Relative Importance of Repair Material Properties
Then and Now

Jim McDonald
McDonald Consulting
Clinton, MS
jmcdonald14@comcast.net

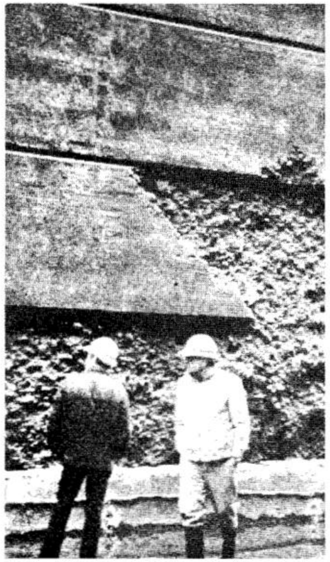
ICRI Convention
Fall 2013

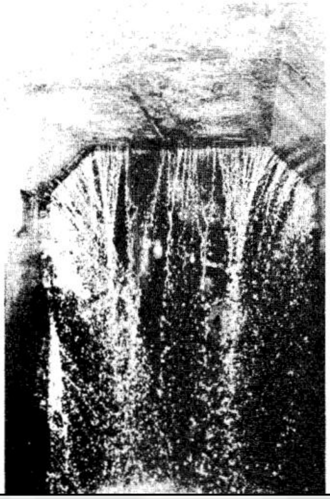
A Look Back

Fort Peck Spillway - 1938

Melvin Price Lock and Dam

US Army Corps of Engineers





REPAIR, EVALUATION, MAINTENANCE, AND REHABILITATION RESEARCH PROGRAM

TECHNICAL REPORT REMR-CS-2

THE CONDITION OF CORPS OF ENGINEERS CIVIL WORKS CONCRETE STRUCTURES

by

James E. McDonald, Roy L. Campbell, Sr.

Structures Laboratory

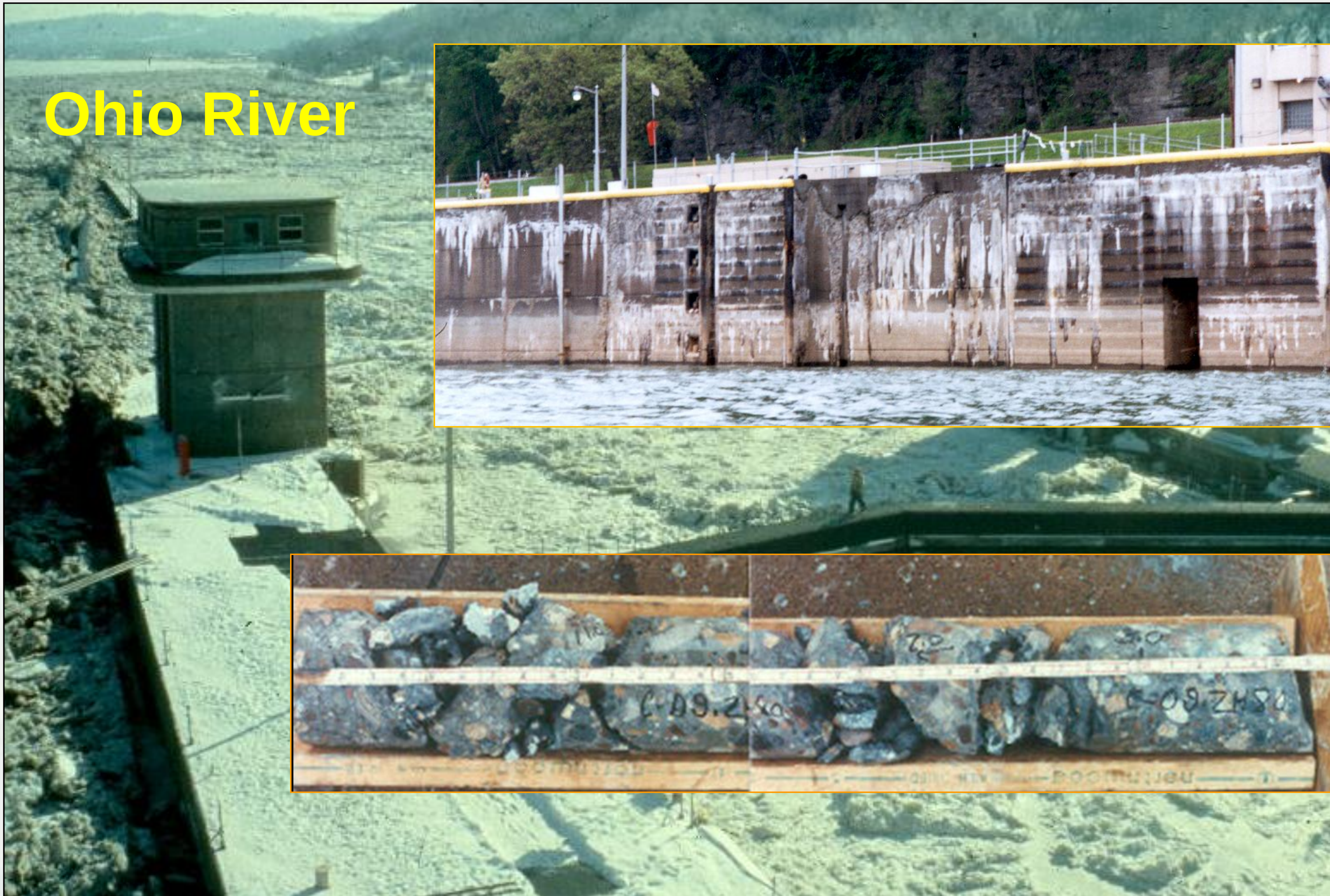
DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

536 dams and 260 lock chambers;
60% were over 20 years age;
>40% were over 30 years age ; and
~50% would reach 50-year design life by 2000.

April 1985

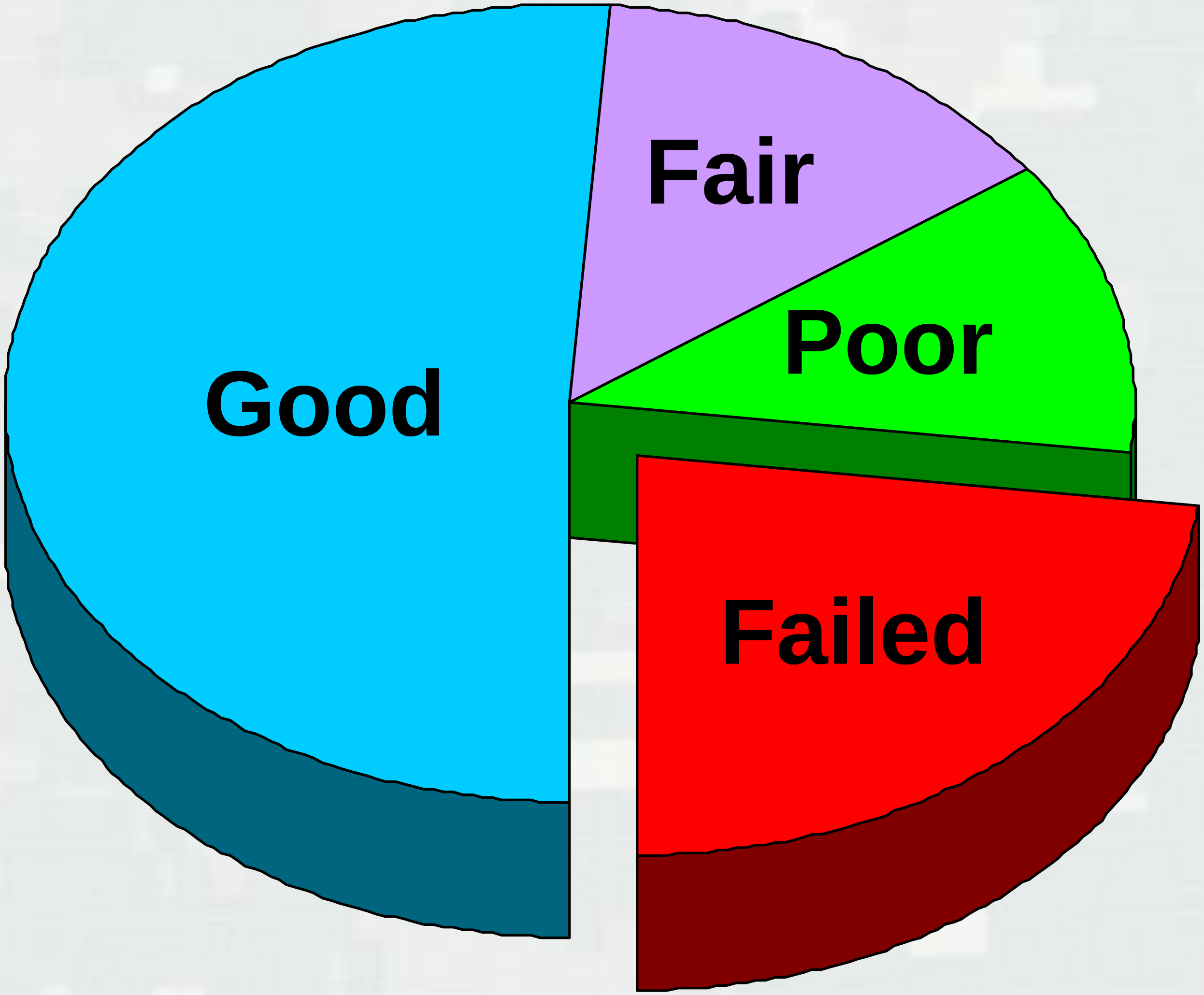
Final Report

Severe Exposure Conditions



Repair Material Performance

http://wri.usace.army.mil/remr/technical_reports/concrete/REMR-CS-2.pdf



“Selecting Repair Materials”

“Some Important Material Properties That Should Be Considered”

By James Warner
Consulting Engineer
Mariposa, California

Concrete Construction
October 1984

http://www.concreteconstruction.net/concrete-articles/selecting-repair-materials.aspx

Repair Material Considerations

"While both bond and compressive strength values are frequently provided by material suppliers, characteristics such as the material's dimensional stability, stiffness and capability of transmitting fluids, vapors and electrical current can be of equal or greater importance."

"To match properties of the base concrete as closely as possible, portland cement concrete or similar cementitious compositions are frequently the best choices for the repair material. But not always."

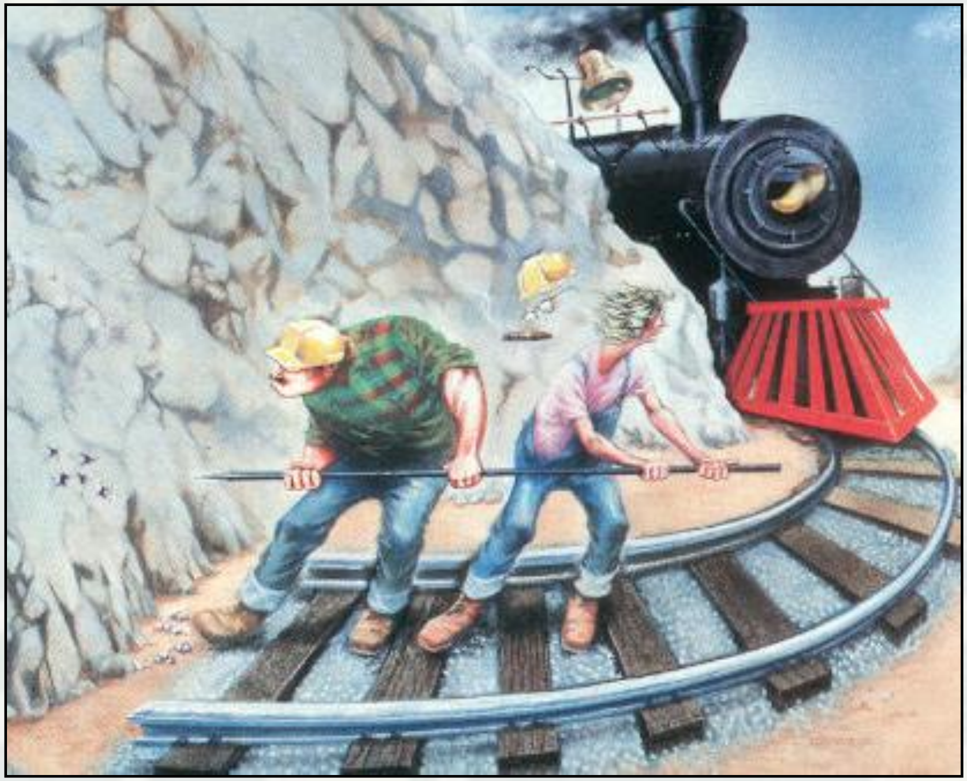
"Once the criteria are known, it will often be found that more than one material can be used with equally good results. Final selection of the material or combination of materials must then take into account the ease of application, cost, and available labor skills and equipment."

(From Warner, 1984)

Choosing A Repair Material

Application and Service Conditions

- Repair thickness, orientation?
- Moisture, temperature, available ventilation?
- Available downtime?
- Chemical attack?
- Heavy traffic?
- Bond to steel & concrete?
- Service temperature range?
- Exposure to vibration?
- Appearance important?
- Desired service life?



(After Warner, 1984)

General Requirements for Repair Materials (1980's)

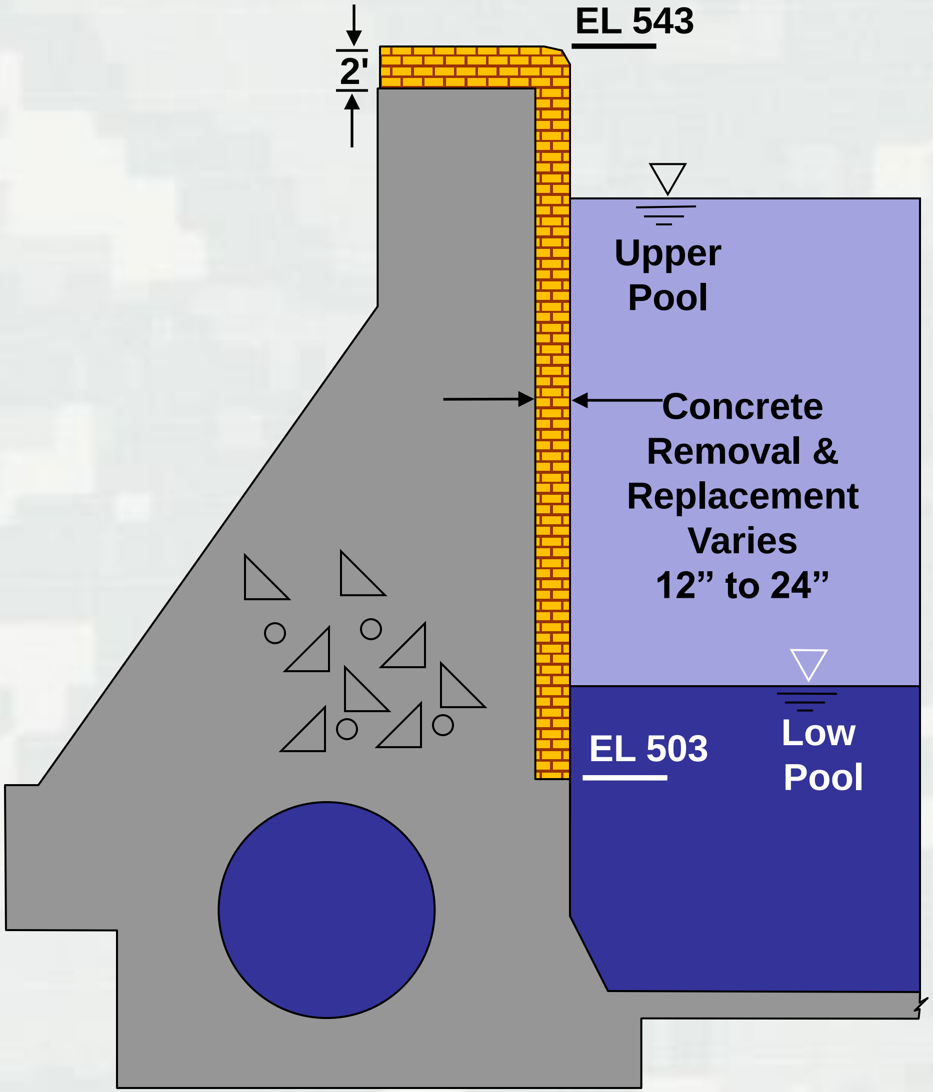
Property	Relationship of Repair Material (R) to Concrete Substrate (C)
Compressive Strength	R > C
Slant-Shear Bond	R > C
Modulus of Elasticity	$R \geq C$
Thermal Expansion/Contraction	$R \leq C$
Unrestrained Shrinkage	R = C

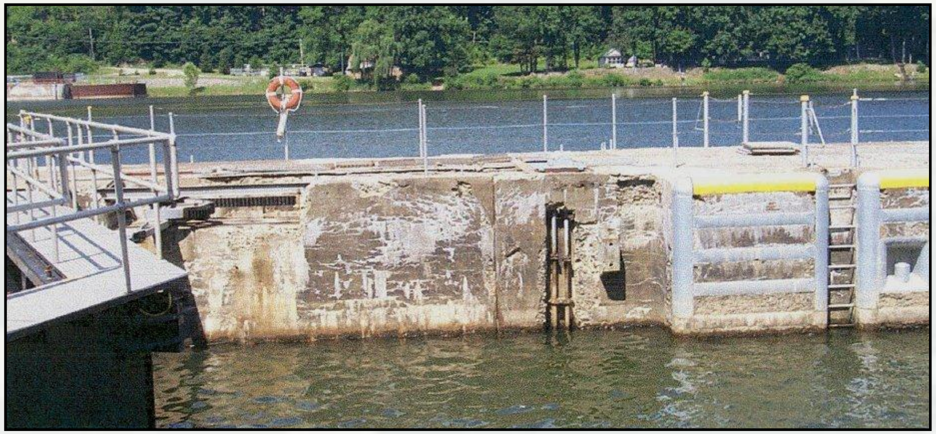
World of Concrete – Jan 1988

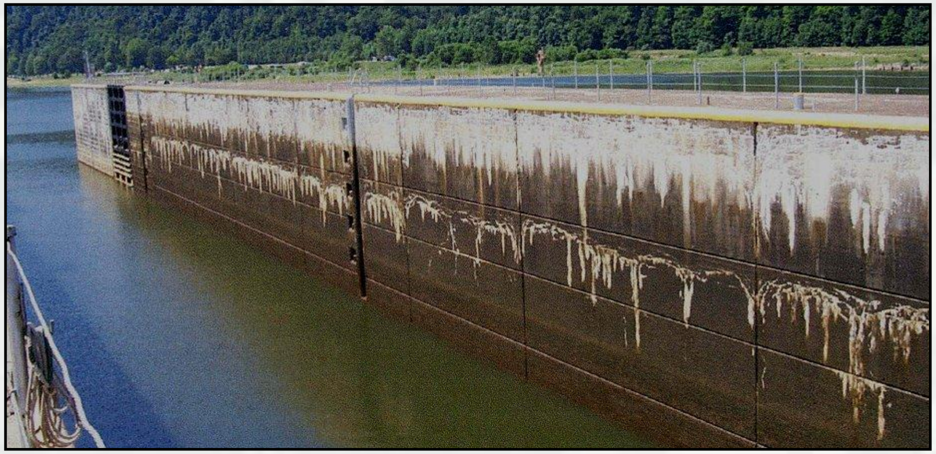
Jim Warner Concrete Repair Seminar

International Concrete Repair Specialists
Naperville, IL May 1988

Typical Lock Wall Rehabilitation

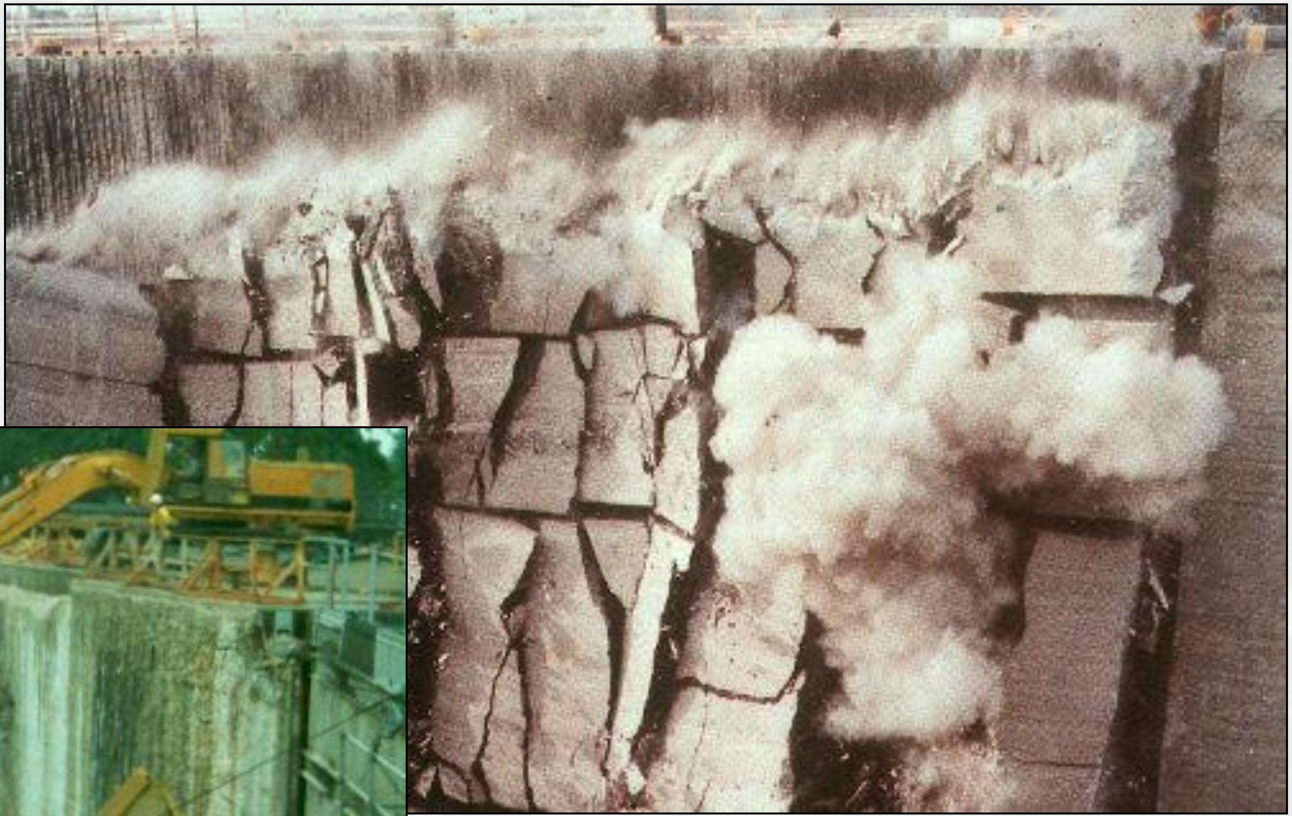






Deteriorated Concrete Removal

Secondary



Primary

Surface Preparation

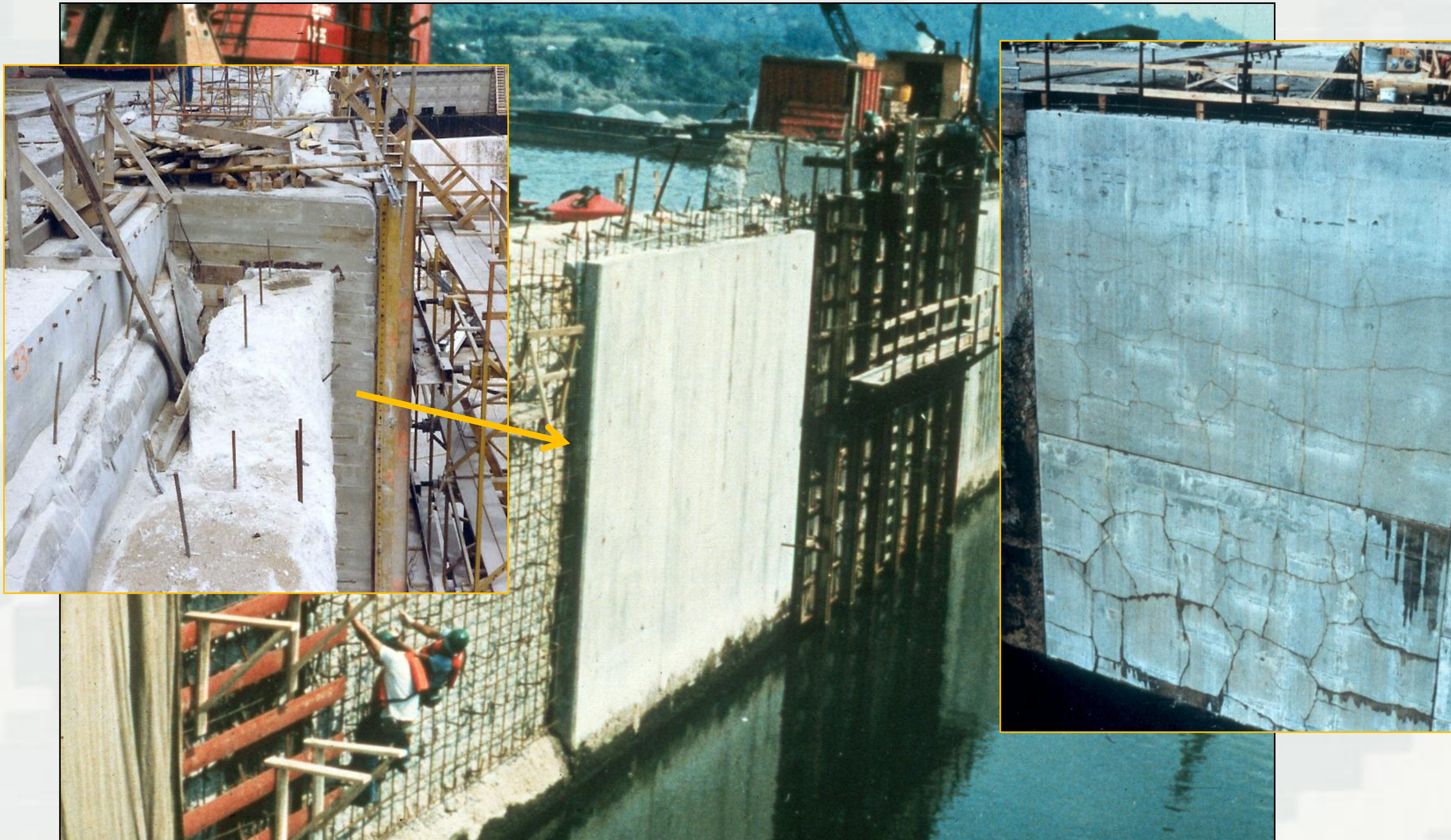
Cast-In-Place Concrete

Concrete Cracking

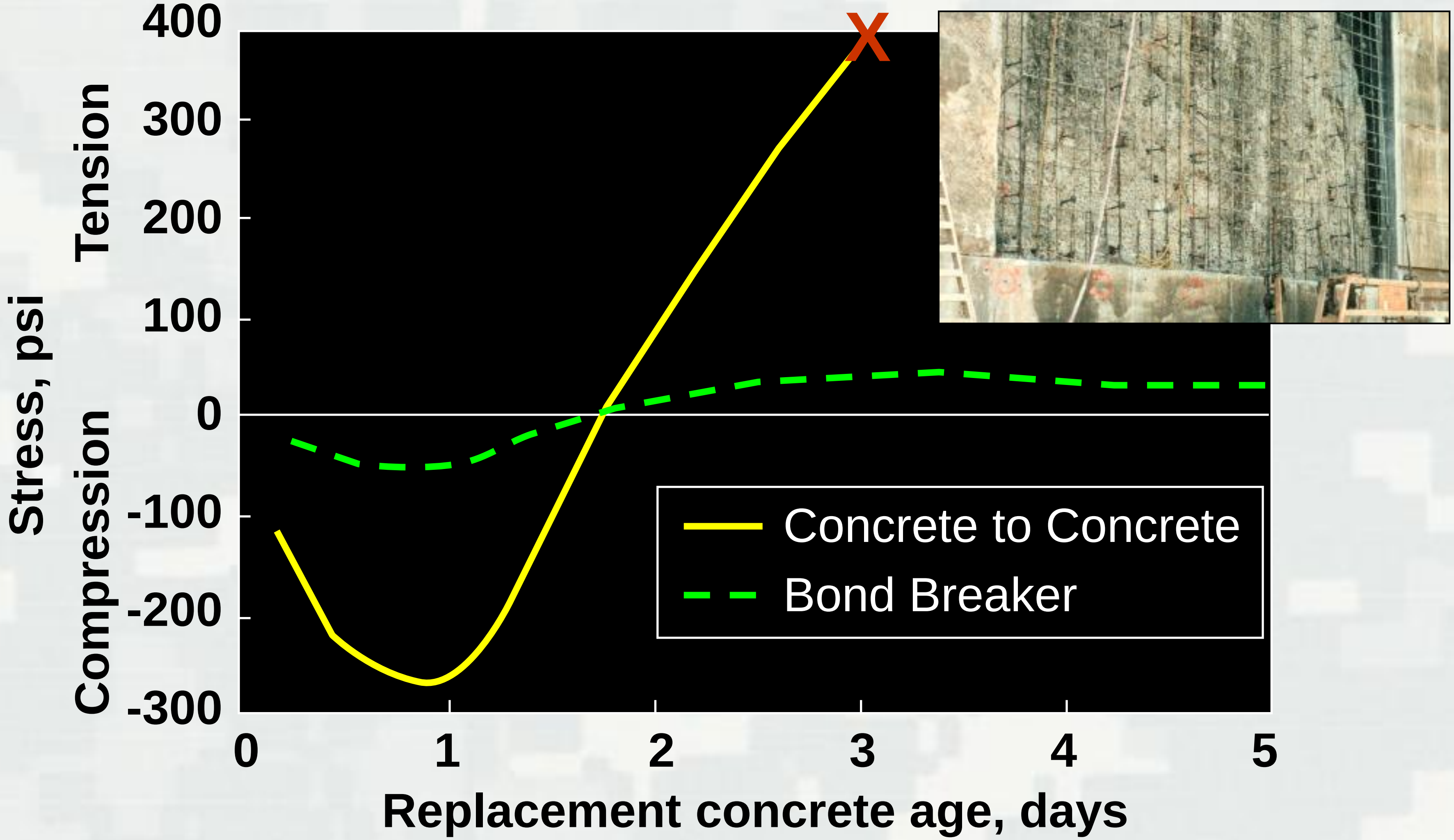



Lock Wall Rehabilitation

Restrained Contraction



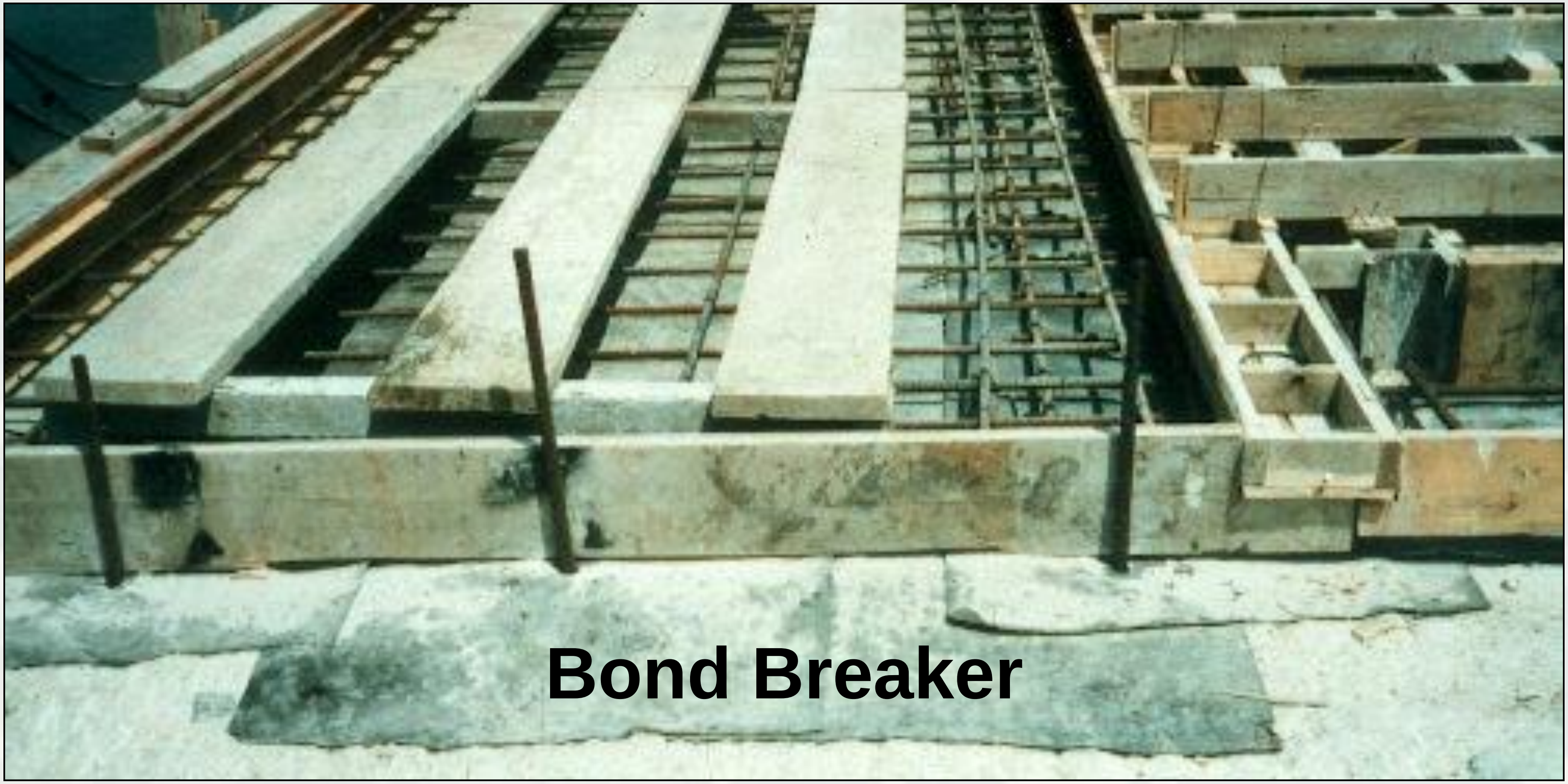
Effect of Restrained Contraction



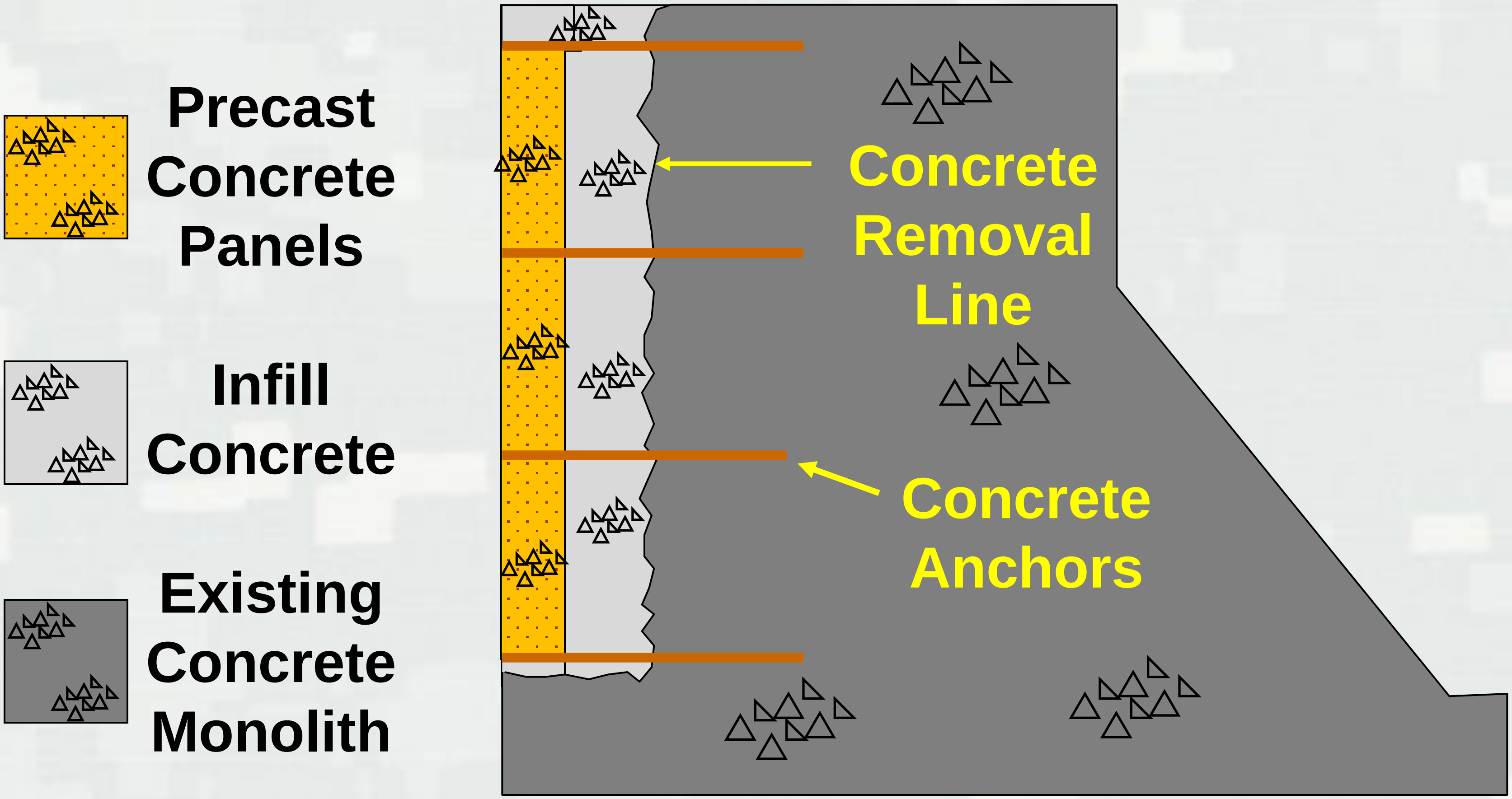
Effect of Restrained Contraction

Brandon Road Dam

Bond Breaker Eliminated Cracking



Precast Concrete Stay-in-Place Forming System



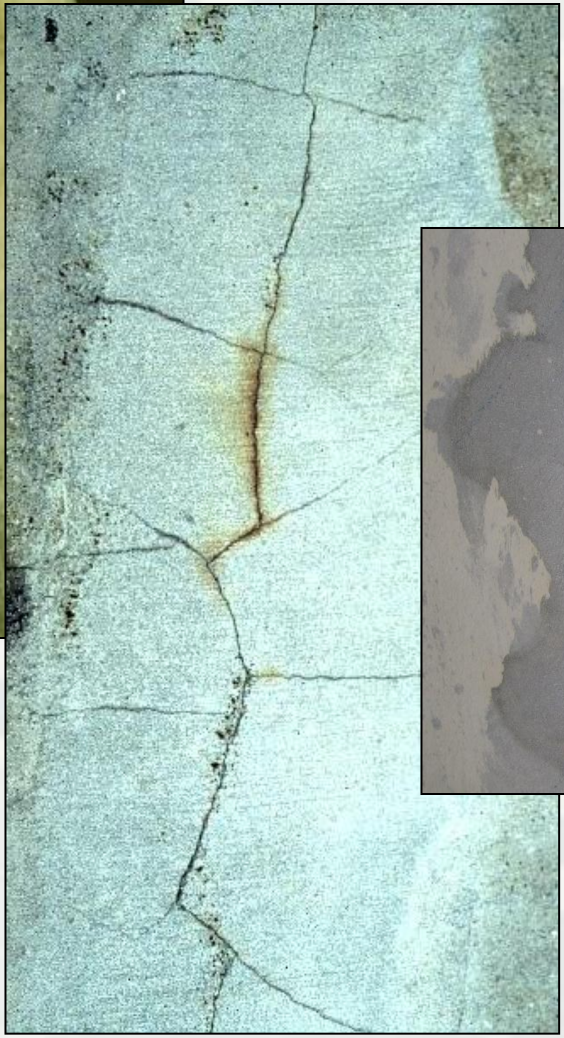
Precast Vs. CIP

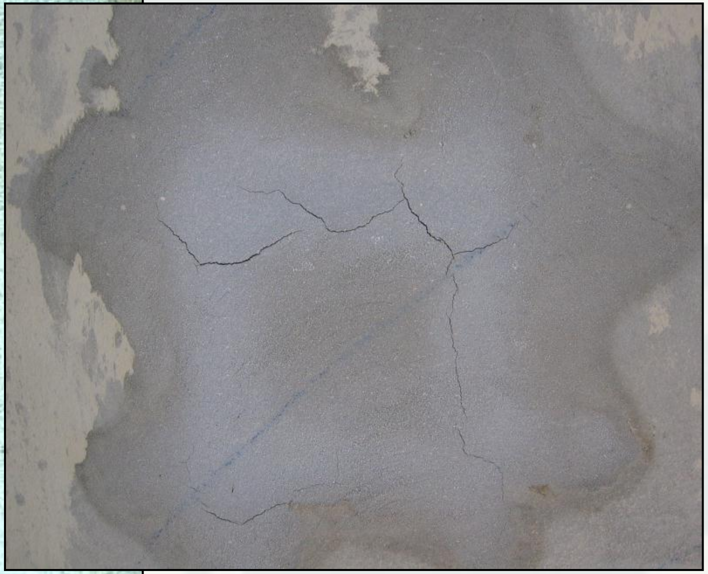
Troy Lock

- Advantages of Precasting
  - Minimal cracking
  - Durability
  - Speed of construction
  - Reduced maintenance
  - Minimizes weather impact
  - Economy ($5/ft^2 < CIP)
- References
  - TR REMR-CS-41
  - REMR-CS-4 (Video)

Effect of Restrained Contraction

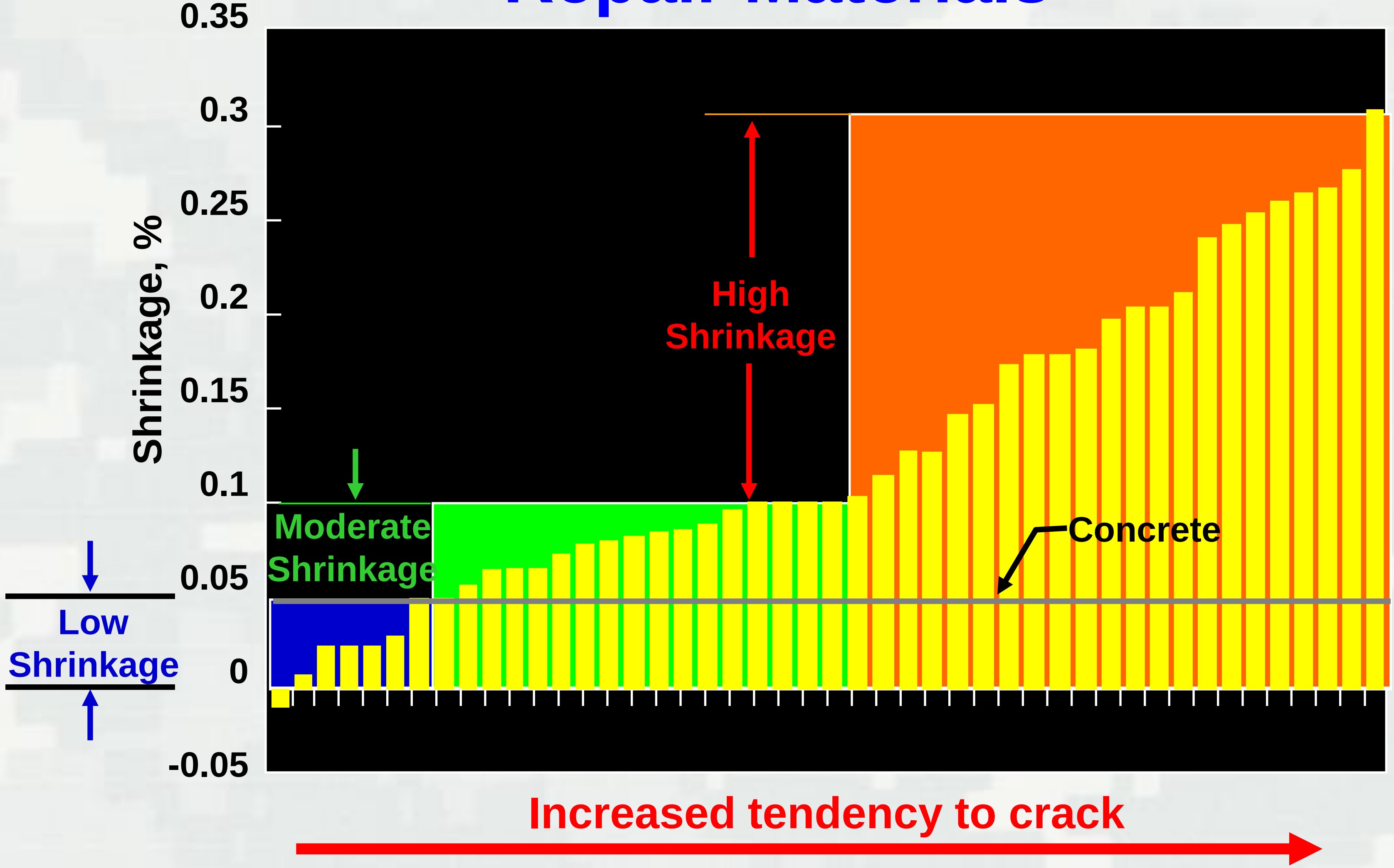
Small Repairs





Shrinkage Test Results

Repair Materials



After Gurjar & Carter (1987)

Technical Report REMR-CS-52
January 1997

US Army Corps of Engineers
Waterways Experiment Station

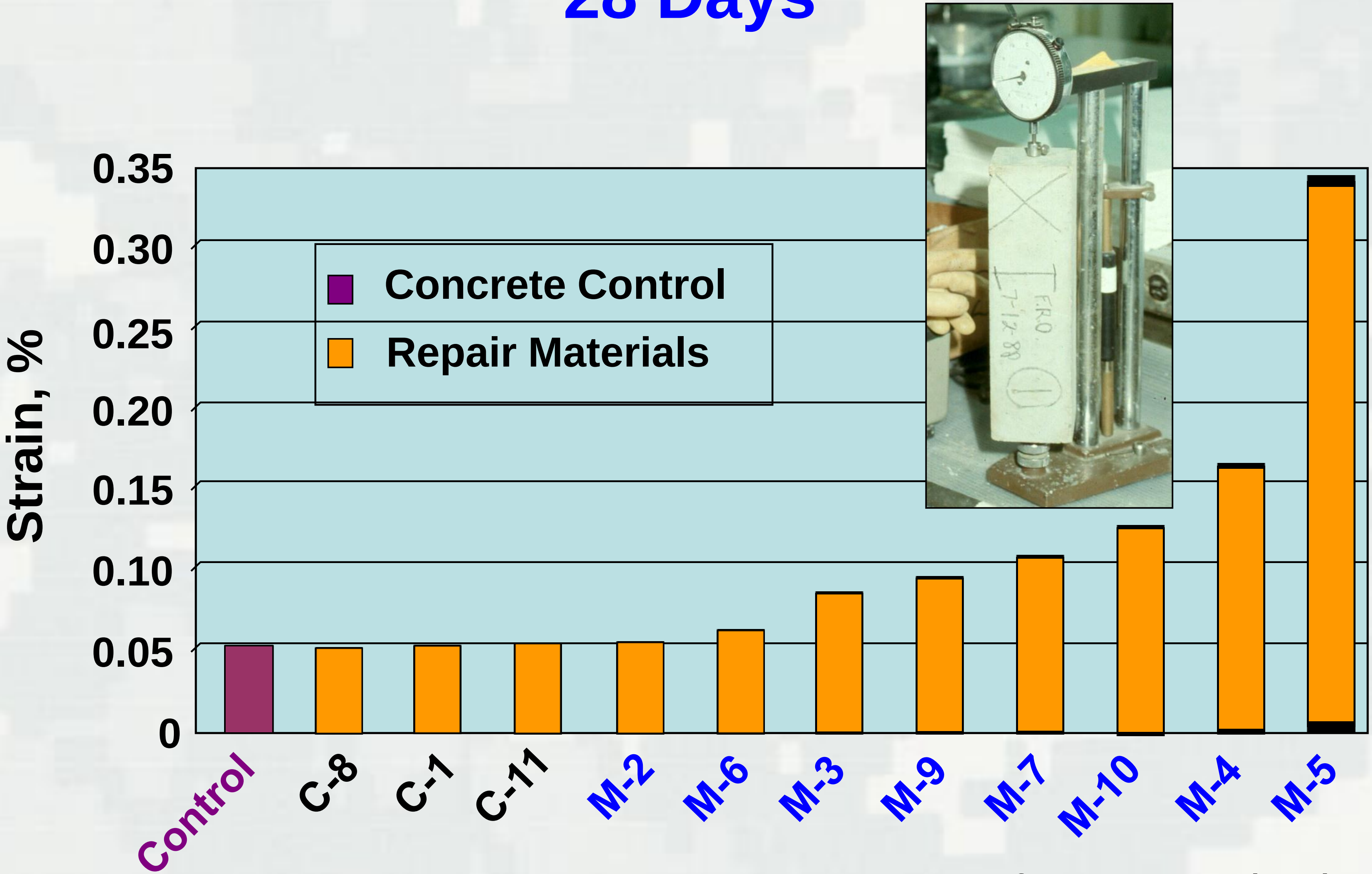
http://www.dtic.mil/dtic/tr/fulltext/u2/a321981.pdf

Repair, Evaluation, Maintenance, and Rehabilitation Research Program

Results of Laboratory Tests on Materials for Thin Repair of Concrete Surfaces

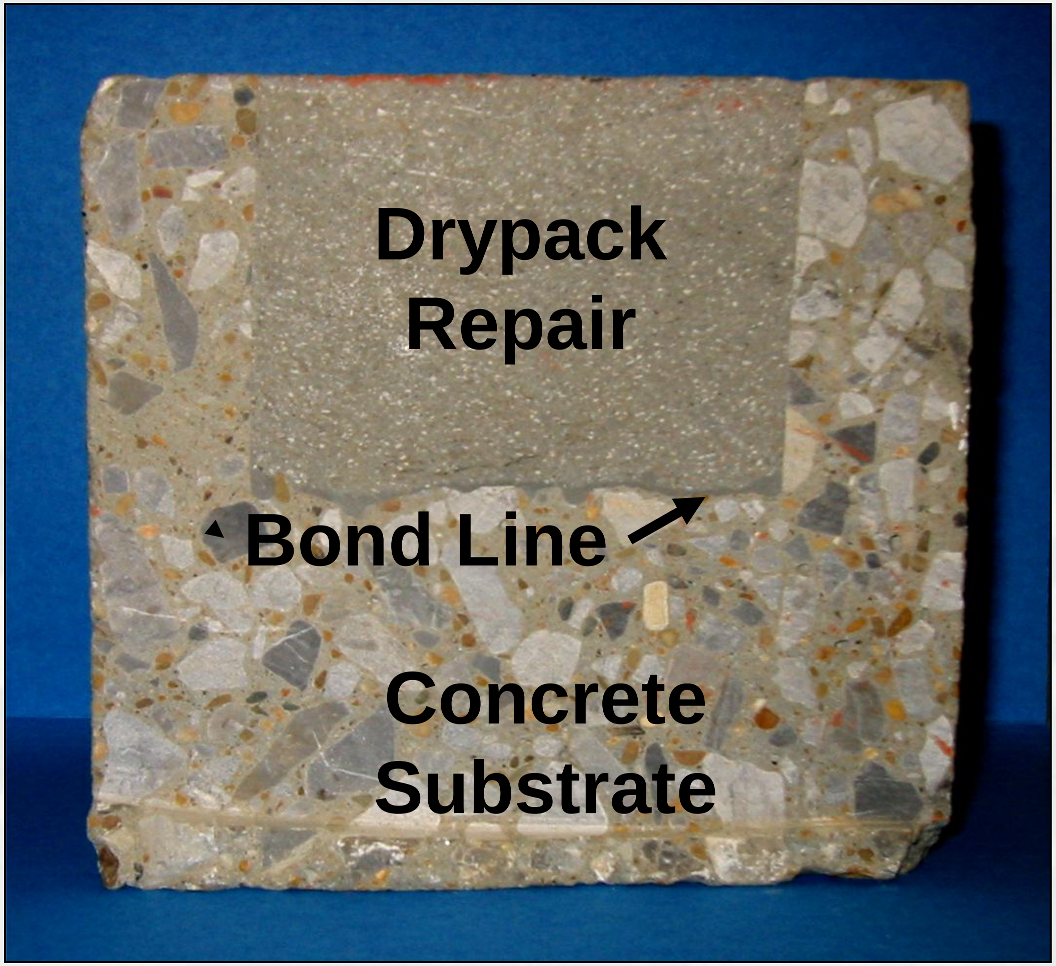
Drying Shrinkage Test Results

28 Days



After REMR CS-52(1997)

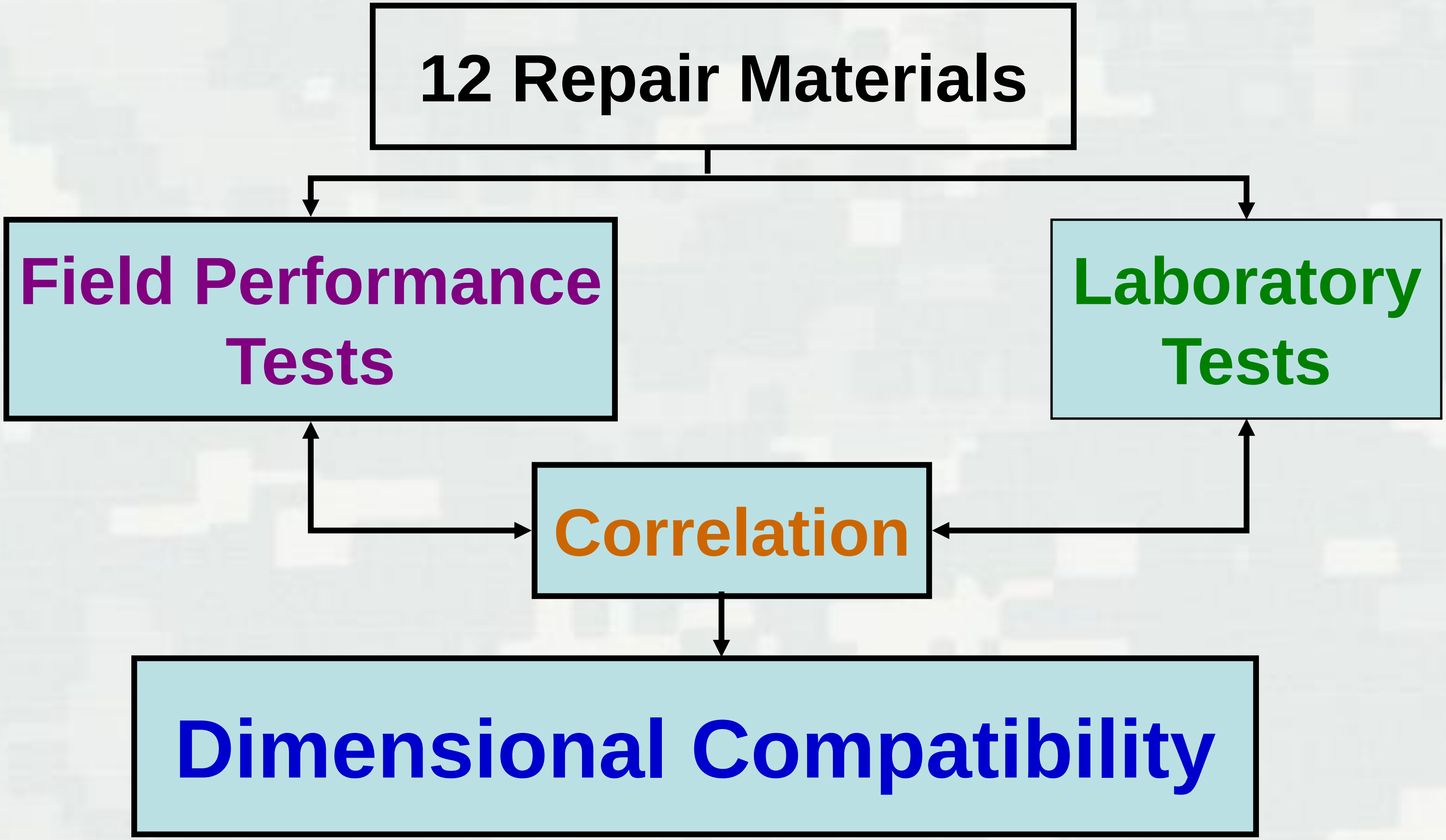
Objective: Composite Repair



A repair produced by combining different materials (e.g., concrete substrate, bonding agent, and repair material) which are so interconnected that the combined components act together as a single unit.

Performance Criteria

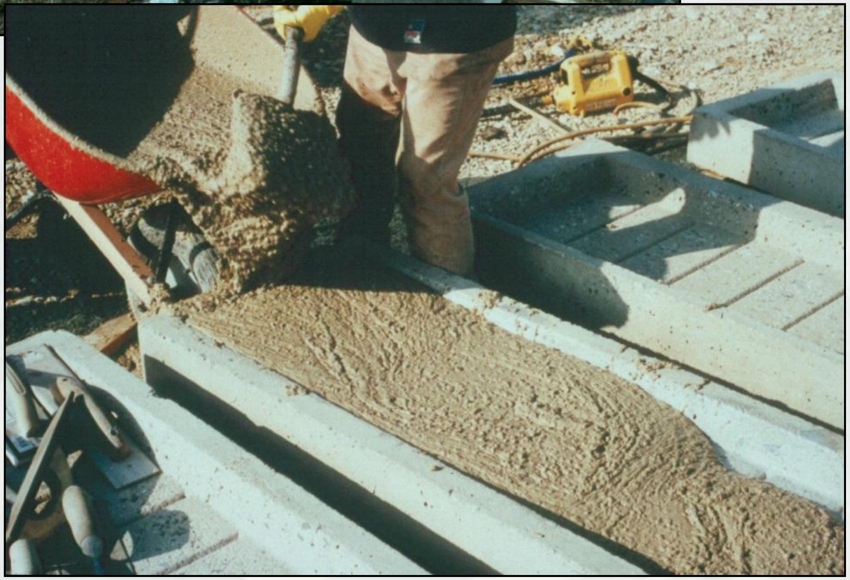
Cement-Based Materials



Performance Criteria
Laboratory Tests

- Drying Shrinkage
  - Unrestrained
  - Restrained
- Modulus of elasticity
- Thermal expansion
- Strength

Performance Criteria
Field Tests



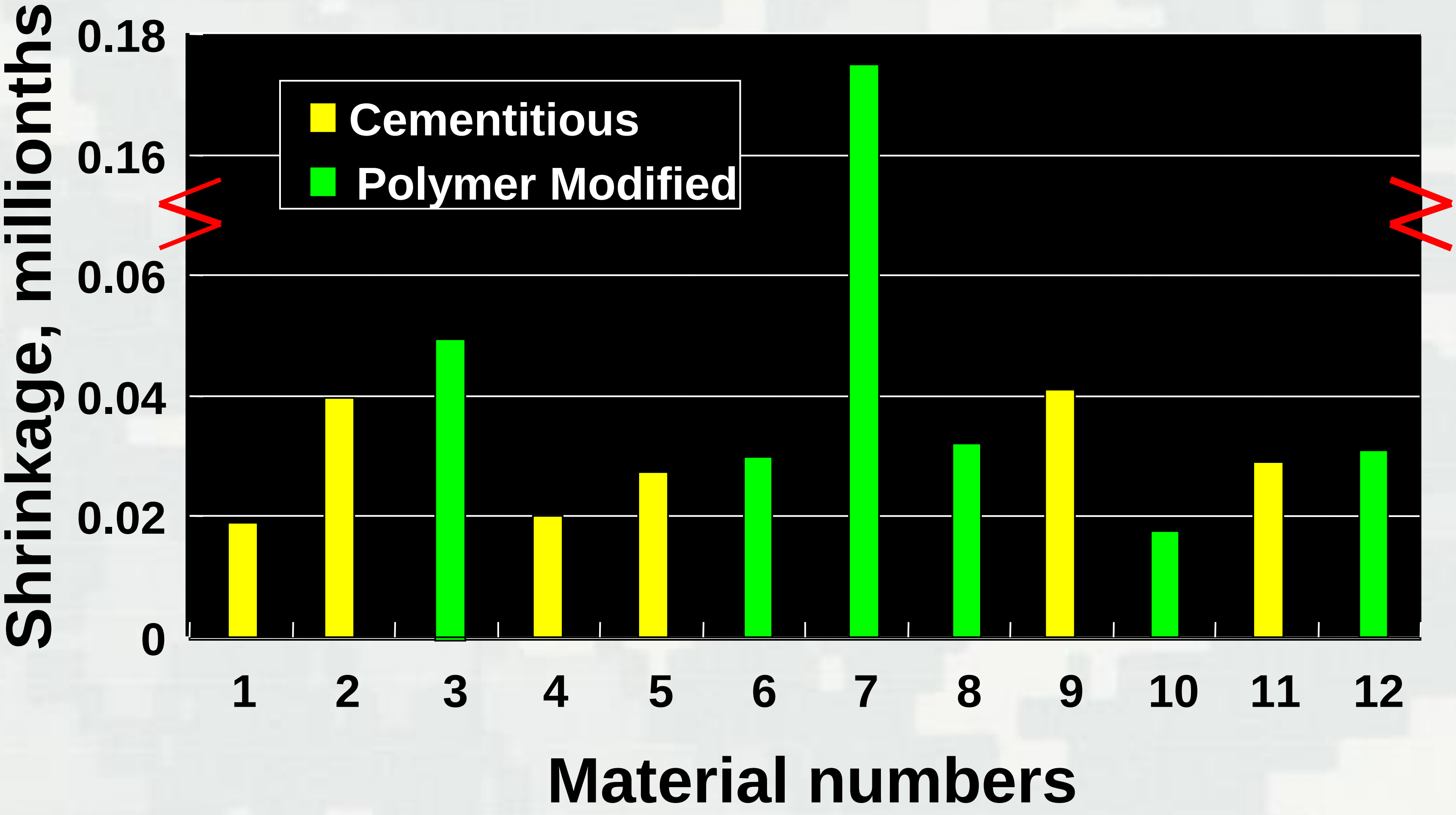
- 3 exposure sites (FL, IL, & AZ)
- 3 repairs with each of the 12 materials
- Conduct restrained shrinkage tests
- Monitor performance

Field Exposure Tests

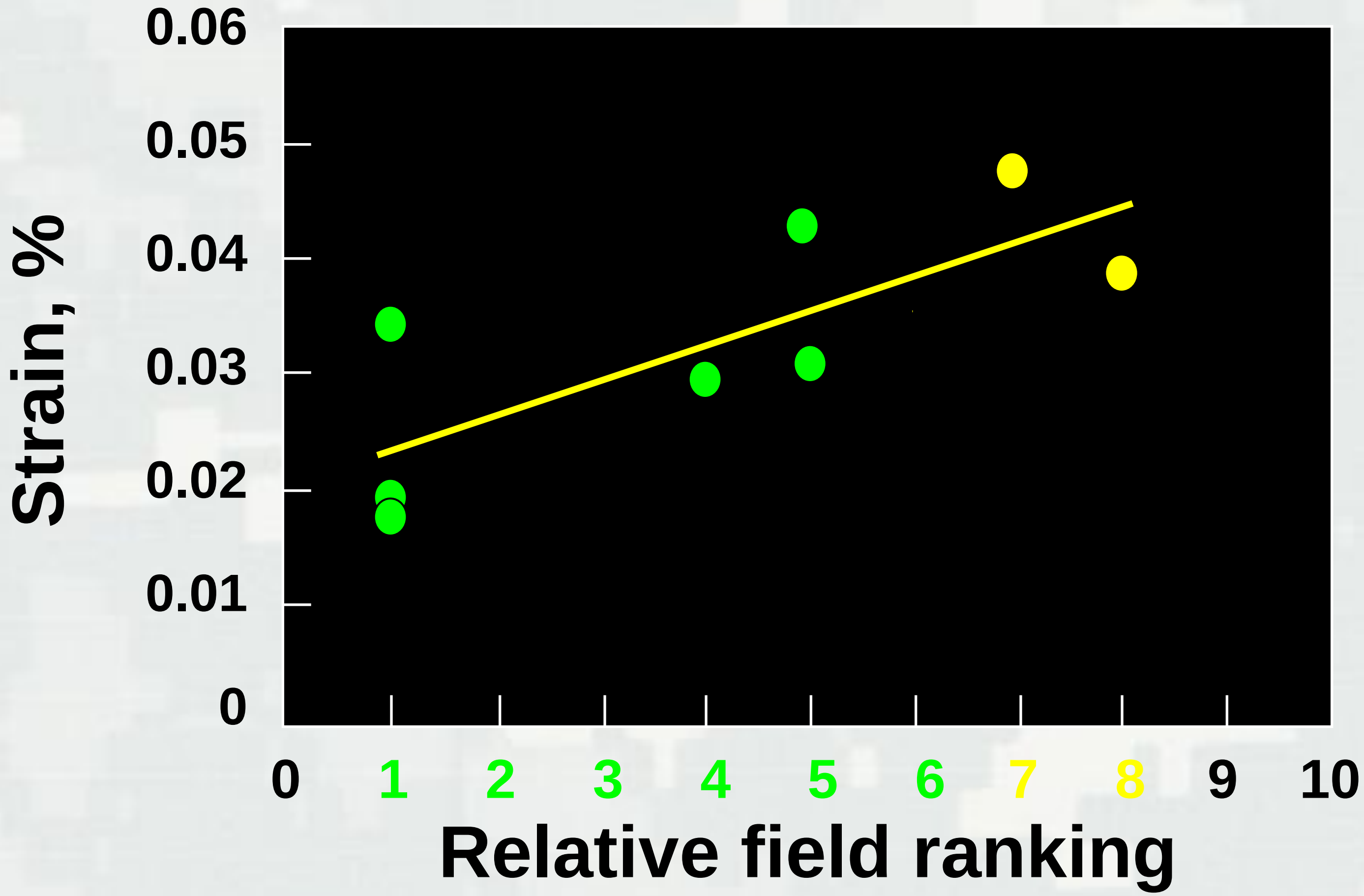
Relative Performance Ratings

Drying Shrinkage

50% RH, 28-Days Age



28-Day Shrinkage & Field Performance
Acceptable Materials



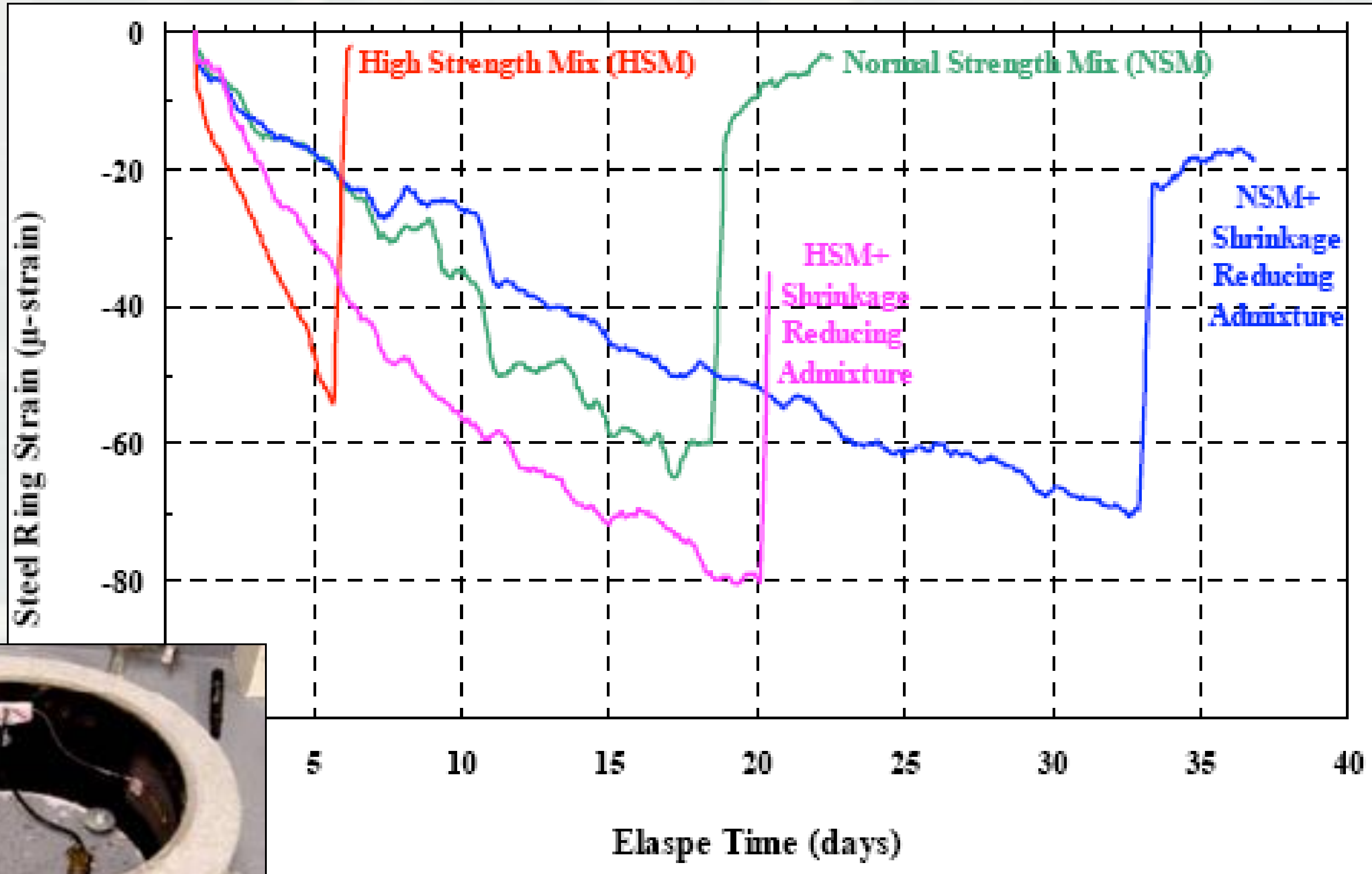
Restrained Drying Shrinkage

Ring Test
10 of 12 Cracked

Criteria
No cracking <14 days age
0.10% max implied strain

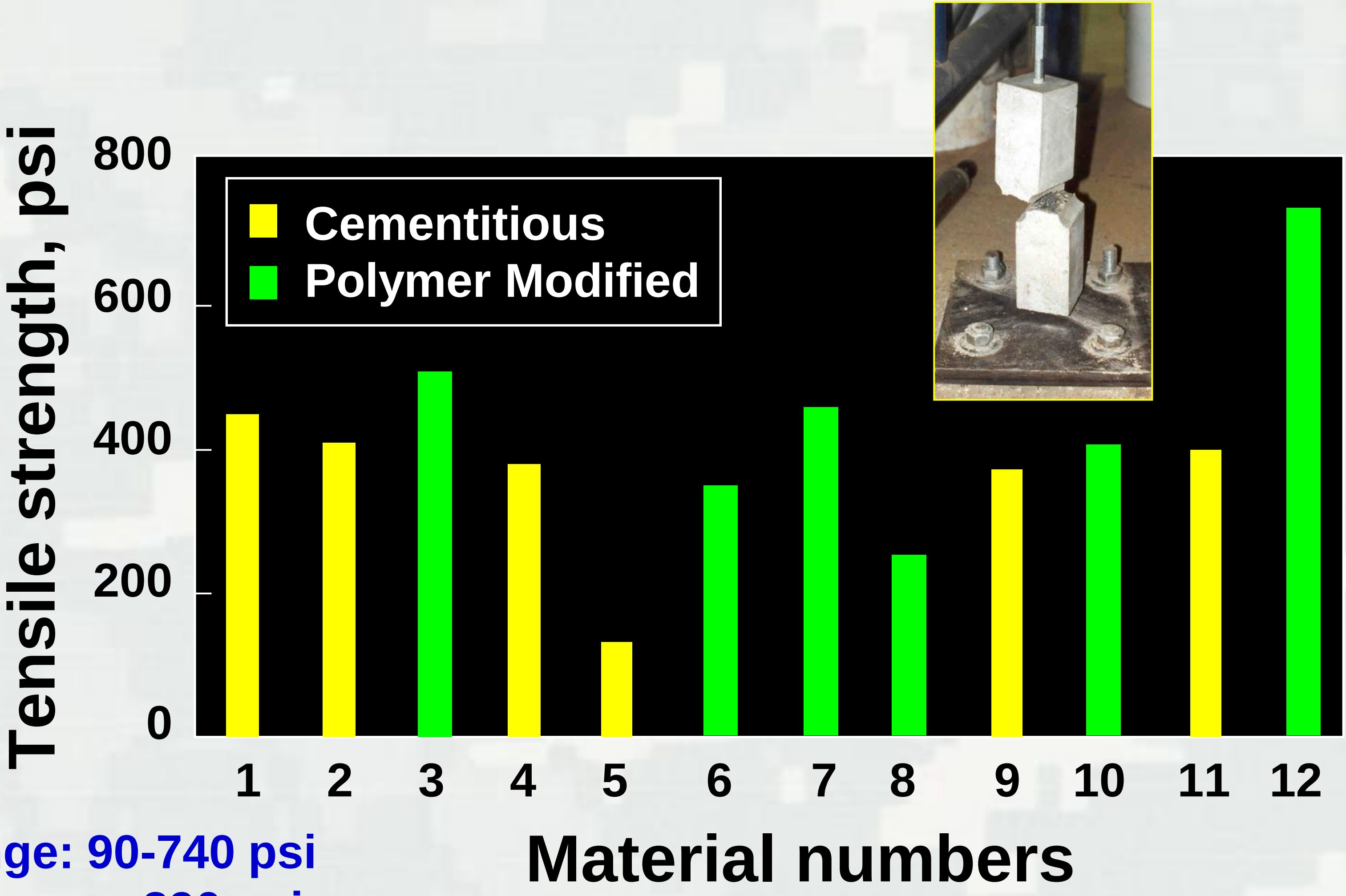
Restrained Shrinkage Test

ASTM C1581-04



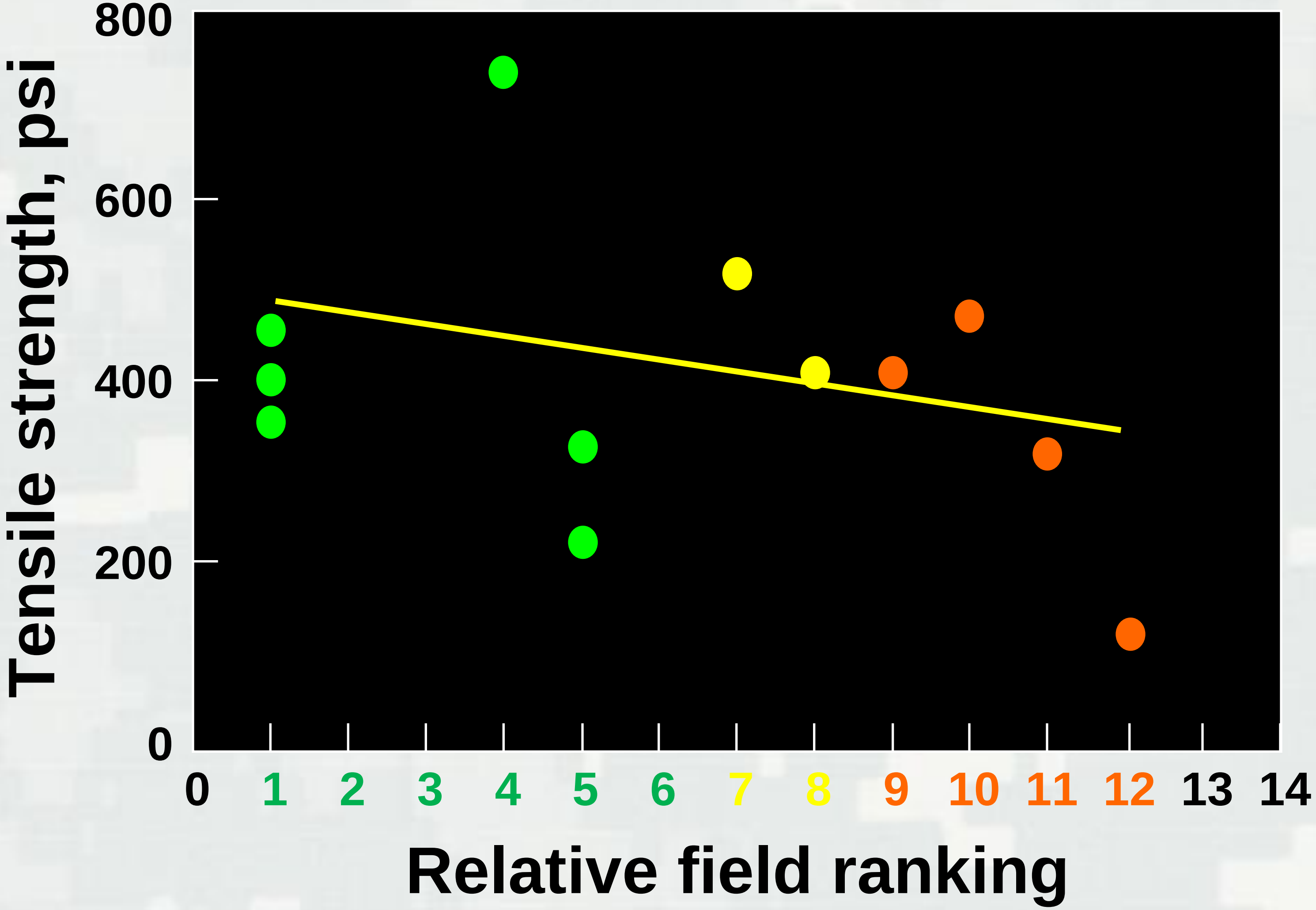
Tensile Strength Test Results

28-Days Age



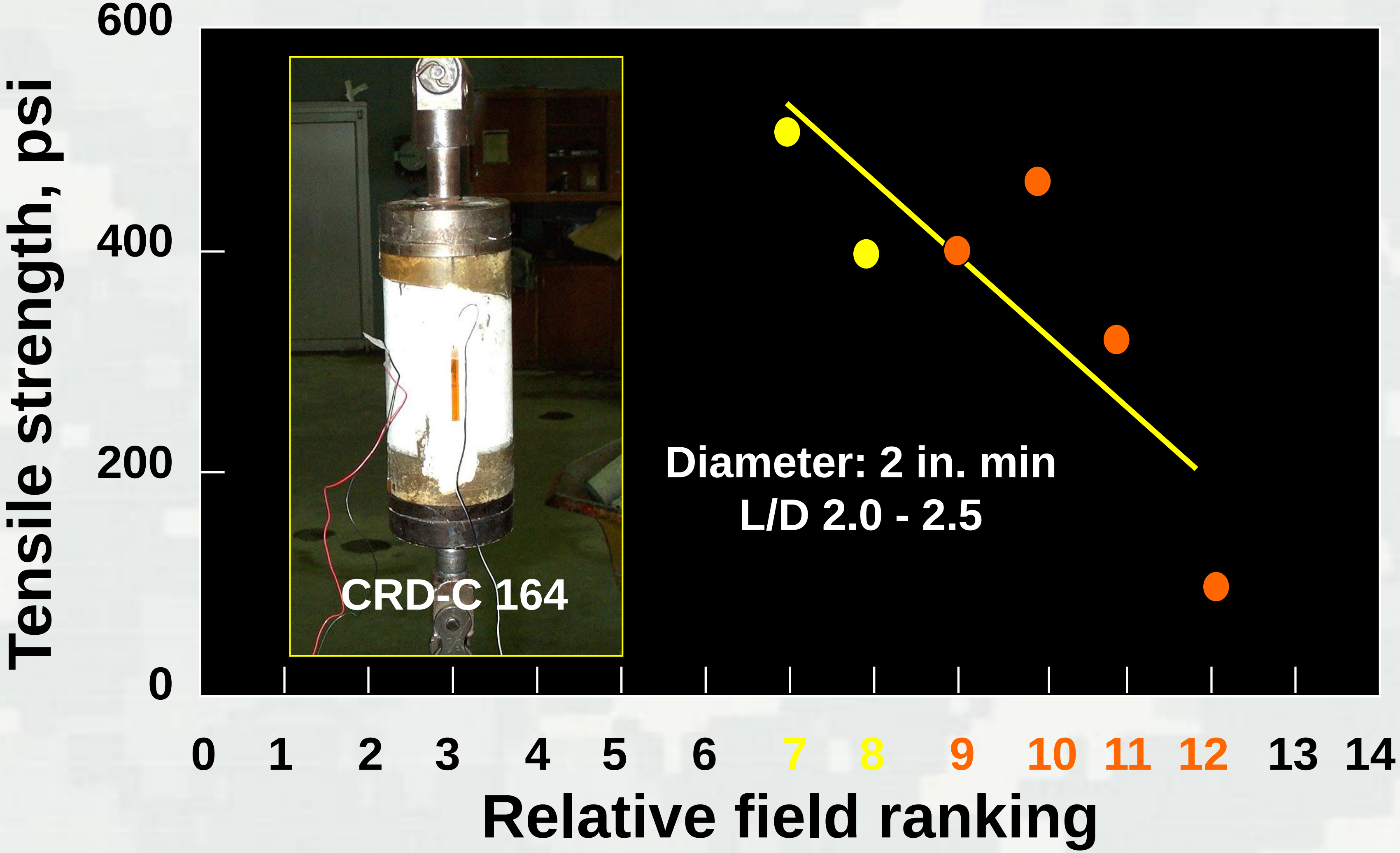
Range: 90-740 psi
Average: 390 psi

Overall Tensile Strength and Field Performance

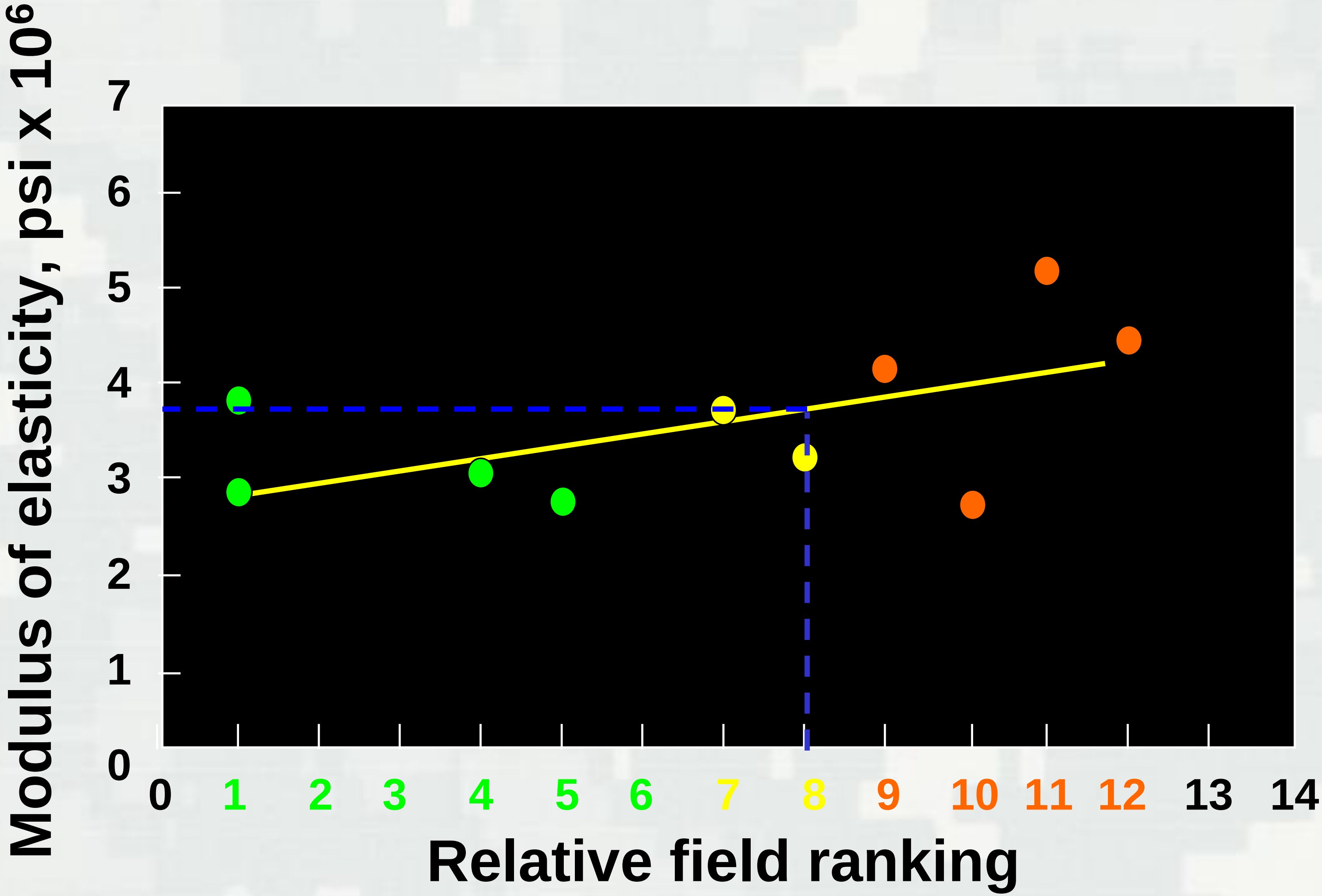


Tensile Strength & Field Performance

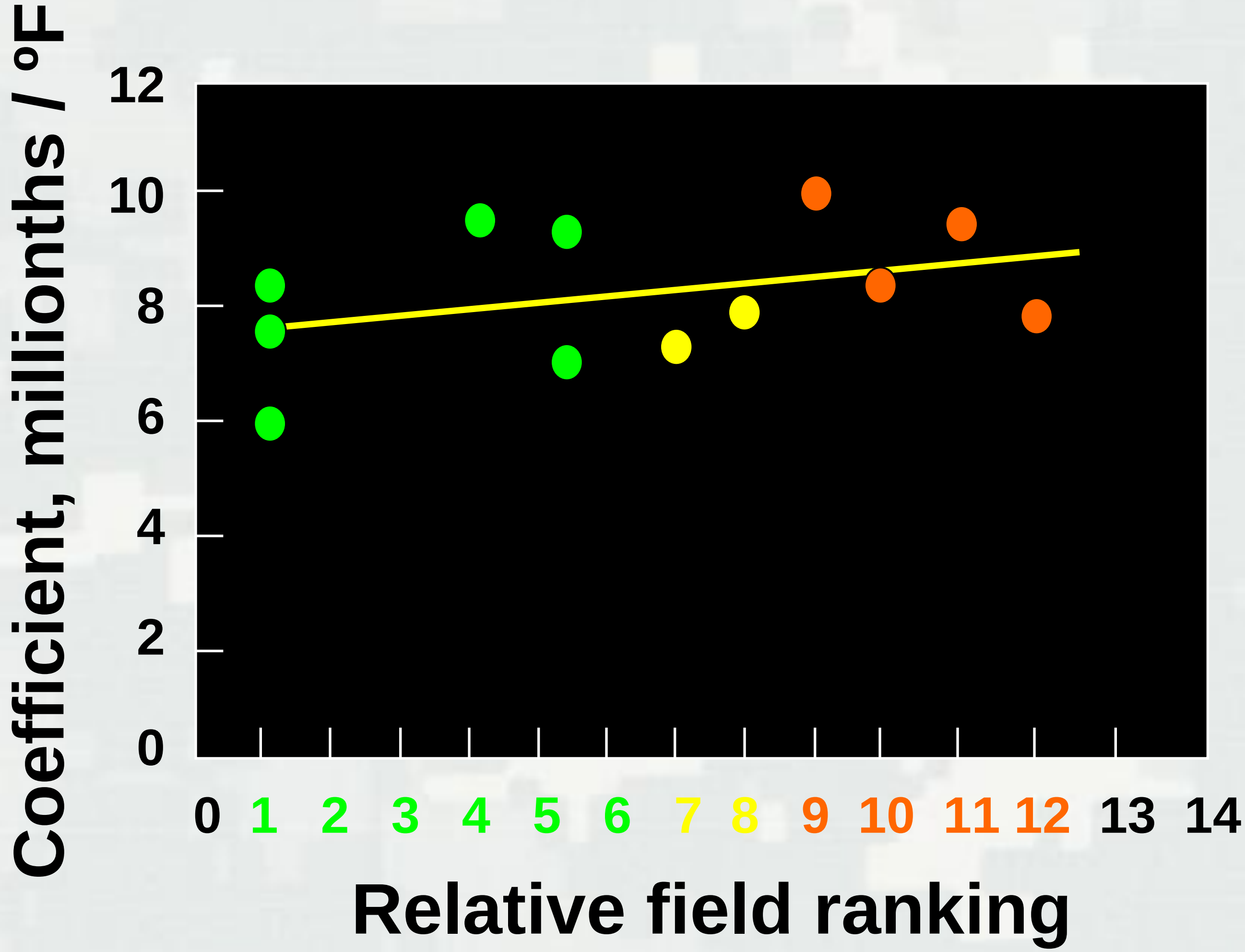
Marginal and Unsatisfactory Materials



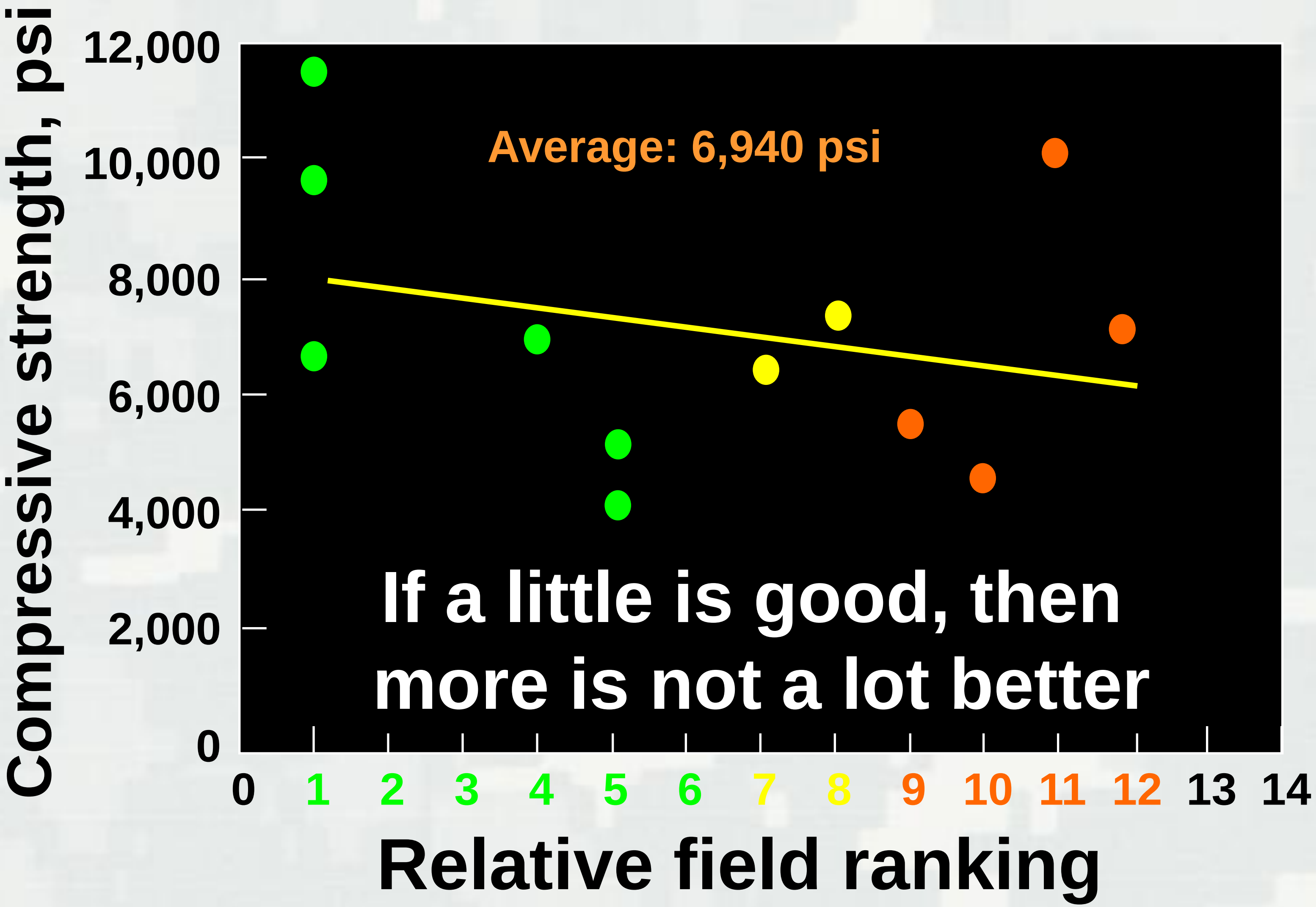
Modulus & Field Performance



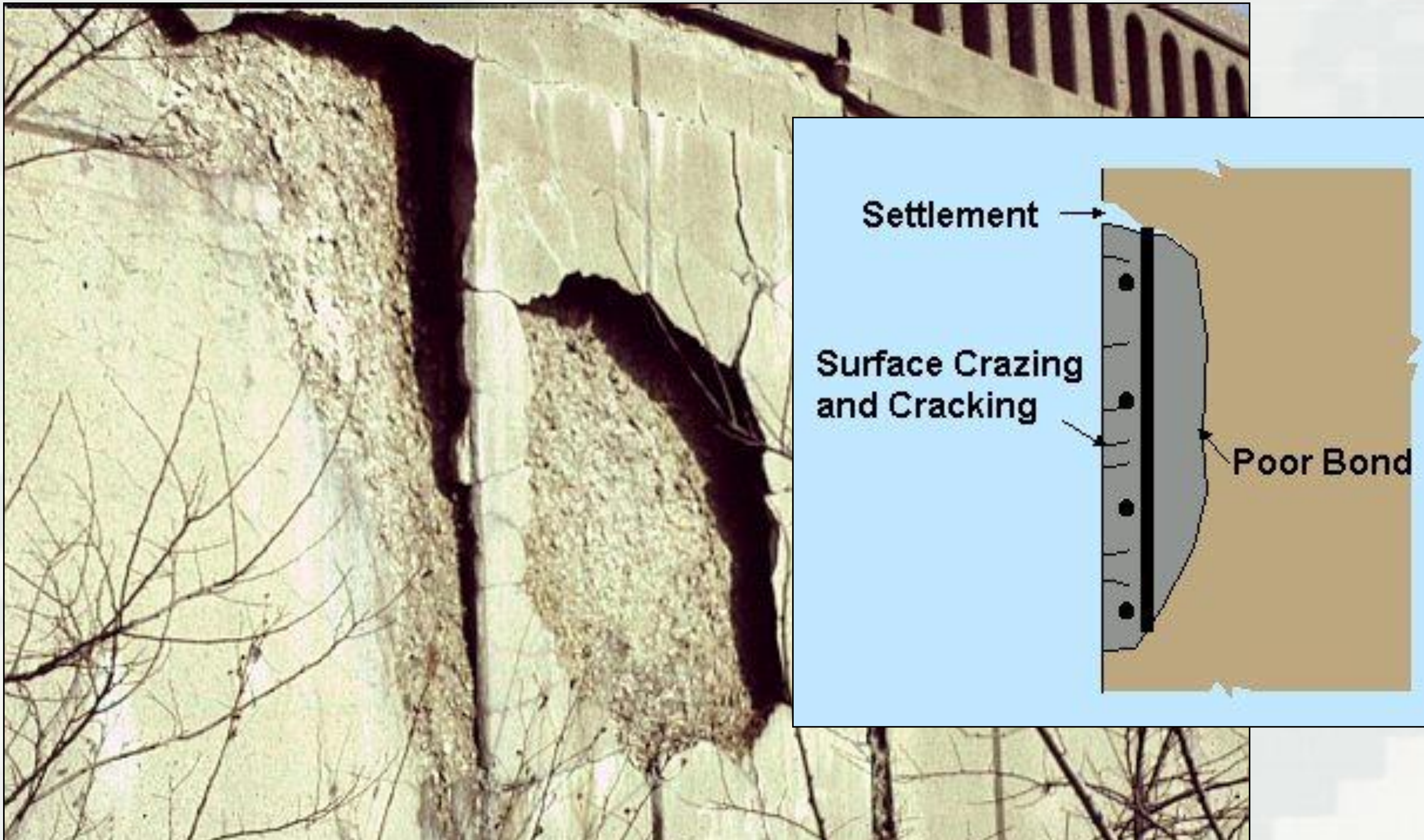
Overall Coefficient of Expansion and Field Performance



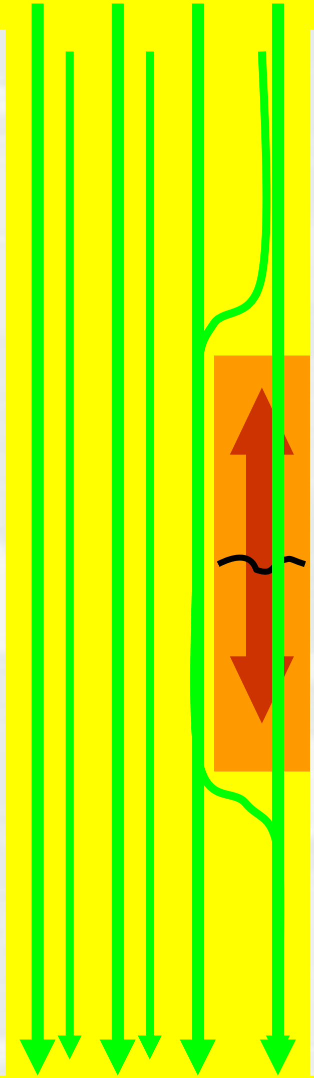
Compressive Strength and Field Performance



Typical Surface Repair



Concrete Slab



Will A Repair In This Column Carry Any Significant Loads?

No, unless …

Interstates 30 & 45

Dallas, TX

Performance Criteria for Cement-Based Repair Materials*

Property	Test Method	Requirement
Tensile strength, min	CRD-C164	400 psi
Modulus of elasticity, max	ASTM C469	3.5×10^6 psi
Thermal coefficient, max	CRD-C39	7 millionths/ °F
Drying shrinkage, max	ASTM C157 (Modified)	
28 days		0.04%
1 year		0.10%
Restrained shrinkage	Ring Method	
Cracks		None < 14 days
Implied strain (1 yr.), max		0.10%

****http://wbdg.org/ccb/DOD/UFGS/UFGS%2003%2001%2032.pdf***

Laboratory/Field Correlation
Satisfactory Performance

Field Rank	Mat'l No.	Tensile Strength, (>400)	Modulus of Elasticity (<3.5)	Thermal Coefficient (<7)	Drying Shrinkage: 28 Days (<0.04)	Drying Shrinkage: Peak (<0.10)	Ring Test: 1st Crack (>14)	Ring Test: Implied Strain (<0.10)
1	1	451	2.8	5.8	0.018	0.037	*6*	0.067
1	4	348	3.8	8.3	0.020	0.070	140	0.056
1	11	390	5.9	7.6	0.034	0.064	14	0.081
4	12	742	3.0	*9.3*	0.029	0.063	None	0
5	8	215	2.7	9.2	0.030	0.110	8	0.122
5	9	323	2.7	6.9	0.043	0.088	23	0.096

Laboratory/Field Correlation

Satisfactory Performance

Field Rank	Mat'l No.	Tensile Strength, (>400)	Modulus of Elasticity (<3.5)	Thermal Coefficient (<7)	Drying Shrinkage 28 Days (<0.04)	Drying Shrinkage Peak (<0.10)	Ring Test 1st Crack (>14)	Ring Test Implied Strain (<0.10)
1	1	451	2.8	5.8	0.018	0.037	*6*	0.067
1	4	348	3.8	8.3	0.020	0.070	140	0.056
1	11	390	5.9	7.6	0.034	0.064	14	0.081
4	12	742	3.0	*9.3*	0.029	0.063	None	0
5	8	215	2.7	9.2	0.030	0.110	8	0.122
5	9#	323	2.7	6.9	0.043	0.088	23	0.096

Conventional Concrete

Laboratory/Field Correlation

4 Top-Ranked Materials

Technical Report REMR-CS-62 (pdf)

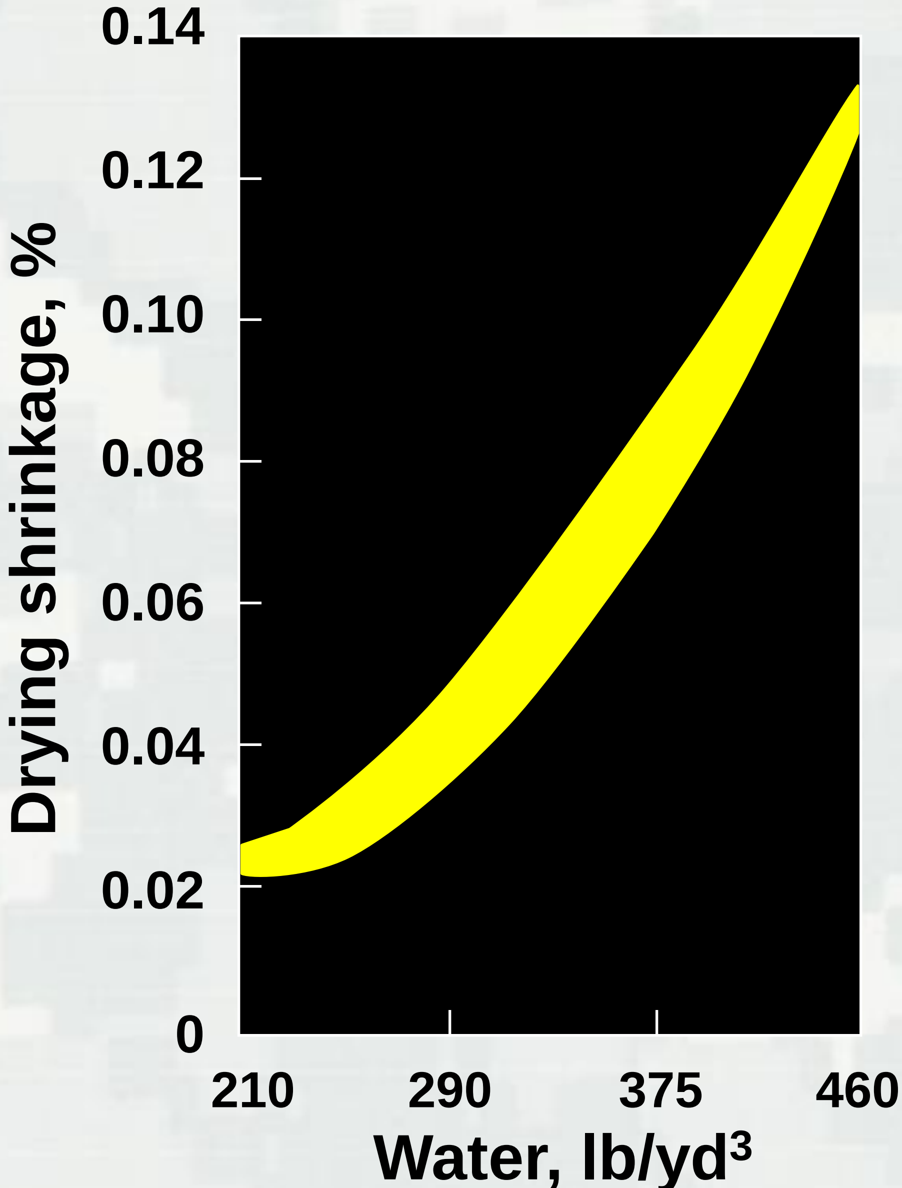
http://acwc.sdp.sirsi.net/client/search/asset/1004732

					Drying Shrinkage		Ring Test	
Field Rank	Mat'l No.	Tensile Strength, (>400)	Modulus of Elasticity (<3.5)	Thermal Coefficient (<7)	28 Days (<0.40)	Peak (<0.10)	1^{st} Crack (>14)	Implied Strain (<0.10)
1	1	451	2.8	5.8	0.018	0.037	*6*	0.067
1	4	348	3.8	8.3	0.020	0.070	140	0.056
1	11	390	5.9	7.6	0.034	0.064	14	0.081
4	12	742	3.0	9.3	0.029	0.063	None	0

Top 4 materials – 15 of 16 shrinkage compliance, 94%

Remaining materials – 18 of 32 compliance, 54%

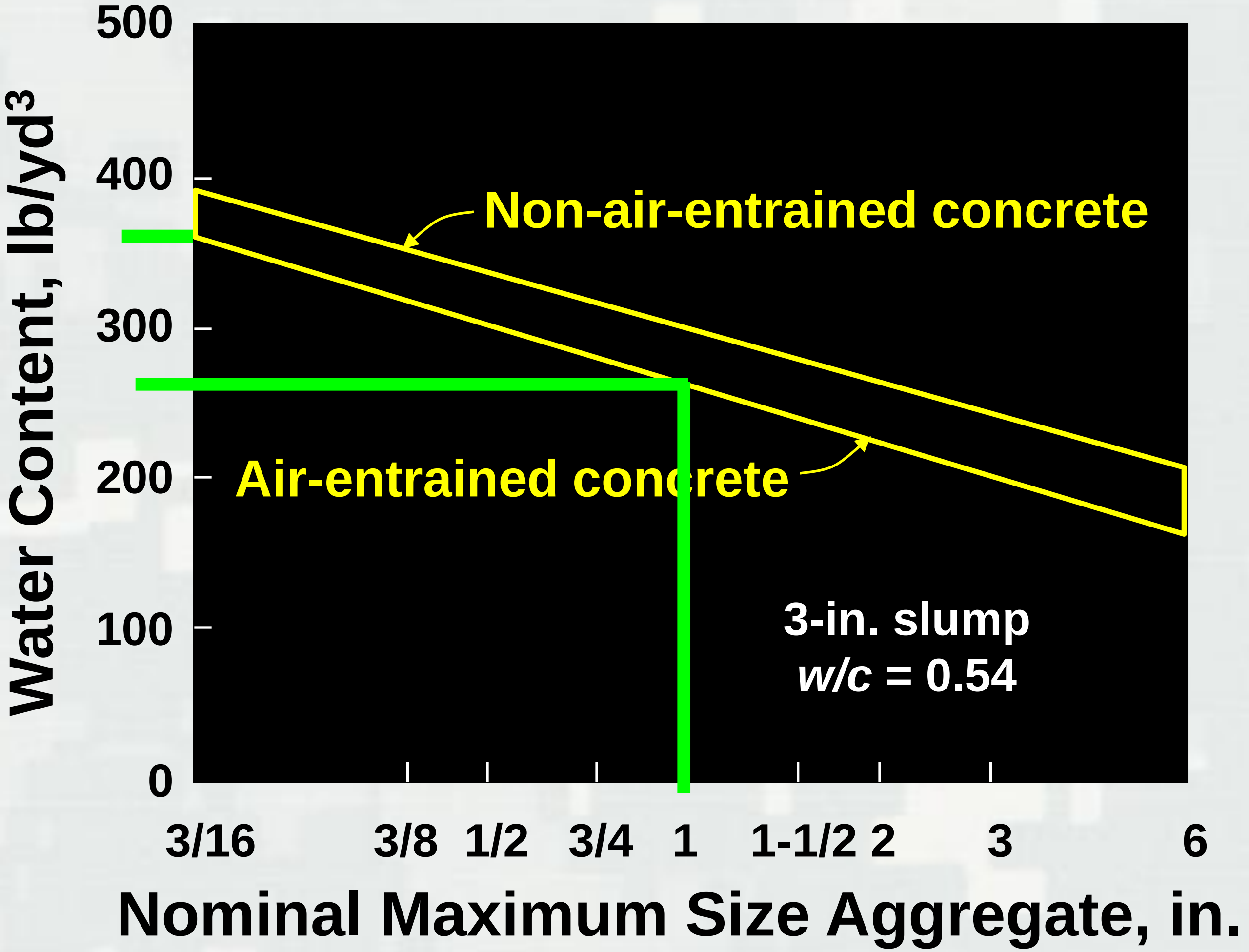
Minimizing Shrinkage Cracking



After PCA (2002)

- *Decrease water content*
- *Decrease paste volume*
- *Increase coarse aggregate*
- Shrinkage-reducing admixtures
- Synthetic fibers
- Crack resistant cement

Effect of MSA on Water Content



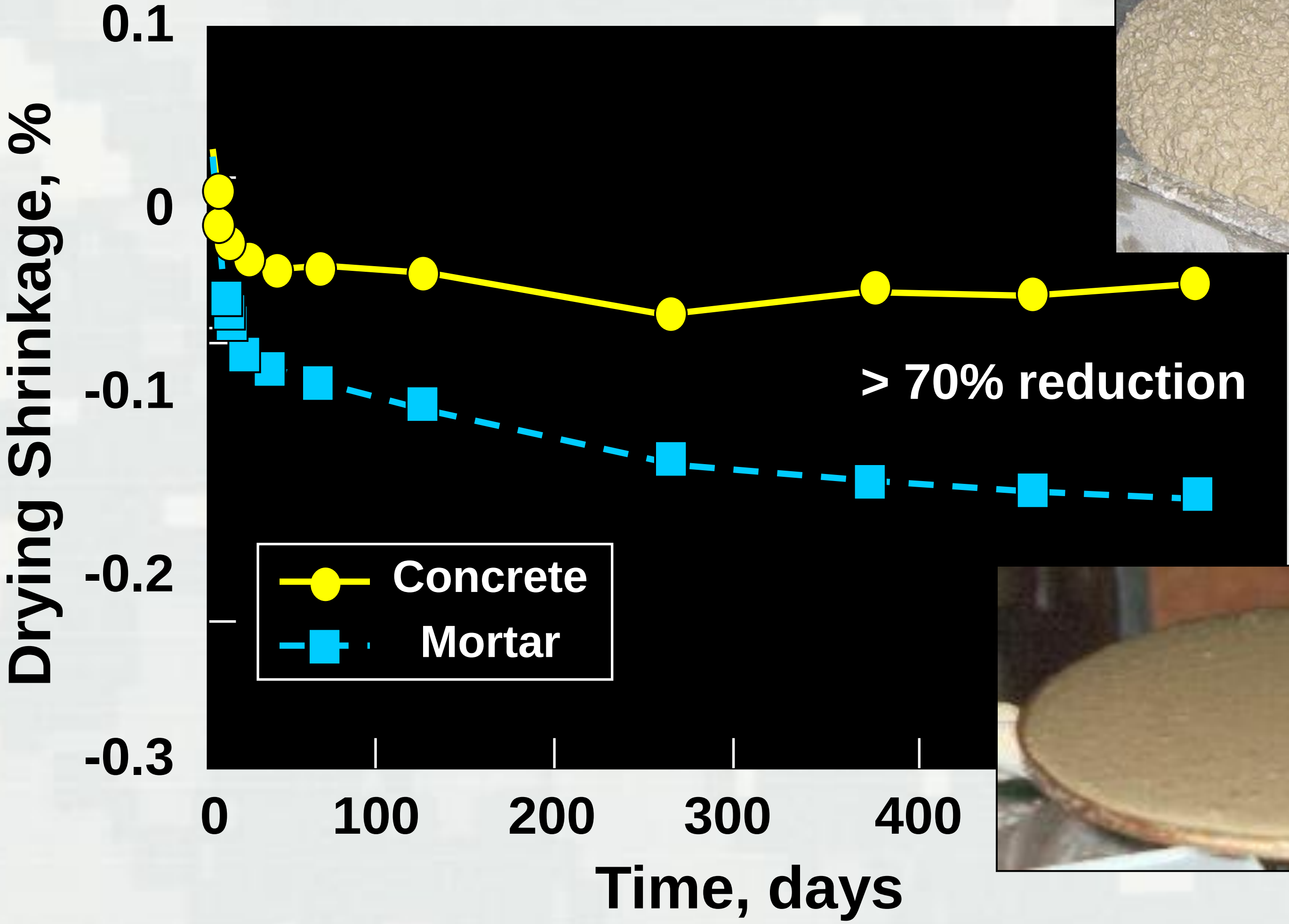
After PCA (2002)

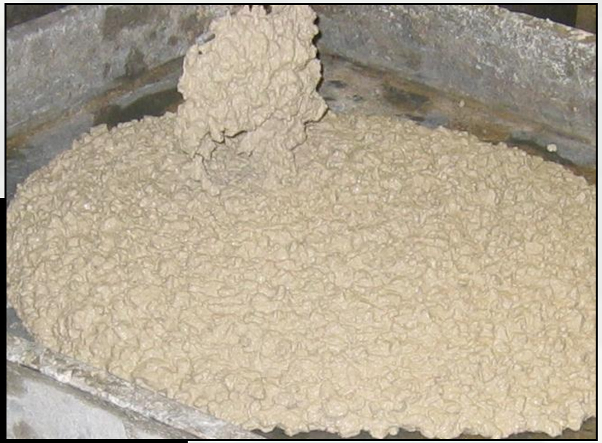
Effect of MSA on Cement Content

After PCA (2002)

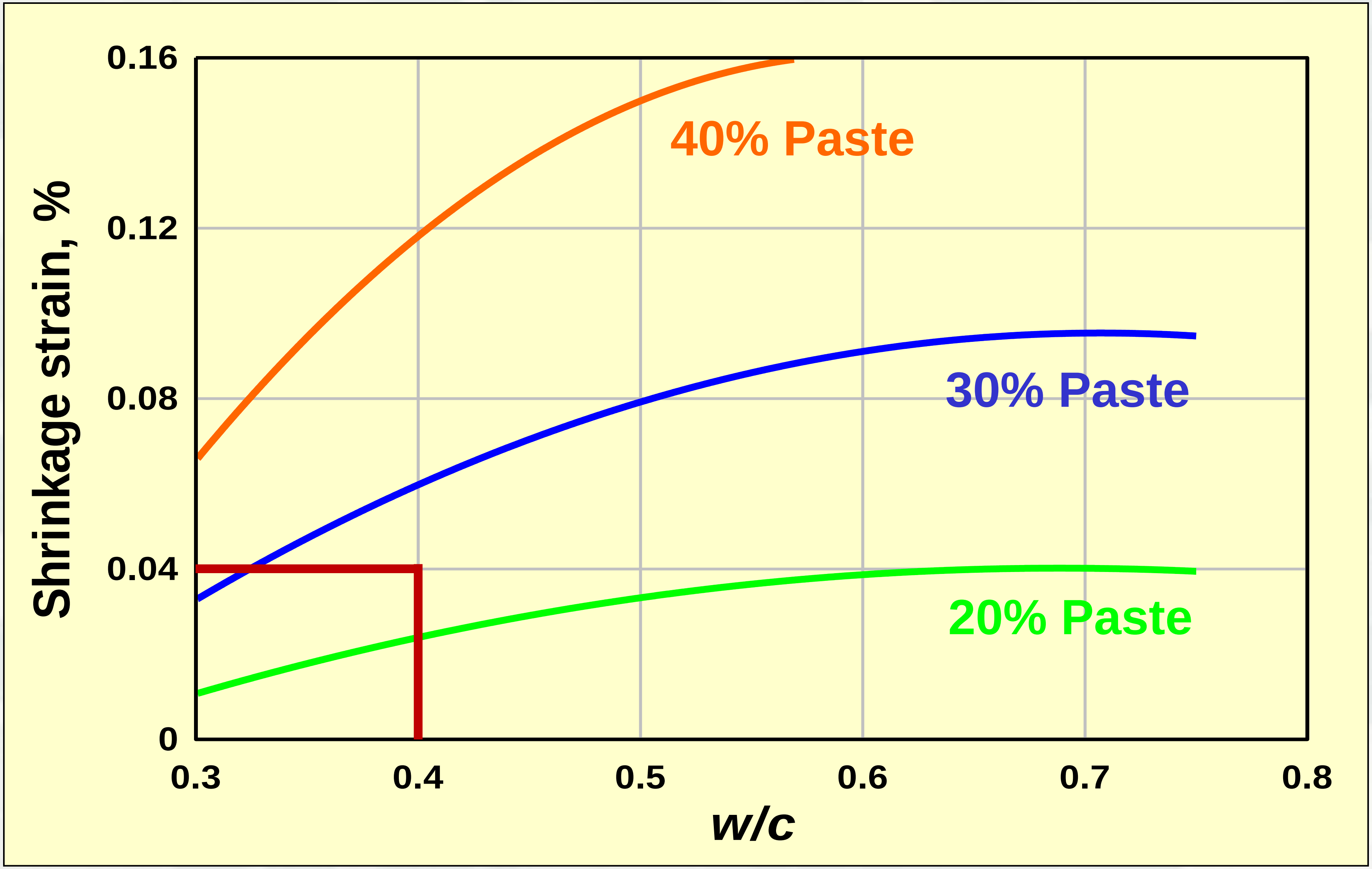
Drying Shrinkage

Effect of 3/4-in. Aggregate



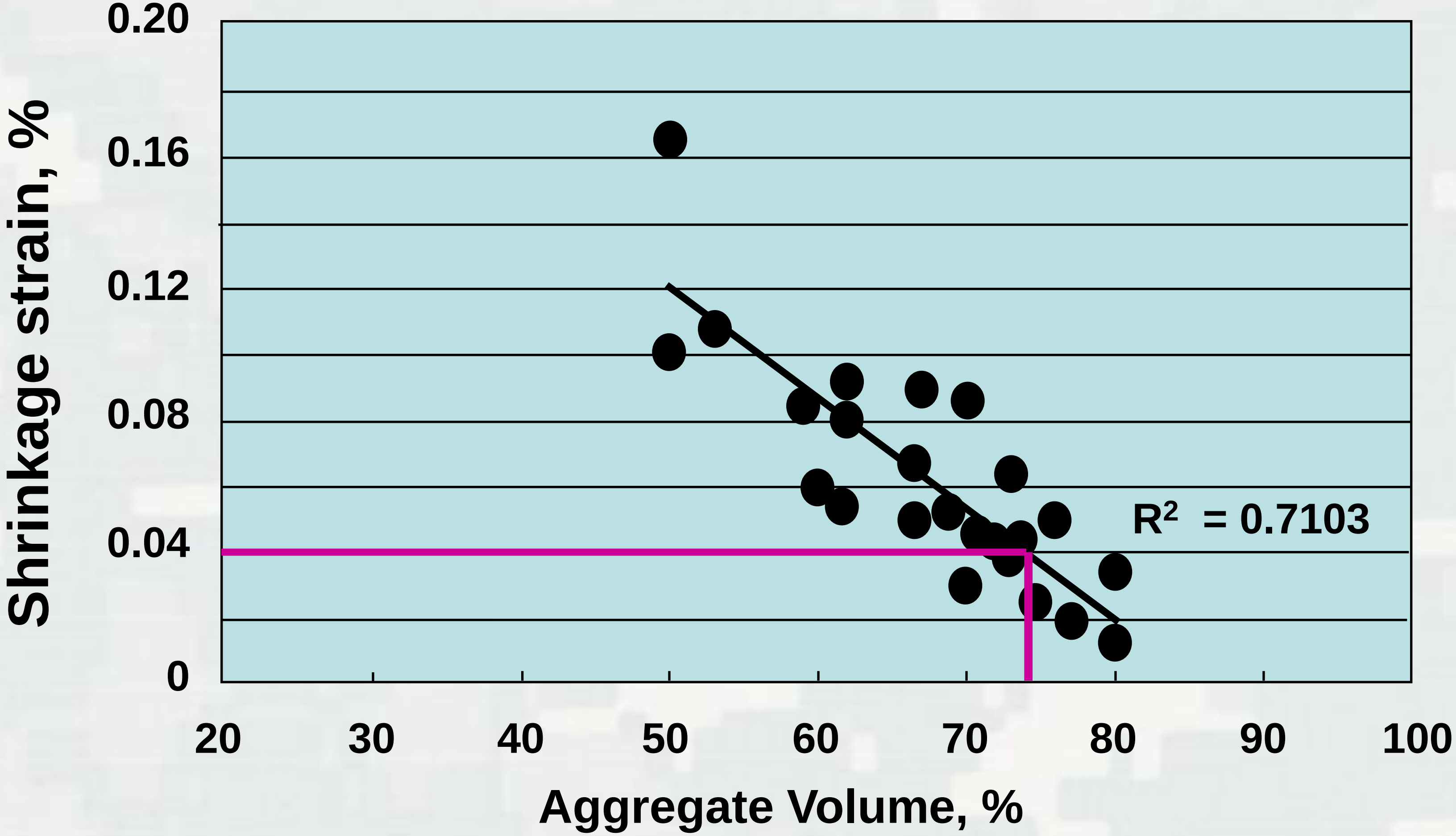


Paste Volume vs Shrinkage



After Nawy (1996)

Effect of Aggregate Volume on Drying Shrinkage



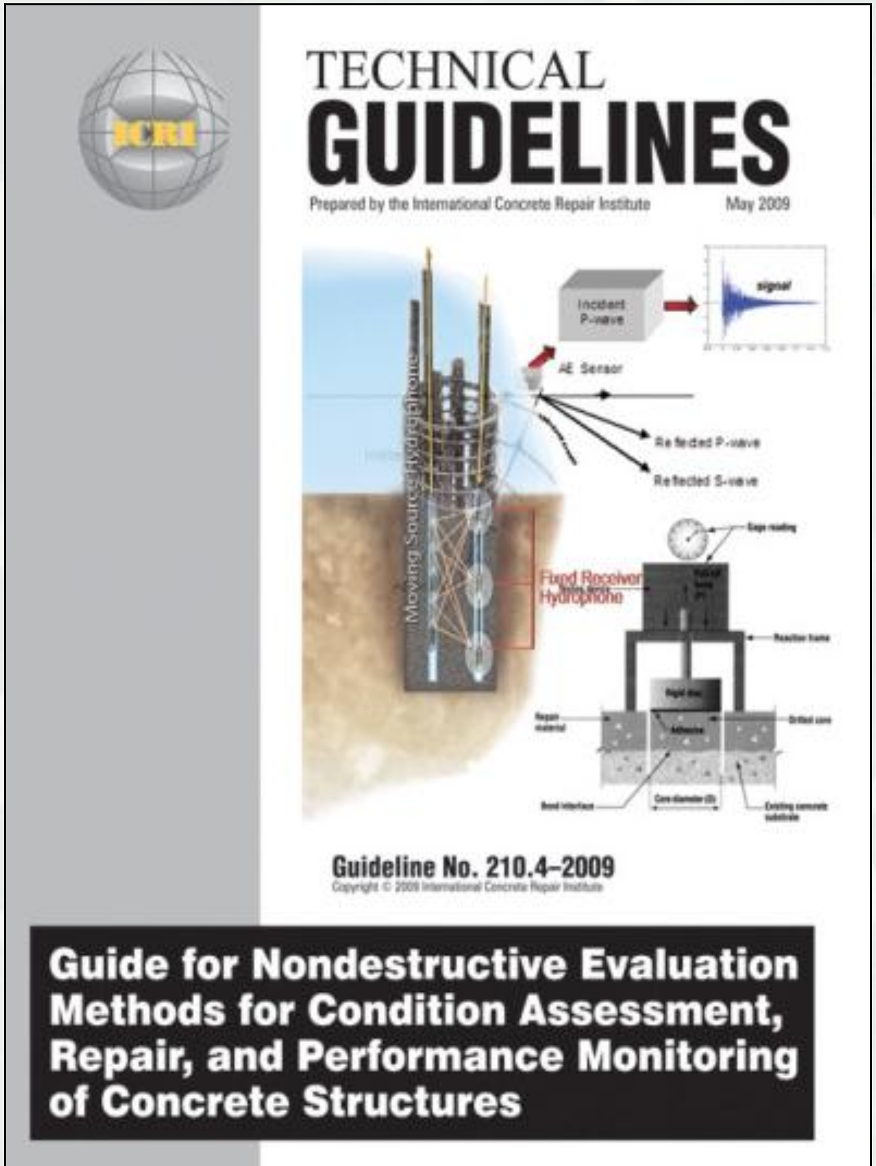
After Price (2002)

Looking Back
1980s

Property	Relationship of Repair Material (R) to Concrete Substrate (C)
Compressive Strength	**R > C**
Slant-Shear Bond	**R > C**
Modulus of Elasticity	**R ≥ C**
Thermal Expansion/Contraction	**R ≤ C**
Unrestrained Shrinkage	**R = C**

Nonstandard or modified test methods
No protocol for testing and reporting information
Lack of performance criteria

"We Have Come A Long Way"



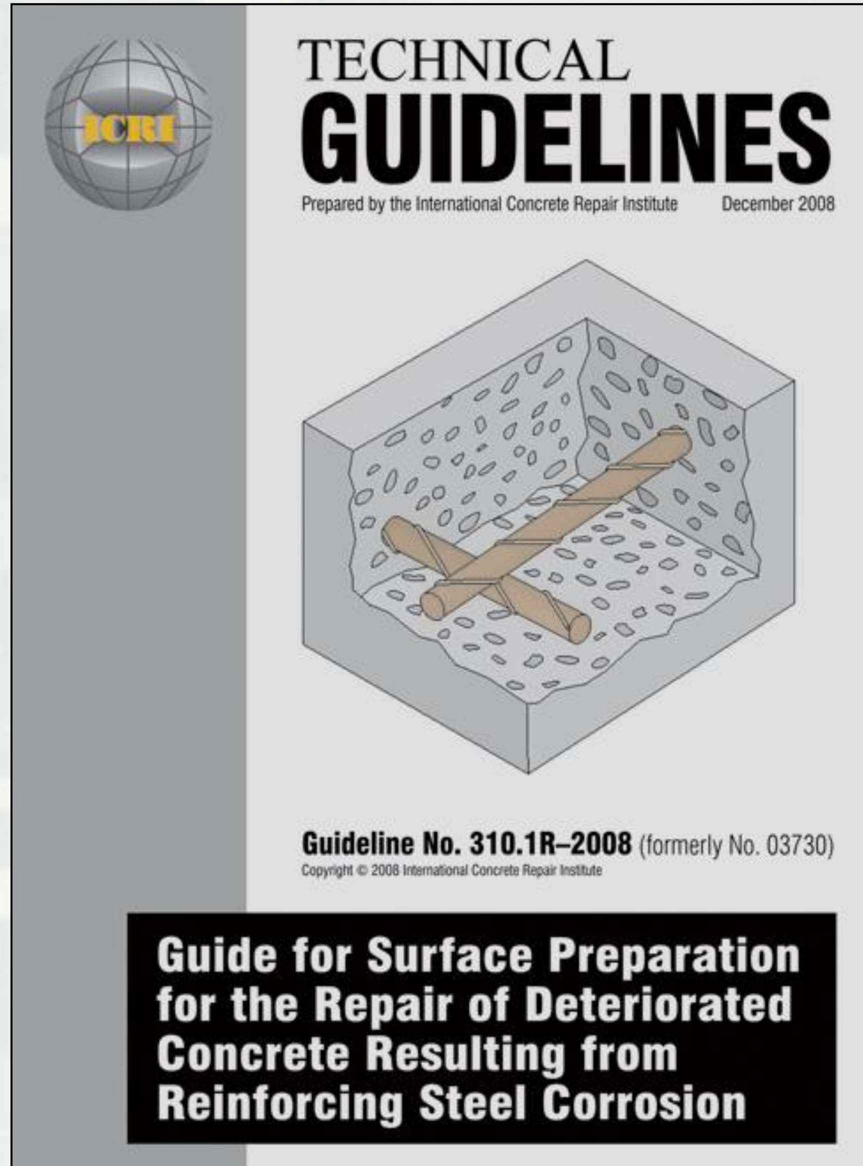
TECHNICAL
GUIDELINES

Prepared by the International Concrete Repair Institute May 2009

Guideline No. 210.4–2009

Copyright © 2009 International Concrete Repair Institute

Guide for Nondestructive Evaluation Methods for Condition Assessment, Repair, and Performance Monitoring of Concrete Structures



TECHNICAL
GUIDELINES

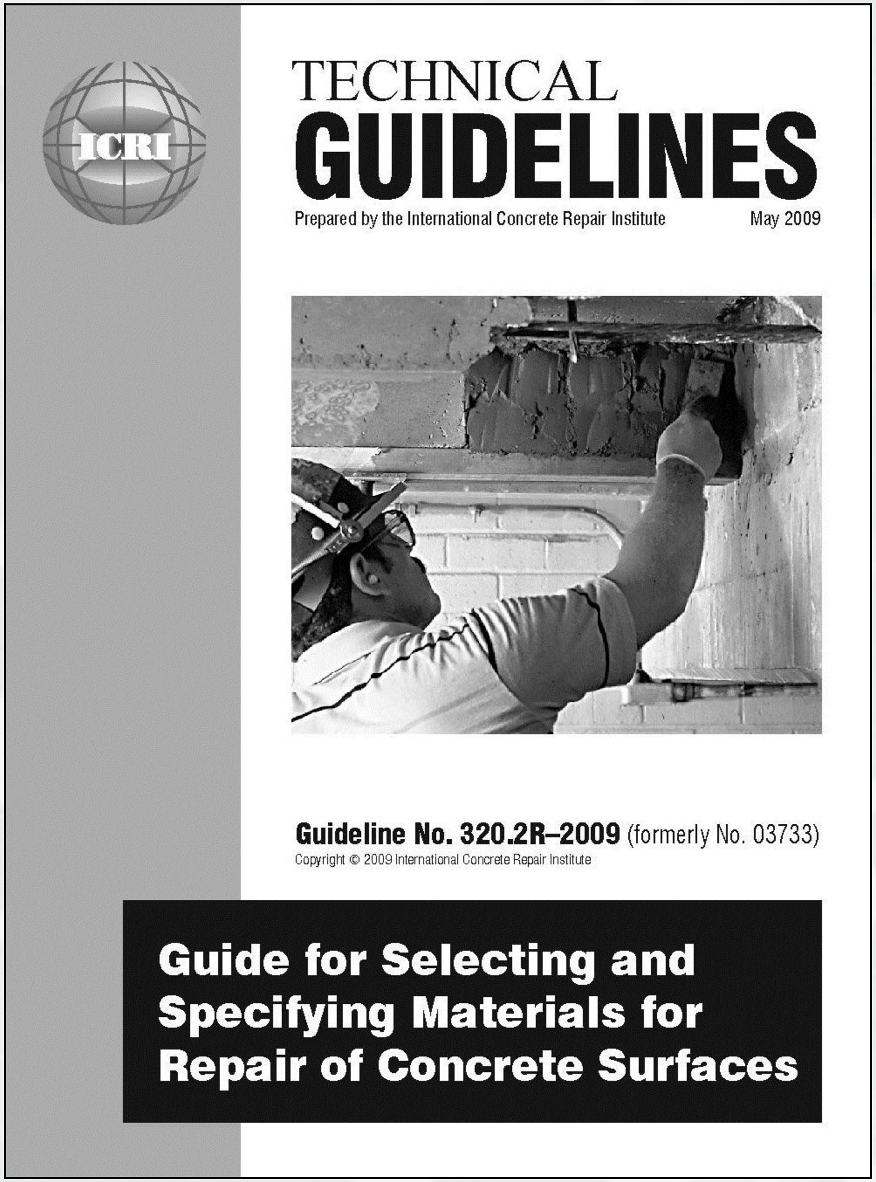
Prepared by the International Concrete Repair Institute December 2008

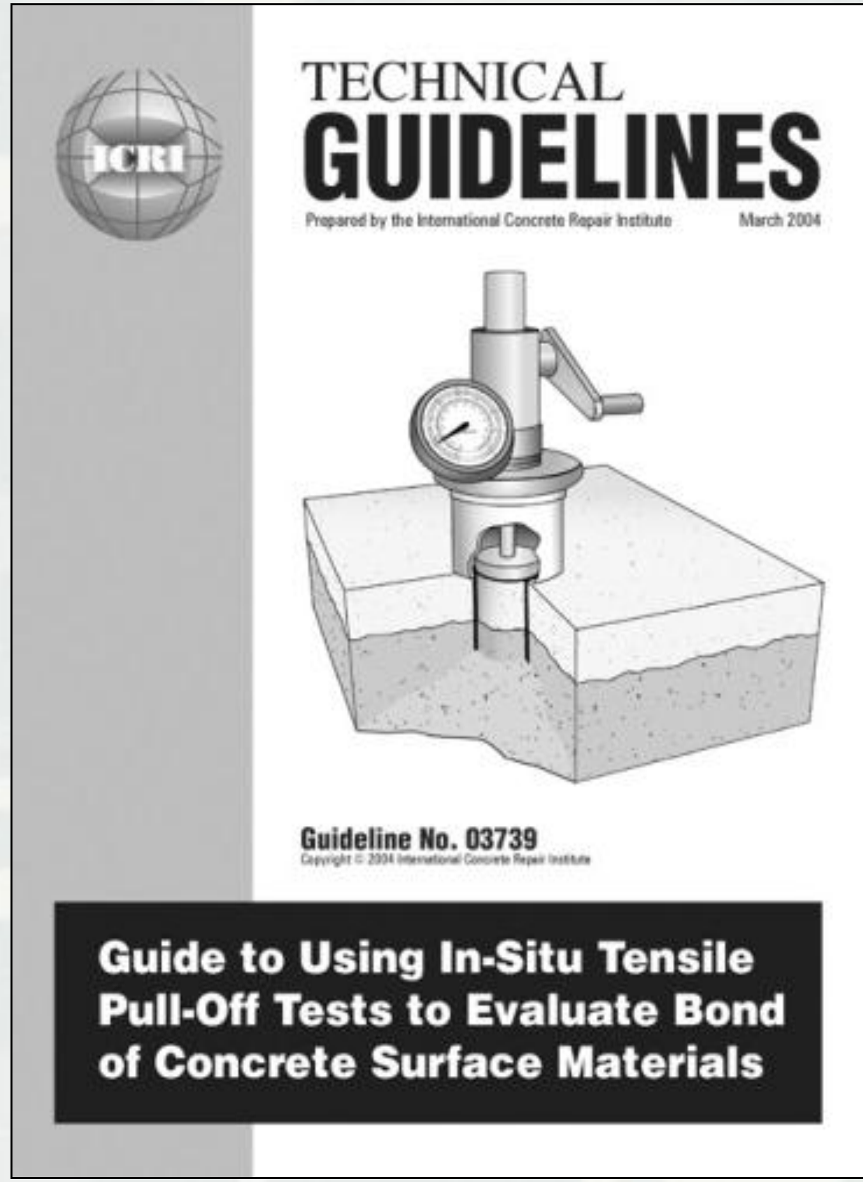
Guideline No. 310.1R–2008 (formerly No. 03730)

Copyright © 2008 International Concrete Repair Institute

Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion

"We Have Come A Long Way"





TECHNICAL
GUIDELINES

Prepared by the International Concrete Repair Institute August 2012

http://www.icri.org/PUBLICATIONS/PDFs/320.3R-2012.pdf

Guideline for Inorganic Repair Material Data Sheet Protocol

Guideline No. 320.3R-2012

ICRI Bookstore Free Download

Standardized protocol for testing and reporting of data for inorganic repair materials

- Repair Material Description
- Composition
- Material Properties (22)
- Packaging and Storage
- How to Use the Material

Dimensionally Compatible Repairs

Properties in Order of Relative Importance

- **Restrained Shrinkage (ASTM C1581)**
  - **No cracks within 14 days**
- **Unrestrained Shrinkage (ASTM C157)**
  - **0.04% max. (28-days); 0.10% max. (ultimate)**
- **Direct Tensile Strength (CRD-C 164)**
  - **400 psi min.**
- **Modulus of Elasticity (ASTM C469)**
  - **3.5×10^6 psi max; similar to substrate (structural)**
- **Thermal Coefficient (CRD-C 39)**
  - **7 millionths/ °F max.**
- **Compressive Strength**
  - **Similar to substrate**

Looking Back

We Have Come A Long Way!