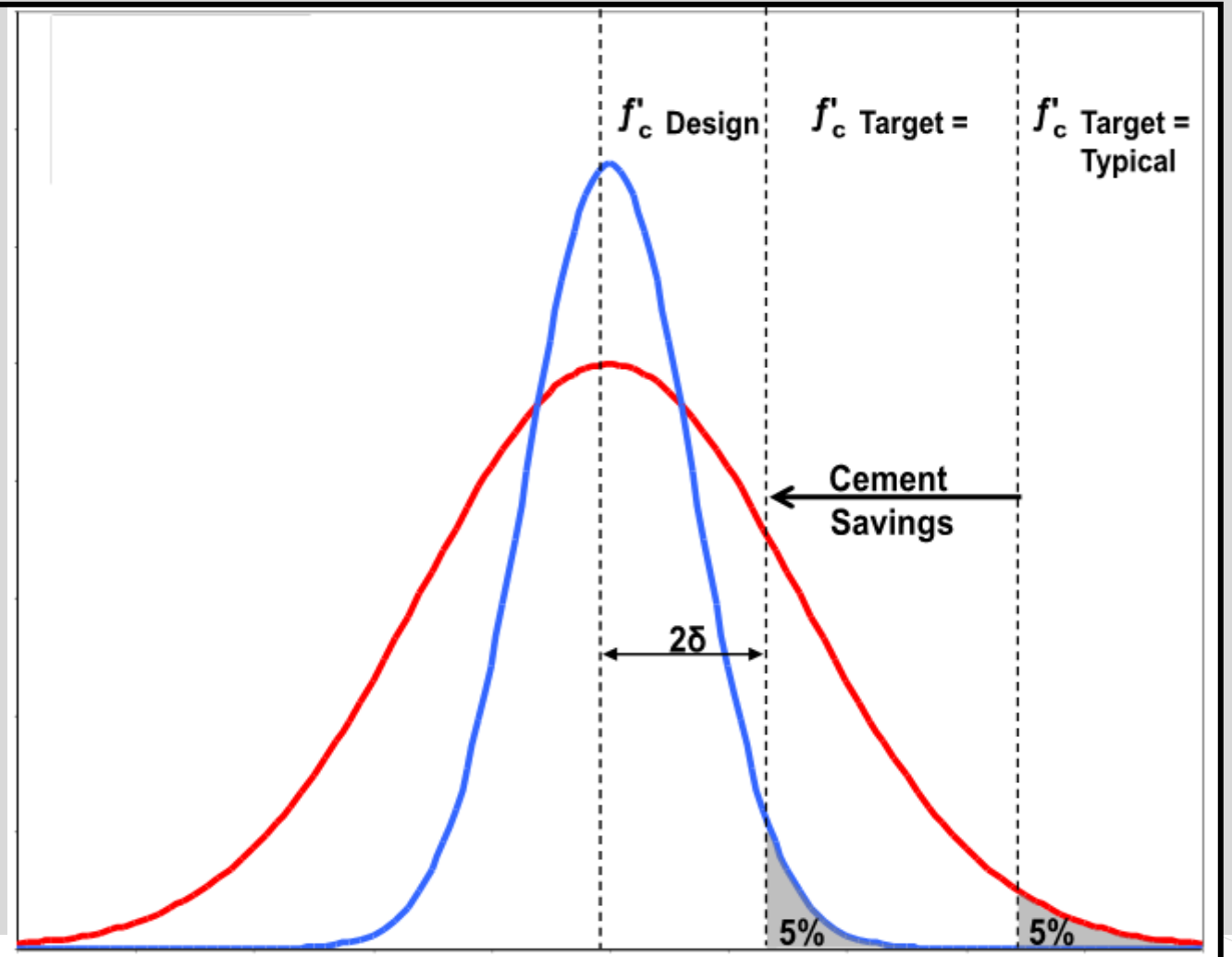
READY MIX PRODUCERS WANT TO AVOID HEADACHES

- Producers increase strength of mixtures for...
 - Set time and high early strength requirements of concrete contractor
 - Avoid problems with testing
 - This “overdesign” cost money and increases embodied carbon
 - What is the cost if no breaks are to be below $f'c$?
 - Hypothetically the project mixes could need an additional 50lb of cement per cubic yard.
 - Can add \$15 per yard. So, for a 100,000 cu yd project, the additional concrete cost could be as much as \$1,500,000!!
 - This extra cement to avoid testing headaches adds embodied carbon to the mixes and reduces the sustainability of the project
 - Also this extra cement can cause increased shrinkage and potential cracking in the concrete members resulting in possible service performance issues.



Reduced Ready-Mix Variability

- Reduce the mix performance variability, will reduce cement required in the mix to ensure target design strengths
 - **Concrete Testing** is the primary source of variability
- Could reduce cement requirements > 20% to 30%



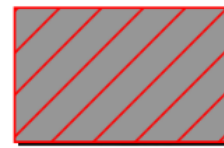
Testing Troubles...

- Strength test measurements are fraught with testing errors that result in lower reported test strength values compared to in-situ concrete
 - Not following ASTM standards
 - Improper sampling from the batch;
 - Variations due to fabrication techniques:
 - Substandard conditions,
 - Incorrect tools,
 - Poor quality, damaged, or distorted molds,
 - **Nonstandard molding and consolidation,**
 - Incorrect handling of fresh test samples;
 - Differences in curing:
 - Delays in beginning initial curing,
 - Temperature variation,
 - Variable moisture control,
 - Nonstandard initial curing,
 - Delays in bringing cylinders to the laboratory,
 - Rough handling of cylinders in transport
 - Improper final curing; and
 - Variations in sample testing:
 - Uncertified tester,
 - Specimen surface preparation,
 - Inadequate or uncalibrated testing equipment,
 - Nonstandard loading rate, and
 - Poor recordkeeping.



So, you have low break report...

- Testing agencies often fail to recognize that a compressive strength test result that indicate results less than $f'c$ can still comply with the acceptance criteria of the code
 - Some testing agencies note on their report “failed” or “non-conforming.”
 - It is not the testing agency's role to accept or reject concrete
 - This is misleading and can cause unnecessary project confusion
 - Some testing agencies provide a single 7-day and 14-day break and report to ownership and the design team if this break does not achieve some assumed % of the 28-day strength
 - Would be better to utilize the additional cast cylinders as “HOLD” to be broken after 28-days versus breaking them early??
- More common with the widespread use of SCM’s and Type 1L cement



Report On: Concrete Compression



Project No: [Redacted] Cust No: [Redacted]

Report No: 239

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Client: [Redacted]
Project: [Redacted]
Location: [Redacted]

Report Date: 08/03/2021 Revised
Prev. Rpt. Date: 07/15/2021 Test Report
Test Date: 07/01/2021
Sampled By: [Redacted]
Engineer: [Redacted]

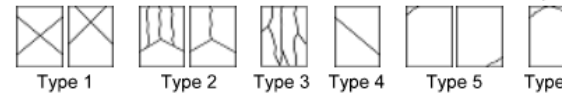
Set: 78

Location:

Number of Specimens: 5

Cylinder Marked	Age Tested (date : days)	Diameter (in)	Area (in ²)	Max Load (lbs)	Break Type	Cure Loc	Compressive Strength (PSI)	Average Strength (PSI)	Tested By
A	07/08/21 : 7	4.00	12.566	67,610	Type 3	Lab	5,380	5,380	[Redacted]
B	07/15/21 : 14	4.00	12.566	70,020	Type 3	Lab	5,570	5,570	[Redacted]
C	07/29/21 : 28	4.00	12.566	82,020	Type 2	Lab	6,530		[Redacted]
D	07/29/21 : 28	4.00	12.566	86,030	Type 3	Lab	6,850		[Redacted]
E	07/29/21 : 28	4.00	12.566	82,740	Type 3	Lab	6,580	6,650*	[Redacted]

FAILS TO MEET REFERENCE VALUE



	<u>Measurement</u>	<u>Specification</u>	Specification: 7,000 psi @ 28 days
Temp.: Ambient:	74°F		Source: [Redacted]
Mix:	78°F		Plant: 111-P1
Slump:	4	3-5	TruckNo: 1303
Air Content:	1.2	0-3	Mix Code: 4891
			Ticket No: 96468
			Sampled At: Truck

Weather:
Transported By:
Placement Date: 07/01/2021
Time Batched: 9:12 am
Time Sampled: 9:56 am
Curing Method:

Quantity Represented: 9 cu. yds. at 243 cu. yds. placed of a 450 cu. yd. total placement
Placement Location: D-E/4-5
Sample Location:
Remarks:
Test Method (As Applicable): Unless noted, concrete was sampled and tested in accordance with ASTM C172, C143, C231 or C173, C1054 and C138. Compressive strength tests per ASTM C39.



Investigating low strength test results

ACI 318 and ACI301 give requirements when low strength test results occur

Engineering judgement should be used to determine the scope of the investigation!

Engineers have tools to investigate low strength breaks

- a) **Using experience and engineering judgement**
- b) Assessing testing variation compared with testing standards
- c) Supplementary data from the hold or reserve cylinder
- d) Non-destructive testing for a relative assessment
- e) Core testing per ACI318 criteria



Engineering Judgement

ACI 318 uses the word “**judgement**” 16 times throughout the document

*“The Code and Commentary cannot replace **sound engineering knowledge, experience, and judgment.**”*

R26.12.6.1 indicates that judgment should be applied as to the significance of low strength test results and whether they are a cause for concern. If further investigation is deemed necessary, such investigation may include in-place tests as described in ACI 228.1R-199 or, in extreme cases, the taking and testing of cores.

- Can review by SE of engineering design allow of acceptance of $f'c$ lower than specified?
- Consider test results as lower bound on strength value. If a testing issue is suspected, the in-situ concrete likely has higher strength.
- Concrete continues to gain strength after 28 days. Compressive strength tests performed on individual reserve cylinders at 56 or 90 days can be utilized as the basis of acceptance
- Low $f'c$ test result may not be the insitu concrete, but a result of the test!!

• Engineering
• Judgement



Use Test Cylinders Wisely!

- In project specifications and preconstruction meeting, engineer to give direction on actions to be taken if low concrete strength test results occur
- Typically, 4 to 6 cylinders are cast from a concrete sample
- “HOLD” cylinders are commonplace and often noted as a requirement in project specifications, and are held to be tested if needed later
- Sometimes engineers are reluctant to accept the results derived from the hold cylinders since there may only be 1 or 2 cylinders
- Owners pay extra to cast, cure, store and test, if necessary, the hold cylinders. Engineers should value information derived from the hold cylinders. If not, why is the owner paying for them?
- Sometimes with test cylinders problems can be identified by simply weighing the samples.



Non-destructive Testing Options...

In-place tests of concrete per ACI 228.1R

- Probe Penetration Test (ASTM C803)
- Rebound Hammer (ASTM C805)
- Pullout Test (ASTM C900)

Unless properly calibrated and correlated with compressive strength per ACI 228.1R, they are of value primarily for comparisons within same structure.

Information for engineering judgement



In-Place Concrete Strength from Core Testing

- Last resort, in “*extreme*” cases per R26.12.6.1
- Only performed after exhausting all other options
- Often an unnecessary expense and frequently leads to core removal and testing that is not in accordance with ASTM C42/C42M

(e) Concrete in an area represented by core tests shall be considered structurally adequate if (1) and (2) are satisfied:

- (1) The average of three cores is equal to at least 85 percent of f'_c .
- (2) No single core is less than 75 percent of f'_c .

and whether they indicate need for concern. If further investigation is deemed necessary, such investigation may include in-place tests as described in [ACI 228.1R](#) or, in extreme cases, measuring the compressive strength of cores taken from the structure.



In-Place Concrete Strength from Core Testing

Very important facts that are often not understood by persons writing purchase orders, evaluating strength test results, or evaluating the results of in-place cored concrete strength specimen:

- A. The Ready Mix concrete producer is responsible for the quality of the concrete as delivered to the job site when the concrete is:
 - a) Sampled according to ASTM C172
 - b) Strength specimens are cast and cured as per ASTM C31
 - c) Compressive strength specimens are tested as per ASTM C39
 - d) Flexure strength specimens are tested as per ASTM C78
 - e) Testing lab and technicians are certified

- B. In-place concrete strength from core testing:
 - a) Generally, test specimens are obtained when doubt exists about the in-place concrete quality due either to low strength test results during construction or signs of distress in the structure.
 - b) These tests results are not the same as outlined in A above and should not be confused.

So many issues and expenses can be avoided by properly testing concrete as per the appropriate ASTM designation.

“The only thing worse than not testing concrete is to not properly test concrete.”



Claims, Credits, and Damages, Oh My!

“The 28-day cylinder strength should be at or above specified strength or the owners are not getting what they paid for”

- **FALSE!** If $f'c$ were a minimum, then, of course, the average of three consecutive strength tests would always exceed $f'c$. Therefore, the Code clearly acknowledges that some individual strength test results will be less than $f'c$!
- Furthermore, below strength concrete may be sufficient, and does not represent a “loss or damages” for the client.
- **The owner is benefiting** from a reduced concrete cost and improved project sustainability by allowing some test results to be below $f'c$.
- **Providing a financial credit for this issue would indeed be granting a windfall to the owner and would not be appropriate.**



Expect Compressive Strength Test Results Less Than Specified Strength on Every Project

Use engineering judgment, test reserve cylinders, and extract cores only if evaluation is warranted

by James Klinger, Colin L. Lobo, Eamonn F. Connolly, and Bruce A. Suprenant

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Hold My Drink



THANK YOU! QUESTIONS?

