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D-CRACKING FREEZE-THAW TESTING FOR COARSE AGGREGATE USED IN ON-GRADE CONCRETE

61st Annual

OHIO TRANSPORTATION ENGINEERING CONFERENCE

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Bowser-Morner Testing Laboratories

- Concrete Use On-Grade
- Aggregate Concrete Durability
- Definition of D-Cracking
- D-Cracking Freeze-Thaw Test
- Test Modifications by State DOT
- State DOT Acceptance Limits
- Michigan Round Robin
- Problems With the Test
- Problems With Various Acceptance Criteria
- Ohio DOT D-Cracking Specification
- Needed Research

On-Grade Concrete

Highway Construction/Maintenance

- Concrete Pavements, Structures, Patching
- Hot Mix Asphalt
- Seal Coat/Cover Coat
- Granular Base, Sub Base, Shoulder
- Rip Rap, Erosional Protection

Building Construction

- Concrete Floors and Walls
- Concrete/HMA Driveways and Parking Lots
- Concrete Sidewalks, Curb and Gutters, Medians
- Footings
- Granular Fill
- Drainage Systems

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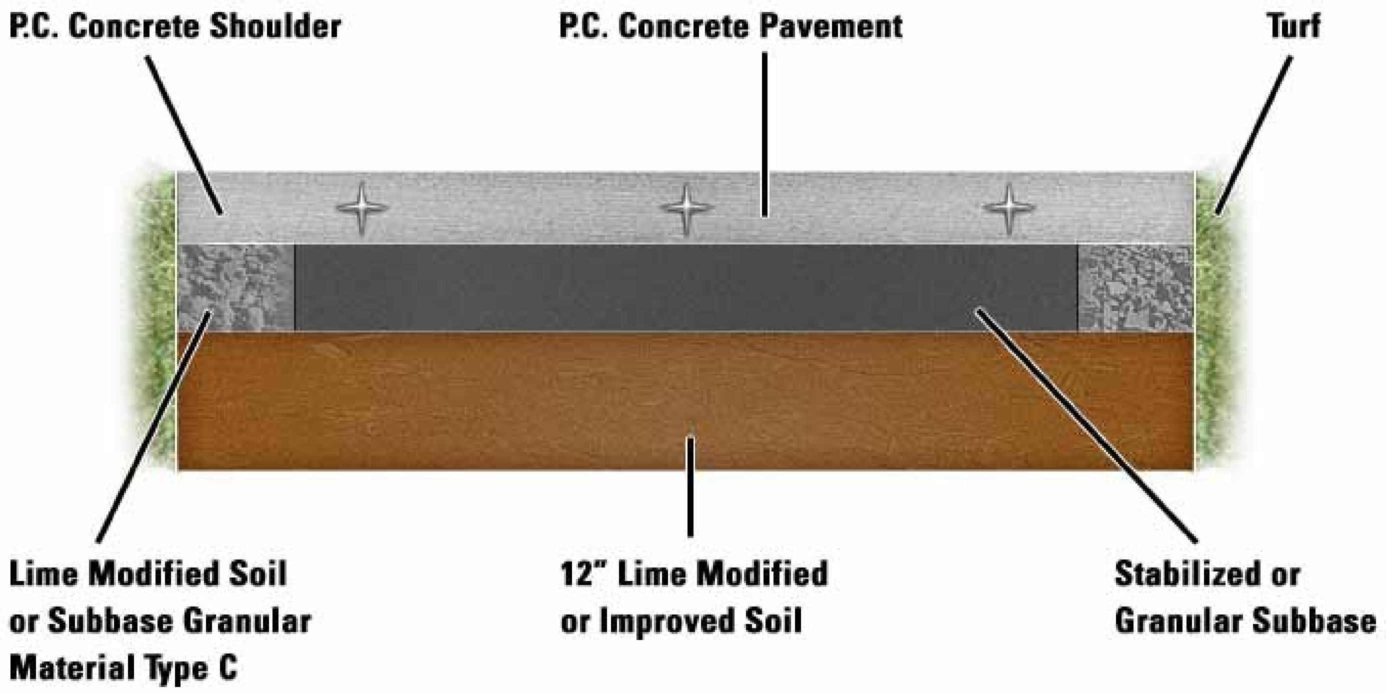
Concrete Pavements



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Extended Life
Concrete Pavements

- Driveways
- Sidewalks
- Parking Lots
- Medians
- Curbs and Gutters
- Patching

Aggregate Quality

- Durability
- Concrete Durability
- Toughness
- Deleterious Particles
- Organic Impurities

AGGREGATE-RELATED DISTRESS EFFECTING CONCRETE DURABILITY

- D-Cracking
- Alkali-Silica Reaction
- Alkali-Carbonate Reaction

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D – CRACKING (DISINTEGRATION CRACKING) OF ON-GRADE CONCRETE

D-Cracking - What is it?

- It is the disintegration cracking of On-Grade concrete due to freeze-thaw failures (cracking) of its aggregate particles and surrounding mortar.

- D-cracking starts in the lower levels of the pavement at cracks and joints and works upward and outward destroying the pavement.

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Factors Causing D-Cracking

- Freeze-Thaw Environment
  Can’t be controlled
- Water
- Susceptible Aggregate
  The best approach to fix the problem

Susceptable Aggregate

Carbonate Rock – Both Limestone & Dolomite
- Large Amount of Critical Size Pores
- Lower Crystalline Strength
- Argillaceous (Clay in the Pore Structure)

Gravel - Containing High Percentage of Total Chert, Lightweight Chert, or Other Deleterious Types of Particles, such as Ironstones, Silty Carbonate, Susceptable Carbonate (as noted above), and Highly Weathered Carbonate.

(D-Cracking is size dependent)

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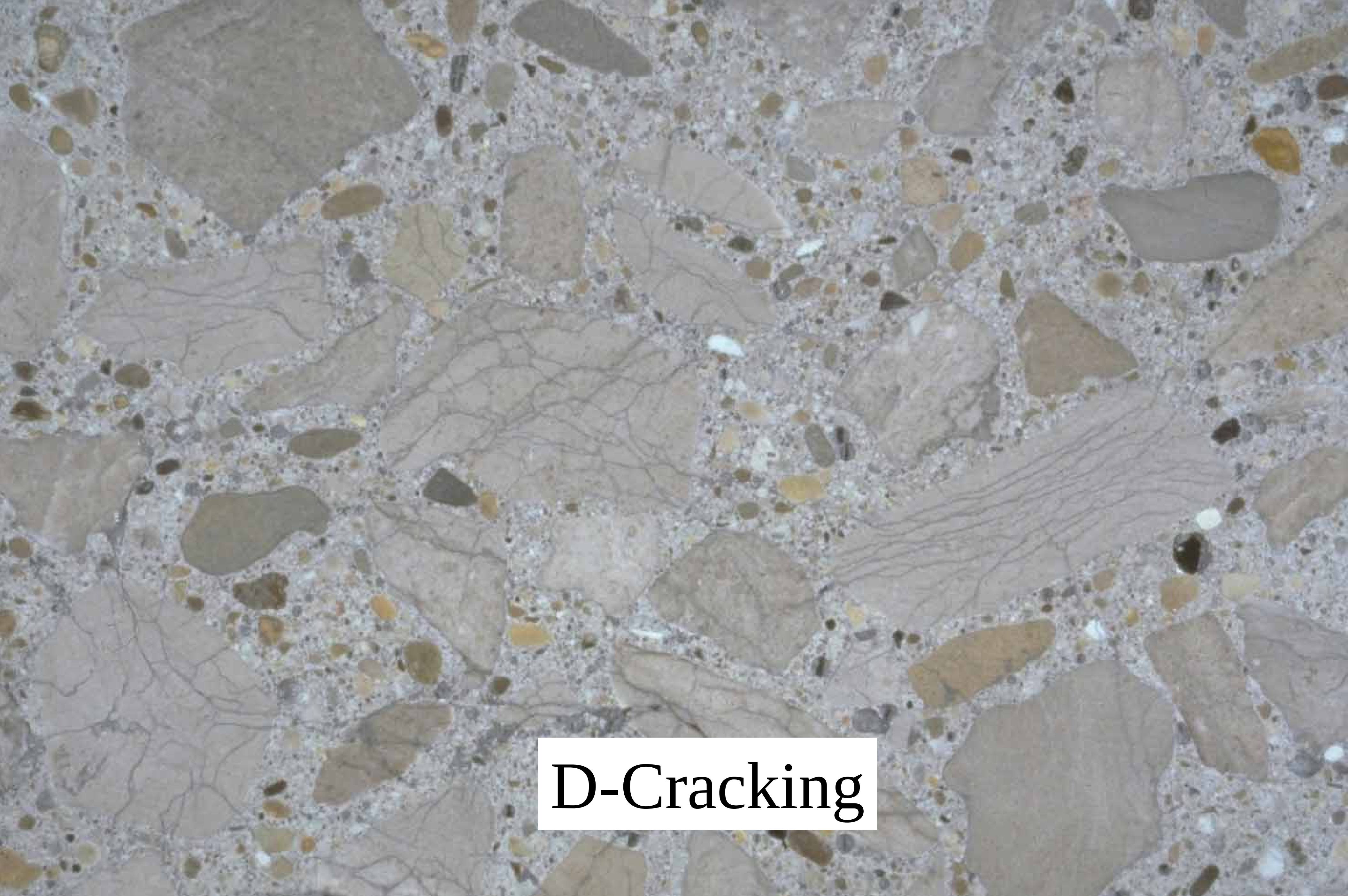
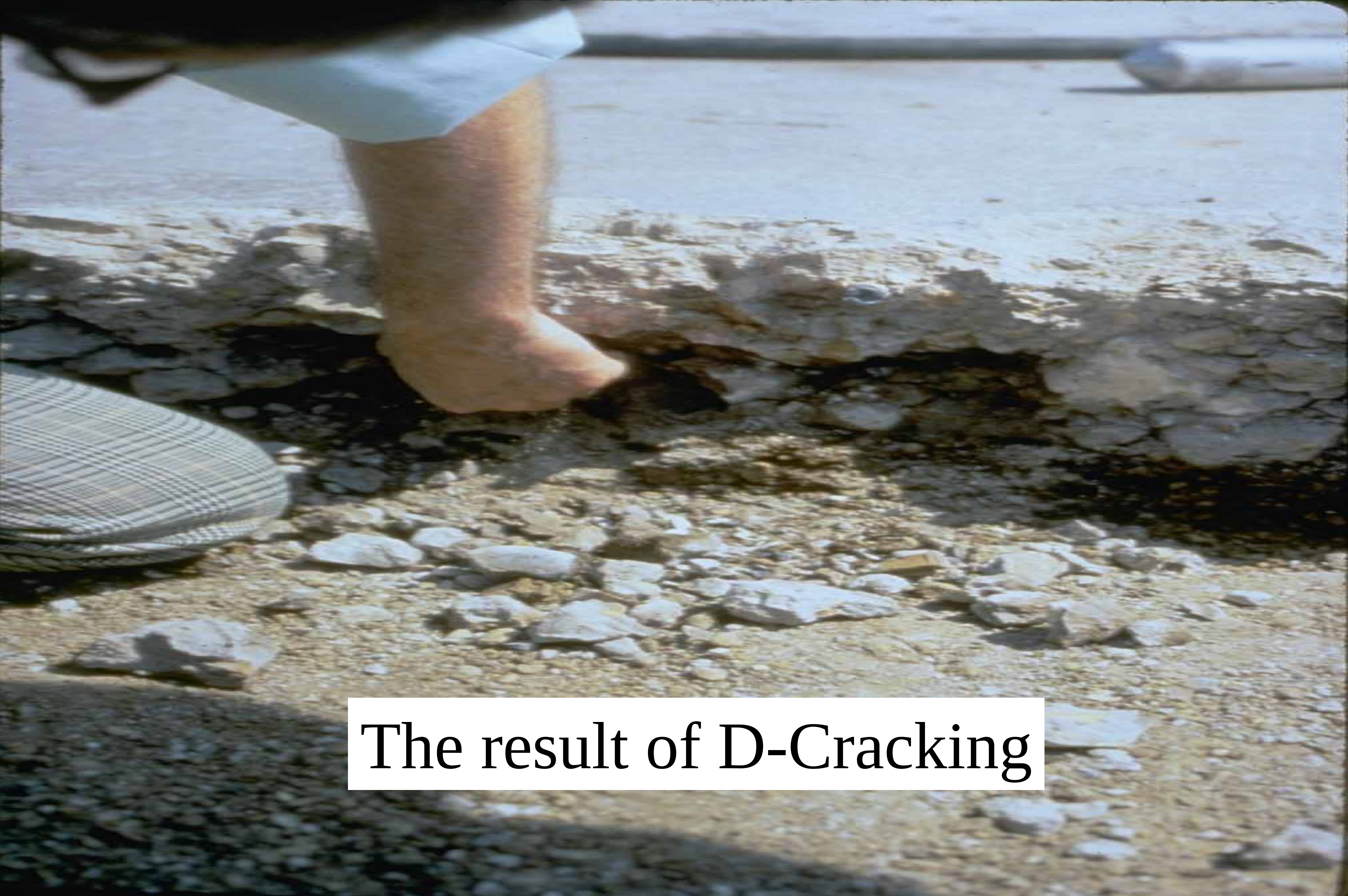
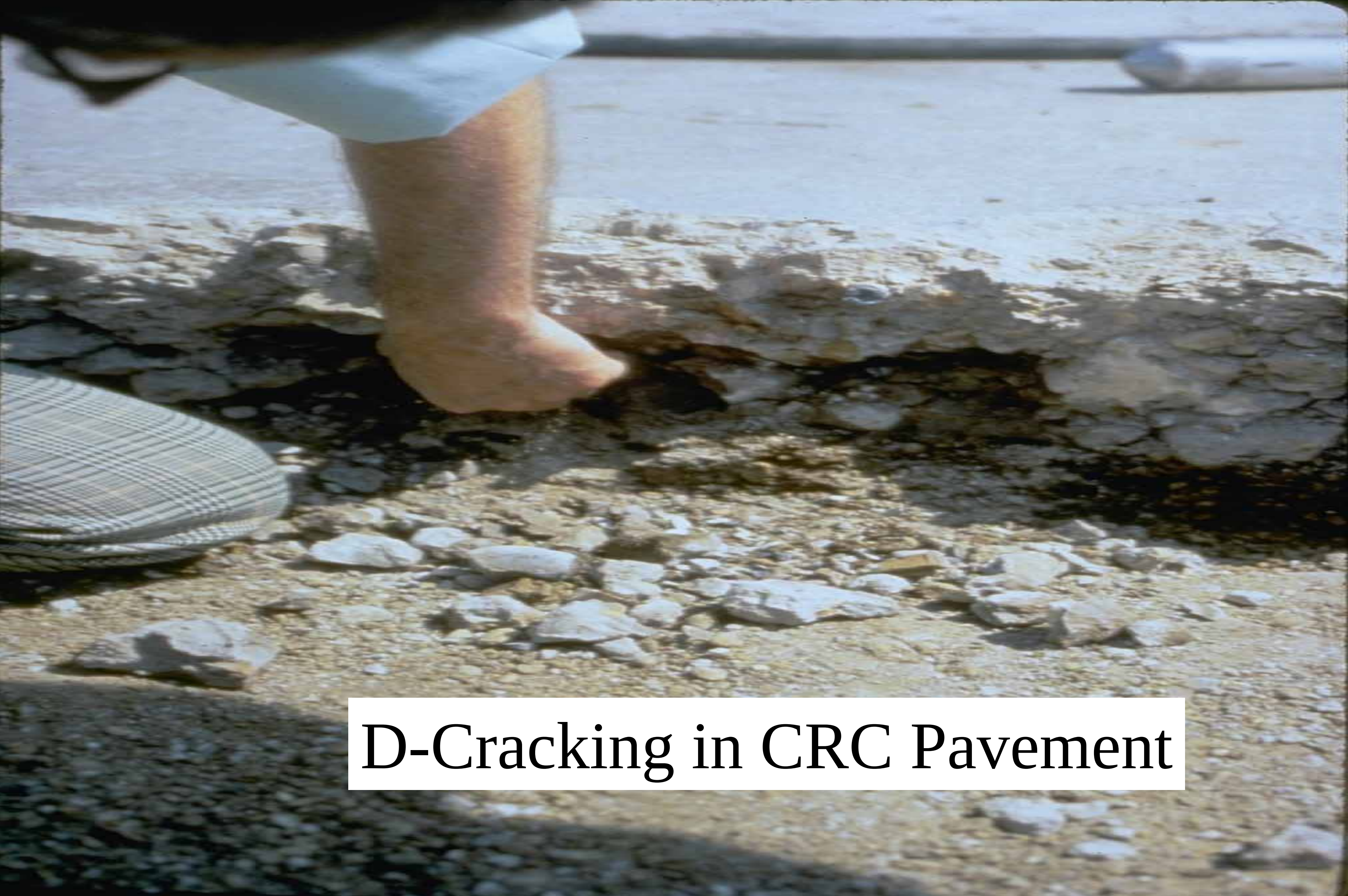

D-Cracking


The result of D-Cracking

D-Cracking in Jointed Pavement


D-Cracking in CRC Pavement



D-Cracking in CRC Pavement

Freeze-Thaw Test

Concrete beam test used to identify aggregate susceptible to D-Cracking

ASTM C 666 / AASHTO T 161
Resistance of Concrete to Rapid Freezing and Thawing

Method A Freeze in Water / Thaw in Water
Method B Freeze in Air / Thaw in Water

Most States used Method B

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D-Cracking Test requires:

- Sample of Coarse Aggregate to be Tested
  (Standard Grading or As Sampled)
- Standard Sand
- Standard Cement
- Standard Admixtures

  * Note: If Using Synthetic Air Entrainment Admixtures, Problems Have Been Noted.

Material is collected. Aggregate may be run as-is or fractionalized and recombined to a specific gradation.

Both the Test Coarse Aggregate and the Standard Sand (Fractionated or As-Is) are Soaked for 24 Hours Prior to Batching.

Aggregate to be Tested and the Standard Ingredients Are Batched as per:

ASTM C 192C / AASHTO R 39

“Making and Curing Concrete Test Specimens in the Laboratory”

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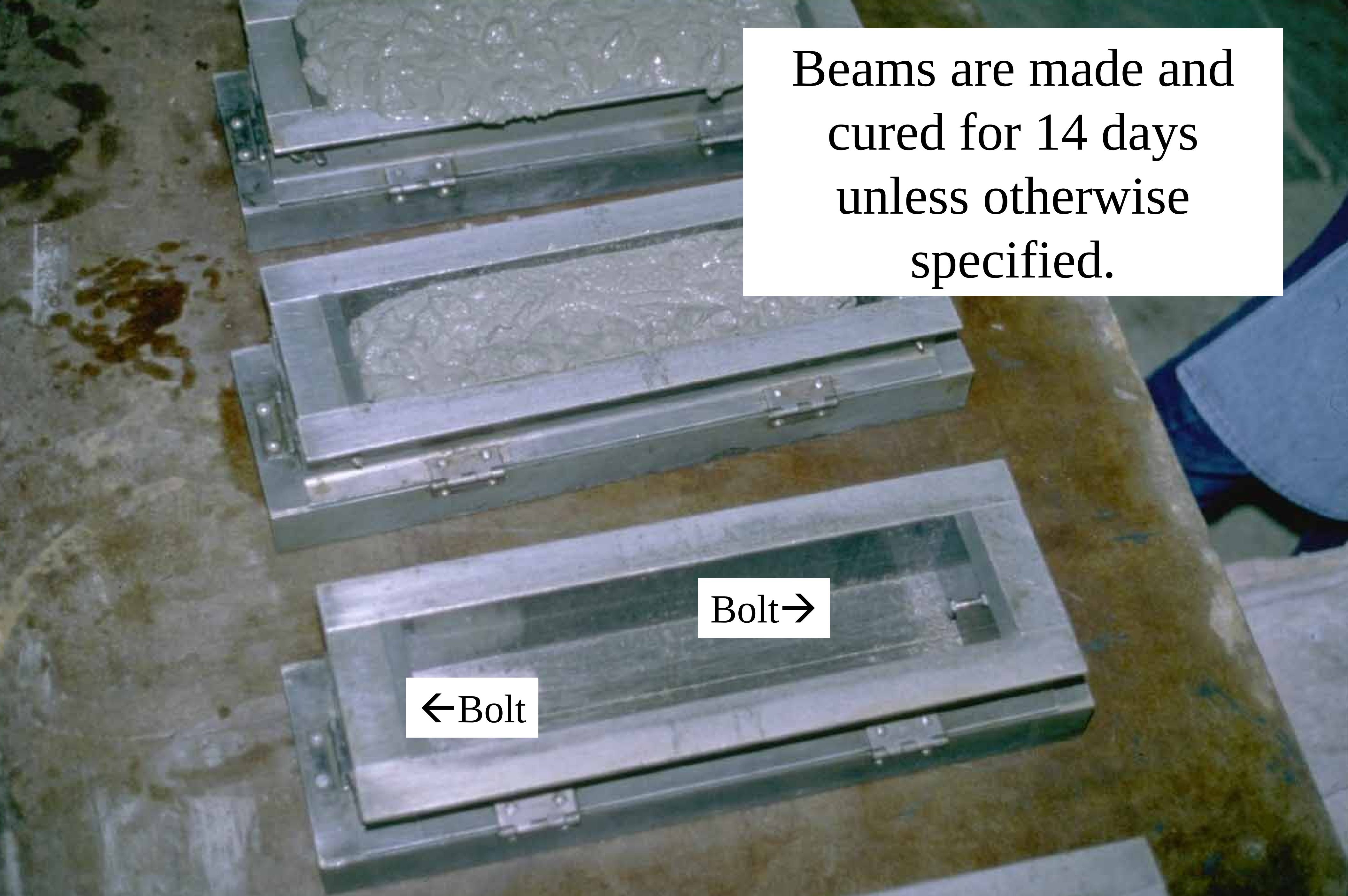
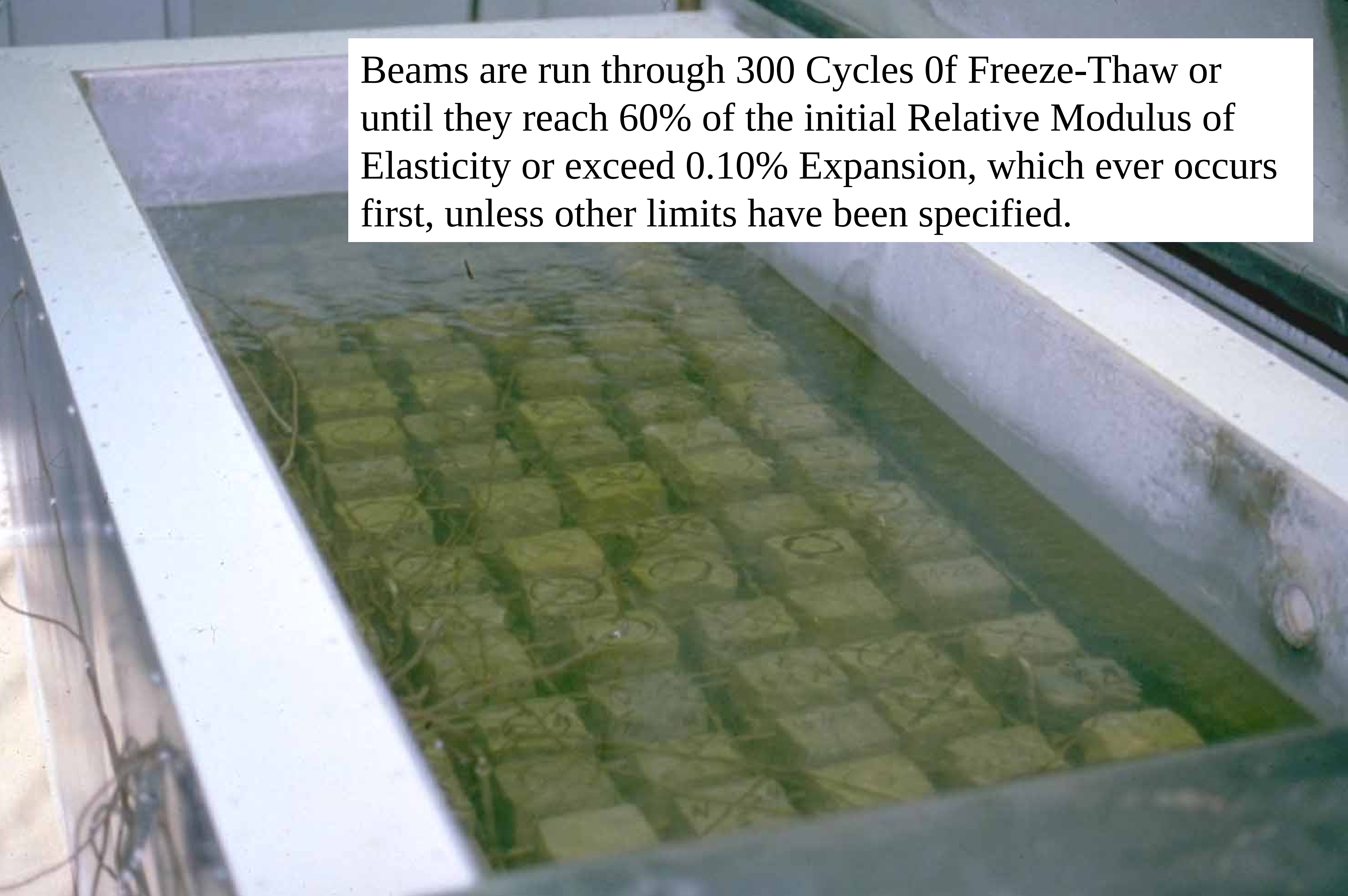
Check the Concrete Mixture for:

- Slump
- Air Content
- Temperature
- Strength


Beams are made and cured for 14 days unless otherwise specified.
Bolt→
←Bolt

Beams are run through 300 Cycles 0f Freeze-Thaw or until they reach 60% of the initial Relative Modulus of Elasticity or exceed 0.10% Expansion, which ever occurs first, unless other limits have been specified.



Beam Criteria

- Number of Beams per Sample 3 or More
- Beam Width/Depth Not < 3” Nor > 5”
- Beam Length Not < 11” Nor > 15”
- Beam End Dimensions 3 Times Nominal Maximum Size of Coarse Aggregate
- Machined Head Bolts – Placed at Each End of Beam to Facilitate Length Measurements

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Freeze-Thaw Cycling

- Cycle Temperature From 40 Degrees F to 0 Degrees F and Back = 1 Cycle
- Cycle Time Not Less Than 2 Hours nor More Than 5 Hours (AASHTO 4)
- Specific Temperature Regiments for Each Beam (Computer-controlled F-T Chamber)

- Beams Are Read During The Thaw Cycle (40 Degrees F)

- No Moisture Loss

- Illinois Uses Tempering Tank And Reads At 70 Degrees F

Methods to Evaluate Beams

- Measure/Calculate Relative Dynamic Modulus of Elasticity (Pc)
  - Forced Resonance
  - Impact Resonance

- Calculate Durability Factor Based on Pc

- Measure % Expansion

Measure / Calculate Relative Dynamic Modulus of Elasticity (Pc)

- Forced Resonance
- Impact Resonance


GrindoSonic
8.28"


NON DESTRUCTIVE MATERIALS TESTING
1767.2 Hz
GrindoSonic
Mk5 "Industrial"
IMPACT
FRONT
1081-1082
8/21/98
PICKUP

Calculation of Relative Dynamic Modulus of Elasticity

$$Pc = (n_1^2 / n^2) \times 100$$

Pc = Relative Dynamic Modulus of Elasticity (%), After C Cycles

n = Fundamental Transverse Frequency at 0 Cycles

n_1 = Fundamental Transverse Frequency at C Cycles

Calculate Durability Factor (DF) From Relative Dynamic Modulus of Elasticity (P)

$$DF = PN/M$$

where:

DF = durability factor of the test specimen

P = relative modulus of elasticity at N cycles

N = # of cycles at which P reaches specified minimum value or specified # of cycles

M = specified # of cycles for the test

Measurement of % Expansion

Beams are measured at intervals not exceeding 36 cycles for expansion

Length changes are measured to 1/10000 of an inch

Length changes are plotted in % expansion on a graph

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Calculation of % Expansion

Beam Length Change in Percent

$$Lc = (l_2 - l_1) / lg \times 100$$

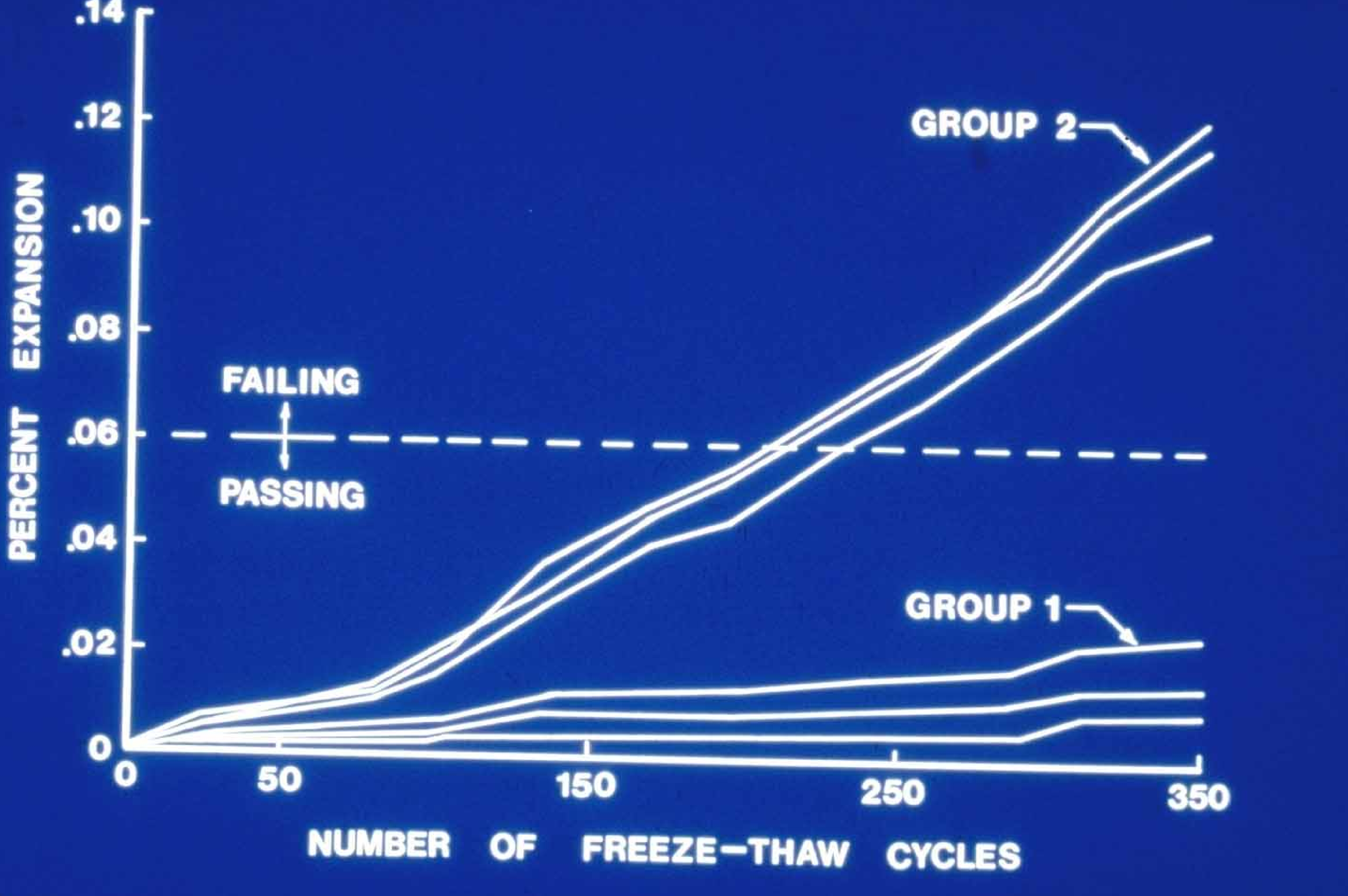
where:

Lc = length change (%) of specimen after C cycles

l_1 = length reading at 0 cycles

l_2 = length reading at C cycles

lg = effective gage length from C 490



.14
.12
.10
.08
.06
.04
.02
0
PERCENT EXPANSION
GROUP 2
FAILING
PASSING
GROUP 1
0
50
150
250
350
NUMBER OF FREEZE-THAW CYCLES

Test Modifications by State DOT

Conditioning of Aggregate by State DOT

- Illinois	Soaking 24 Hours
- Indiana	Soaking 24 Hours
- Kentucky	Soaking 24 Hours
- Michigan	Vacuum Saturation
- Missouri	Soaking 24 Hours
- Ohio	Soaking 24 Hours

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Beam Criteria by State DOT

	# of Beams	Beam Length
Illinois	3	3”x 4”x 15”
Indiana	3	3”x 4”x 15”
Kentucky	2 or 3	3”x 4” x 16”
Michigan	9	3”x 4”x 15.5”
Missouri	3	3.5”x 4.5”x16.5”
Ohio	4/6	3”x 4”x 15”

Scheduled Beam Curing by State DOT

Illinois	14 Days
Indiana	14 Days
Kentucky	14 Days
Michigan	14 Days
Missouri	35 Days
Ohio	14 Days
Iowa	90 - 120 Day
Kansas	90 Days

Required Number of Freeze-Thaw Cycles by State DOT

Illinois	350 cycles
Indiana	350 cycles
Kentucky	350 cycles
Michigan	100/300 cycles
Missouri	300 cycles
Ohio	350 cycles

Number of Freeze-Thaw Cycles Per Day By State DOT

Illinois	8/Day
Indiana	8/Day
Kentucky	10/Day
Michigan	8/Day
Missouri	8/Day
Ohio	12/Day

State DOT Acceptance Criteria

Illinois	<.060% Expansion(20 year)
Indiana	<.060% Expansion
Kentucky	<.060% Expansion
Michigan	<.060% Expansion-100 cycles
Missouri	DF 75% Minimum
Ohio	Area Under the Curve- Maximum 2.05

Michigan Round Robin

Illinois

Kansas

Michigan

Ohio

State DOT Ratings

State	Aggregate Source A	B	C	D	Notes
Illinois	Fail	Fail	Pass	Fail	(1)
Kansas	Fail	Fail	Pass	Pass	(7)
Michigan	Pass	Fail	Pass	Fail	(2,6)
Minnesota	Pass	Fail	Pass	Fail	(3)
Ohio	Fail	Fail	Pass	Pass	(4,5)

Problems

- Test Procedure / Equipment

- Acceptance Criteria

Problems With Test Procedure / Equipment

- Synthetic Air Entrainment Admixture

- Equipment Malfunction
  * Freeze-Thaw Chamber
  * Length Comparator
  * Forced Resonance/Impact Resonance Apparatus

- Distress From Pop-outs, Expansive Particles, Etc.

- Batching Problems

- As-Graded Sample

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Solution –

Inspect Beam/s for Pop-out or Expansive Particle

Cut Any Beam/s Which Exceed The Acceptance Criteria

Inspect The Beam/s For Cracked Aggregate

Do Not Consider Any Results In Which A Beam Or Beams Do Not Show Significant Cracking Of The Aggregate Particles or Show a Pop-out or Expansive Particle Which Affects a Bolt

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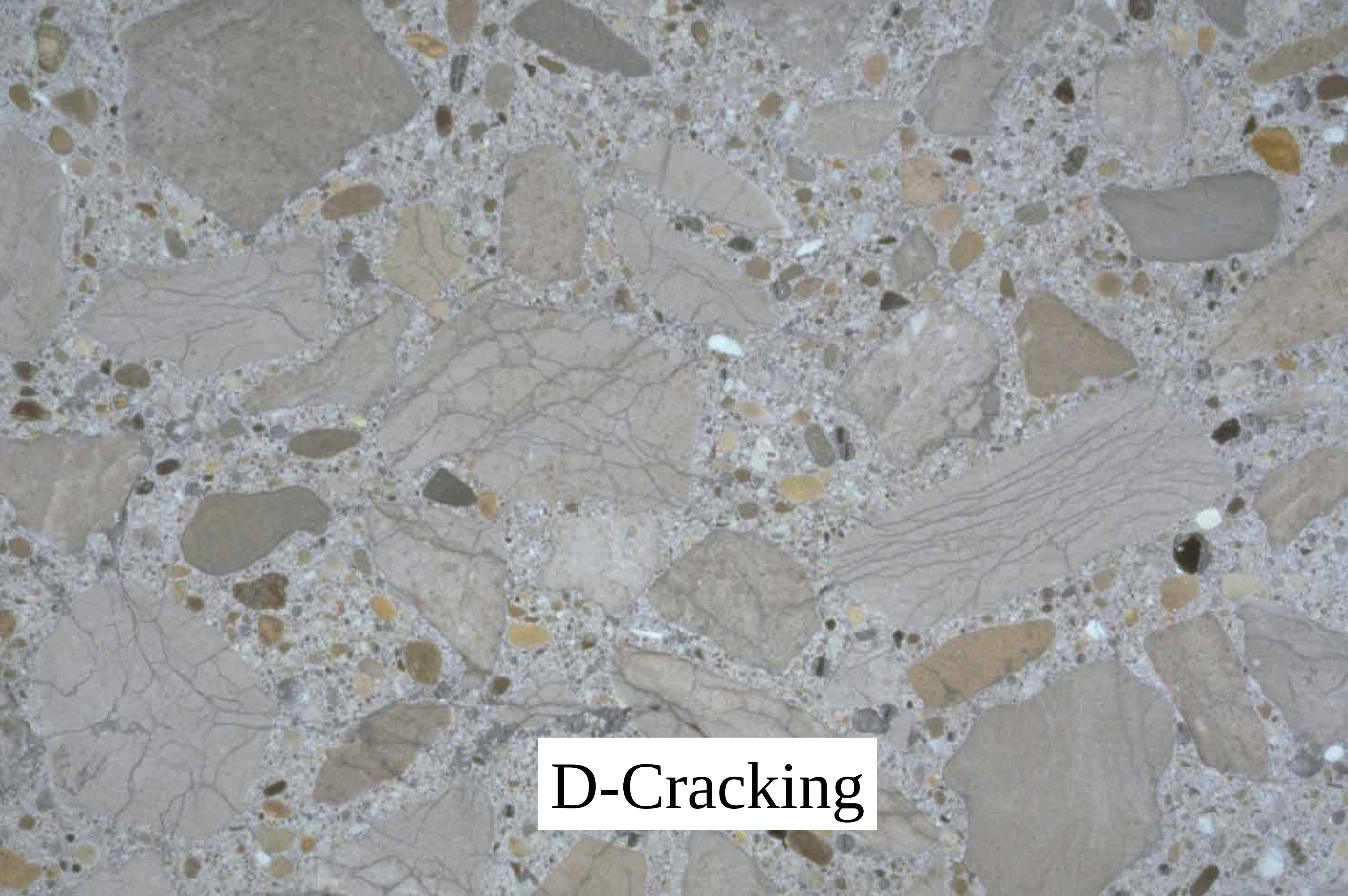

D-Cracking

Acceptance Criteria Problems

Problems -

* Equipment Change
  - New Freeze-Thaw Chamber
  - Compressor, Computer/Software, Etc.

* Over-Conservative Acceptance Criteria

* Method of Measurement Does Not Correlate With Other Methods of Measurement

* Error Built Into Acceptance Criteria During Development

Ohio DOT
D-Cracking Specification

- Uses ASTM C 666 Method B 350 Cycles

- Measures % Expansion and Calculates
  Area Under The Curve – Max. 2.05

- Developed From Two Studies Conducted in
  1974 and 1979 by ODOT

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Industry Concerns

- Different Freeze-Thaw Equipment Presently Being Used by ODOT

- Aggregate Identified as Showing No Sign Of D-Cracking But Exceeded Area Under the Curve in 1979 Study and Vice-Versa

- Conservative Specification

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Conservative Specification?

- Area Under the Curve Max. 2.05 Equates to 0.012% Expansion Assuming a Straight-Line Relationship Using 1979 Report Data

- Compared to the Following State Specifications, ODOT Appears to be Very Conservative

Illinois	0.060% Expansion
Indiana	0.060% Expansion
Kentucky	0.060% Expansion

ODOT / OAIMA
Freeze-Thaw Committee
2007

Needed Research

- Effect of % Entrained Air / Strength / Etc. on D-Cracking Results
- Effect of Gradation Variance on D-Cracking Results
- Development of Visual Standards for Comparison of % Cracked Particles to Freeze-Thaw Results (Forensic Procedure)

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