Core Testing
Obtaining and Testing
Cores ASTM and ACI Approaches

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Day 1

- Evaluation of in-place strength
  - EN Standards
  - Testing cores-ASTM Approach
  - Rebound hammer
  - Pullout test
  - Pull-off test
- Stress-Wave Methods
  - Introduction to stress-waves and UPV method
  - Impact-echo method
  - Impulse-response method and case study
  - Ultrasonic-echo method

Obtaining and Testing Cores ASTM and ACI Approaches

- Planning
- Apparatus
- Core dimensions
- Moisture conditioning
- End preparation and L/D correction
- In-place characteristic strength (ACI 214.4R)

Why Take Cores?

- Investigate low test results from standard-cured specimens
- Develop correlation with other in-place or nondestructive (NDT) tests
- Confirm interpretation of NDT methods
- Obtain samples for petrographic analysis
- Estimate the in-place " specified (characteristic) strength" for structural evaluations

How Many Cores?

- Will depend on the objective
- For investigating low standard-cured test results, ACI 318 (design standard) requires at least three for "area in question"
- EN 13791 requirements depend on purpose
- For estimating the equivalent in-place characteristic strength, a larger number is required, depending on:
  - Variability of in-place strength
  - Desired confidence level

Where to Take Cores?

- Depends on objective
- For evaluating low standard-cured test results, take cores from concrete represented by the low test results
- Forensic investigations:
  - Depends on uniformity of concrete in the structure (ASTM C823/C823M)
- Avoid taking cores from top of placement (weaker concrete)

ASTM C823/C823M

Designation: C823/C823M – 12 (Reapproved 2017)

Standard Practice for Examination and Sampling of Hardened Concrete in Constructions[1]

This standard is issued under the fixed designation C823/C823M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice outlines procedures for visual examination and sampling of hardened concrete in constructions. Reference is made to the examination and sampling of concrete in prefabricated building units, precast products, and laboratory specimens.

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

Concrete Specimens

C295 Guide for Petrographic Examination of Aggregates for Concrete

C457 Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete

C597 Test Method for Pulse Velocity Through Concrete

C670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

C856 Practice for Petrographic Examination of Hardened Concrete

E105 Practice for Probability Sampling of Materials

E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a

ASTM C823/C823M—Sampling

- Concrete in structure is similar
  - Sampling locations spread randomly or systematically over the entire structure
  - Treat data as belonging to same population
- Concrete in two or more portions likely to have different properties
  - Sample from each portion
  - Use statistical methods to establish if there are differences in properties

ASTM C42/C42M

Designation: C42/C42M − 16

American Association State
Highway and Transportation Officials Standard
AASHTO No.: T24

Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete[1]

This standard is issued under the fixed designation C42/C42M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope*

1.1 This test method covers obtaining, preparing, and testing cores drilled from concrete for length or compressive strength or splitting tensile strength determinations. This test method is not applicable to cores from shotcrete.

NOTE 1—Test Method C1604/C1604M is applicable for obtaining, preparing, and testing cores from shotcrete.

NOTE 2—Appendix X1 provides recommendations for obtaining and testing sawed beams for flexural performance.

C78/C78M Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)

C174/C174M Test Method for Measuring Thickness of Concrete Elements Using Drilled Concrete Cores

C496/C496M Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens

C617/C617M Practice for Capping Cylindrical Concrete Specimens

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ACI 214.4R

ACI 214.4R-10

Not a mandatory-language standard

Guide for Obtaining Cores and Interpreting Compressive Strength Results

Reported by ACI Committee 214

Concrete international / NOVEMBER 2001

In My Judgment

by Adam Neville

Core Tests: Easy to Perform, Not Easy to Interpret

Many engineers have the experience of ordering the taking of cores. The operation is not difficult, usually undertaken by skilled specialist personnel. Once first place the value of the load in Newtons (or pounds), under which failure by crushing occurs, which is then to be divided by the cross-sectional area of the core in square millimeters (or square inches). Dividing the first of these by the second gives a number in megapascals (or psi); but does this number represent the compressive strength of concrete in the structure from which the core was cut?

The answer is no. Not only must the number be processed, but the resulting value of strength also must be carefully interpreted. Because cores are generally taken when there is a problem, or suspected problem, with concrete, the situation usually involves two or more parties, and they may have than specified. But there may be other reasons: the cylinders may have been incorrectly consolidated (compacted); they may have been damaged in transit, subjected to freezing at a very early age, badly cured, or incorrectly tested; or the resulting compressive strength may have been incorrectly calculated or recorded.

The contractor has reasons to suggest that it is the cylinders that are unsatisfactory, while the concrete in the structure is as specified. On the other hand, the engineer has a professional responsibility to ensure the structural adequacy of the concrete, as well as a responsibility to the client (or owner) to ascertain that the quality of concrete corresponds to

Apparatus for Drilling Cores

- Water-cooled, diamond-impregnated drill bit
- Stable support for drilling machine
- Low feed pressure, high speed

Traditional Coring Machine

www.penhall.com

Lightweight CORECASE

CORECASE Features

Flexible rubber coupling between drill machine and coring bit; transfers only torque

Thin walled (2 mm) diamond bit; less material is cut

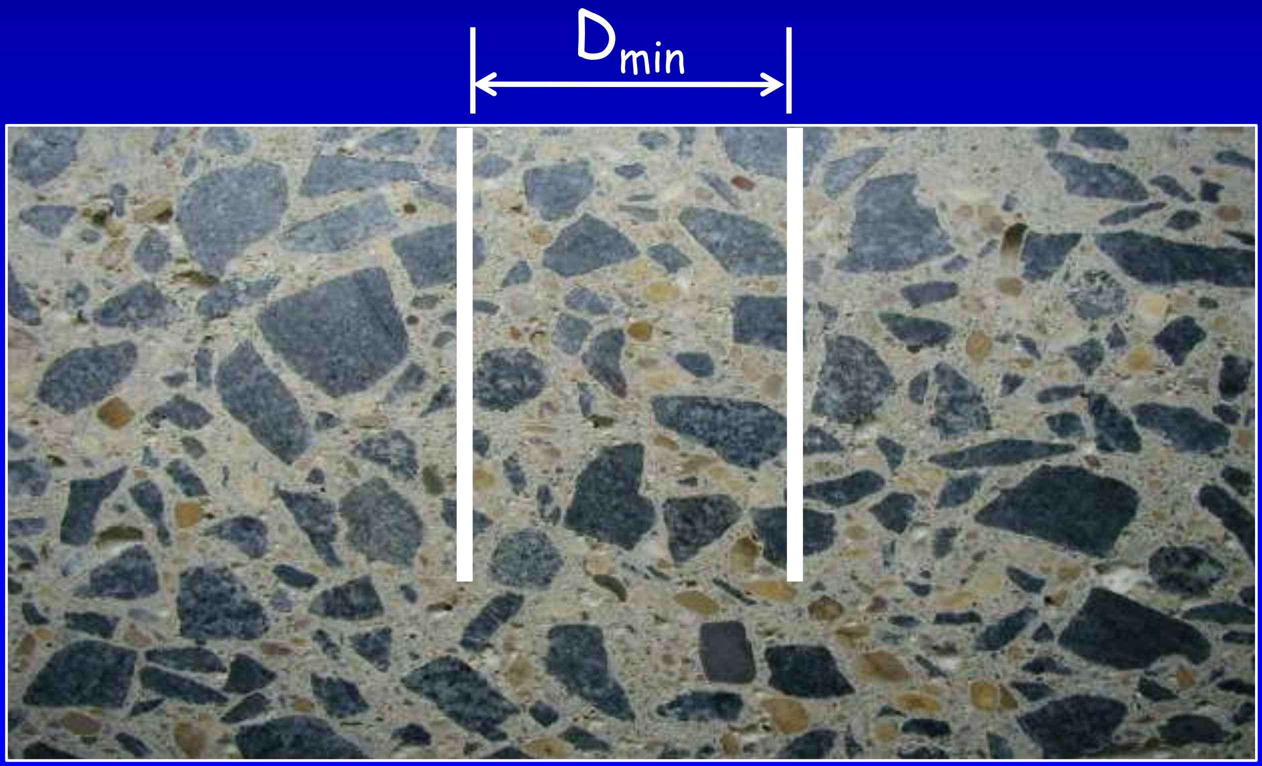
Barrel is advanced in axial direction with no bending.

Features

- Long coring bit life (~800 cores)
- Coring with little force (fingertip pressure only)
- Straight cores
- Little space required
- Simple to core in any direction

Minimum Core Diameter

- D_{min} = 94 mm (nominal 100-mm core drill) or 2 times nominal maximum size of aggregate, whichever is larger



Length-Diameter Ratio (L/D)

- If specified strength based on cylinder
  - Preferred L/D: 1.9 to 2.1
  - L/D cannot be less than 1
  - For L/D < 1.75, strength correction required
- If specified strength based on cube
  - L/D = 1.0

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Moisture Conditioning

- In the past, cores were tested after a period of air drying or after being submerged for at least 40 h
- In high w/c concrete, storage under water for 40 h resulted in saturation
- With modern concrete and lower w/c, storage under water leads to moisture gradient

Research Findings

ACI MATERIALS JOURNAL TECHNICAL PAPER

Title no. 91-M21

ACI Materials Journal / May-June 1994

Effect of Moisture Condition on Concrete Core Strengths


by F. Michael Bartlett and James G. MacGregor

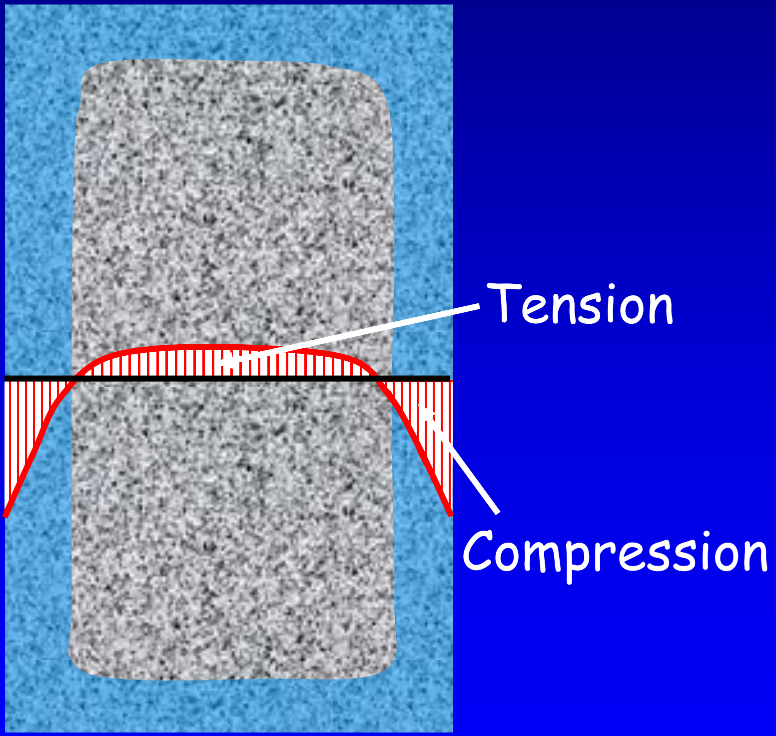
In accordance with the provisions of ASTM C 42-90 and ACI 318-89, it is current practice to either dry concrete core specimens in air for 7 days or soak them in lime-saturated water for at least 40 hr before they are tested. In this paper, the effect of moisture condition on the strengths of mature cores obtained from well-cured elements is investigated by reviewing available literature and performing regression analyses of data from tests of 727 core specimens.

It is shown that the compressive strength of a concrete specimen is

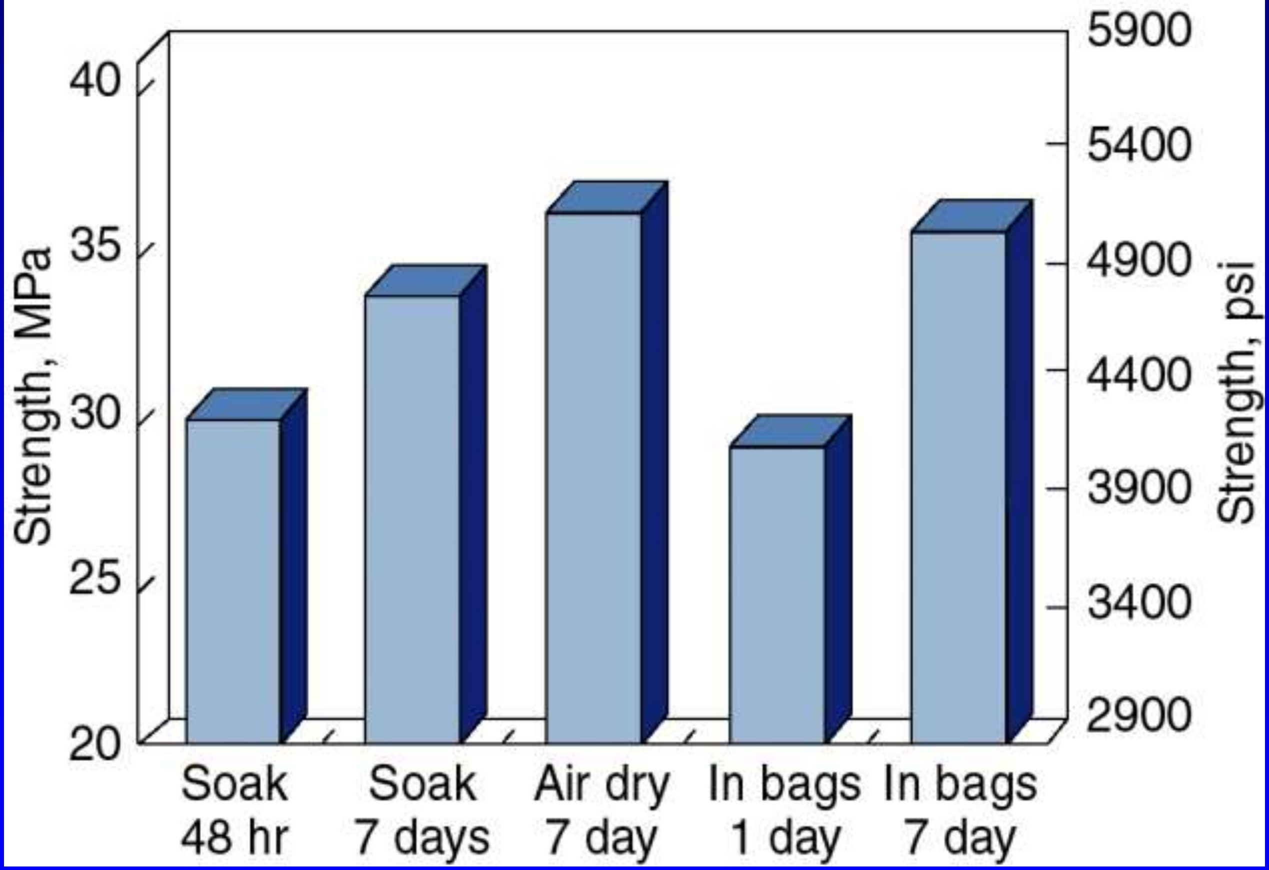
crete Society[6] recommends that cores be capped and then soaked for at least 2 days before testing. If the concrete in the structure is wet, the equivalent actual cube strength is taken to be 1.5 times the crushing strength of a core with length-to-diameter ratio equal to 1. If the concrete in the structure is dry, the equivalent actual cube strength is taken to be 1.65 times the core crushing strength.

Moisture Gradients Immediately After Wet Drilling

- Moistened concrete tends to swell
- Swelling is restrained by dry interior
- Results in internal stresses; outer region in compression
- Measured strength is reduced



Effect of Core Conditioning on Strength



www.cement.org CT003

Moisture Conditioning ASTM C42/C42M

- Wipe off drilling water, surface dry
- Place in watertight containers
- Wait at least 5 days between wetting due to drilling or sawing and testing
- Other procedure permitted when required by the "specifier of tests"

End Preparation

- Capping with sulfur mortar ASTM C617/C617M)
  - Ends of cores have to be relatively flat and close to perpendicular to core axis

If necessary, saw the ends of cores that will be capped so that prior to capping, the following requirements are met:

7.4.1 Projections, if any, shall not extend more than 5 mm [0.2 in.] above the end surfaces.

7.4.2 The end surfaces shall not depart from perpendicularity to the longitudinal axis by a slope of more than 1:8*d* or [1:0.3*d*] where *d* is the average core diameter in mm [or inches].

End Preparation

- Grinding
  - Ends of cores must meet ASTM C39/C39M requirements for molded cylinders
  - Plane within 0.05 mm
  - Perpendicular to within 0.5 degrees

- Unbonded caps (ASTM C1231/C1231M)
  - Approved in 2011

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Unbonded Caps

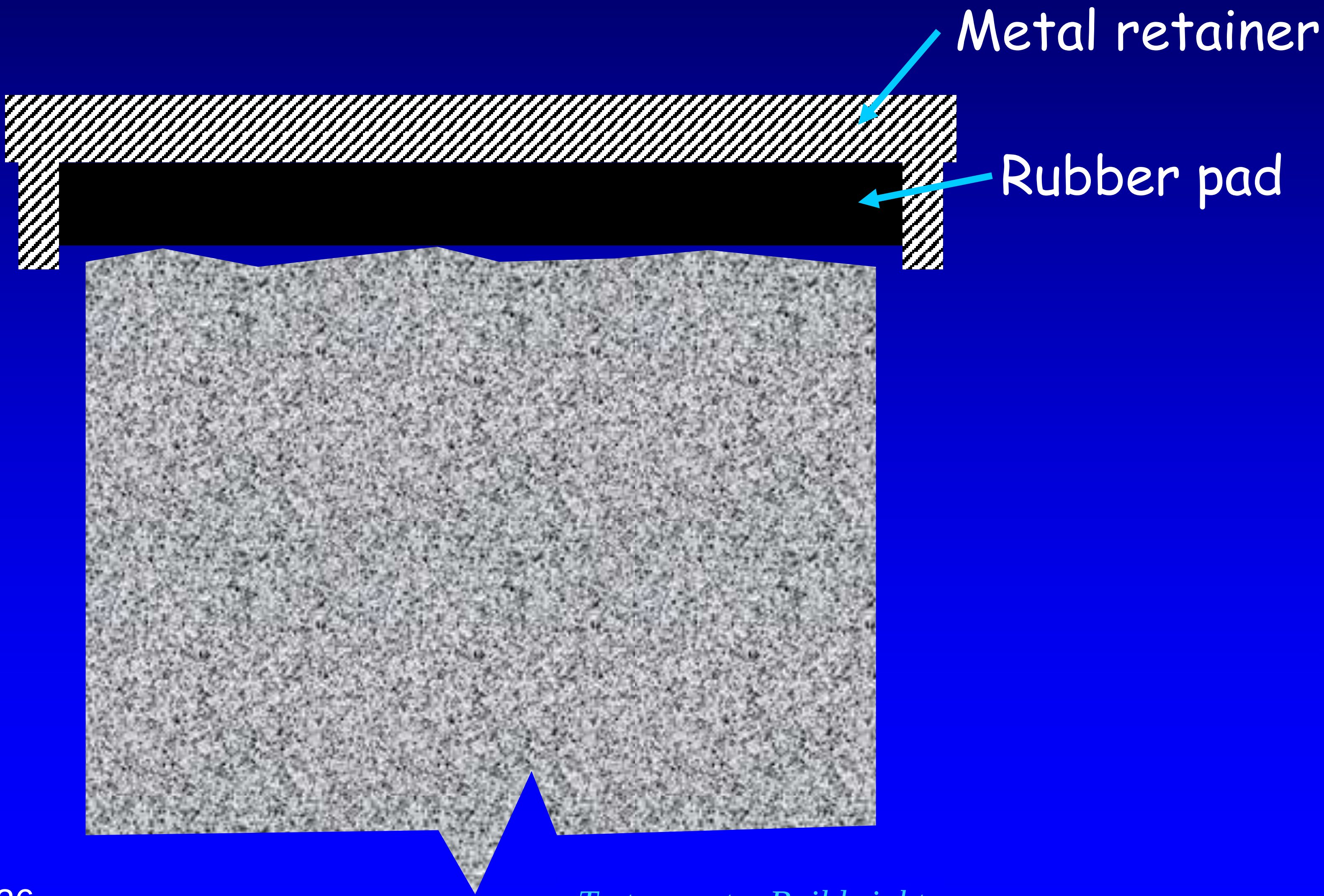
Retainer

Rubber Pads

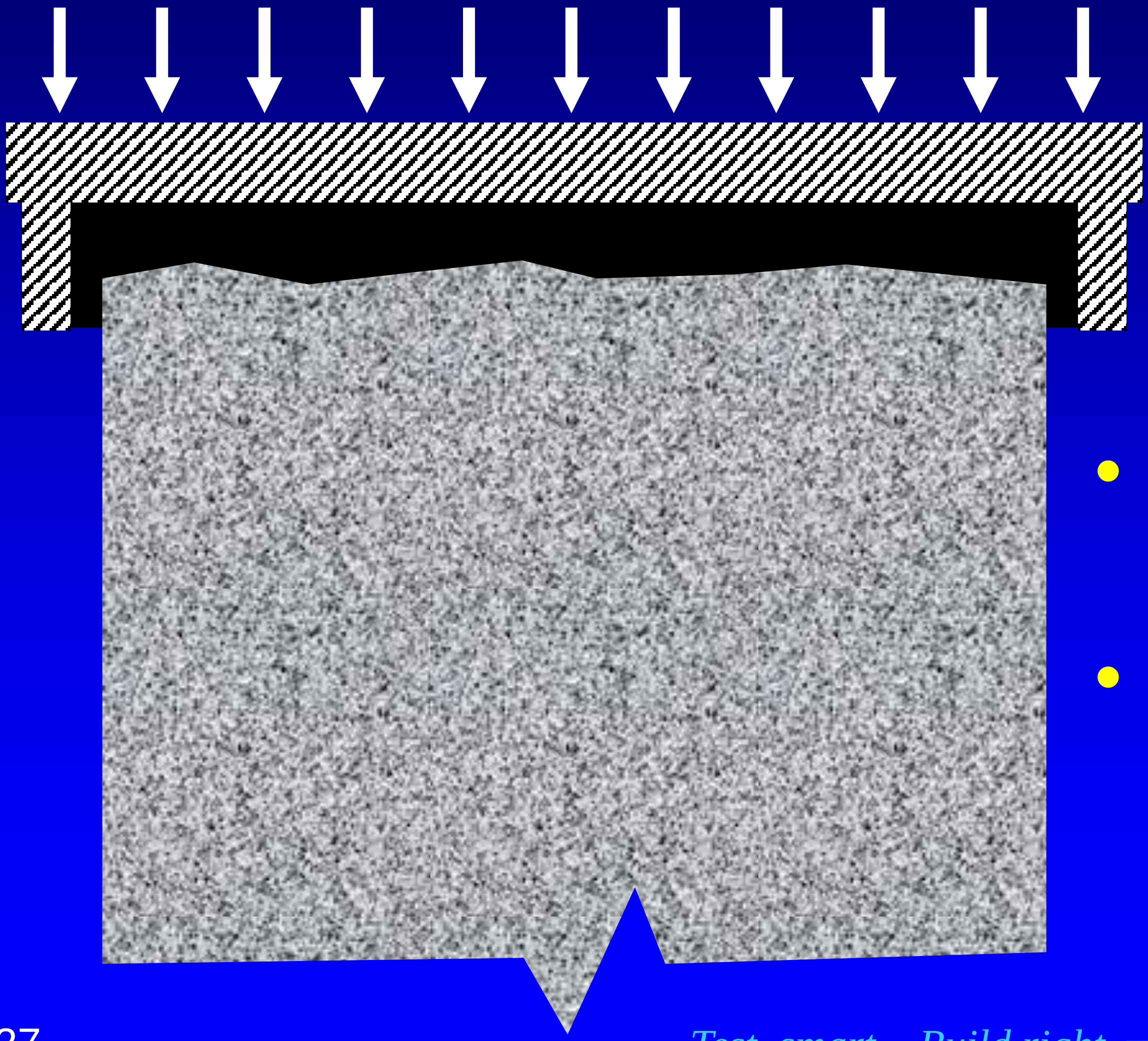
Retainer

Source: PCA

Unbonded Cap



Unbonded Cap



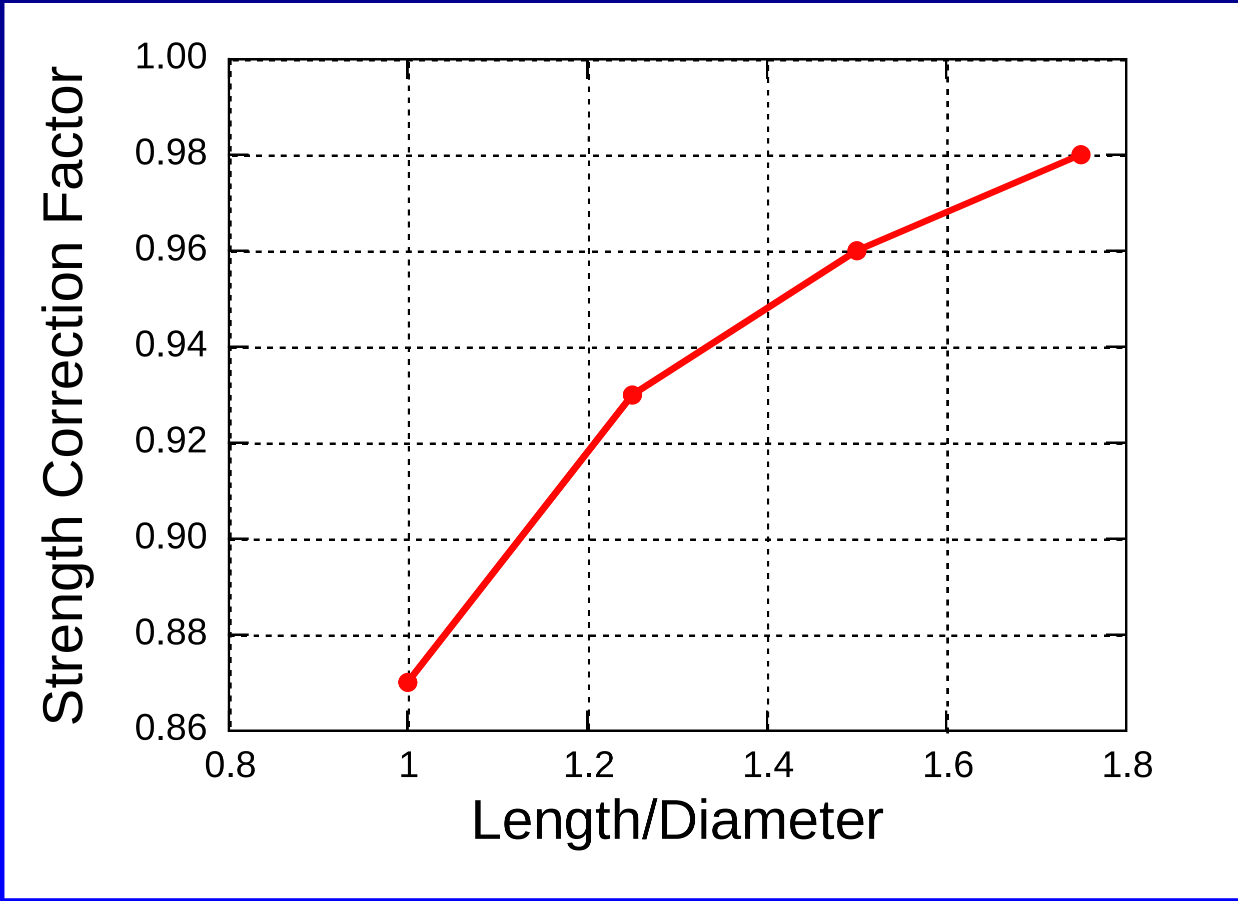
- Pad conforms to end surface
- Retainer prevents pad from lateral flow

Testing for Compressive Strength

- Before capping and testing, measure mass of core to obtain estimate of density
  - In 2011 made mandatory
- Test in accordance with ASTM C39/39M
- If L/D < 1.75, multiply the measured compressive strength by a strength correction factor

L/D Correction Factor

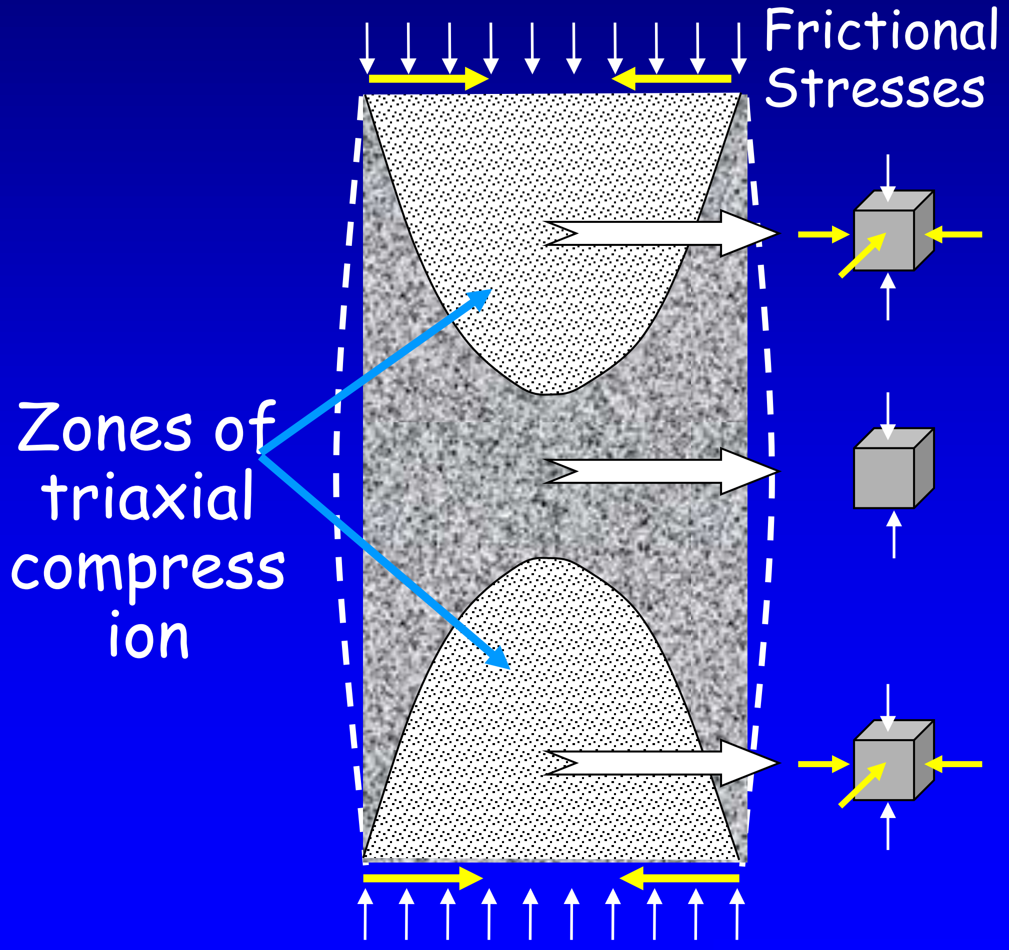
- Convert measured strength to equivalent strength for L/D = 2

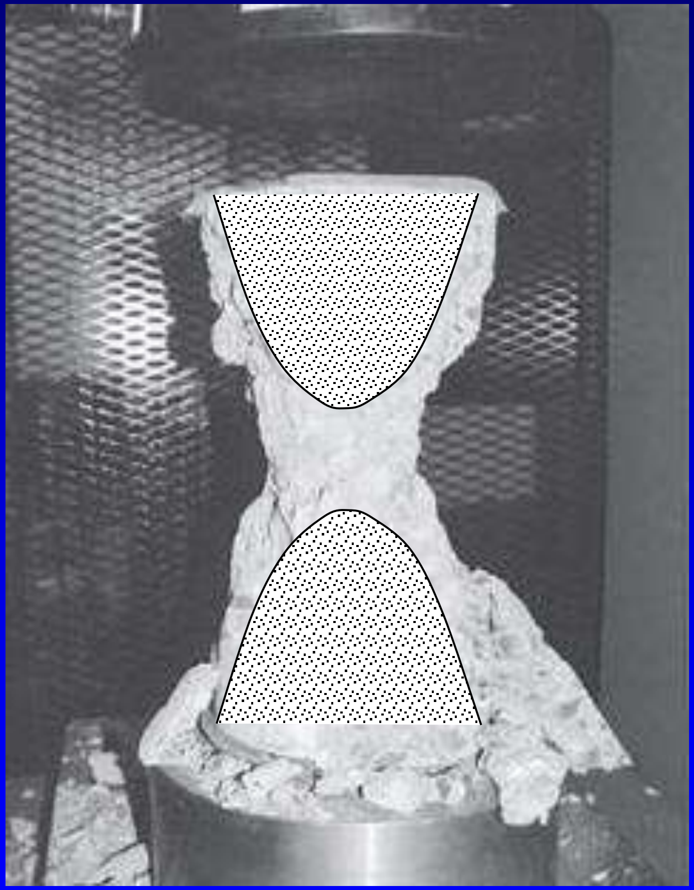


Why Do We Need a Correction Factor?

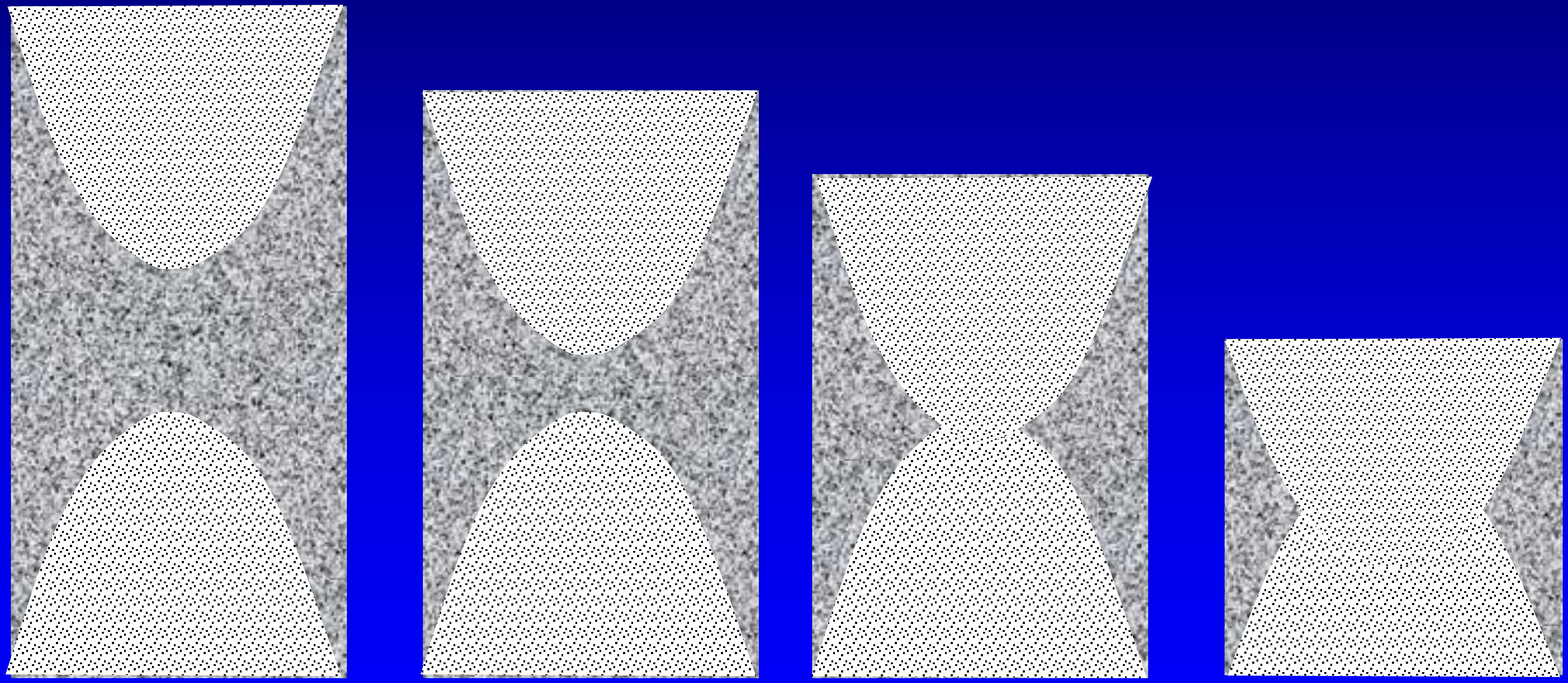
- The apparent compressive strength of a cylindrical specimen increases as L/D decreases
- This is due to the effect of friction between the ends of the specimens and the loading plates of the testing machine

Effect of End Friction – Triaxial Compression



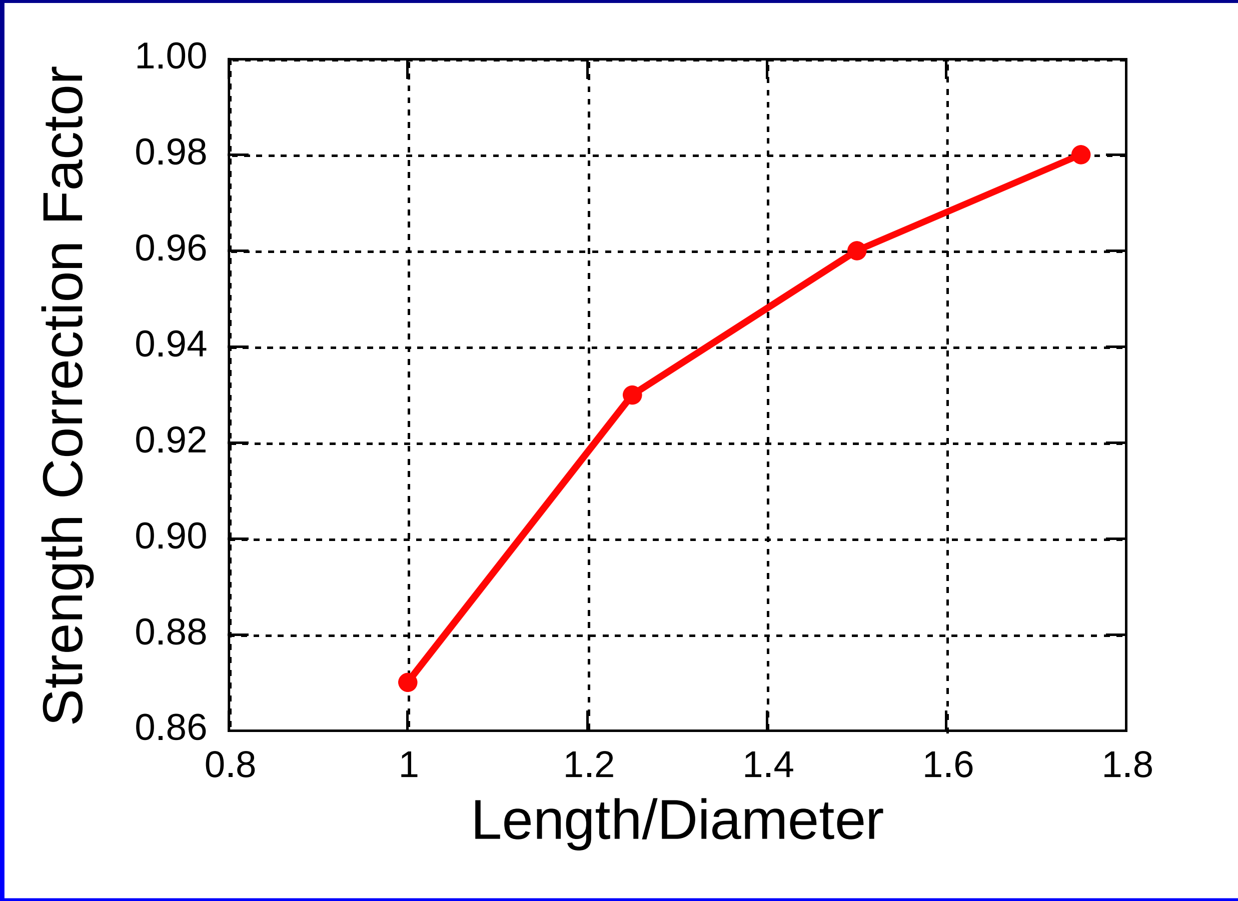


As L/D Decreases
Strength Increases



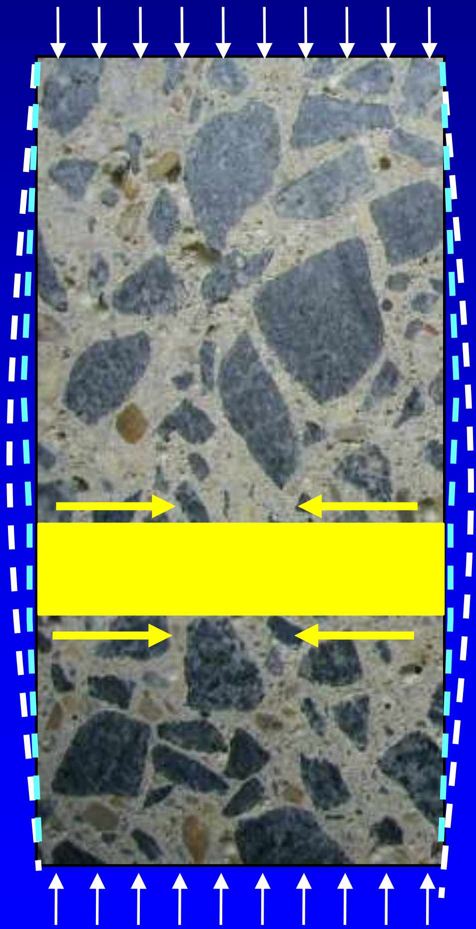
L/D Correction Factor

- Convert measured strength to equivalent strength for L/D = 2

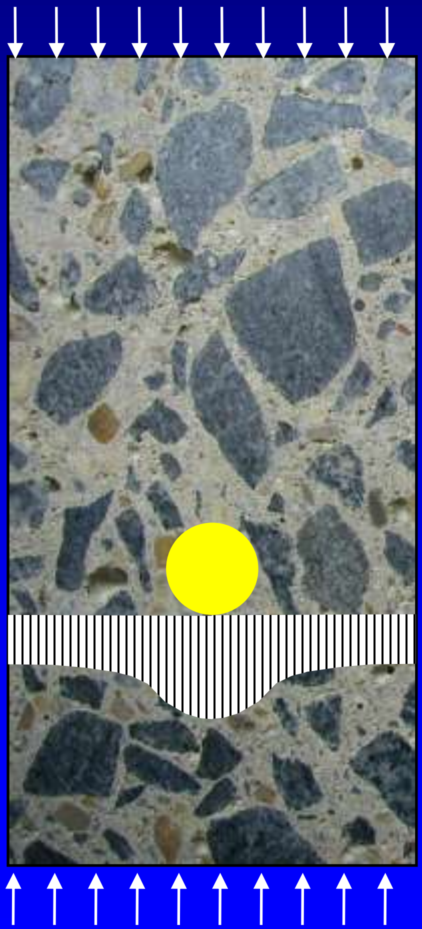


Effects of Steel Bar

Restrains lateral expansion



Causes stress concentration



Limited Research

- Strength reduction due to steel varied from 0 % to >10 %
- No reliable correction factors have been developed by ASTM

How much embedded steel is permissible in cores?

ASTM C42/C42M-10

5.1.2 Specimens containing embedded reinforcement shall not be used for determining compressive, splitting tensile, or flexural strength.

Cores with Steel

- Preferred
  - Trim core to remove steel
  - Maintain L/D ≥ 1.0
- In 2011, text was revised to allow testing cores with steel if steel can't be avoided

5.1.3 If it is not possible to prepare a test specimen that meets the requirements of 7.1 and 7.2 and that is free of embedded reinforcement or other metal, the specifier of the tests is permitted to allow testing of cores with embedded metal (see Note 4). If a core tested for strength contains embedded metal, the size, shape, and location of the metal within the core shall be documented in the test report.

Core Strength Acceptance Criteria

- In the absence of other legal requirements, specifier of tests should provide the acceptance criteria
- *ACI 318* criteria is for acceptance of in-place concrete when standard-cured cylinders fail to meet requirements (*ACI 318-19*; 26.12.6.1(e))

(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'.

In-Place "Specified Strength"

- In new design, engineer uses the specified strength, f'_c
- In a strength evaluation, need value of f'_c to use in member capacity equations

ACI 214.4R

Convert core strength to in-place concrete strength.

$$f_c = F_{\ell/d} F_{dia} F_{mc} F_d f_{core}$$

In-place strength

Correction for L/D

Correction for D

Correction for moisture content

Correction for "damage" due to coring

Core strength

Table 8.1 Provides the values of the F-factors

Table 8.1—Magnitude and accuracy of strength correction factors for converting core strengths into equivalent in-place strengths*

Factor	Mean value	Coefficient of variation V, %
$F_{\ell/d}$: ℓ/d ratio†		
As-received‡	$1-\{0.130-\alpha f_{core}\}\left(2-\frac{\ell}{d}\right)^2$	$2.5\left(2-\frac{\ell}{d}\right)^2$
Soaked 48 h	$1-\{0.117-\alpha f_{core}\}\left(2-\frac{\ell}{d}\right)^2$	$2.5\left(2-\frac{\ell}{d}\right)^2$
Air dried‡	$1-\{0.144-\alpha f_{core}\}\left(2-\frac{\ell}{d}\right)^2$	$2.5\left(2-\frac{\ell}{d}\right)^2$
F_{dia}: core diameter		
50 mm (2 in.)	1.06	11.8
100 mm (4 in.)	1.00	0.0
150 mm (6 in.)	0.98	1.8
F_{mc}: core moisture content		
As-received‡	1.00	2.5
Soaked 48 h	1.09	2.5
Air dried‡	0.96	2.5
F_d: damage due to drilling	1.06	2.5

Equivalent Specified Strength

Equivalent specified strength

$$f'_{c,eq} = K\,\overline{f_c}$$

Average in-place strength

Statistical factor

- K depends on:
  - Number of core tests
  - Variability of core strengths
  - Confidence level

Summary

- Cores are taken for different reasons
- When taking cores for evaluating in-place strength, standard procedures must be followed to obtain comparable results
  - Moisture conditioning is very important
  - End preparation in strict accordance with applicable standard (ASTM C42/C42M, EN 12390-1)
- In the absence of governing provisions, the licensed design professional is responsible for defining acceptance criteria

Summary

- For strength evaluation of existing construction, careful planning to select location and number of cores
  - Use NDT to locate "good" and "bad" concrete
  - Number of cores depend on variability and acceptable uncertainty of population mean
- ACI 214.4R provides method to obtain equivalent specified strength (characteristic strength)