

# Strength Problems



# Strength



- Compressive Strength- Measured Resistance of Concrete to Axial Loading.





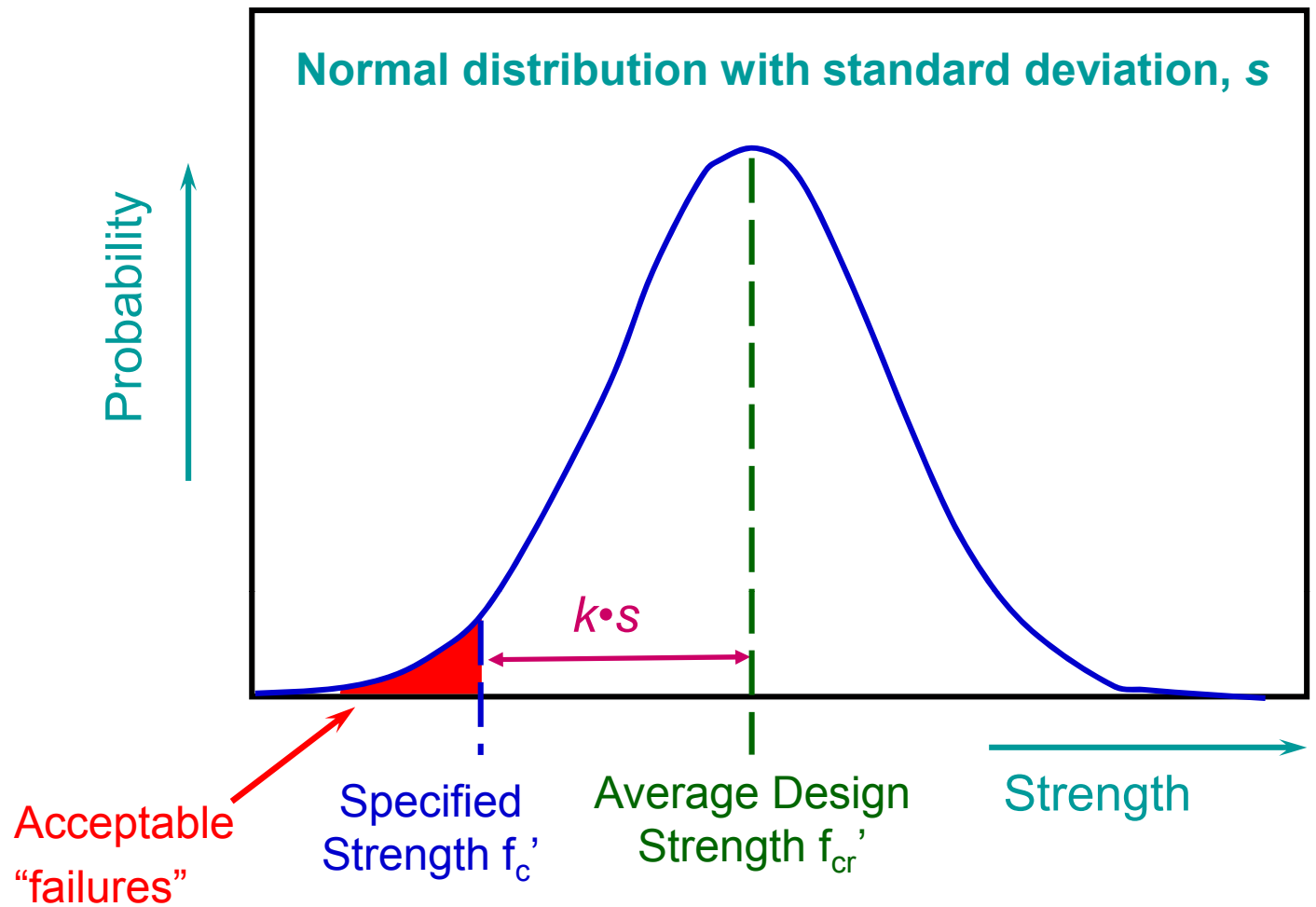
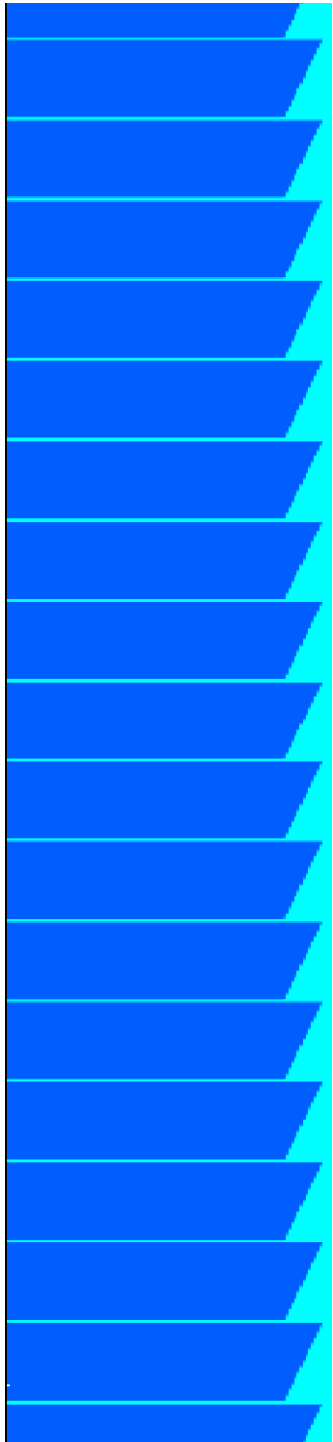
# Strength Requirements

**Specified strength,  $f_c'$  , is determined from:**

- **Structural design considerations**
- **Durability considerations**

**Note:**

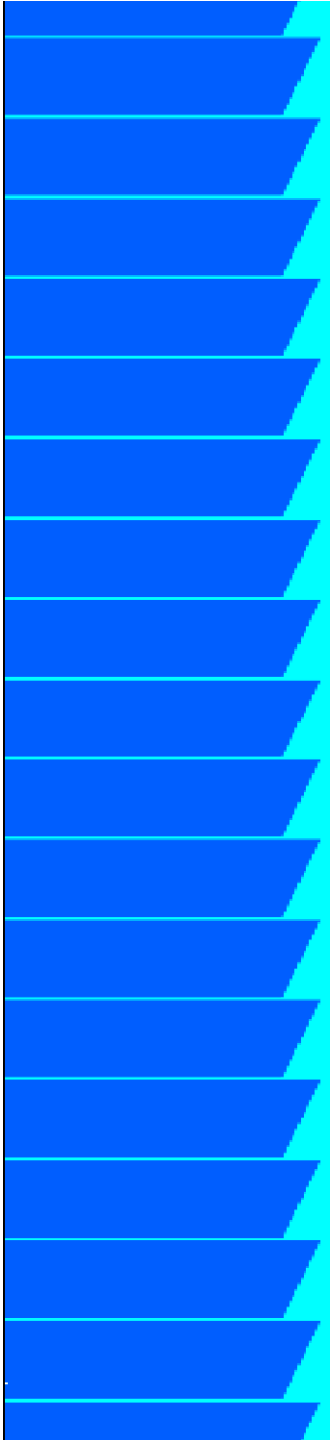
Although the durability of concrete is not directly related to strength – strength is used as an indirect means of assuring adequate durability



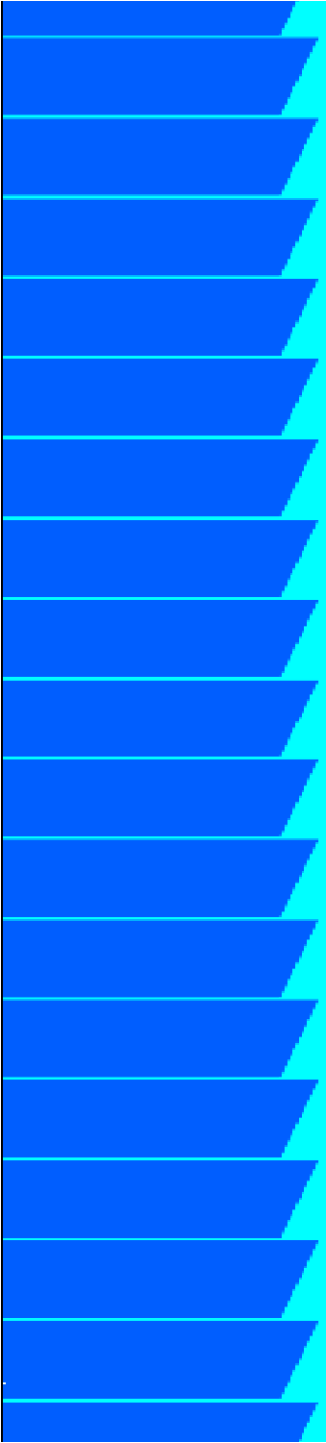
$$f_{cr}' > f_c'$$

**Design strength  $>$  Specified strength**





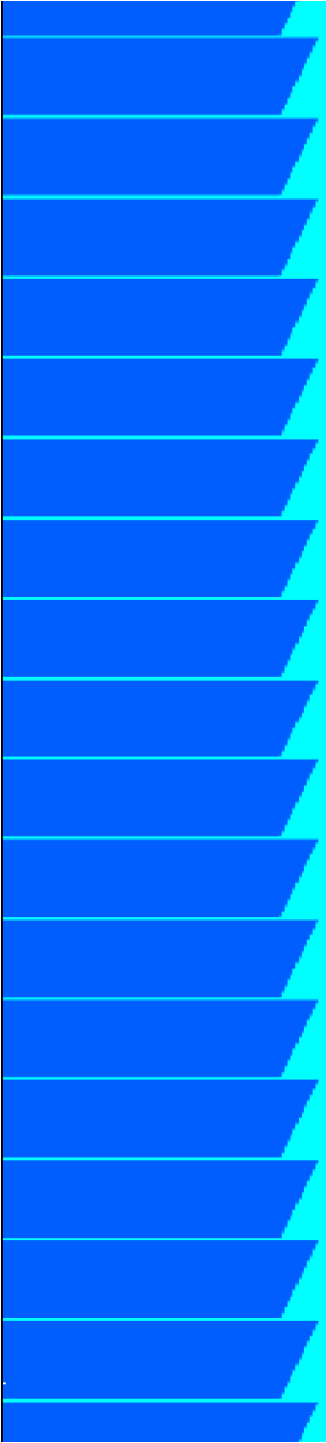
The standard deviation should be based on at least 30 consecutive strength tests, representing concrete whose design strength is within 7 MPa (1000 psi) of that required for the work made with similar materials and under similar conditions to those expected.



If only 15 to 29 consecutive tests are available – multiply the standard deviation by the following modification factors:

Number of Tests	Modification Factor
Less than 15	Use Tables
15	1.16
20	1.08
25	1.03
30 or more	1.00





If less than 15 consecutive tests are available - the following table can be used to determine the required average strength  $f_{cr}'$

Specified Strength $f_c'$ (MPa)	Required Average Strength $f_{cr}'$ (MPa)
Less than 21	$f_c' + 7.0$
21 to 35	$f_c' + 8.5$
Over 35	$1.10f_c' + 5.0$

Specified Strength $f_c'$ (psi)	Required Average Strength $f_{cr}'$ (psi)
Less than 3000	$f_c' + 1000$
3000 to 5000	$f_c' + 1200$
Over 5000	$1.10f_c' + 700$

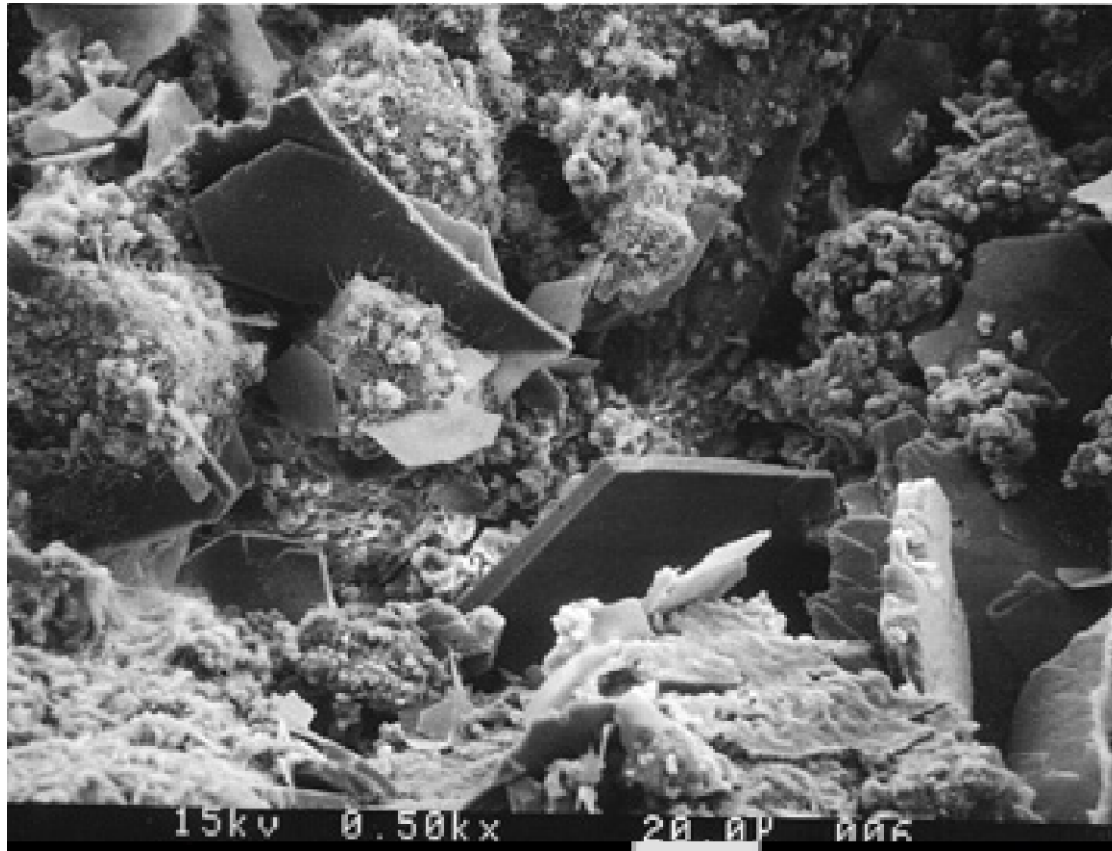
# Factors Impacting Strength



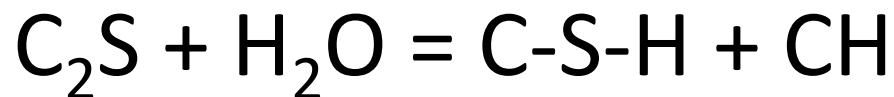
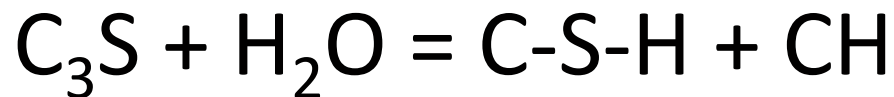
- w/cm
- Age
- Air Content
- Aggregate Bond
- Handling
- Curing Temperature
- Testing Errors



# Hydration



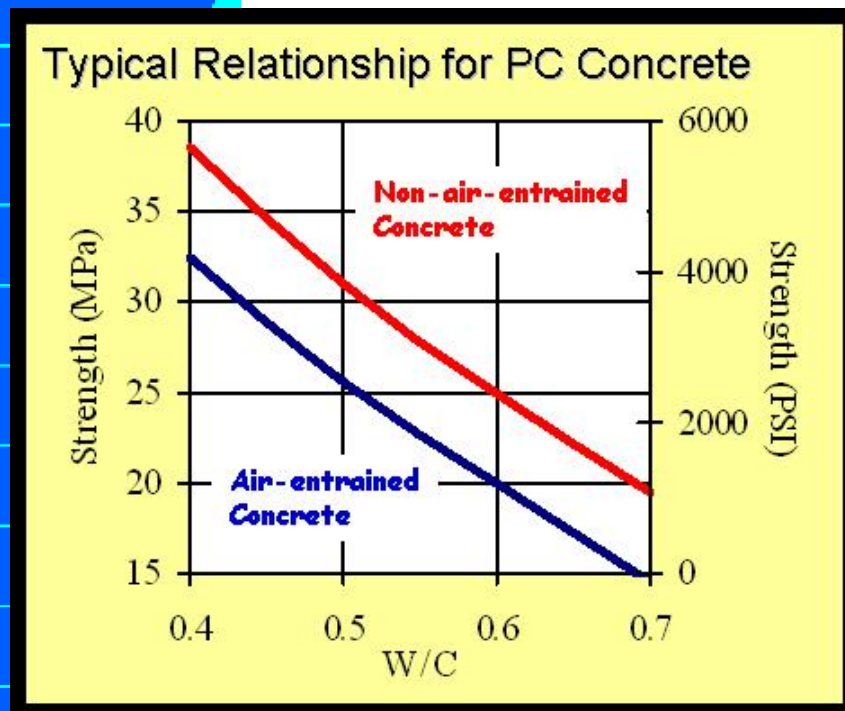
## Cement + Water



# The Water-Cement Ratio Law

For given materials the strength of the concrete (so long as we have a plastic mix) depends solely on the relative quantity of water as compared with the cement, regardless of mix or size and grading of aggregate.

*Duff A. Abrams  
May, 1918*





# Air Content

Effect of air content on water demand

Rule of thumb: decrease water by  $3 \text{ kg/m}^3$  ( $5 \text{ lb/yd}^3$ ) for each 1% air







109104-Sample 111142

Field of view approximately 9 mm.



# Strength Testing

- Test Methods
  - ◆ ASTM C 39 – Cylinders
  - ◆ ASTM C 78 – Simple Beam
  - ◆ ASTM C 496 – Tensile Splitting
- Cores and In-Situ Tests



# Test Cylinders

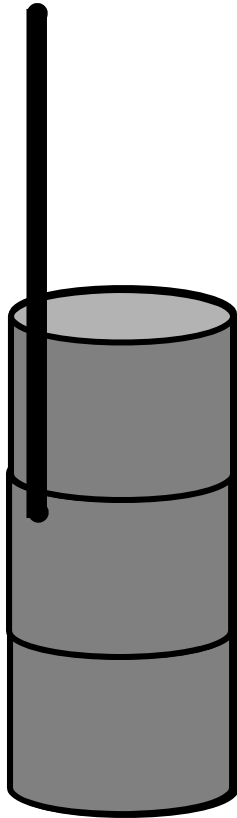
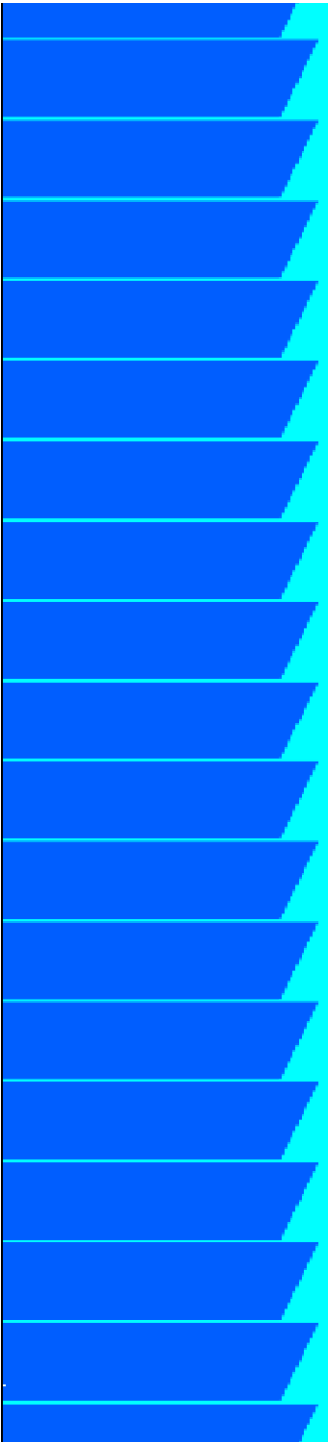
- Slump
  - ◆ 3 in. or more – rodded
  - ◆ 1 to 3 in. – rodded or vibrated
  - ◆ Less than 1 inch – vibrated
- Excess concrete struck
- Sealed
  - ◆ Plastic cap, oiled glass, steel plate
  - ◆ Sealed in a plastic bag



# Sampling 3-in Slump

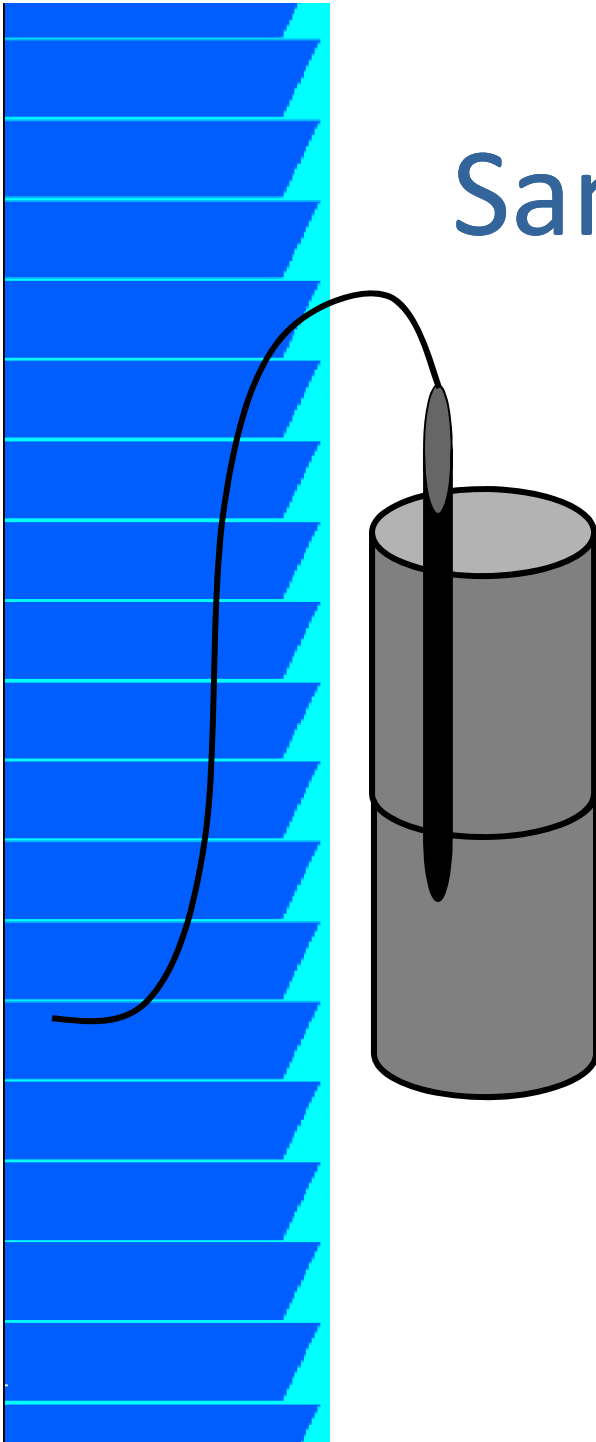
- 6x12 cylinder molds- Three layers
- 4 x 8 cylinder molds- Two layers

- Rodded 25 Times
- Bottom Rodded to Depth
- 1-in. Into Lower Layer





# Sampling 1-in Slump



- 6x12 cylinder molds- Two layers
- 4 x 8 cylinder molds- Two layers
- Vibrated Until Top Is Smooth
- Bottom to Full Depth
- 1-in. Into Lower Layer

# Curing Test Specimens























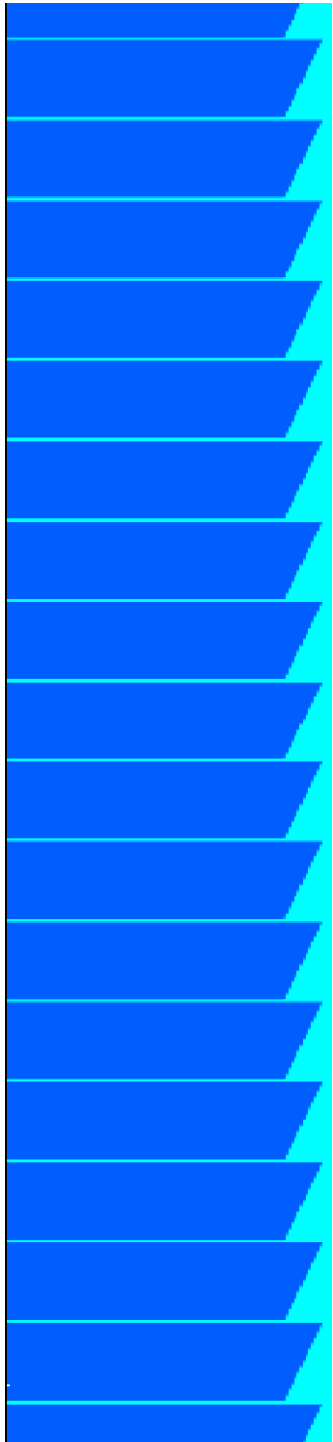














# Field Cured Cylinders

- Required to determine form removal time
  - ◆ Flexural members (Beams, Floors, and Roofs)
- May be required for unusual weather conditions
  - ◆ Particularly cold weather
  - ◆ Concrete gains strength slower at lower temperatures



# Curing and Protection

- Cylinders protected in same condition as concrete
- Procedures acceptable if field cured strengths within 85% of standard cured strengths for many specs.
- Both tests at specified time, usually 28 Days
- Also acceptable if  $f'_c$  exceeded by 500 psi





# Transporting Test Cylinders



- After One Day
- Packed in a Sturdy Box
- Surrounded with Wet Sand or Wet Saw Dust
- Protected Against Freezing

# Test Cylinders at the Lab



- ASTM C 39 – Testing Cylinders
- Capping
  - ◆ ASTM C 617 – Capping
  - ◆ ASTM C 1231 – Unbonded Caps
- Measurements
- Testing
  - ◆ Maximum Load
  - ◆ Strength, within 10 psi
- Conical Failure

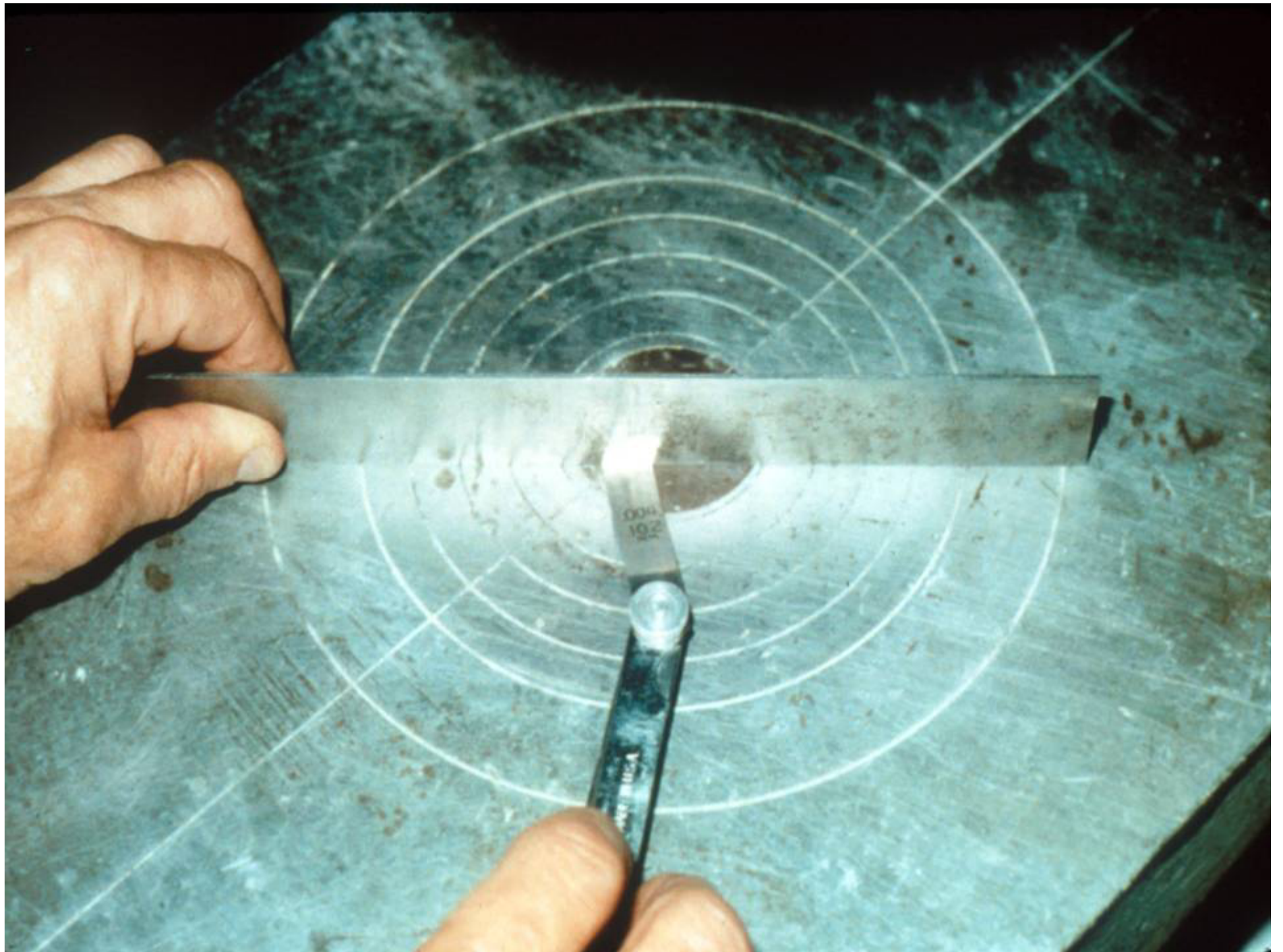




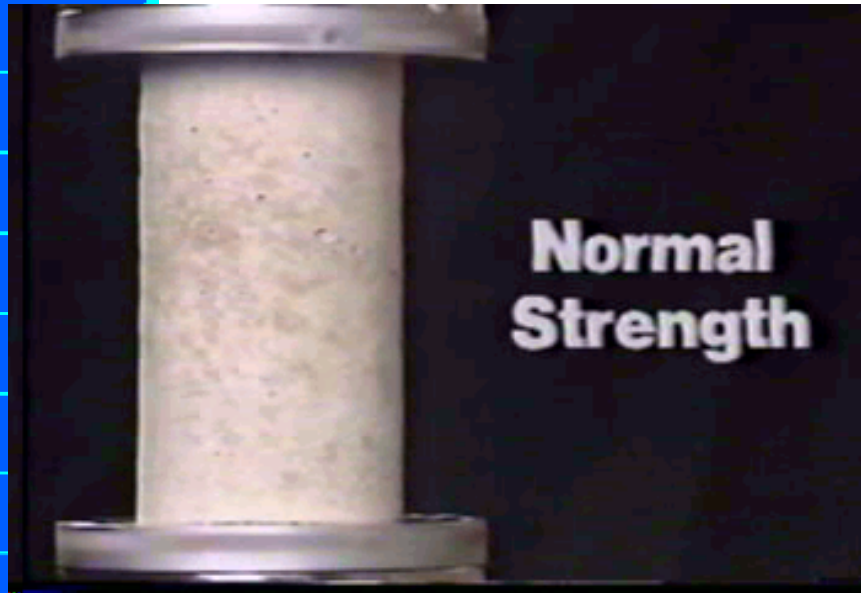




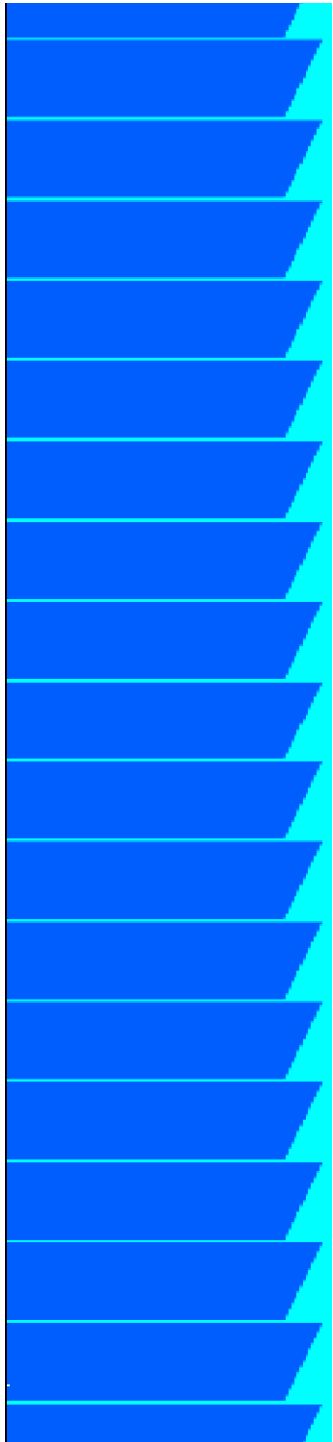




# Testing Compressive Strength















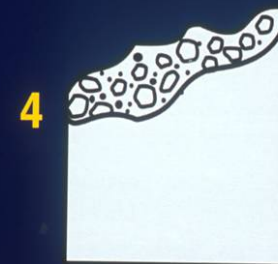
**Typical Break**



**Shear Break**

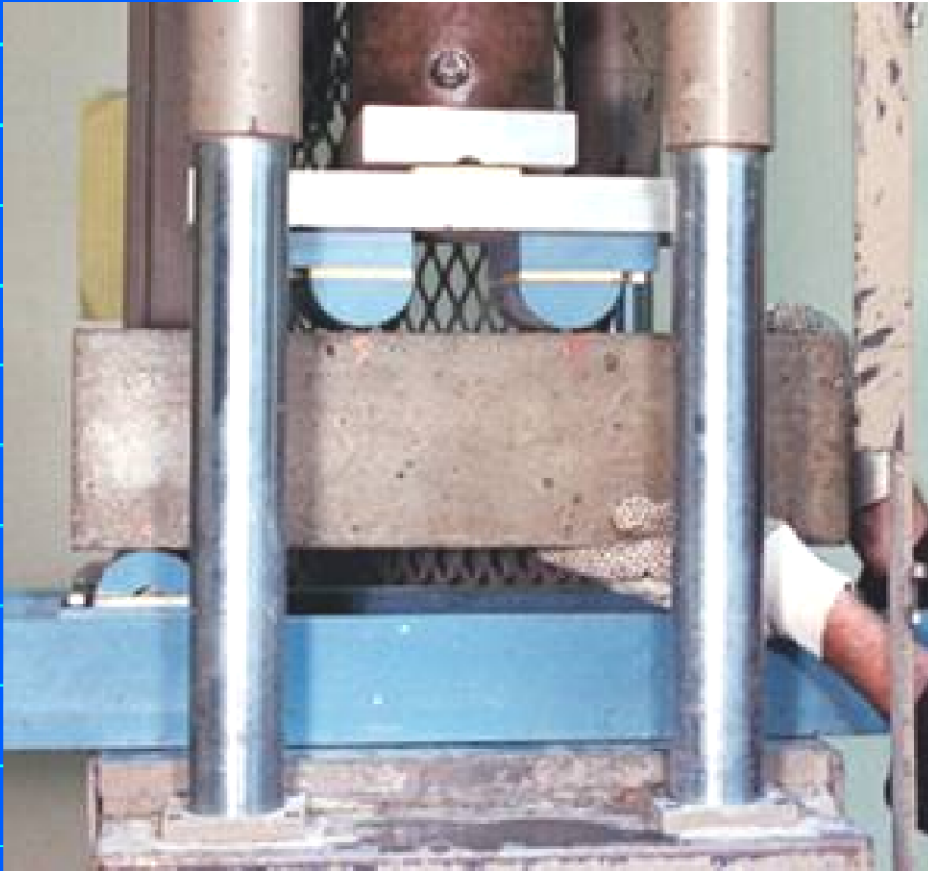


**Poor Compaction**



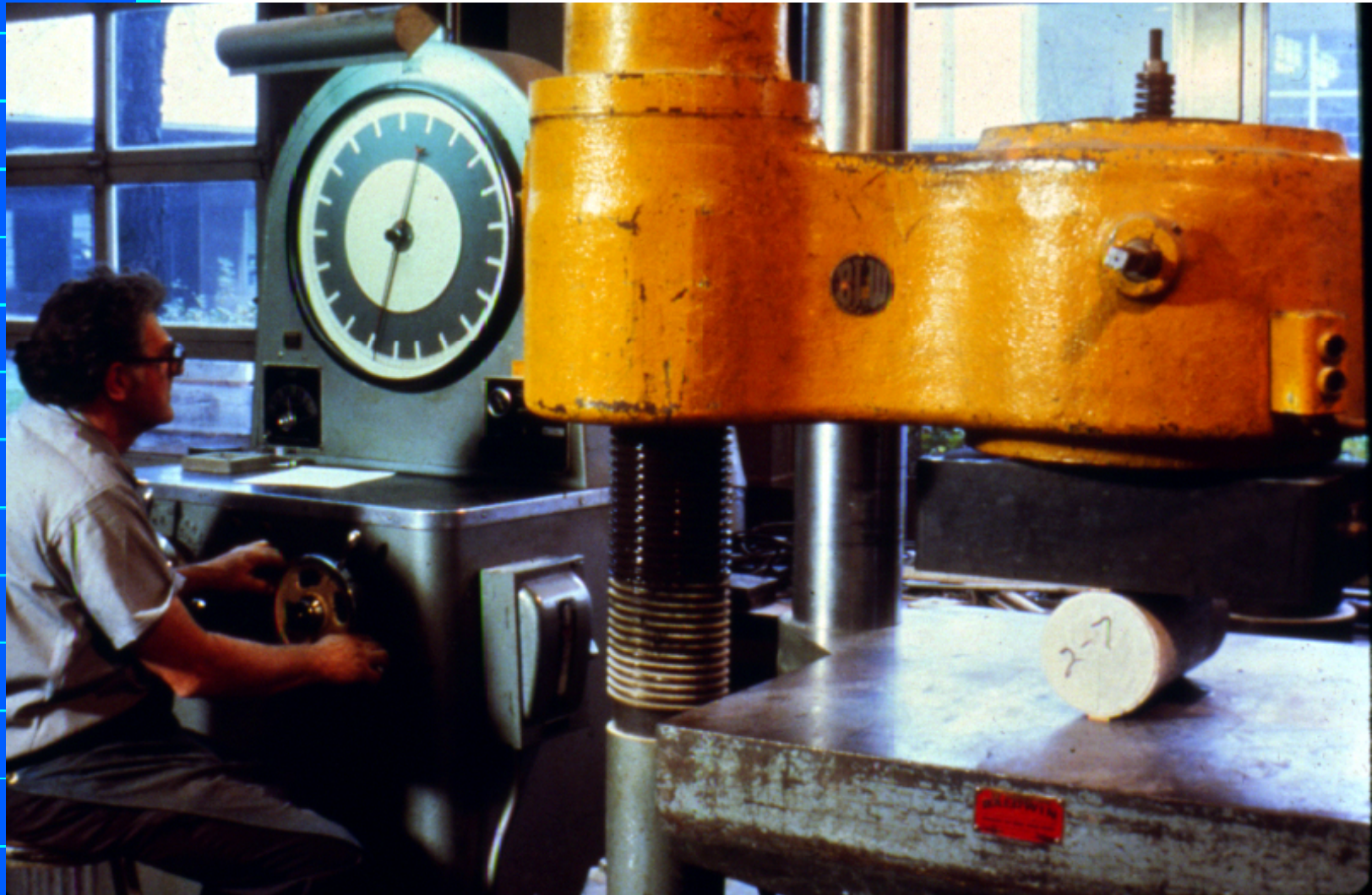
**Shear and Poor Compaction**

# Testing Flexural Strength





# Splitting Tensile Test





# Typical Specification Limits

## ASTM C 94 (ACI 318)

- The average of any three consecutive strength tests shall be equal to, or greater than, the specified strength,  $f'_c$ .
- No individual strength test shall be more than 500 psi [3.5 MPa] below the specified strength,  $f'_c$ .

# Low Strengths

Test	Individual Strengths $f'_c = 3000$	Aver of 2 Strengths	Avg. of 3 Tests	Evaluation
1	$3110 + 3080 = 6190$	3095	-	OK
2	$3060 + 3020 = 6080$	3040	-	OK
3	$3120 + 3160 = 6280$	3140	3092	OK
4	$2980 + 3010 = 5990$	2995	3058	OK
5	$2800 + 2860 = 2830$	2830	2988	Avg of 3
6	$3040 + 3100 = 3070$	3070	2965	Avg of 3
7	$2510 + 2460 = 2485$	2485	2795	< 500 psi Avg of 3





# What to Do?

- Increase Cementitious Materials
- Change Mix Proportions
- Reduce or Better Control Slump
- Reduce Delivery Time
- Closer Control of Air Content
- Improve Quality of Testing



# Apply Judgement

- 1 in 100 Tests Fail Even Though Concrete Strength and Uniformity May Be Satisfactory
- Allowance for Statistically Expected Variations
- Investigation of Low Strengths
  - ◆ Nondestructive Testing
  - ◆ Compressive Strengths of Cores



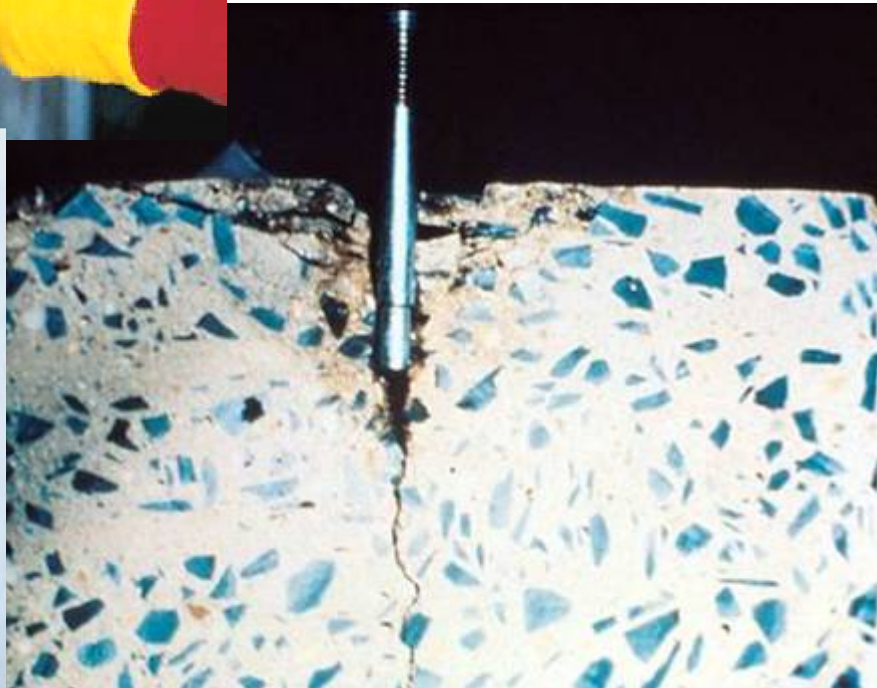
# Nondestructive Evaluation Methods

Property	Recommended Methods	Possible Methods
Strength	Penetration Probe Rebound Hammer Pullout Methods	Pulse Velocity
Rebar Size and Location	Covermeter (Pachometer) Gamma Radiography	X-ray Radiography Ultrasonic Pulse Echo Reader
Presence of Subsurface Voids	Acoustic Impact Gamma Radiography Ultrasonic Pulse Velocity	Thermal Inspection X-Ray Radiography Ultrasonic Pulse Echo

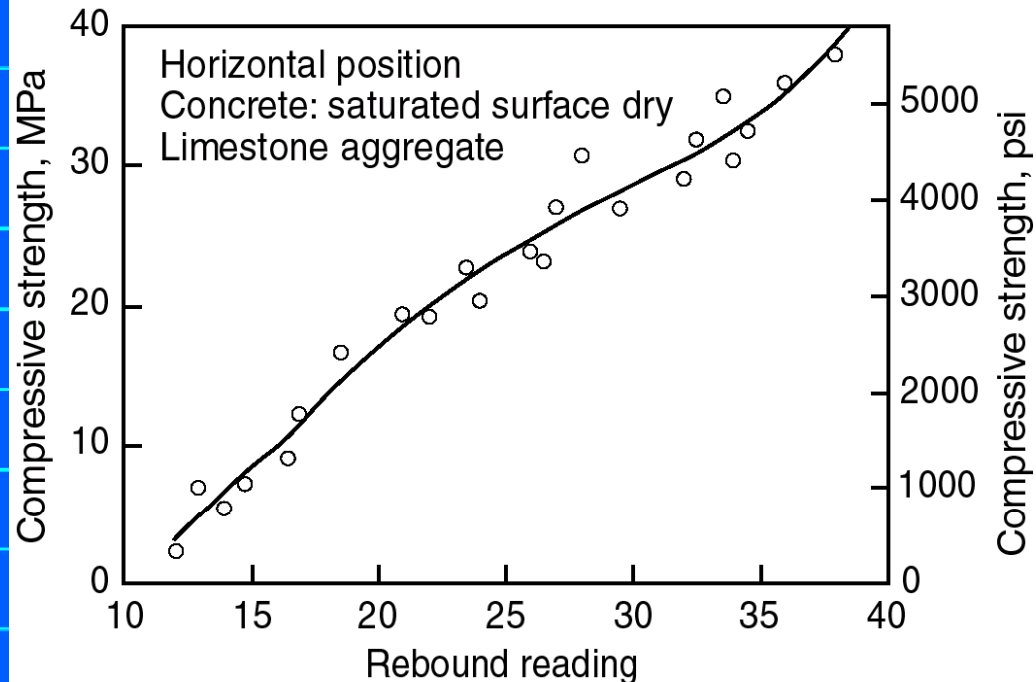


# Windsor Probe

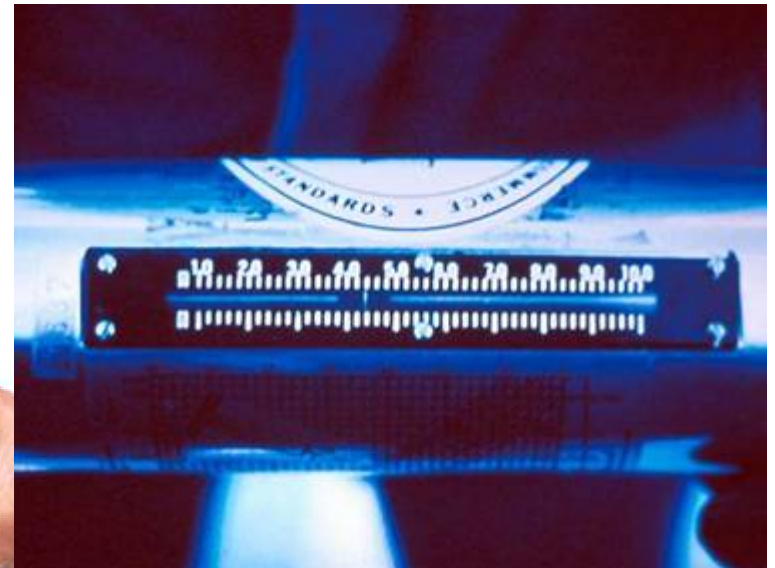
- ASTM C830
- Uniformity
- Indicator from one area of concrete to another



# Schmidt Rebound Hammer



- ASTM C805
- Indicator
- Measures Uniformity





# Pull Off Testing

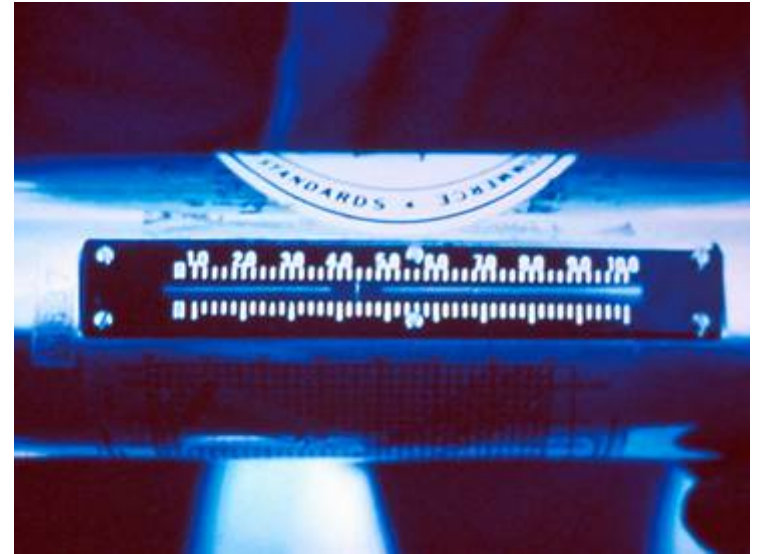
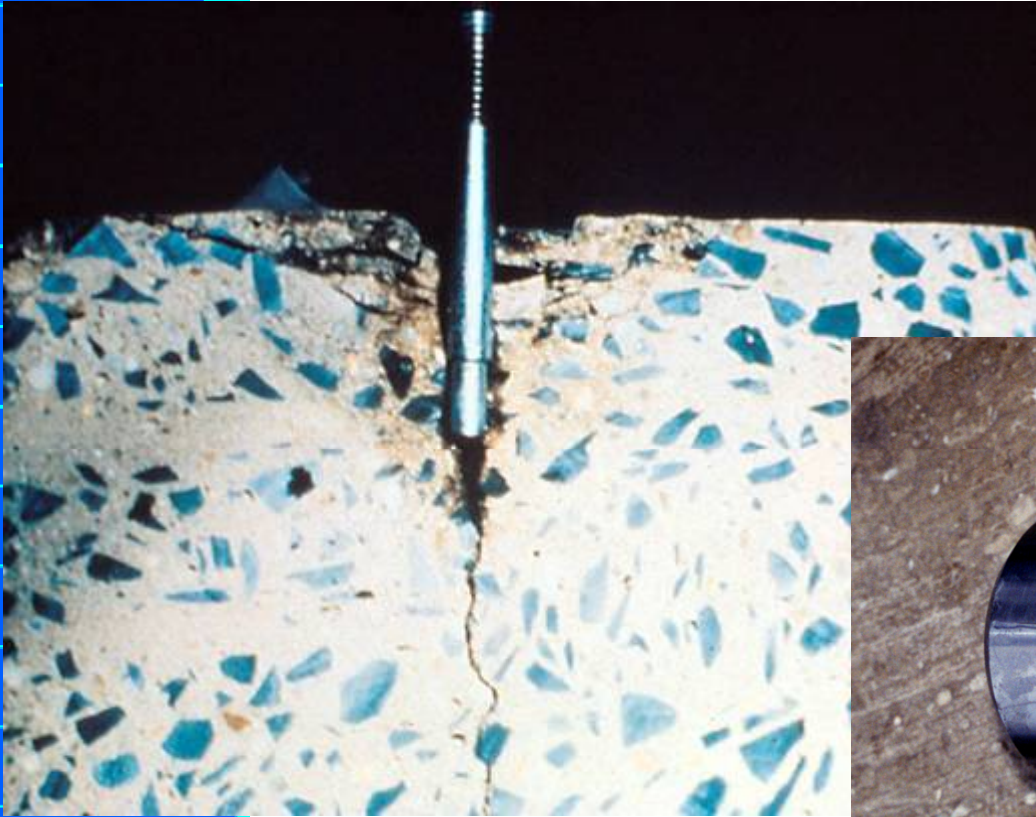
- ASTM C900- Tensile & Bond Strength

Measures  
direct shear  
strength





- Reliability of NDT?



# Cores

- ASTM C 42 – Obtaining and Testing Drilled Cores and Sawed Beams



# Number of Cores

- 3 For Each Test
  - ◆  $500 \text{ psi} < f'_c \leq 5,000 \text{ psi}$
- 3 For Each Test
  - ◆  $0.10 f'_c < f'_c > 5,000 \text{ psi}$



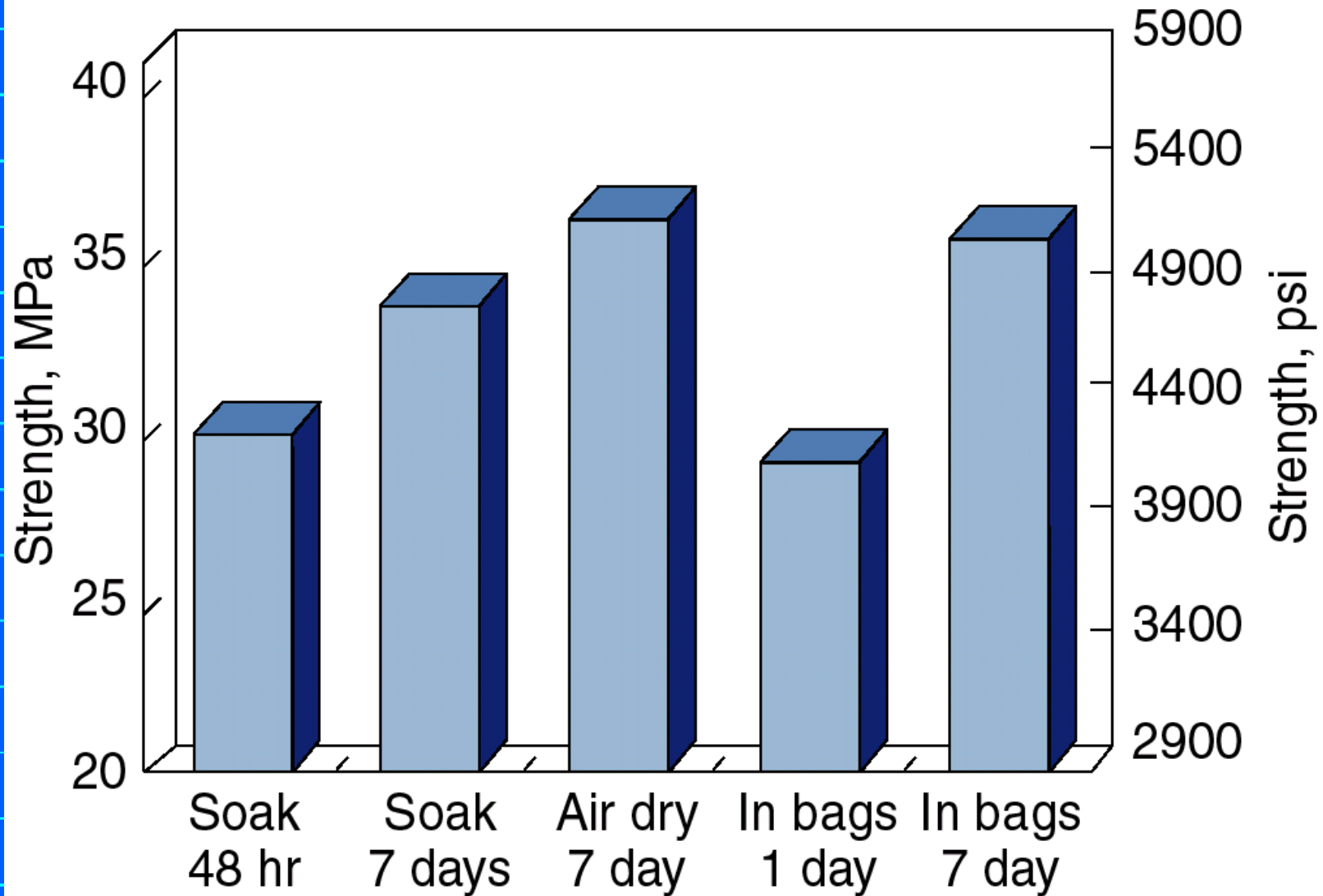


# Testing Cores



- Test Within 7 Days But Not Before 48 Hours
- Concrete Deemed Adequate If:
  - ◆ Average of 3 cores  $> 0.85 f'_c$
  - ◆ No single core  $< 0.75 f'_c$

# Effect of Core Conditioning on Compressive Strength



# Load Testing



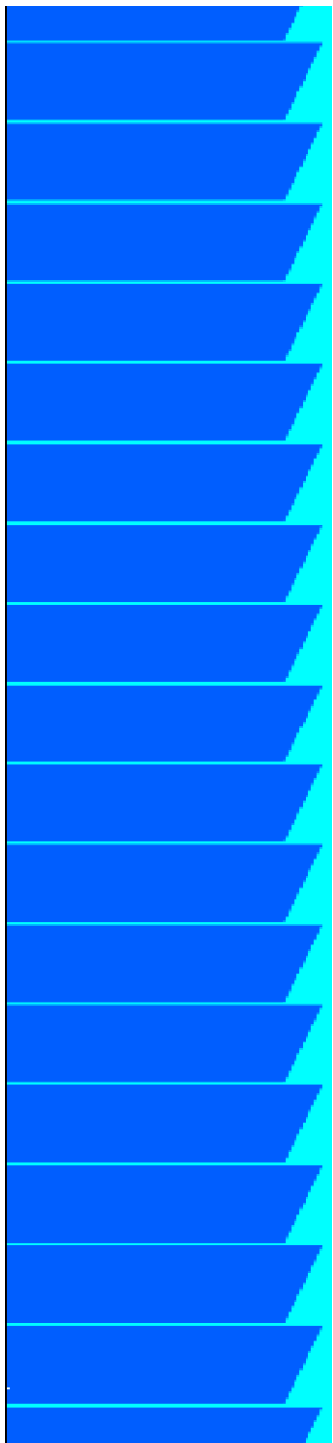
- When Core Tests Fail
- Concrete At Least 56 Days Old
- Chapter 20 of ACI 318





# Summary

- w/cm
- Age
- Air content
- Aggregate bond
- Handling
- Curing temperature
- Testing errors



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