

## Designing Concrete Structures:

Evaluation of Concrete Cores Test Results According to ACI 318-19



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Reported by ACI Committee E702

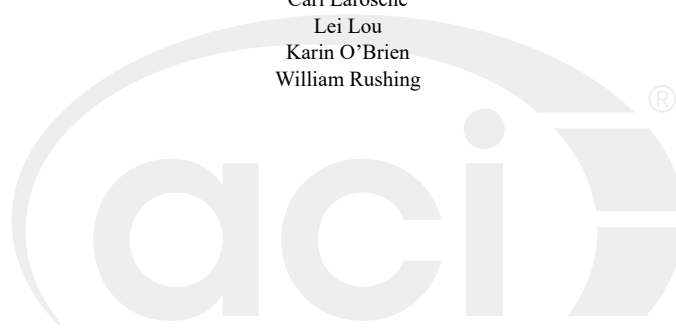
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This document is intended as a voluntary field guide for the Owner, design professional, and concrete repair contractor. It is not intended to relieve the user of this guide of responsibility for a proper condition assessment and structural evaluation of existing conditions, and for the specification of concrete repair methods, materials, or practices by an experienced engineer/designer.

ACI E702.8-22 Evaluation of Concrete Cores Test Results According to ACI 318-19, “Building Code Requirements for Structural Concrete and Commentary”.

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## Evaluation of Concrete Cores Test Results According to ACI 318-19

### Introduction

This document will present three separate case studies with different concrete core test data and perform an evaluation according to Section 26.12.6 of ACI 318-19, “Building Code Requirements for Structural Concrete and Commentary,” to determine if concrete core test results from placed concrete meets adequate strength as described in ACI 318 for a member’s specified concrete compressive strength.

There are many reasons why cores may be taken. Cores may be required because the cylinders were never made, lost, damaged, or improperly cured; to investigate other properties of the concrete; or, in our case, the tested cylinders were below the required strength. The licensed design professional or the building official is instructed to take cores in extreme cases. Cores to evaluate the concrete strength are to be taken when the structural adequacy is in question and when calculations indicate that the documented strength is not considered to be adequate. In the Code commentary, it is also discussed that lower strength may be tolerated and the licensed design professionals or the building official should consider if cores are required. In these examples, the licensed design professional determined the compressive cylinder strengths indicated that the structural integrity of the suspended slab was in question and required coring to evaluate the concrete.

### Problem Statement for Case No. 1, 2, and 3 (all cases)

The compressive strength of the concrete cylinders in one area of a suspended slab did not meet the strength acceptance criteria. The licensed design professional required that cores be taken to evaluate the strength of the concrete (ACI 318-19, 26.12.3.1(a) 26.12.3.1(c)).

The project specifications state that the compressive strength is to be 4000 psi at 28 days. The cores were removed from the slab 45 days after the concrete was placed.

**Note:** Example of determining acceptance of concrete compressive strength test results can be found in ACI E702.3-21, “Designing Concrete Structures: Acceptance of Concrete Compressive Strength Test Results According to ACI 318-19.”

Assumptions	Reference
Removal of the cores were done per ASTM C42/C42M “Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete.”	ACI 301, 1.7.4.3(a)
Cores were tested by procedures outline in ASTM C42/C42M.	ACI 301, 1.7.5.2
The locations of the cores were in the areas of the suspected low-strength concrete.	ACI 301, 1.7.4.3(b)

**Note:** Although the Code does not state this as a requirement, the licensed design professional or the building official should be involved in determining the core locations. They have the responsibility of determining if the core results meet the Code requirements, and they should make certain reasonable coring locations were used.

Assumptions	Reference
Certified laboratory technicians performed all required laboratory tests.	ACI 318, 26.12.1.1(d)
Cores were tested between 5 and 7 days after coring and the cores were trimmed.	ACI 318, 26.12.1.1(c)

**Notes:**

- a. The licensed design professional or the building official can modify the ASTM C42/C42M procedures. Modifications can include the diameter of the cores, time of testing and curing conditions, or both (ACI 318-19, R26.12.6.1(c)).
- b. The specifier (licensed design professional or the building official) of the test must be aware of the potential reduction in strength if cores are tested before the moisture gradients are allowed to dissipate. This also implies that any variation to the procedures as given in ASTM C42/C42M may result in a change in the strength of the cores (ACI 318-19, R26.12.6.1).
- c. Coring operations are sometimes performed by companies that specialize in sawing and coring of concrete. The people doing the coring may not know that these cores are being used to evaluate concrete strength and that exact coring and handling procedures are required. A person experienced in the procedures outlined in ASTM C42/C42M, or as modified by the licensed design professional or the building official, should witness and document that the coring procedure did follow ASTM C42/C42M or procedures approved by the licensed design professional or the building official.
- d. Many slabs-on-ground have a vapor retarder installed below the concrete. If the cores are to be removed from a slab-on-ground (our example is a suspended slab; thus, this is not a concern), great care should be taken so that the core removal does not penetrate or damage the vapor retarder.
- e. Cores should not have any reinforcement or embedded items in them. These items should be located prior to coring operations and core locations selected so that the cores do not have any embedded items. There are several nondestructive testing methods available to locate reinforcement and embedded items.
- f. The ideal core diameters should be at least 3.70 in. and the length be 1.9 to 2.1 times the diameter. Smaller diameter cores are allowed if this size core cannot be obtained. Cores can have length/diameter ( $L/D$ ) as low as 1.0. If the  $L/D$  is less than 1.75, correction to the final strength must be made as outlined in ASTM C42/C42M.

Calculations	References
When coring is required to determine concrete strength, three cores are to be taken.	ACI 318, 26.12.6.1.(b)
Concrete represented by cores is considered structurally adequate if the average of the three cores equals or exceeds 85 percent of $f'_c$ , with no single core being less than 75 percent of $f'_c$ .	ACI 318, 26.12.6.1(e)

**Case No. 1**

Three cores were removed from the slab and tested by the testing agency of record. Their results were:

**Table 1: Case No. 1**

Core	Tested compressive strength, psi
Core 1	3140
Core 2	3810
Core 3	3460

Determination of the average core compressive strength

$$\frac{\text{Core 1} + \text{Core 2} + \text{Core 3}}{3} = \text{Average core strength}$$

$$\frac{3140 \text{ psi} + 3810 \text{ psi} + 3460 \text{ psi}}{3} = 3470 \text{ psi}$$

By observation, the lowest core strength is 3140 psi.

ACI 318, 26.12.6.1(e)



<p><u>Check structural adequacy of concrete in the area cored</u></p> <ol style="list-style-type: none"> <li>1. Average strength must exceed 85% of specified <math>f_c'</math>  <math>0.85(f_c') = 0.85(4000 \text{ psi}) = 3400 \text{ psi} &lt; 3797 \text{ psi}</math>    OK</li> <li>2. No single core being less than 75% of specified <math>f_c'</math>  <math>0.75(f_c') = 0.75(4000 \text{ psi}) = 3000 \text{ psi} &gt; 2160 \text{ psi}</math>    Not OK</li> </ol> <p><u>Results</u></p> <p>The average core strength exceeded the required strength by ACI 318.</p> <p>The lowest core strength does <u>not</u> meet the required strength by ACI 318.</p> <p><u>Conclusion</u></p> <p>The concrete in the area cored does not meet the requirements as stated in ACI 318 and may not be structurally adequate.</p>	<p>ACI 318, 26.12.6.1(e) ACI 301, 1.7.6.3</p> <p>ACI 318, 26.13.6.1(e)</p>
<p><b>Notes:</b></p> <ol style="list-style-type: none"> <li>a. There are many reasons why one core could have low strength. Coring is a robust activity and requires careful attention to the details of obtaining, handling, and testing the cores. These procedures are spelled out in ASTM C42/C42M and must be followed. It is possible that the low core strength result is due to a procedural problem or that the concrete has low strength in the area where that core was taken.</li> <li>b. The licensed design professional and the building official have the discretion of accepting the coring results if they are convinced this data does verify the structural adequacy of the concrete has been obtained.</li> <li>c. There are no statements in ACI 318 that allow for taking an additional core(s) so that a low core result can be ignored or substituted with other core(s). If the licensed design professional or building official is convinced that these cores were not properly removed or tested, they have the discretion to require an additional set of cores.</li> </ol>	<p>ACI 318, R26.12.6.1</p>
<p><b><u>Additional notes on evaluating the concrete:</u></b></p> <p>If one or more of the cores are considered to have erratic strength, extracting additional cores from that area is permitted.</p> <p>The Code does not give a definition of an erratic core. The licensed design professional or the building official determines what is an erratic core. There are statistical methods of determining an erratic (outlier) test result. The Code does not reference any of these statistical methods.</p> <p>If the second set of cores meet the requirements as stated in ACI 318 (see Case No. 1), the concrete is considered to be structurally adequate. If the second set of cores do not meet the strength criteria established in ACI 318 and if the structural adequacy remains in doubt, there are several options to assess questionable areas of the structure.</p>	<p>ACI 318, 26.12.6.1(f)</p> <p>ACI 318, R26.12.6.1</p> <p>ACI 318, R26.12.6.1</p>

<p>1. Load testing as permitted.</p> <p>2. Improve the strength of the concrete by supplemental wet curing and additional evaluation.</p> <p>The licensed design professional may want to consider other options such as strengthening, repairing, or removing the concrete that did not pass the core evaluation.</p> <p>The Code does not assign responsibility for strength deficiencies.</p>	<p>ACI 318, R26.12.6.1(g) ACI 318, R26.12.6.1(a)</p> <p>ACI 318, 26.12.6.1(g)</p> <p>ACI 318, R26.12.6.1</p>
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**Case No. 3**

<p>Problem Statement Case No. 3 (Same as for Case No. 1) Three cores were removed from the slab and tested by the tested agency of record. Their results were:</p> <p style="text-align: center;"><b>Table 3: Case No. 3</b></p> <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th>Core</th> <th>Tested compressive strength, psi</th> </tr> </thead> <tbody> <tr> <td>Core 1</td> <td>3270</td> </tr> <tr> <td>Core 2</td> <td>3360</td> </tr> <tr> <td>Core 3</td> <td>3180</td> </tr> </tbody> </table> <p><u>Determination of the average core compressive strength</u></p> $\frac{\text{Core 1} + \text{Core 2} + \text{Core 3}}{3} = \text{Average core strength}$ $\frac{3270 \text{ psi} + 3360 \text{ psi} + 3180 \text{ psi}}{3} = 3270 \text{ psi}$ <p>By observation, the lowest core strength is 3180 psi.</p> <p><u>Check structural adequacy of concrete in the area cored</u></p> <p>1. Average strength must exceed 85% of specified <math>f_c'</math></p> $0.85(f_c') = 0.85(4000 \text{ psi}) = 3400 \text{ psi} > 3270 \text{ psi} \quad \text{Not OK}$ <p>2. No single core being less than 75% of specified <math>f_c'</math></p> $0.75(f_c') = 0.75(4000 \text{ psi}) = 3000 \text{ psi} < 3180 \text{ psi} \quad \text{OK}$ <p><u>Results</u></p> <p>The average core strength does <u>not</u> exceed the required strength by ACI 318.</p> <p>The lowest core strength exceeded the required strength by ACI 318.</p>	Core	Tested compressive strength, psi	Core 1	3270	Core 2	3360	Core 3	3180	<p>ACI 318, 26.12.6.1(e)</p> <p>ACI 318, R26.12.6.1(e)</p> <p>ACI 318, 26.12.6.1(e) ACI 301, 1.7.6.3</p>
Core	Tested compressive strength, psi								
Core 1	3270								
Core 2	3360								
Core 3	3180								

<p><u>Conclusion</u></p> <p>The concrete in the area cored does not meet the requirements as stated in ACI 318 and may not be structurally adequate.</p>	<p>ACI 318, 26.12.6.1(e)</p>
<p><b>Notes:</b></p> <ol style="list-style-type: none"> <li>a. Because there does not appear to be any erratic core results, there is strong evidence that the concrete may be below strength the specified strength.</li> <li>b. The licensed design professional or the building official has the discretion of accepting the coring results if they are convinced this data does verify the structural adequacy of the concrete that has been obtained. Lower strength may be tolerated under many circumstances, but this is a matter of judgment on the part of the licensed design professional or the building official.</li> </ol>	<p>ACI 318, R26.12.6.1</p>
<p><b><u>Additional notes on evaluating the concrete:</u></b></p> <ol style="list-style-type: none"> <li>1. An additional set of cores can be obtained for evaluation if questions remain whether proper curing and testing procedures of the cores were followed.</li> <li>2. Load testing may be permitted.</li> <li>3. Improve the strength by supplemental wet curing and additional strength evaluation.</li> </ol> <p>The Code does not assign responsibility for strength deficiencies.</p>	<p>ACI 318, 26.12.6.1(g) ACI 318, R26.12.6.1</p> <p>ACI 318, R26.12.6.1</p>
<p><b><u>Additional reading:</u></b></p> <ul style="list-style-type: none"> <li>• ACI E702.3-21—Designing Concrete Structures: Acceptance of Concrete Compressive Strength Test Results According to ACI 318-19</li> <li>• ACI 214-11 (Reapproved 2019)—Guide to Evaluation of Strength Test Results of Concrete</li> <li>• ACI PRC-214.4-21—Obtaining Cores and Interpreting Core Compressive Strength Results</li> <li>• ACI 228.1-19—Report on Methods for Estimating In-Place Concrete Strength</li> <li>• ACI 228.2-13—Report on Nondestructive Test Methods for Evaluation of Concrete in Structures</li> <li>• ACI 301-20—Specifications for Concrete Construction</li> <li>• ASTM C42/42M-20—Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete</li> </ul>	