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2024
FALL CONVENTION

DENVER, COLORADO | OCTOBER 22-25, 2024

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IN-PLACE CONRETE
STRENGTH DETERMINATION

Presented By: Zachoriah J. Ballard, MCE, P.E.

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Live Content Slide

When playing as a slideshow, this slide will display live content

Poll: What method do you currently use most often for assessing concrete strength?

PRESENTATION OBJECTIVES

- Understand Key Methods
- Evaluate Factors Affecting Strength
- Apply Testing Procedures
- Assess and Ensure Structural Integrity

CORING

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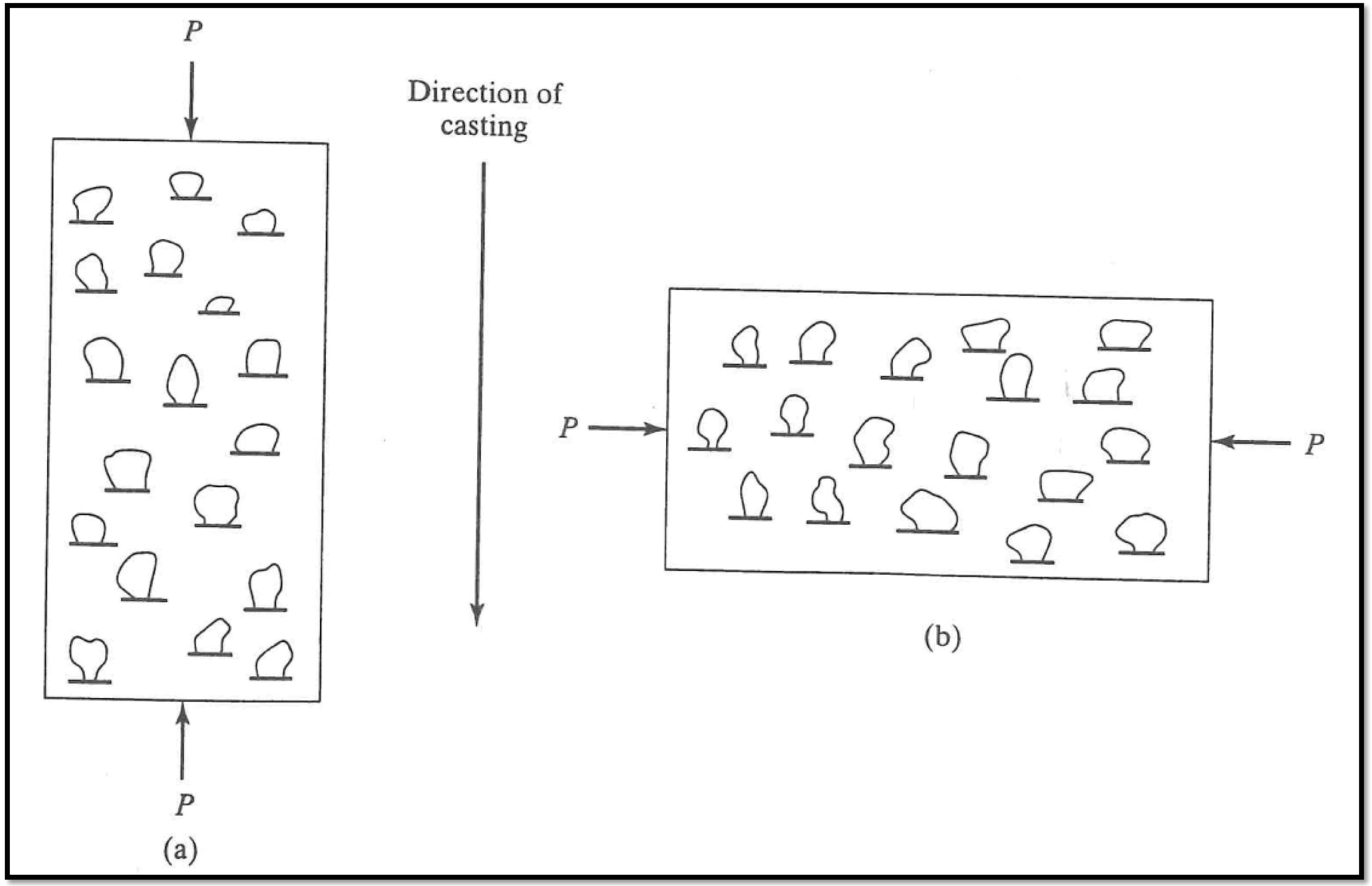
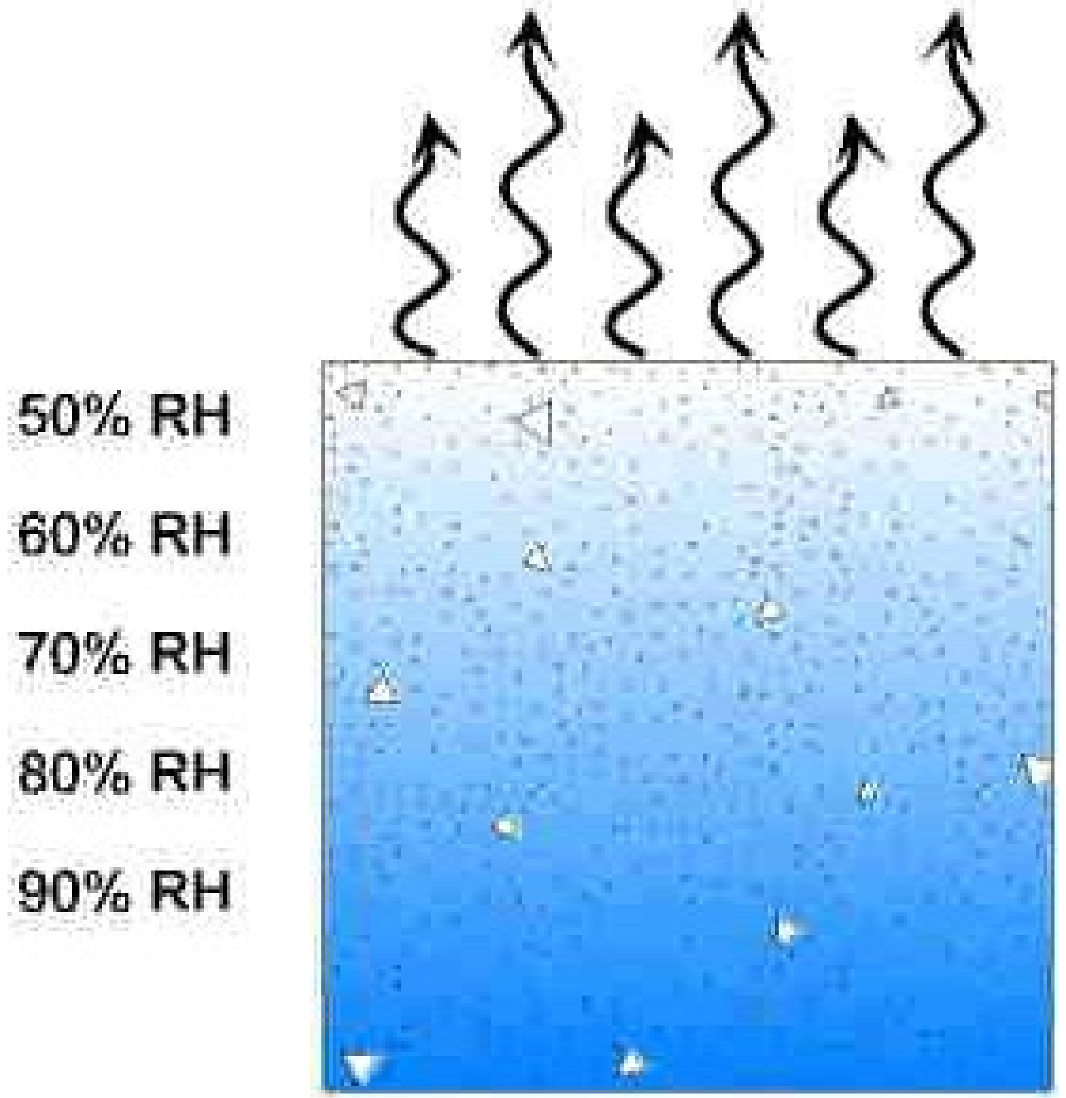

P
Direction of
casting
P
P
P
(a)
(b)

CONCRETE MOISTURE

- Strength affected by moisture and moisture gradients
- ASTM C42 conditioning periods
  - 48 hours to 7-days
- Too short for uniform moisture
- Cores air dried for 7-days are typically 5-9% higher in compressive strength



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REBOUND HARDNESS

- Likely the most common nondestructive test
- Developed in 1948
- Test measures the rebound of a hardened steel hammer impacted on the surface of the concrete
- Universally used mainly due to its simplicity
- ASTM C805

PARAMETERS AFFECTING RESULTS

- Surface finish of the concrete being tested
- Moisture content of the concrete
- Temperature
- Rigidity of the member
- Carbonation
- Direction of impact

WHAT DOES ASTM SAY?

Designation: C805/C805M – 18

between strength and rebound number for a given concrete and given apparatus (see Note 1). Establish the relationship by correlating rebound numbers measured on the structure with the measured strengths of cores taken from corresponding locations (see Note 2). At least two replicate cores shall be

Sta

Rebound Number of Hardened Concrete[1]

WINDSOR PROBE

- Measures the resistance of concrete to penetration
- ASTM C803
- Drivers exerts a known amount of energy to a steel pin
- Measure the exposed length of the pin after firing

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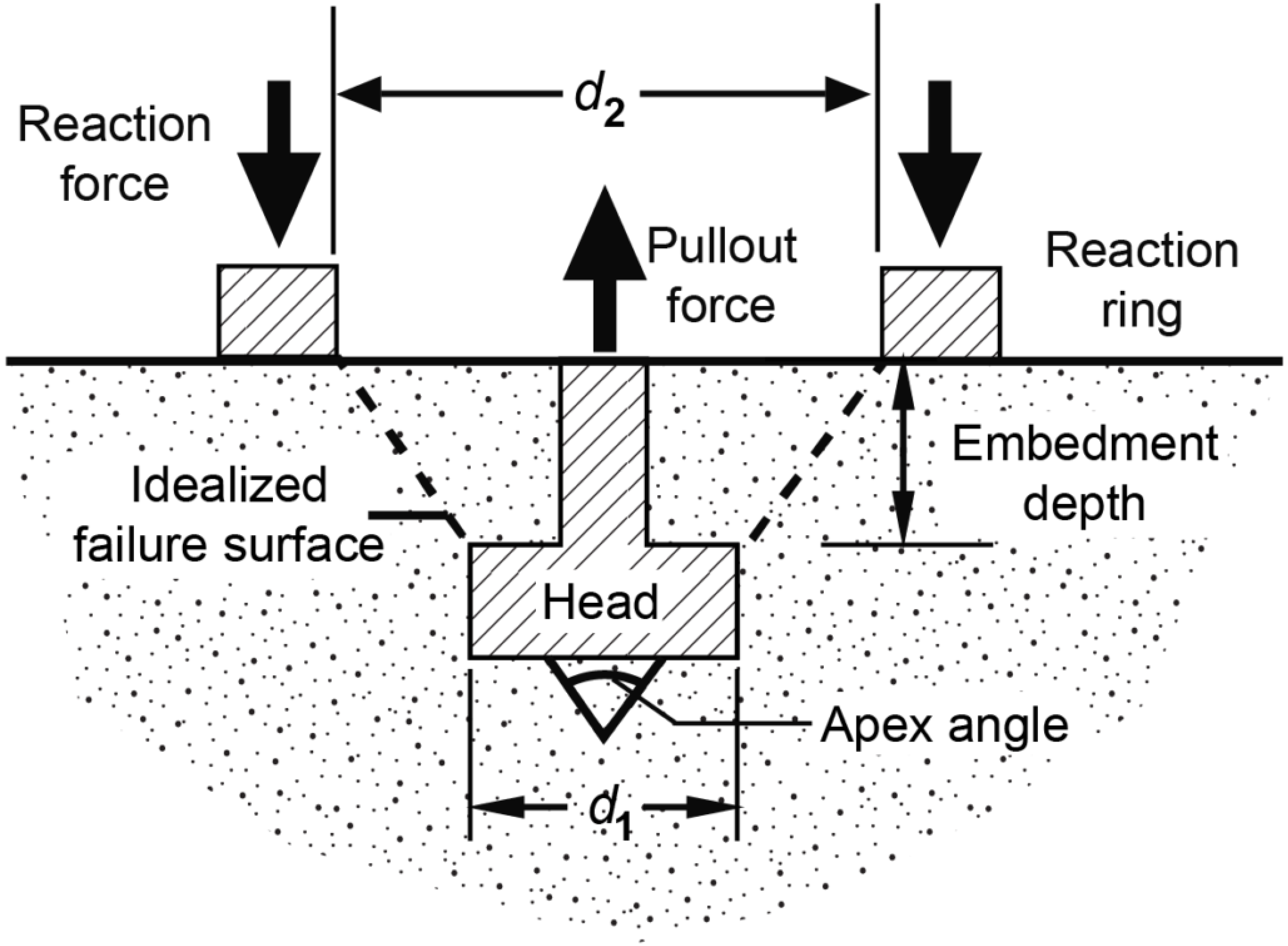
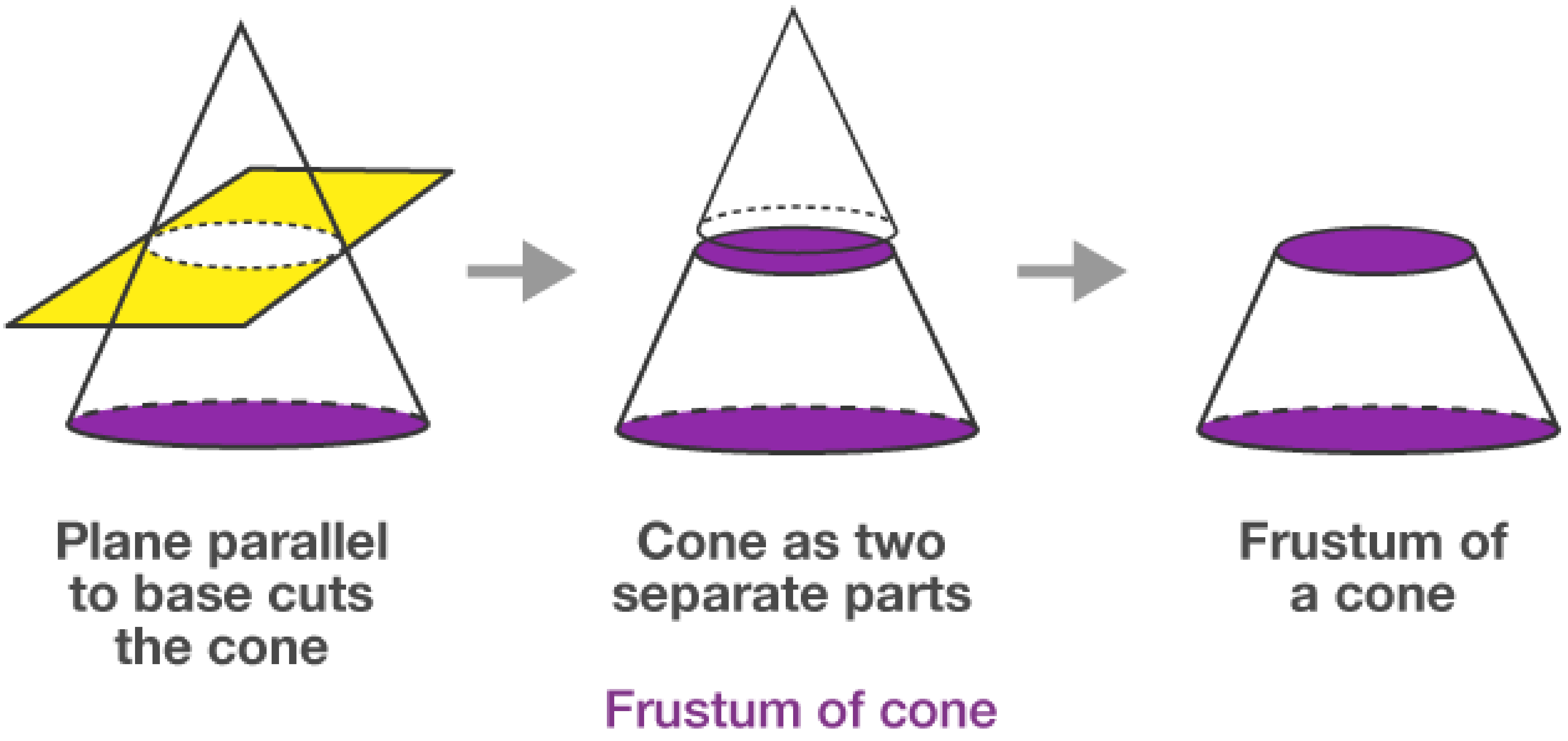
PULL-OUT TESTS

- Force required to pull an insert out of concrete
- Embedded during casting or installed after casting
- ASTM C900



Reaction force
d_2
Pullout force
Reaction ring
Idealized failure surface
Embedment depth
Head
Apex angle
d_1


Plane parallel to base cuts the cone
Cone as two separate parts
Frustum of a cone
Frustum of cone

$$f_n = (P/A)\sin\alpha$$

$$\sin\alpha = (d_3 - d_2)/2s$$

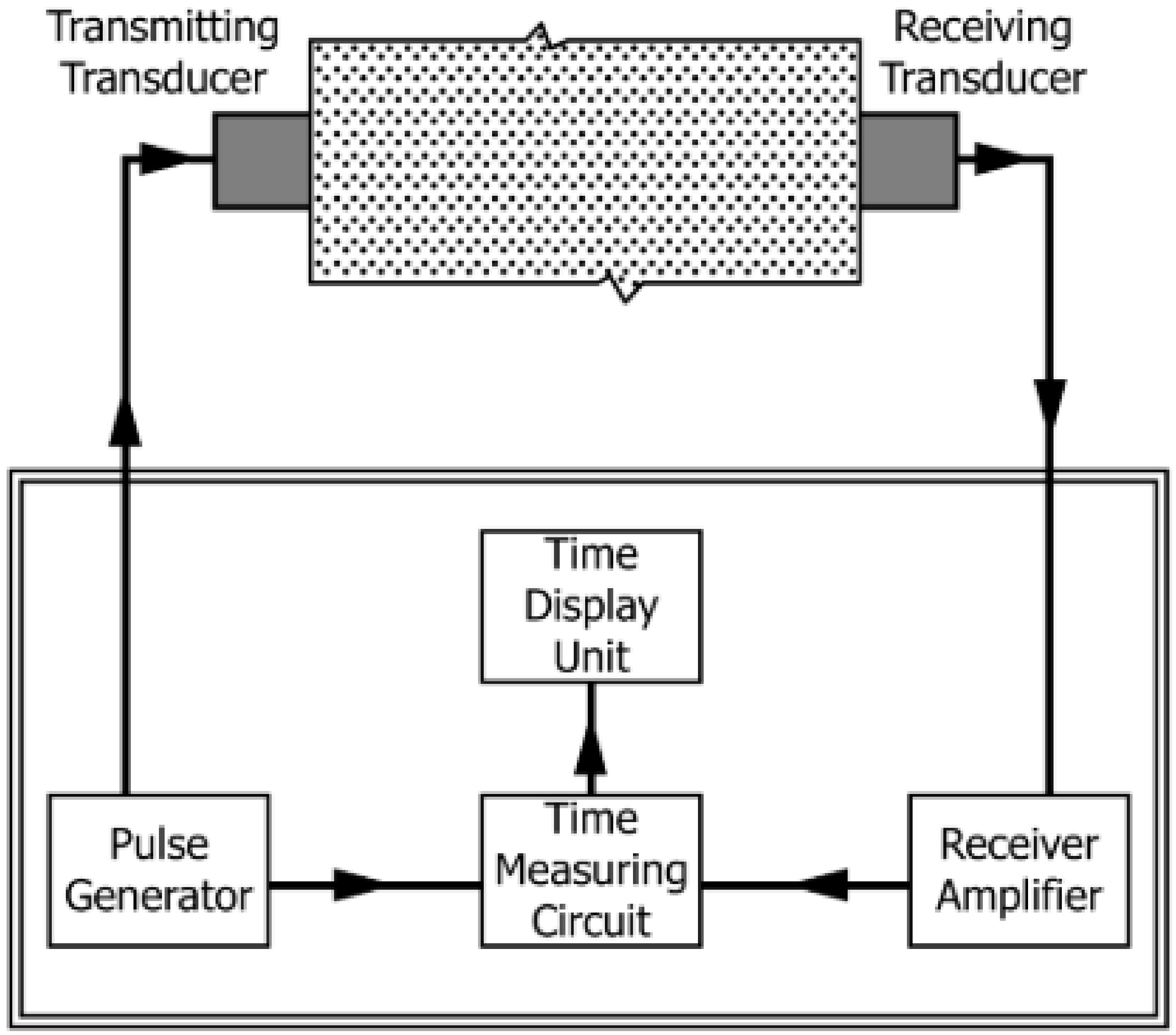
$$A = \pi S(d_3 + d_2)/2$$

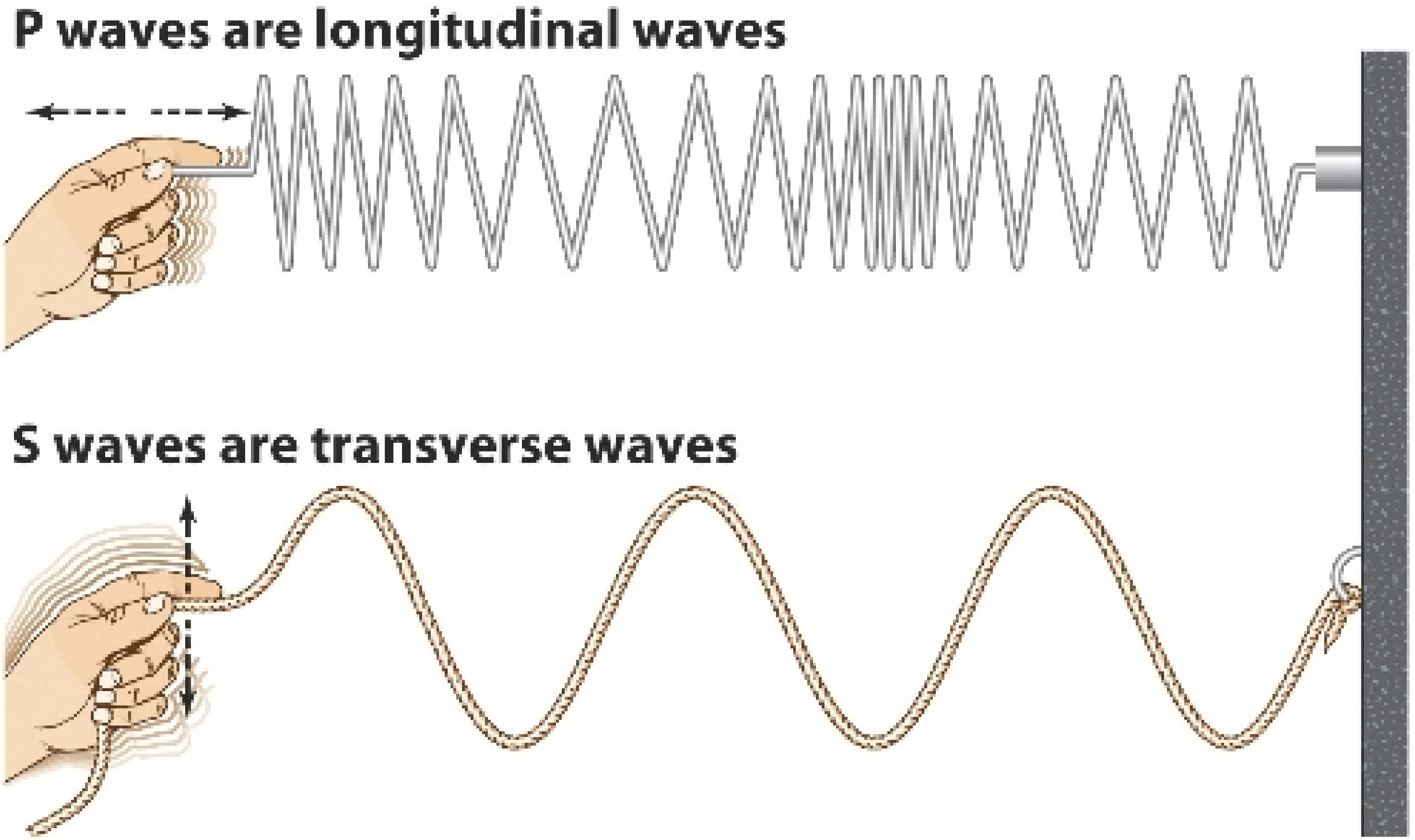
$$S = \sqrt{h^2 + ((d_3 - d_2)/2)^2}$$

where
f_n = nominal normal stress, MPa;
P = pullout force, N;
α = ½ the frustum apex angle = $\tan^{-1}(d_3 - d_2)/2h$;
A = fracture surface area, mm^2;
d_2 = diameter of pullout insert head, mm;
d_3 = inside diameter of bearing ring, mm;
h = height of conic frustum, mm;
S = slant height of the frustum, mm.

ULTRASONIC PULSE VELOCITY

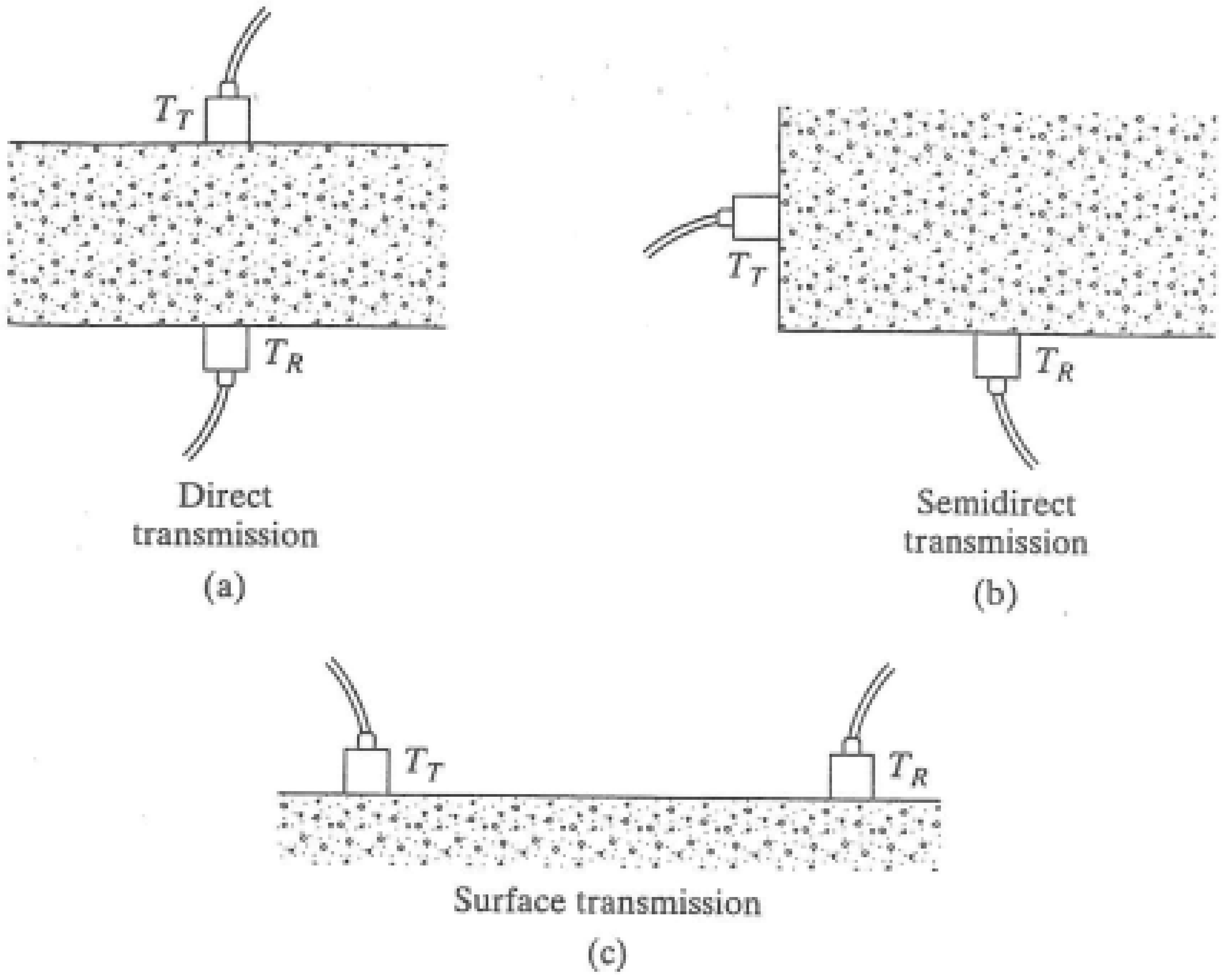
- Pulses of longitudinal ultrasonic stress waves through concrete (P-Waves)
- Propagation of these waves is then picked up by a receiver
- ASTM C597


Transmitting Transducer
Receiving Transducer
Time Display Unit
Pulse Generator
Time Measuring Circuit
Receiver Amplifier

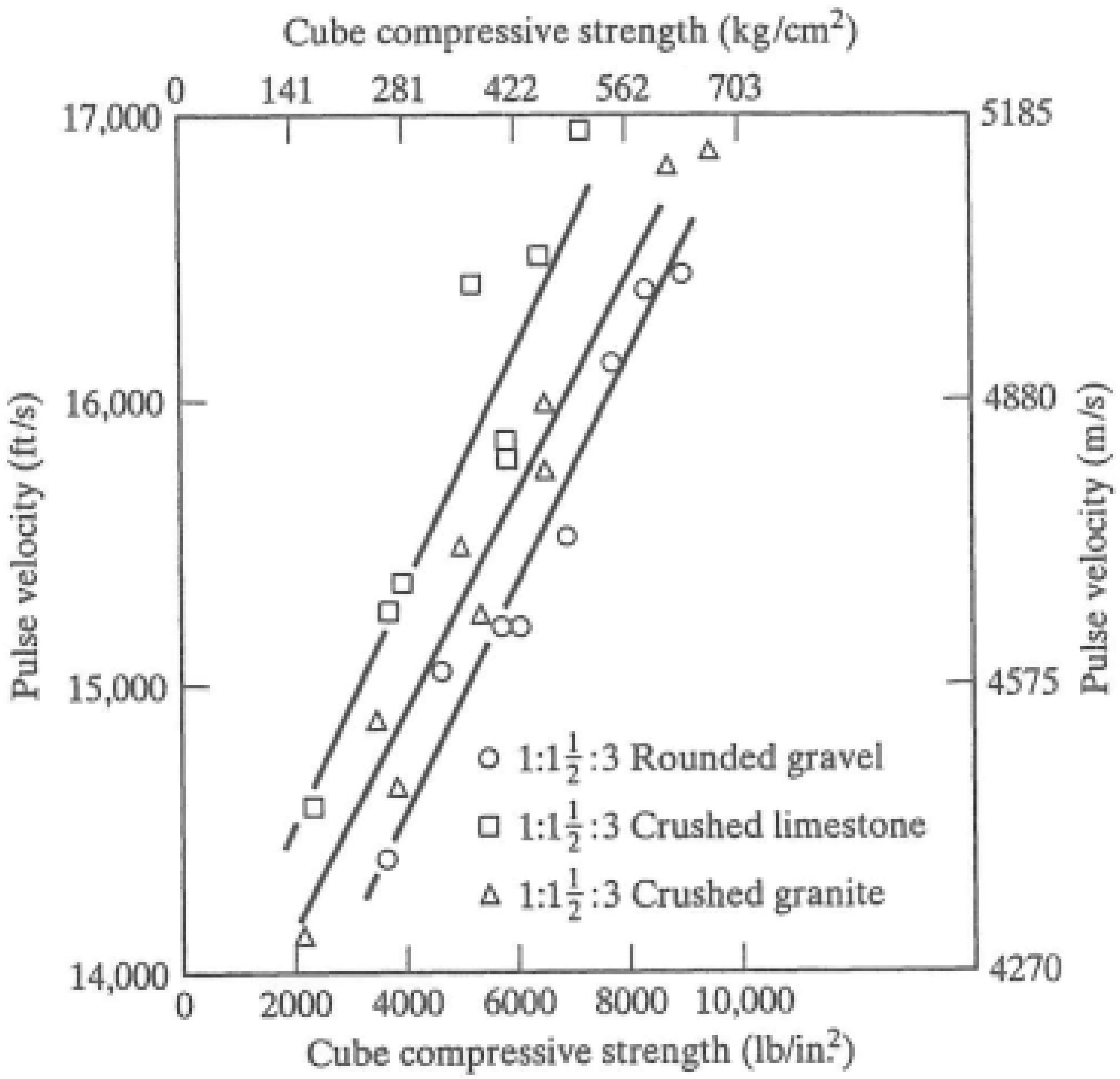

P waves are longitudinal waves
S waves are transverse waves

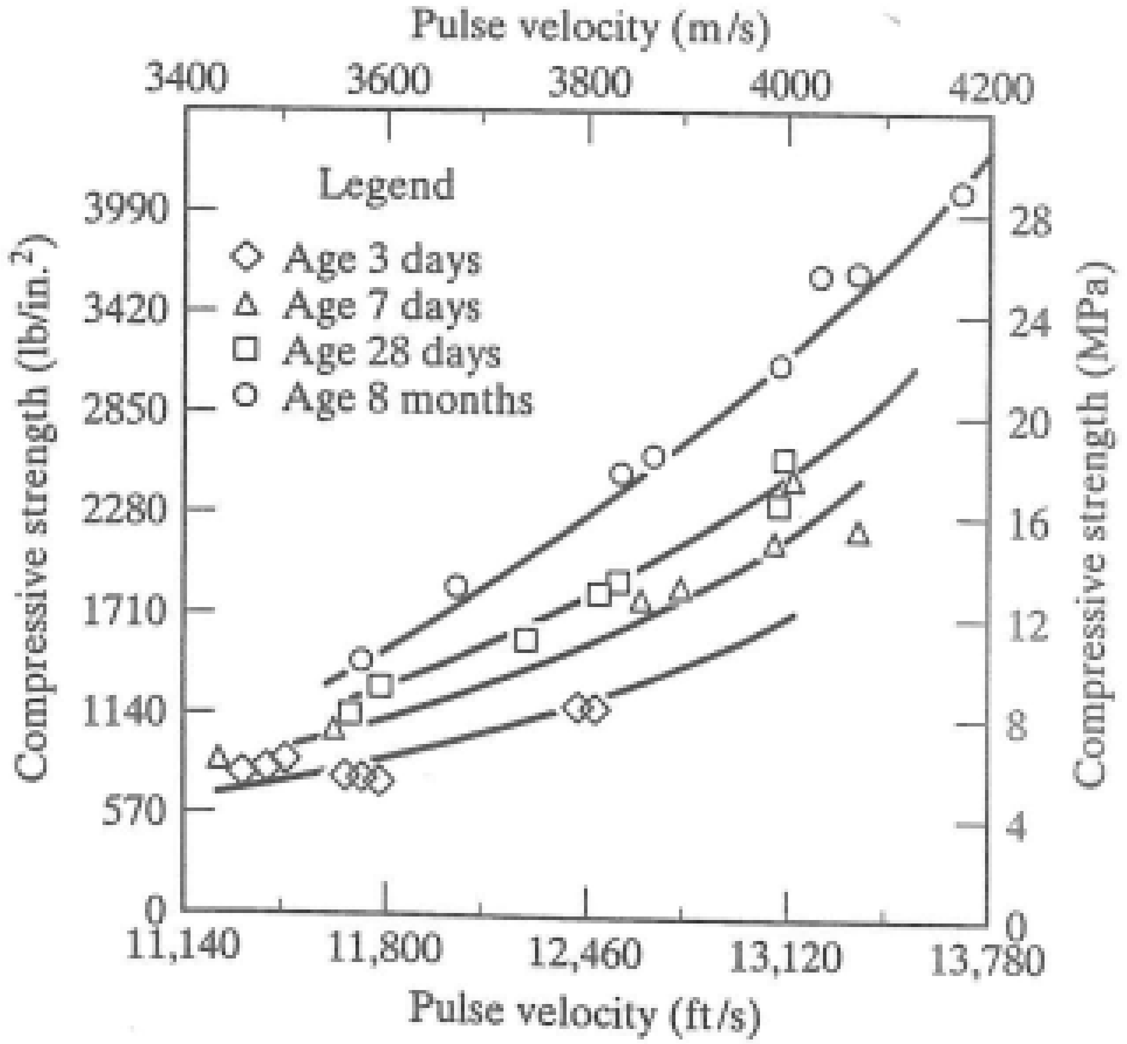
PARAMETERS AFFECTING RESULTS

- Contact surface smoothness
- Path length
- Temperature
- Moisture content
- Reinforcing steel
- Concrete strength



T_T
T_R
Direct
transmission
(a)
T_T
T_R
Semidirect
transmission
(b)
T_T
T_R
Surface transmission
(c)





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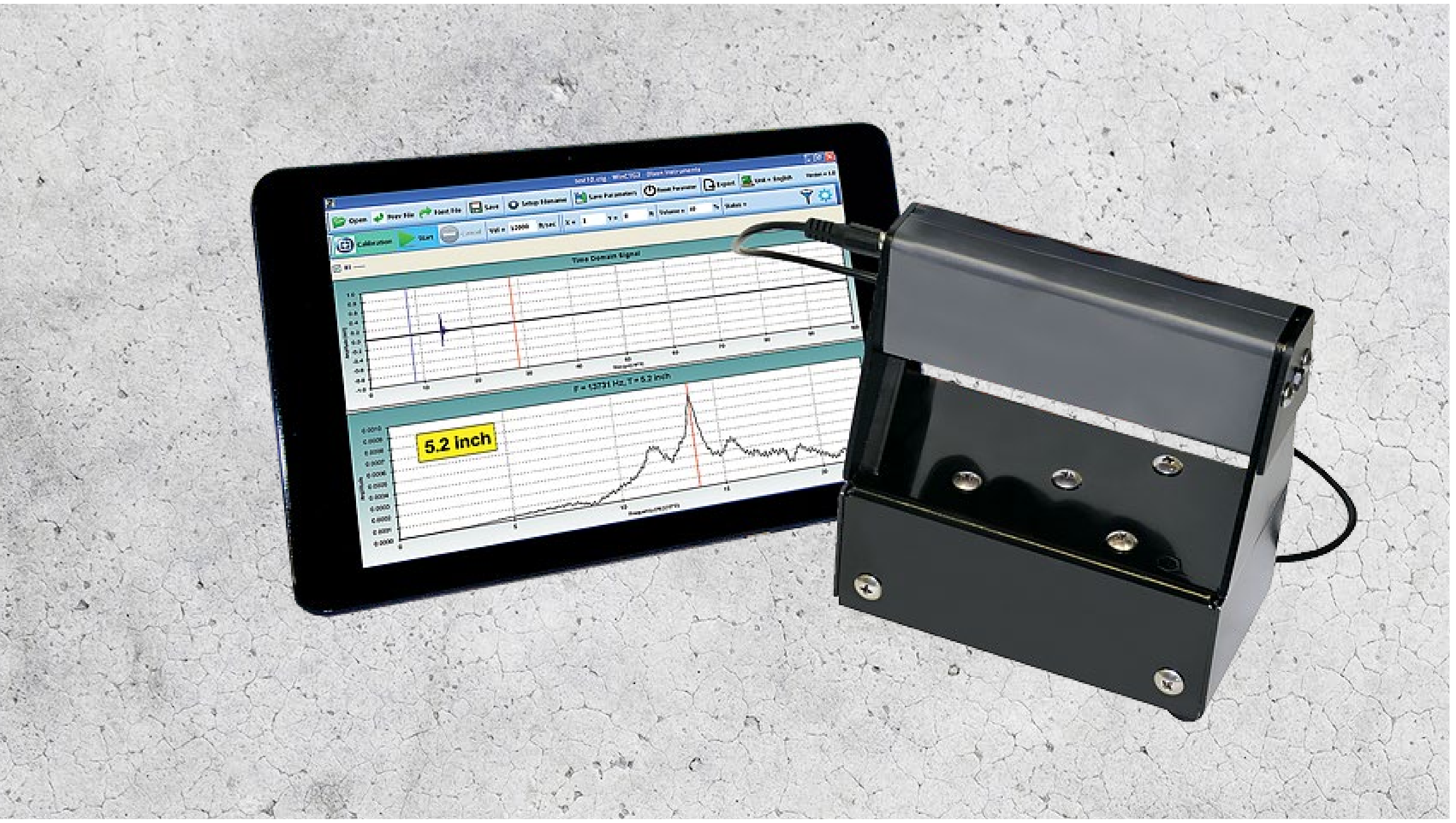


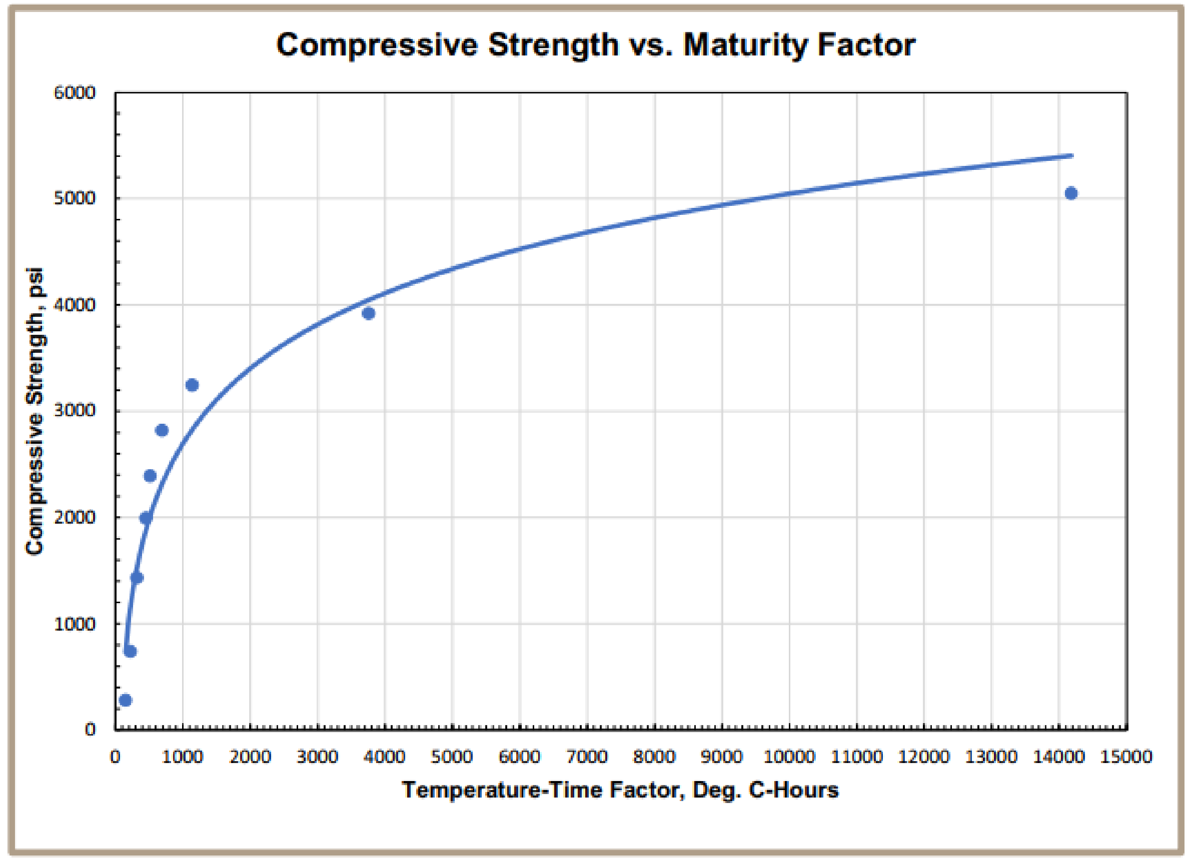
IMPACT ECHO

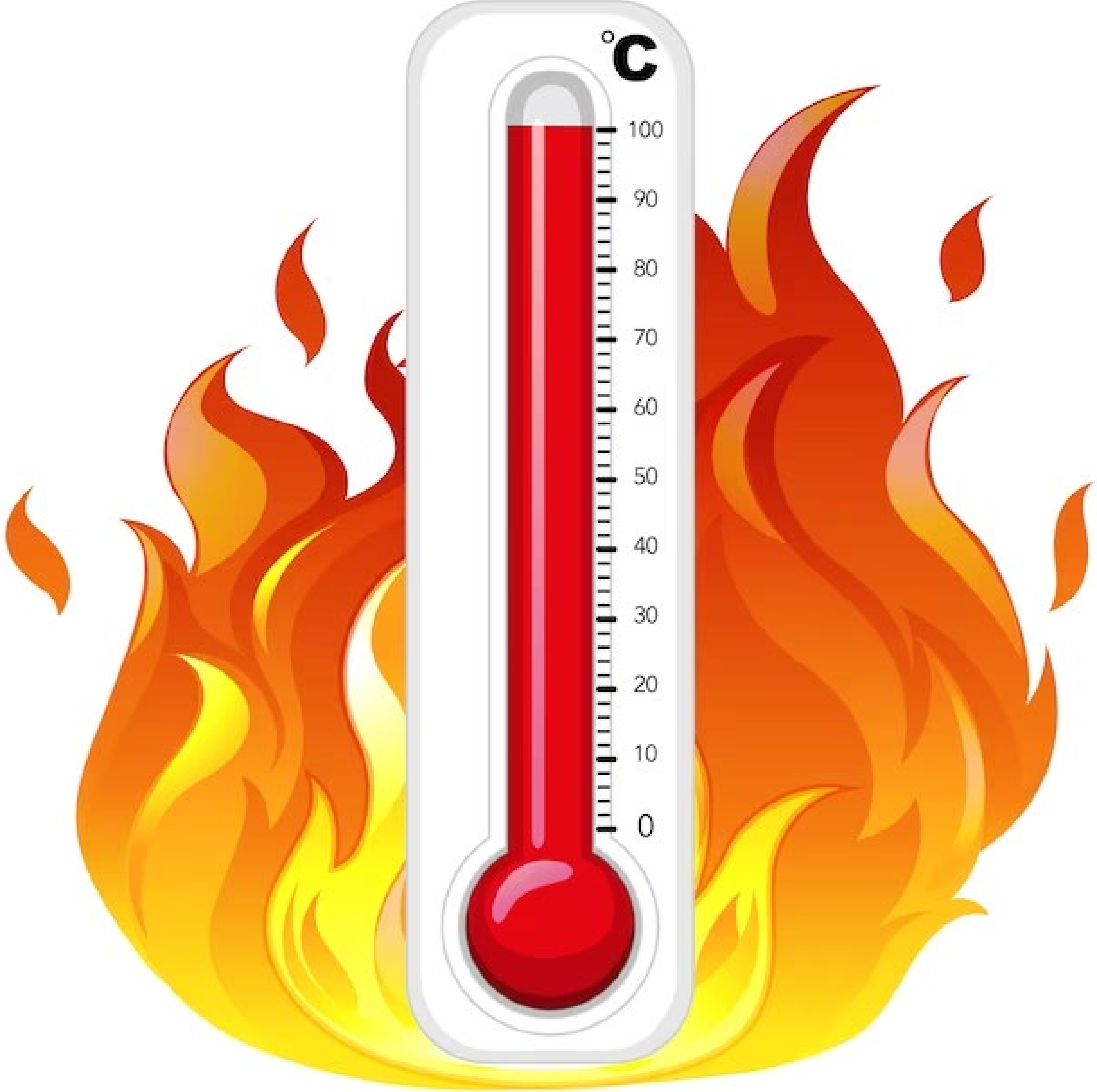
- Concrete surface is mechanically impacted
- P-Waves, S-Waves, and R-Waves
- Member thickness, location of large flaws or discontinuities
- ASTM C1383

MATURITY

- Strength-maturity relationship is developed
- Field temperature history is used to calculate the maturity index
- Maturity index and the strength-maturity relationship is used to estimate concrete strength in the field
- ASTM C1074

Date / Time	Elapsed Time (hrs)	Avg Temp (Deg C)	Avg Maturity (Deg-hrs)	Avg Comp Strength (psi)
2/16/23 2:30 PM	7.92	27.0	147	280
2/16/23 5:30 PM	10.92	24.0	222	739
2/16/23 9:30 PM	14.92	23.0	316	1432
2/17/23 3:30 AM	20.92	22.0	451	1993
2/17/23 6:30 AM	23.92	21.0	514	2391
2/17/23 2:30 PM	31.92	24.0	689	2820
2/18/23 10:00 AM	51.42	22.0	1136	3246
2/23/23 3:30 AM	164.92	20.0	3755	3920
3/16/23 8:00 AM	673.42	21.0	14180	5050





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MATURITY FUNCTIONS

Nurse-Saul Expression

$$M(t) = \sum (T_a - T_o)\,\Delta t$$

Arrhenius Equation

$$t_e = \sum e^{-Q\left(\frac{1}{T_a} - \frac{1}{T_s}\right)}\,\Delta t$$

DATUM TEMPERATURE

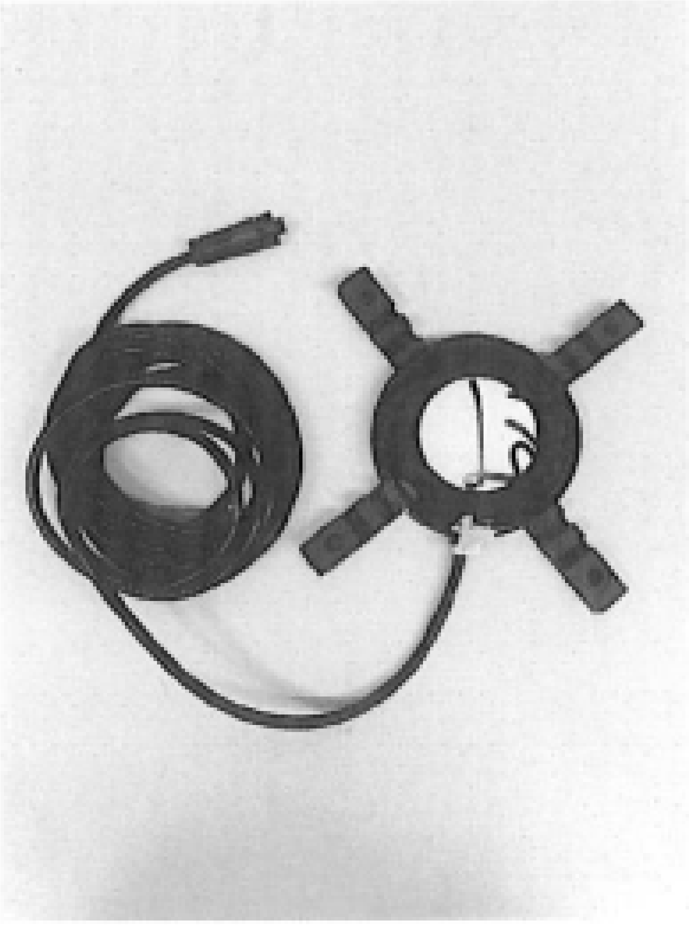
- 41^oF to -4^oF
- 5^oC to -20^oC

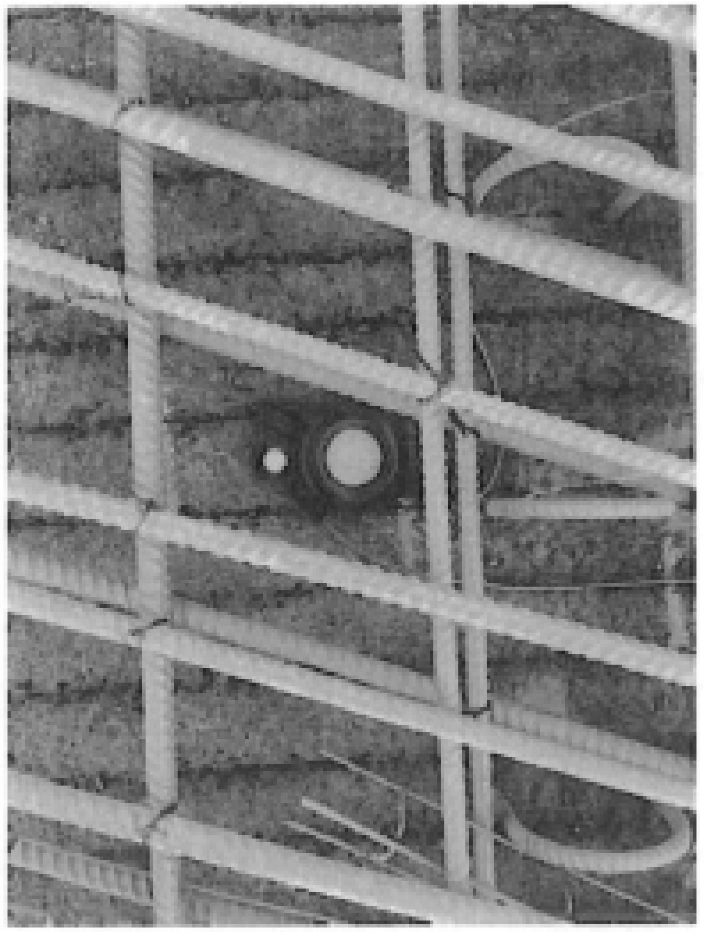
MATURITY LIMITATIONS

- Maturity functions must be developed in the lab prior to using in the field
- New concrete placements (cannot assess existing concrete)
- Must develop datum temperature or activation energy
- Does not account for moisture or humidity conditions during curing
- Not useful if large temperature variations are experienced during curing

CAST-IN-PLACE CYLINDERS

- Special mold and hardware that is left in the concrete member
- Concrete is placed and finished as normal
- Specimens removed from sleeves after curing
- ASTM C873
- Allows for strength specimens without coring
- Does require patching





AASHTO T 412

Standard Method of Test for Real-Time Estimate of In-Place Concrete Strength Using Acoustical Resonance Method

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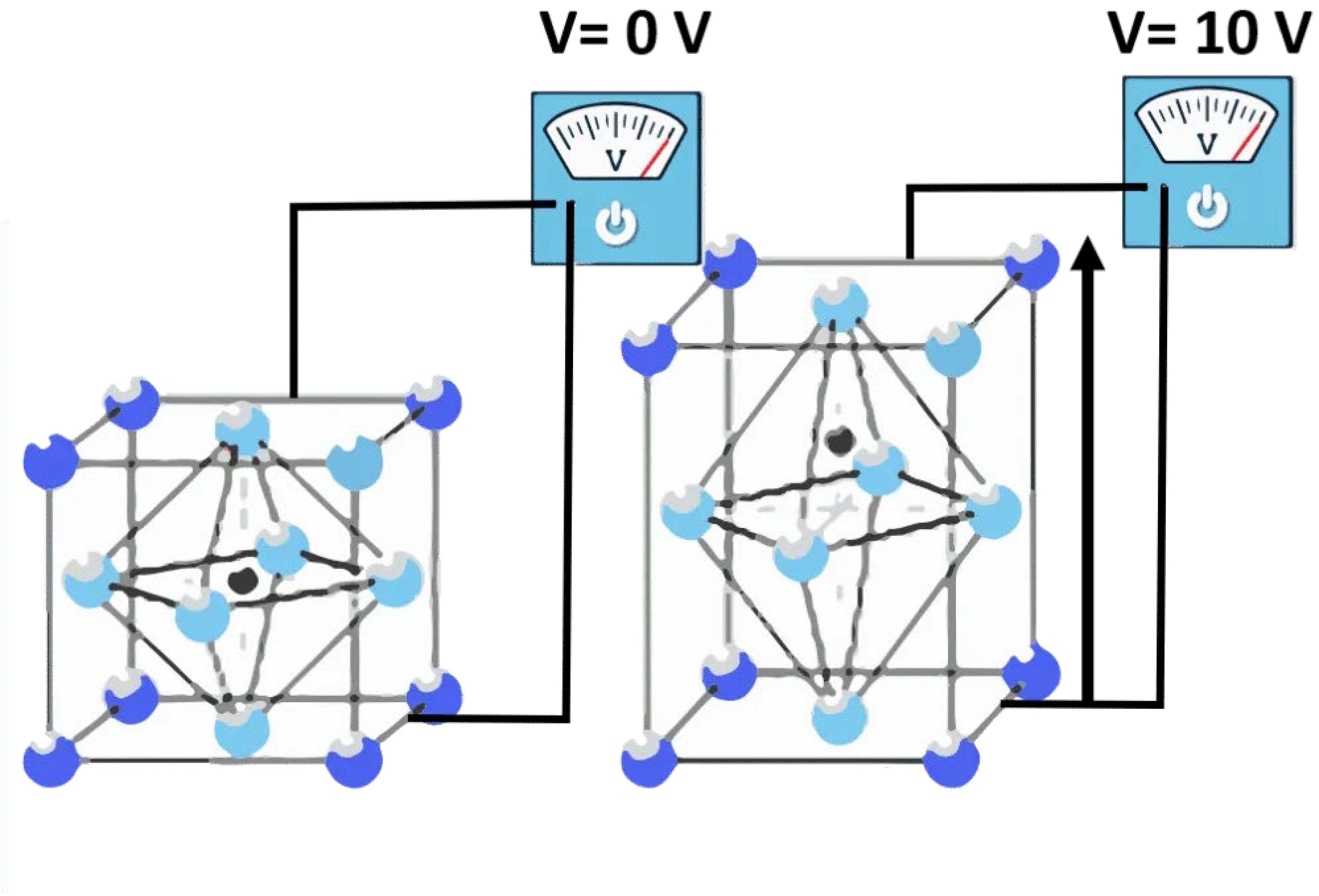
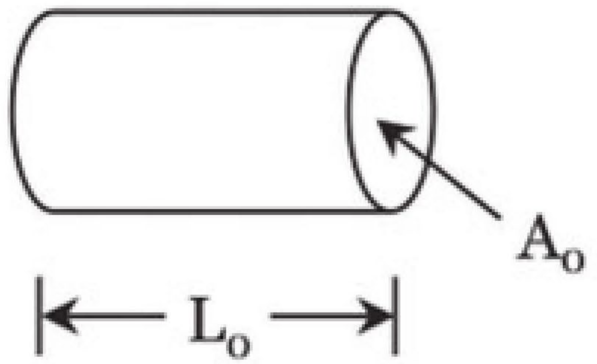
SCOPE OF TEST METHOD

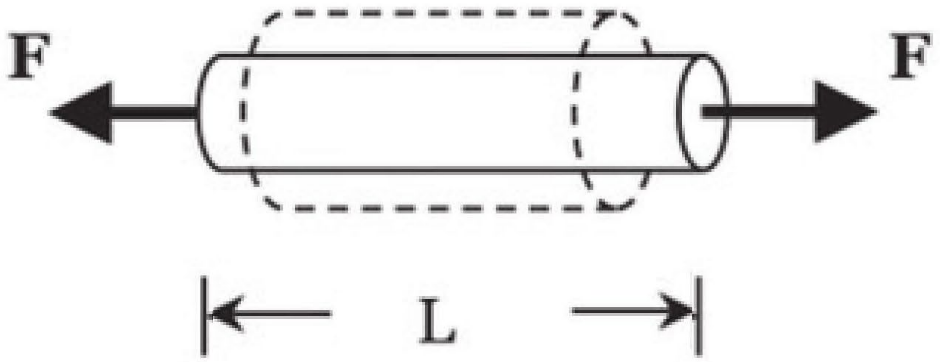
- Estimate in-place mechanical properties of concrete structures
- Specialty designed sensor measures the dynamic modulus of concrete
- Calculates strength of the concrete
- Direct, in-place measurements
- Requires NO specific mix design information


V= 0 V
V= 10 V
V
V

$$E = \frac{stress}{strain}$$



$$E = \frac{F/A}{\Delta l/l_o}$$



Young's Modulus

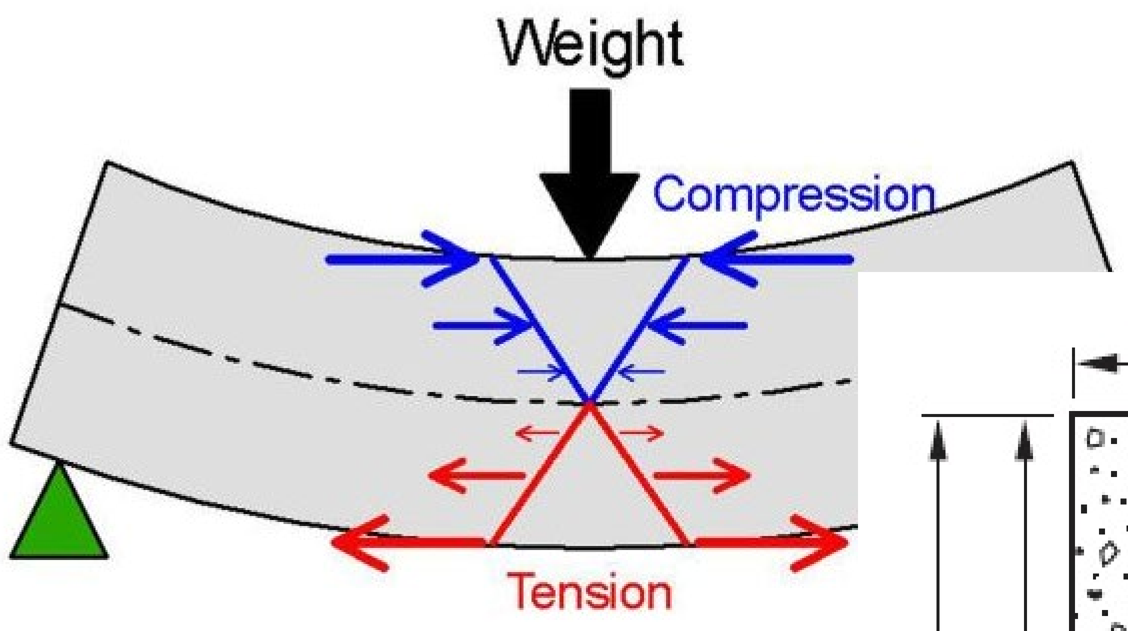
LIMITATIONS

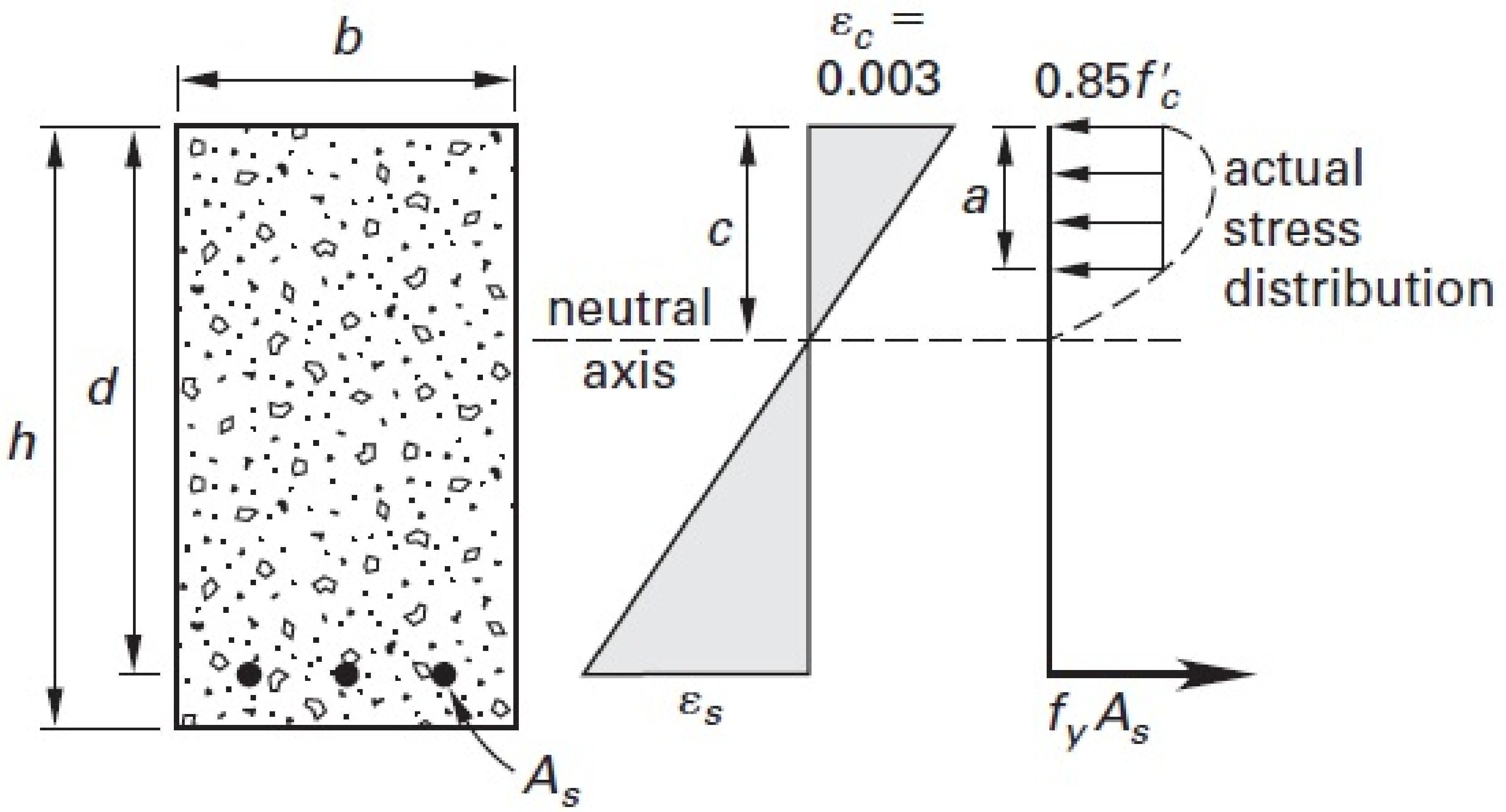
- New
- Limited availability
- Must be placed in fresh concrete
- Acceptance?

SUMMARY OF METHODS

Test Method	ASTM Standard	Accuracy – New Construction	Accuracy – Existing Construction	Ease of Use
Rebound Number	C805	+	+	++
Penetration Resistance	C803	+	+	++
Pullout	C900	++	++	+
Pulse Velocity	C597	++	+	+
Maturity	C1074	++[a]	N/A	+
Cast-in-place cylinder	C873	++	N/A	+
Acoustical resonance	T 412 (AASHTO)	++	N/A	+

WHY IS THIS IMPORTANT?





REFERENCES

- Various ASTM & AASHTO Standards
- Concrete, 2nd Edition, Mindess, Young, Darwin
- ACI 228.1R-19 Report on Methods for Estimating In-Place Concrete Strength
- Non-destructive Testing of Concrete, R. Jones, Cambridge University Press, England, 1962
- Proceedings, Symposium on Nondestructive Testing of Concrete and Timber, I. Facaoaru, Institution of Civil Engineers, London, pp. 23-33

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FOR YOUR ATTENTION

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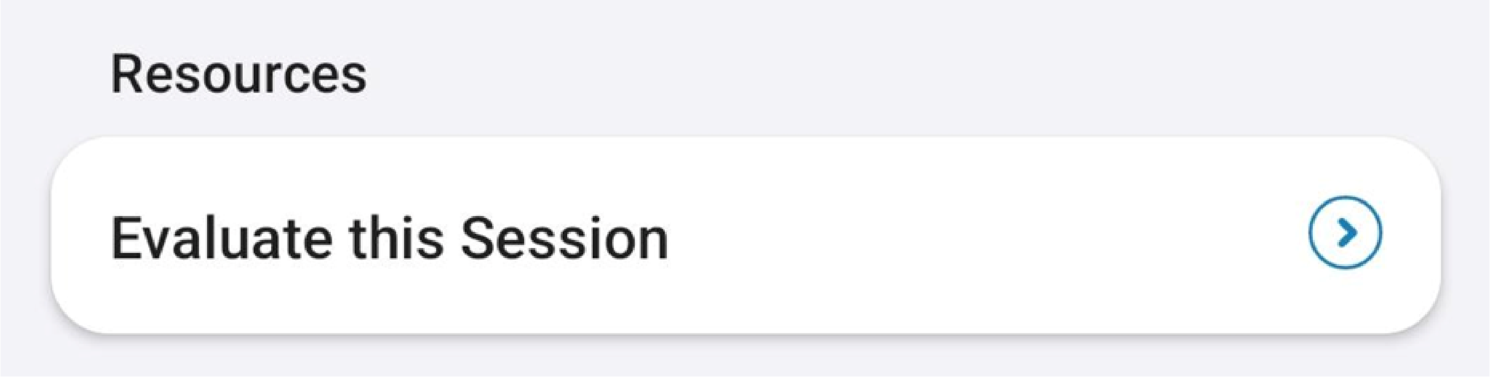
SESSION EVALUATION



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