

Strength Problems



Strength



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



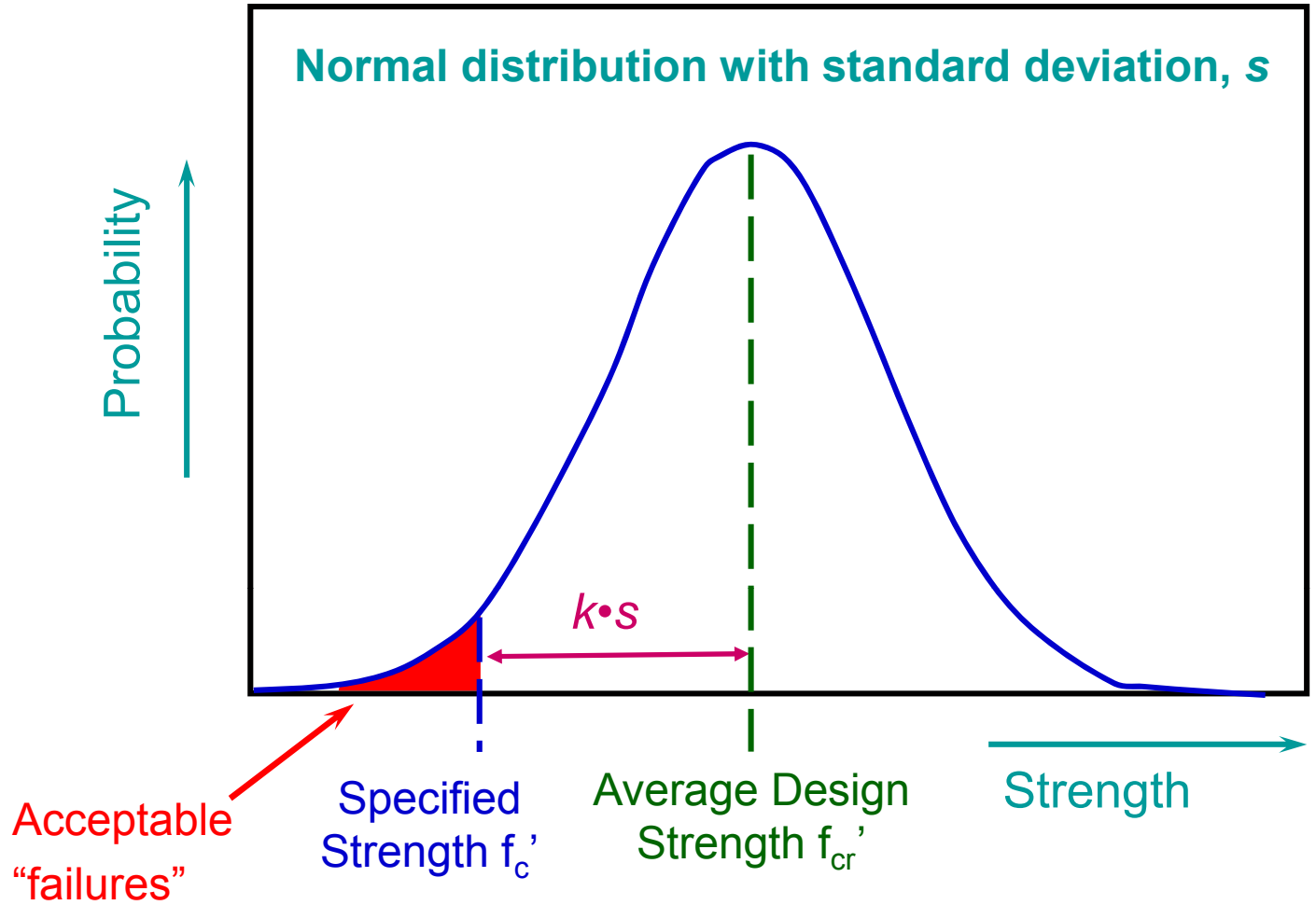
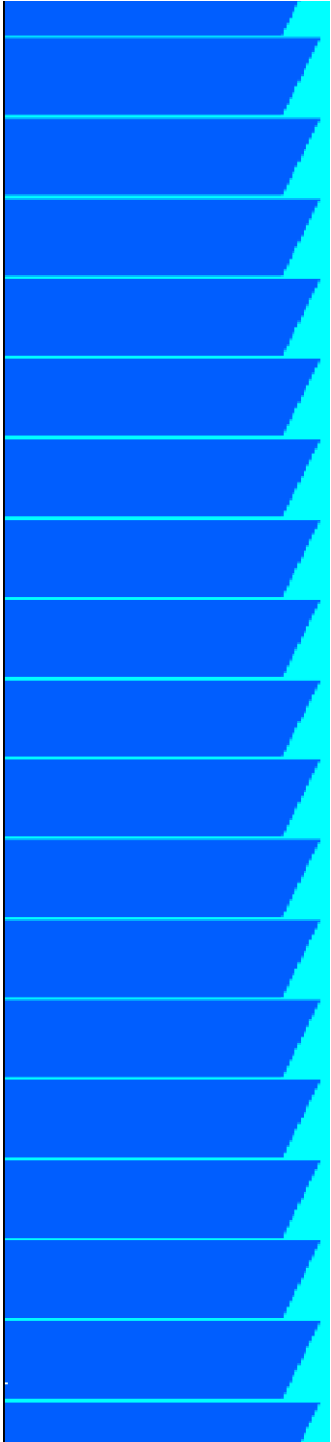
Strength Requirements

Specified strength, f_c' , is determined from:

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

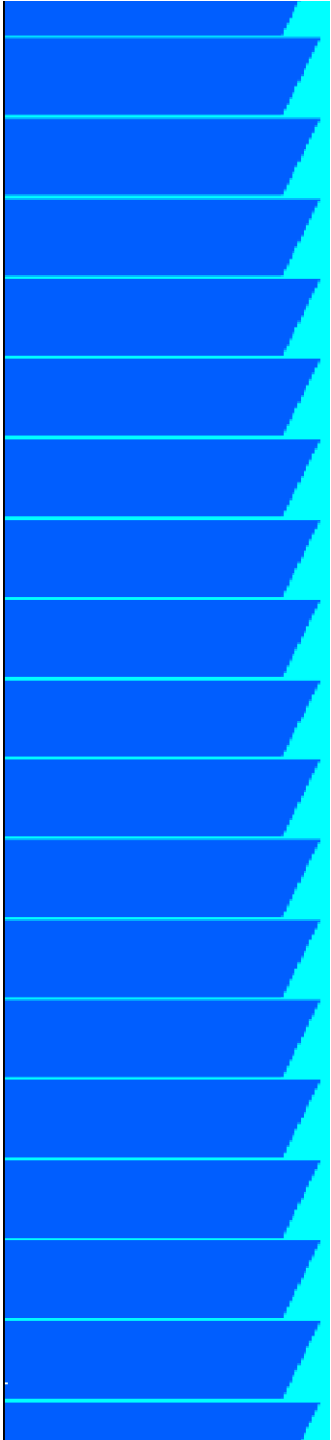
Note:

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

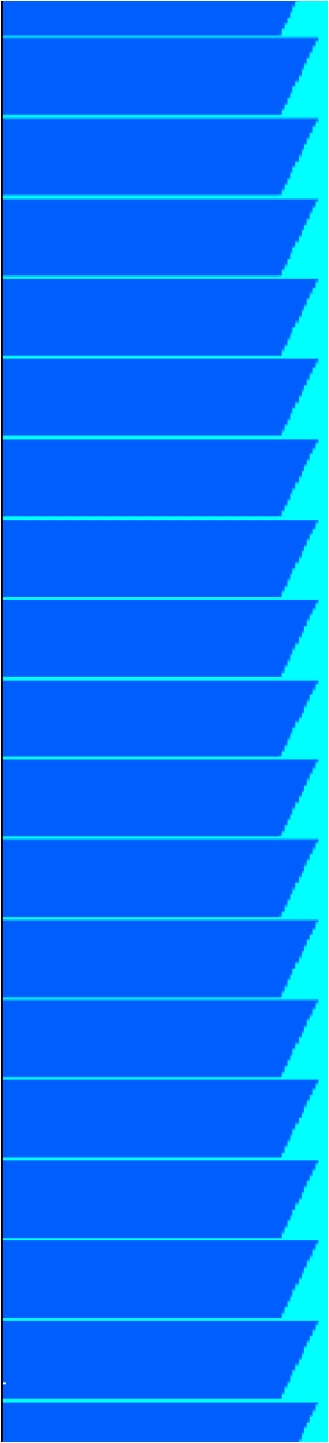


$$f_{cr}' > f_c'$$

Design strength $>$ Specified strength

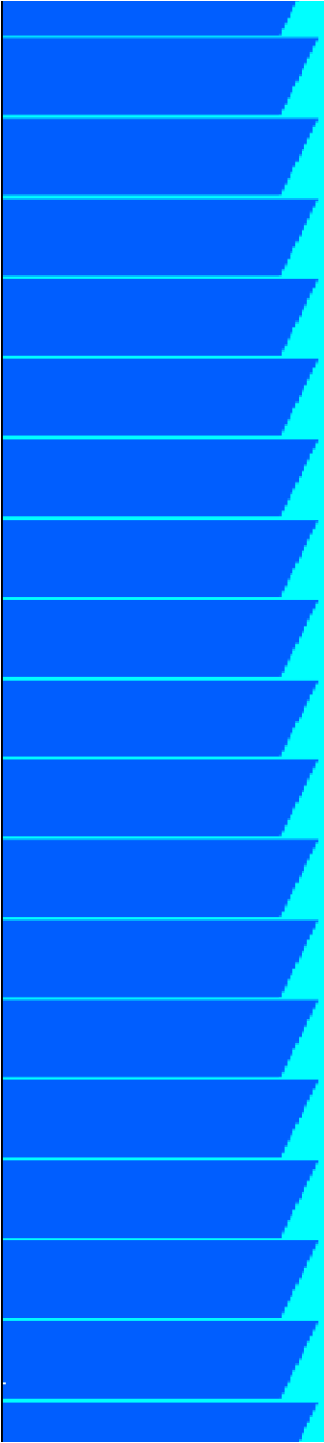


The standard deviation should be based on at least 30 consecutive strength tests, representing concrete whose design strength is within 7 MPa (1000 psi) of that required for the work made with similar materials and under similar conditions to those expected.



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 | $1.10f_c' + 5.0$ |

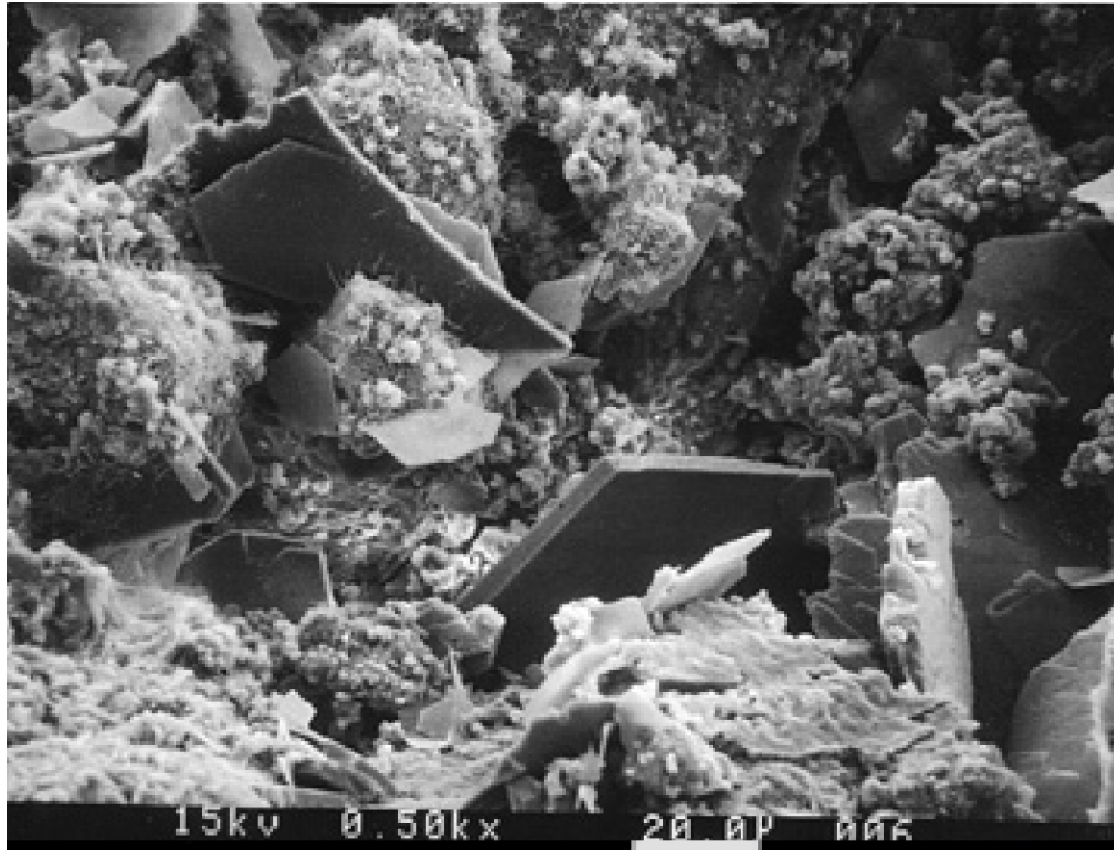
| Specified Strength f_c' (psi) | Required Average Strength f_{cr}' (psi) |
|---------------------------------|---|
| Less than 3000 | $f_c' + 1000$ |
| 3000 to 5000 | $f_c' + 1200$ |
| Over 5000 | $1.10f_c' + 700$ |

Factors Impacting Strength

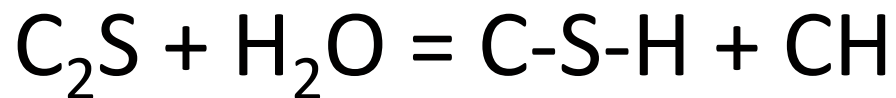
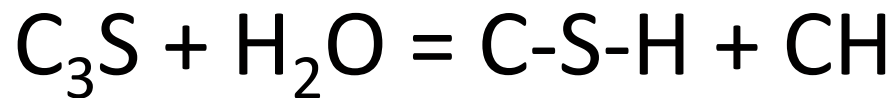


- w/cm
- Age
- Air Content
- Aggregate Bond
- Handling
- Curing Temperature
- Testing Errors

Hydration



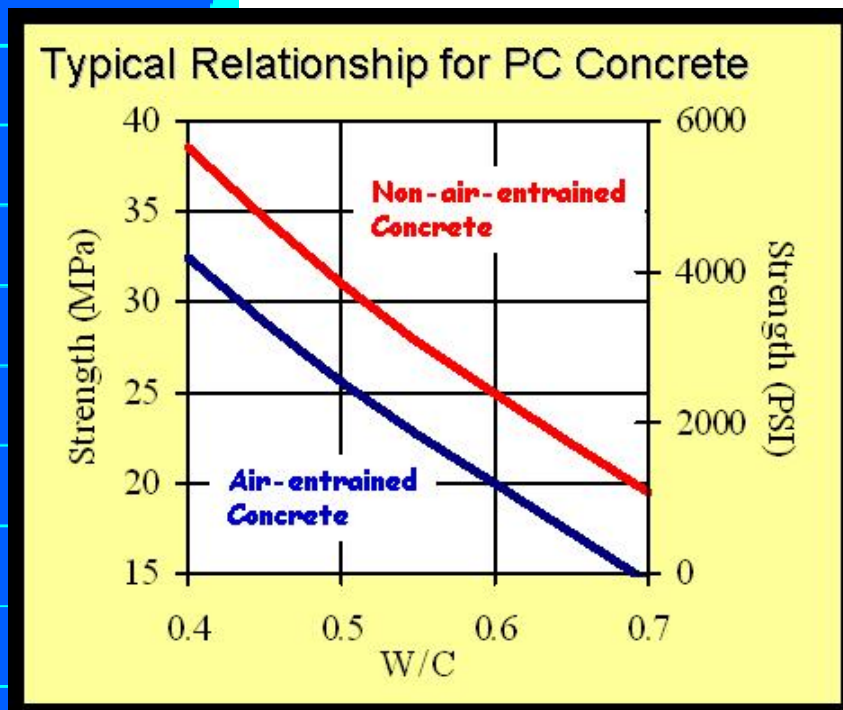
Cement + Water



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 kg/m^3 (5 lb/yd^3) for each 1% air





109104-Sample 11142

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

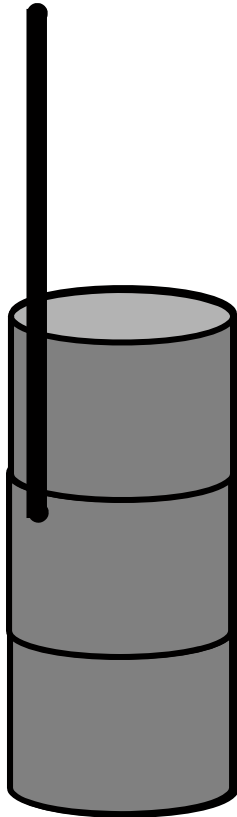
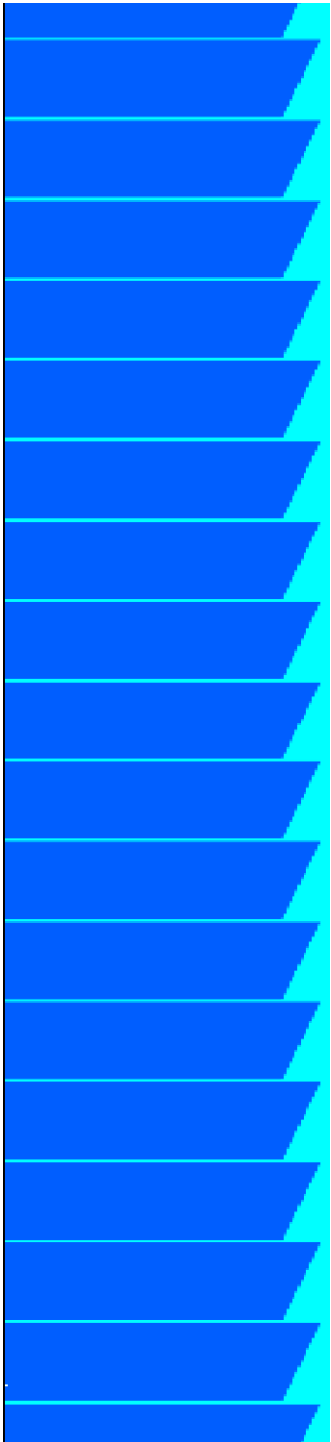
- Slump
 - ◆ 3 in. or more – rodded
 - ◆ 1 to 3 in. – rodded or vibrated
 - ◆ Less than 1 inch – vibrated
- Excess concrete struck
- Sealed
 - ◆ Plastic cap, oiled glass, steel plate
 - ◆ Sealed in a plastic bag



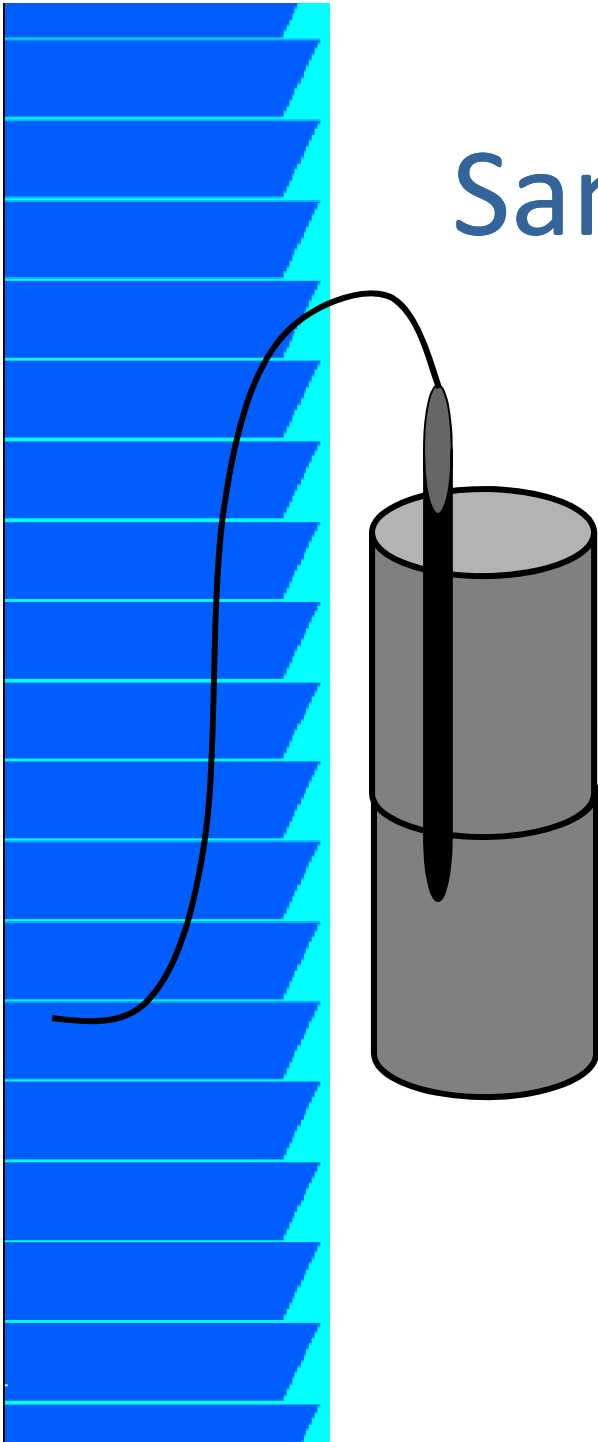
Sampling 3-in Slump

- 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











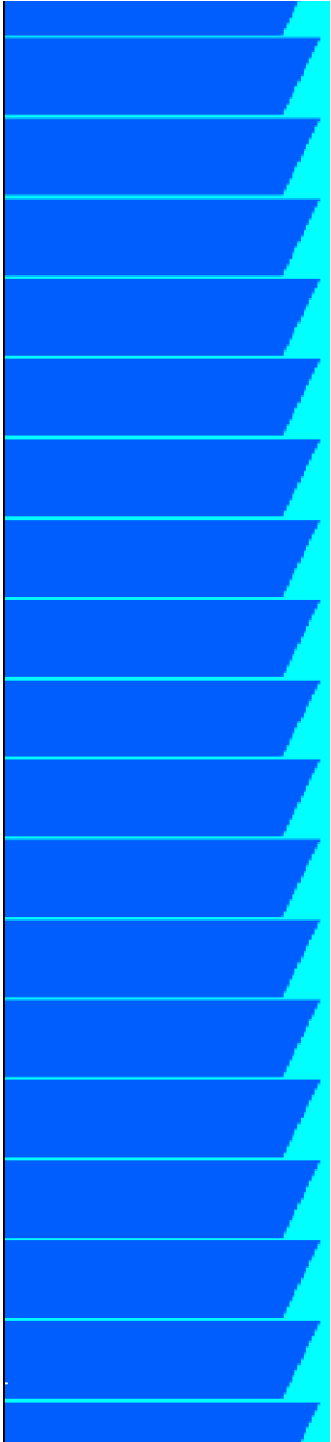














Field Cured Cylinders

- 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

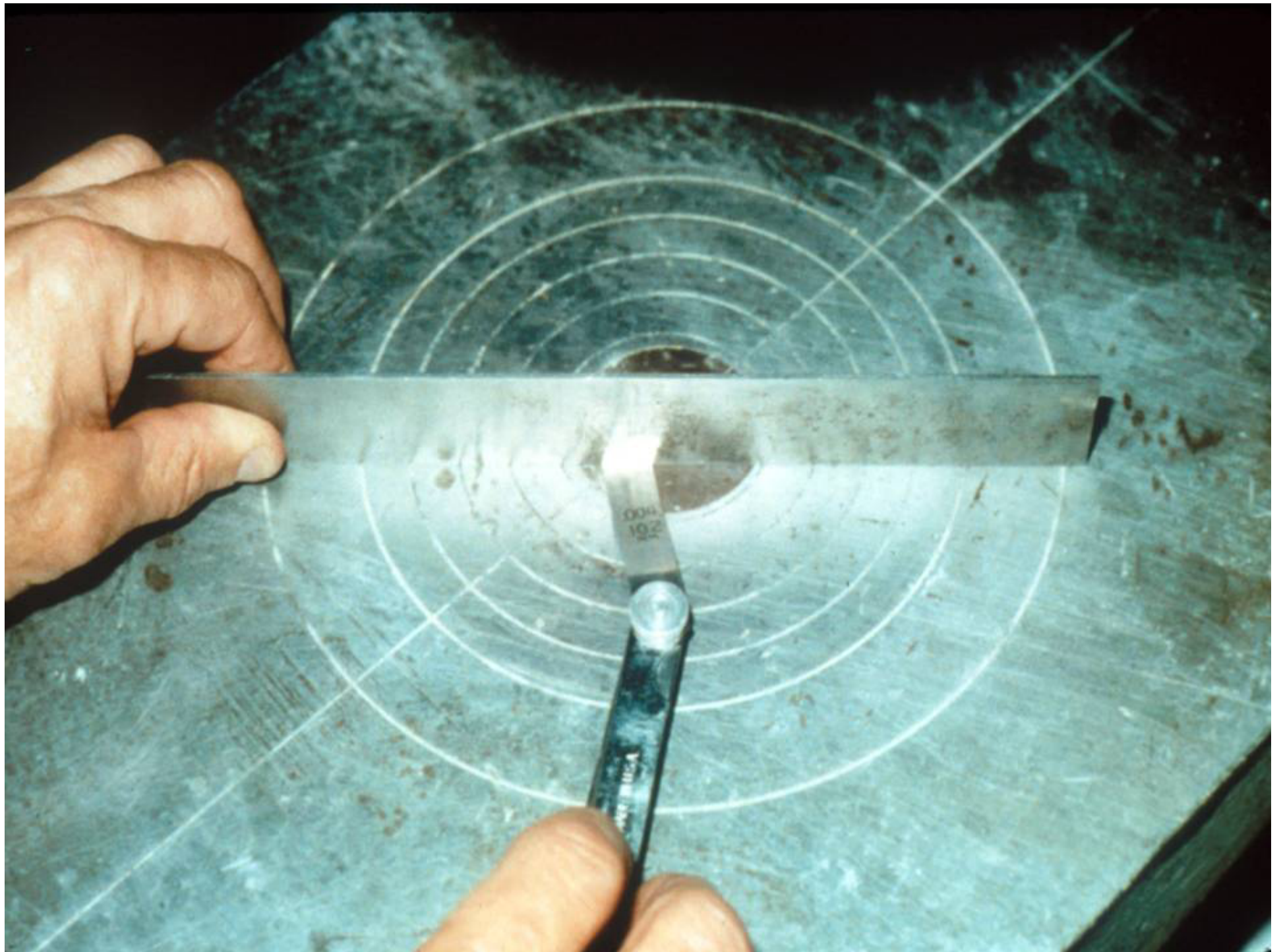


- ASTM C 39 – Testing Cylinders
- Capping
 - ◆ ASTM C 617 – Capping
 - ◆ ASTM C 1231 – Unbonded Caps
- Measurements
- Testing
 - ◆ Maximum Load
 - ◆ Strength, within 10 psi
- Conical Failure

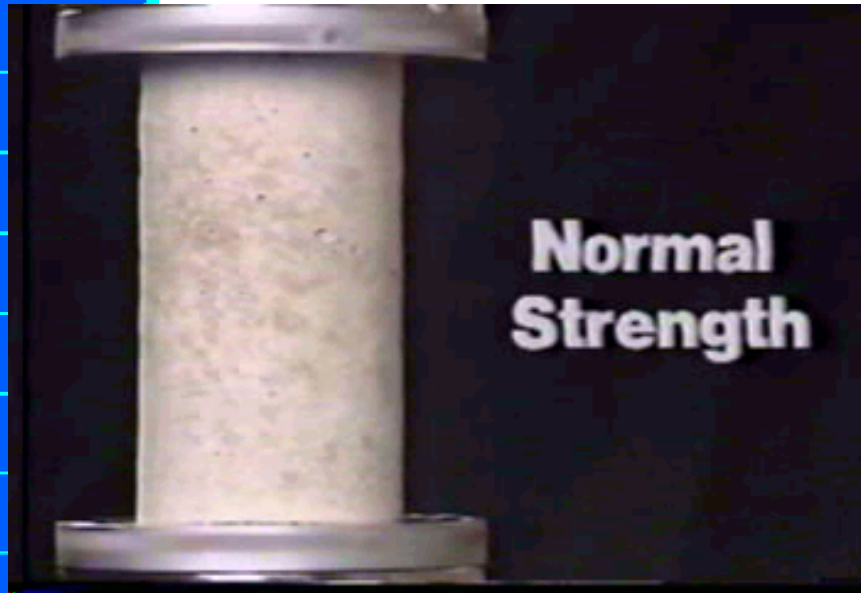


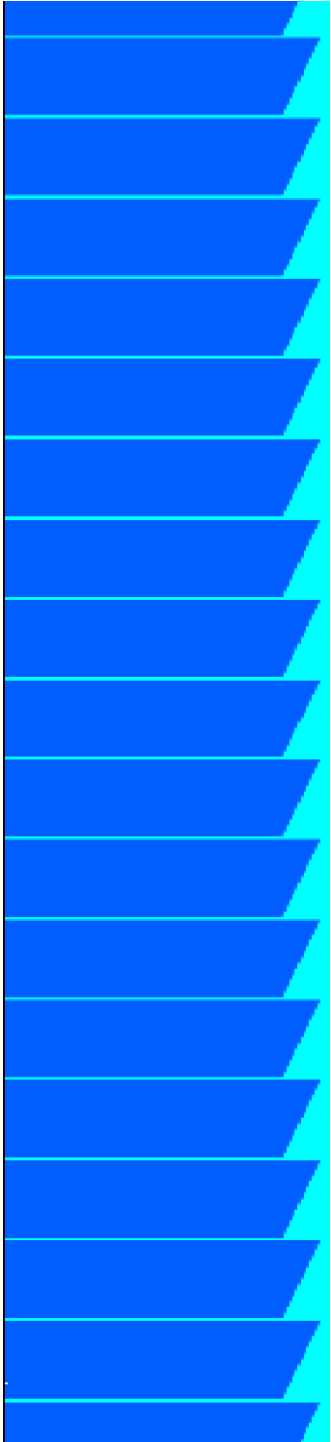






Testing Compressive Strength







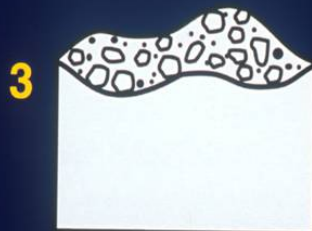




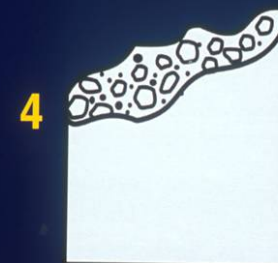
Typical Break



Shear Break

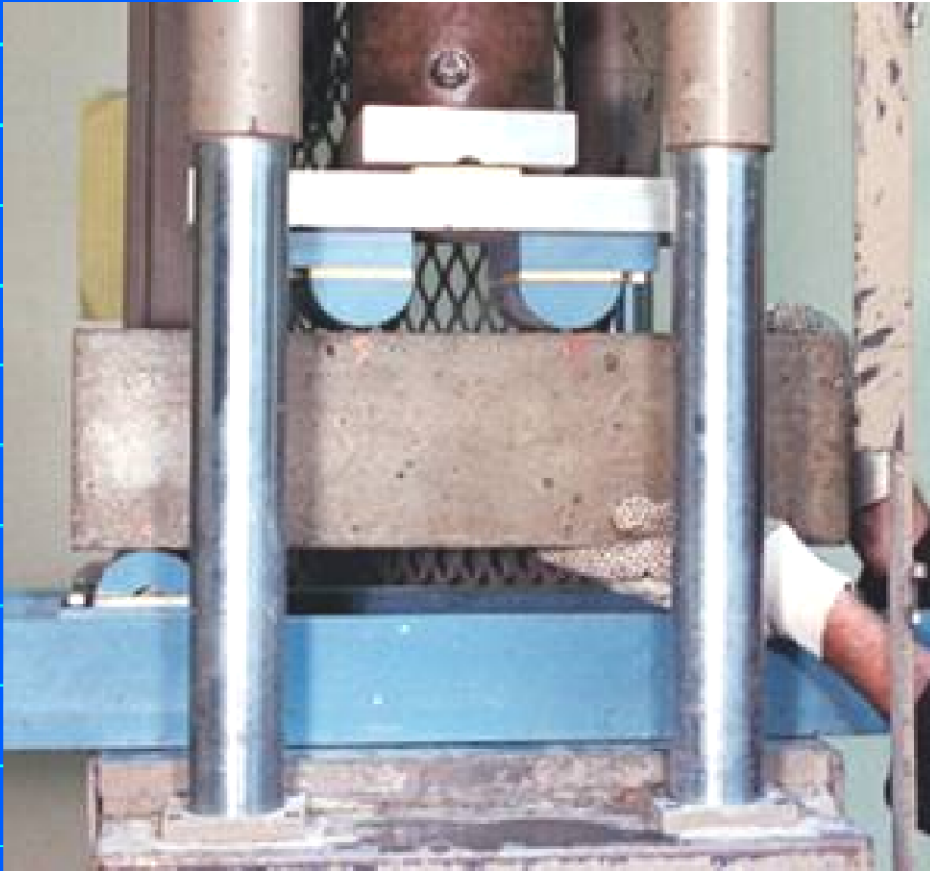


Poor Compaction

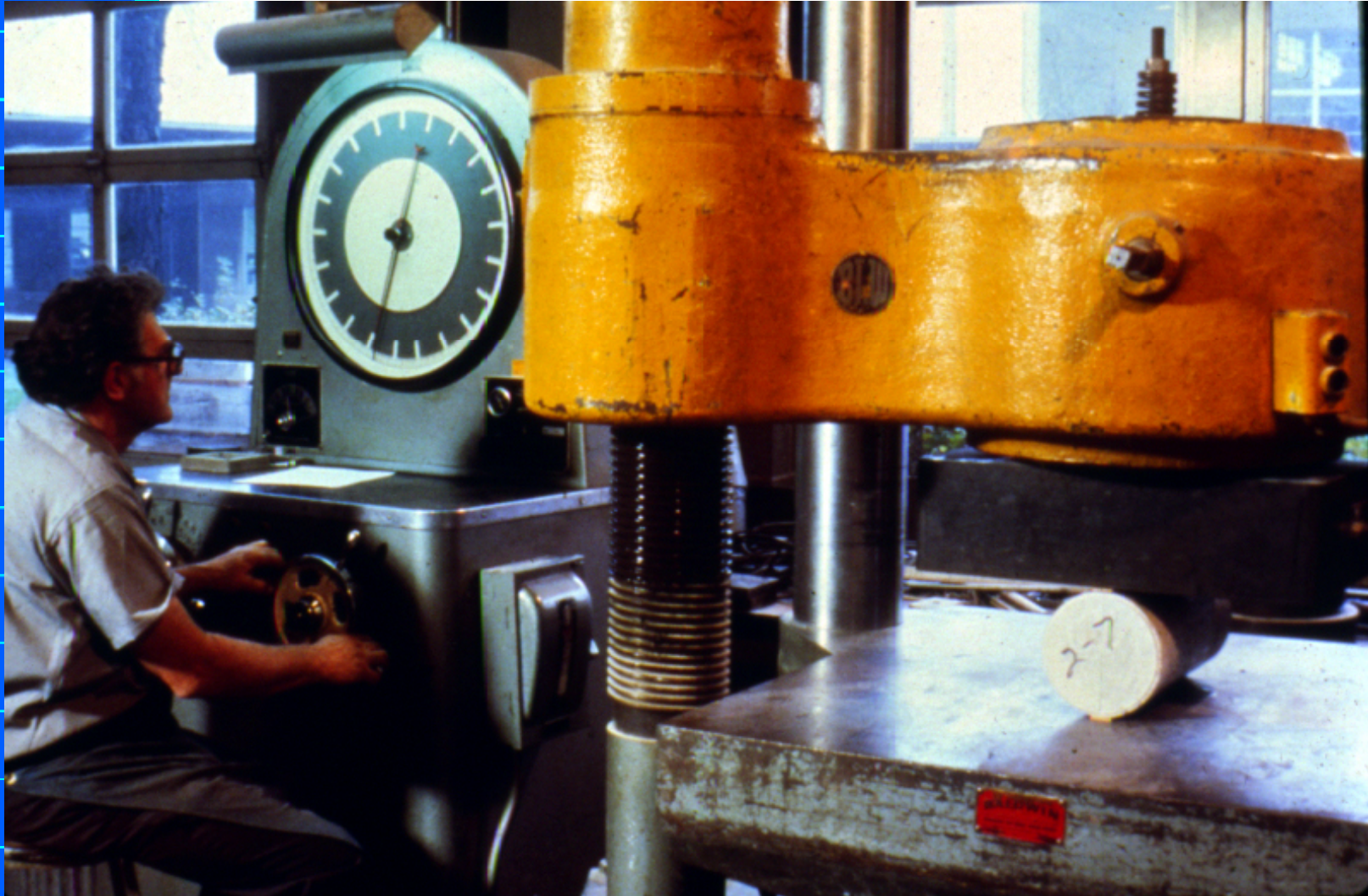


Shear and Poor Compaction

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

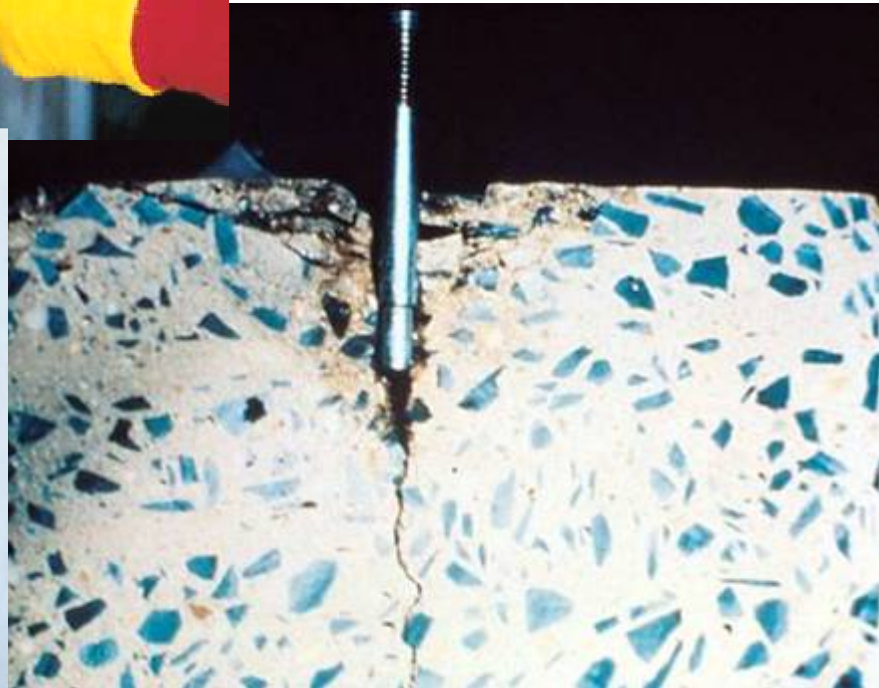


Nondestructive Evaluation Methods

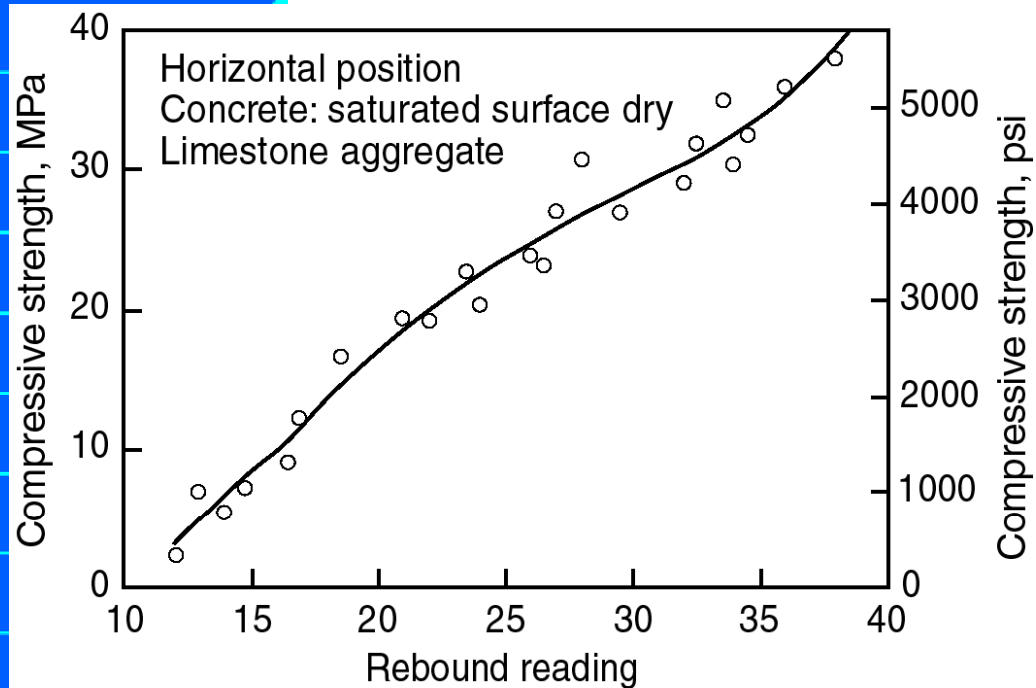
| Property | Recommended Methods | Possible Methods |
|------------------------------|--|---|
| Strength | Penetration Probe Rebound Hammer Pullout Methods | Pulse Velocity |
| Rebar Size and Location | Covermeter (Pachometer) Gamma Radiography | X-ray Radiography Ultrasonic Pulse Echo Reader |
| Presence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

Windsor Probe

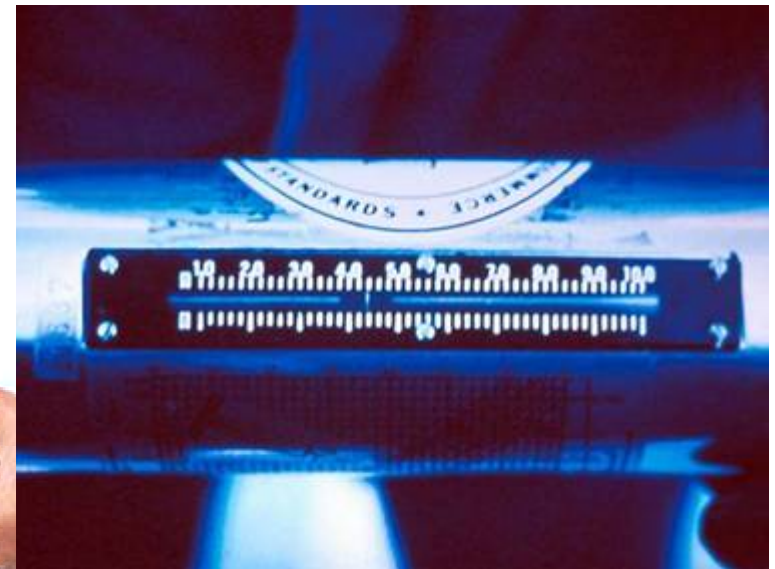
- ASTM C830
- Uniformity
- Indicator from one area of concrete to another



Schmidt Rebound Hammer



- ASTM C805
- Indicator
- Measures Uniformity



Pull Off Testing

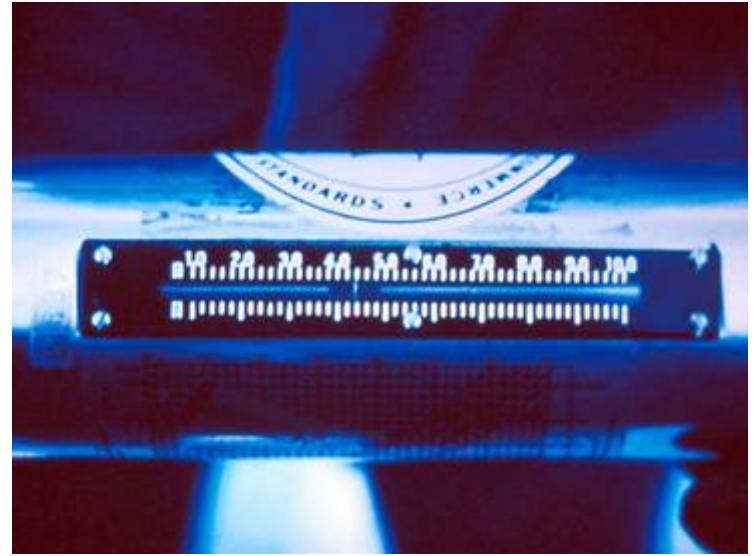
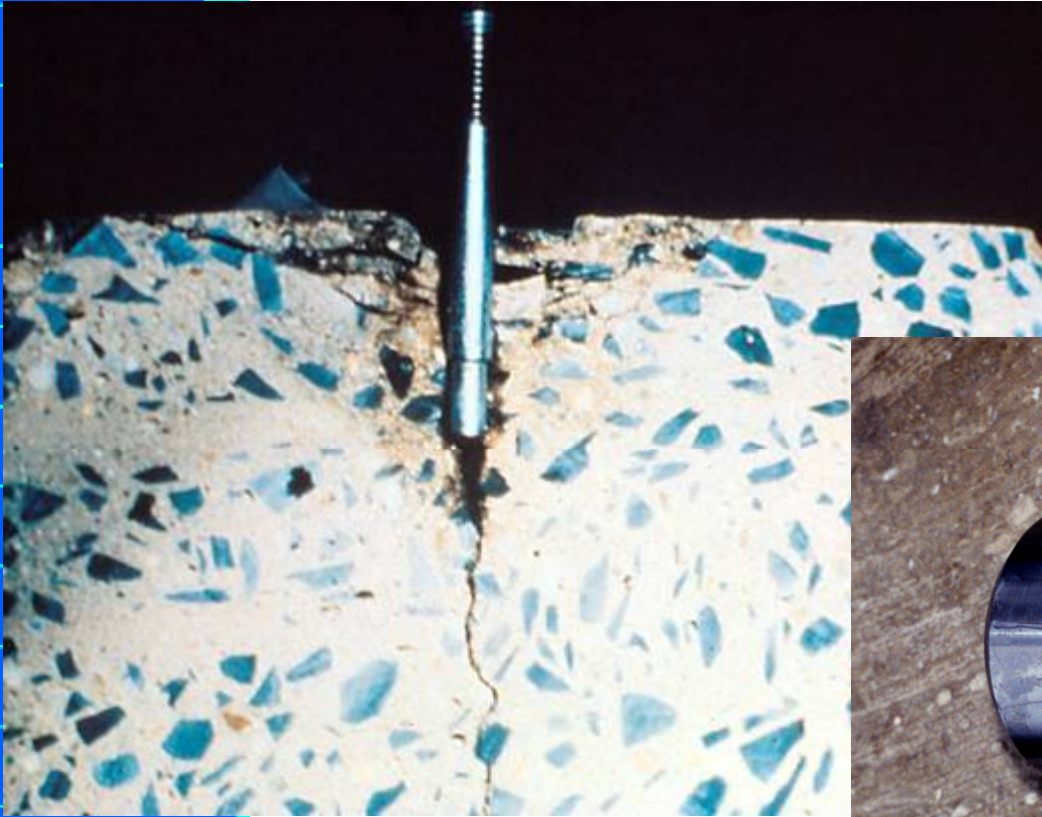
- ASTM C900- Tensile & Bond Strength



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
 - ◆ $0.10 f'_c < f'_c > 5,000 \text{ psi}$

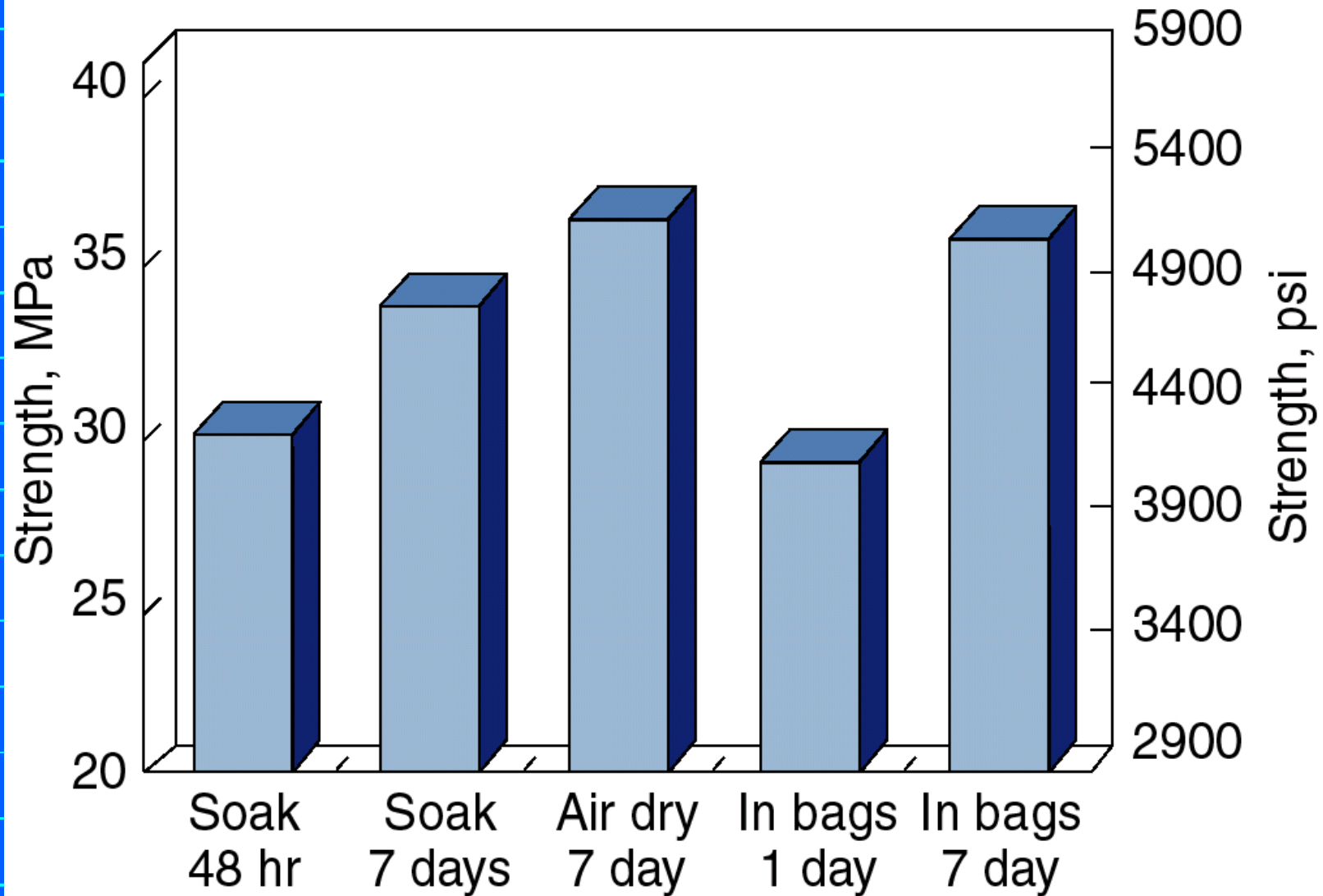


Testing Cores



- 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

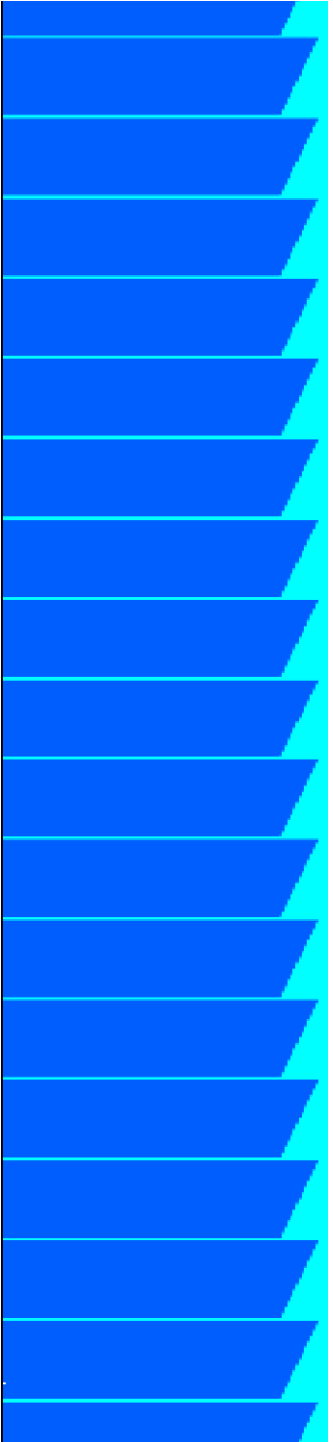


- When Core Tests Fail
- Concrete At Least 56 Days Old
- Chapter 20 of ACI 318



Summary

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



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