

Relative Importance of Repair Material Properties Then and Now

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ICRI Convention
Fall 2013



A Look Back

Fort Peck Spillway - 1938

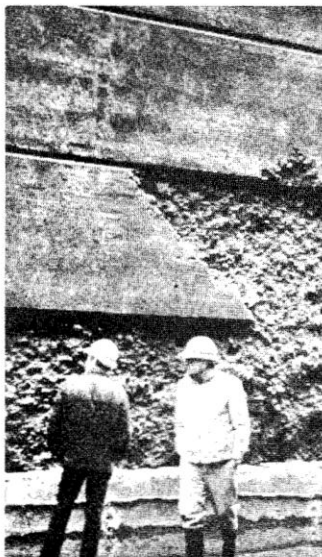


Melvin Price Lock and Dam





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

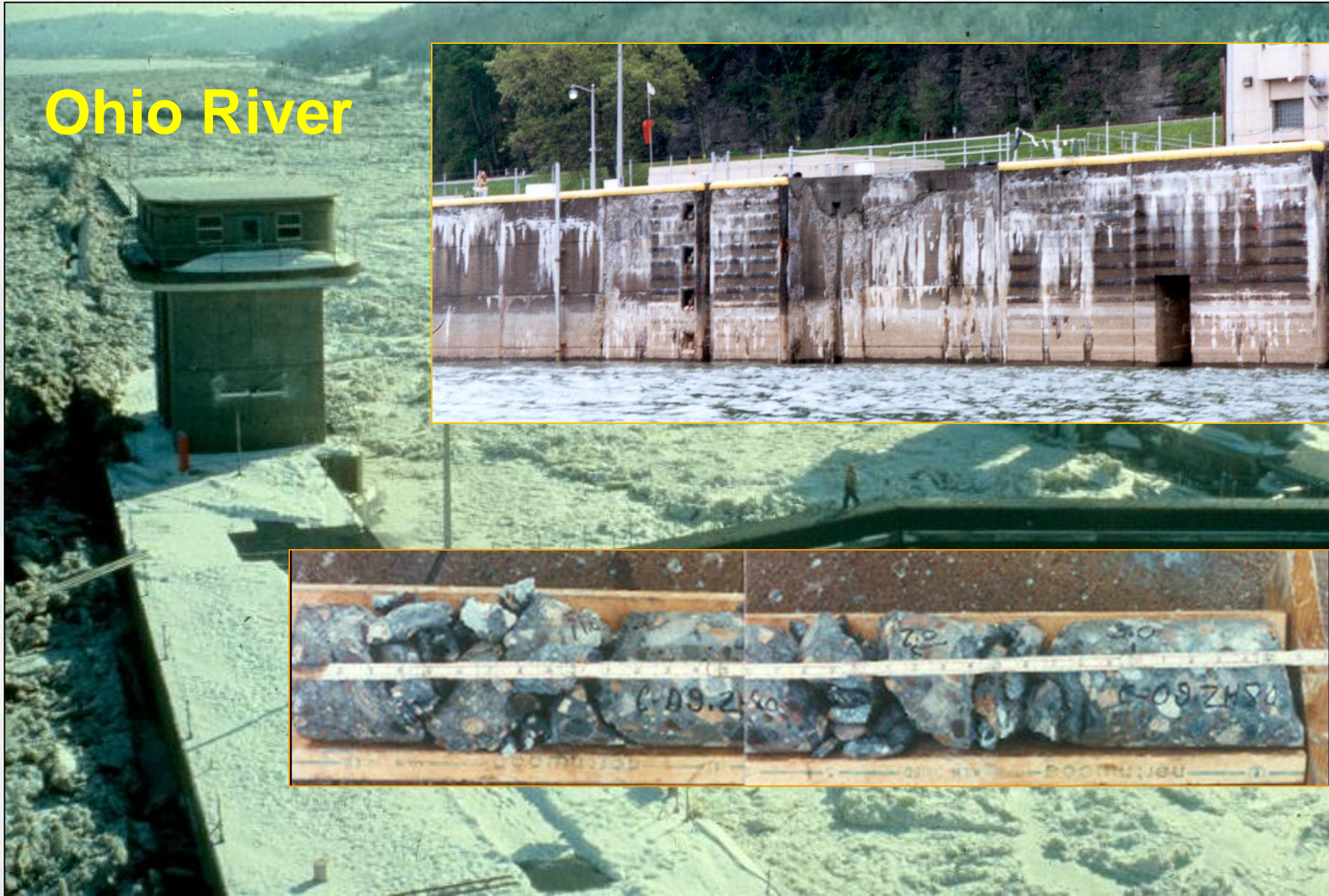
**536 dams and 260 lock chambers;
60% were over 20 years age;
>40% were over 30 years age ; and
~50% would reach 50-year design
life by 2000.**



April 1985
Final Report

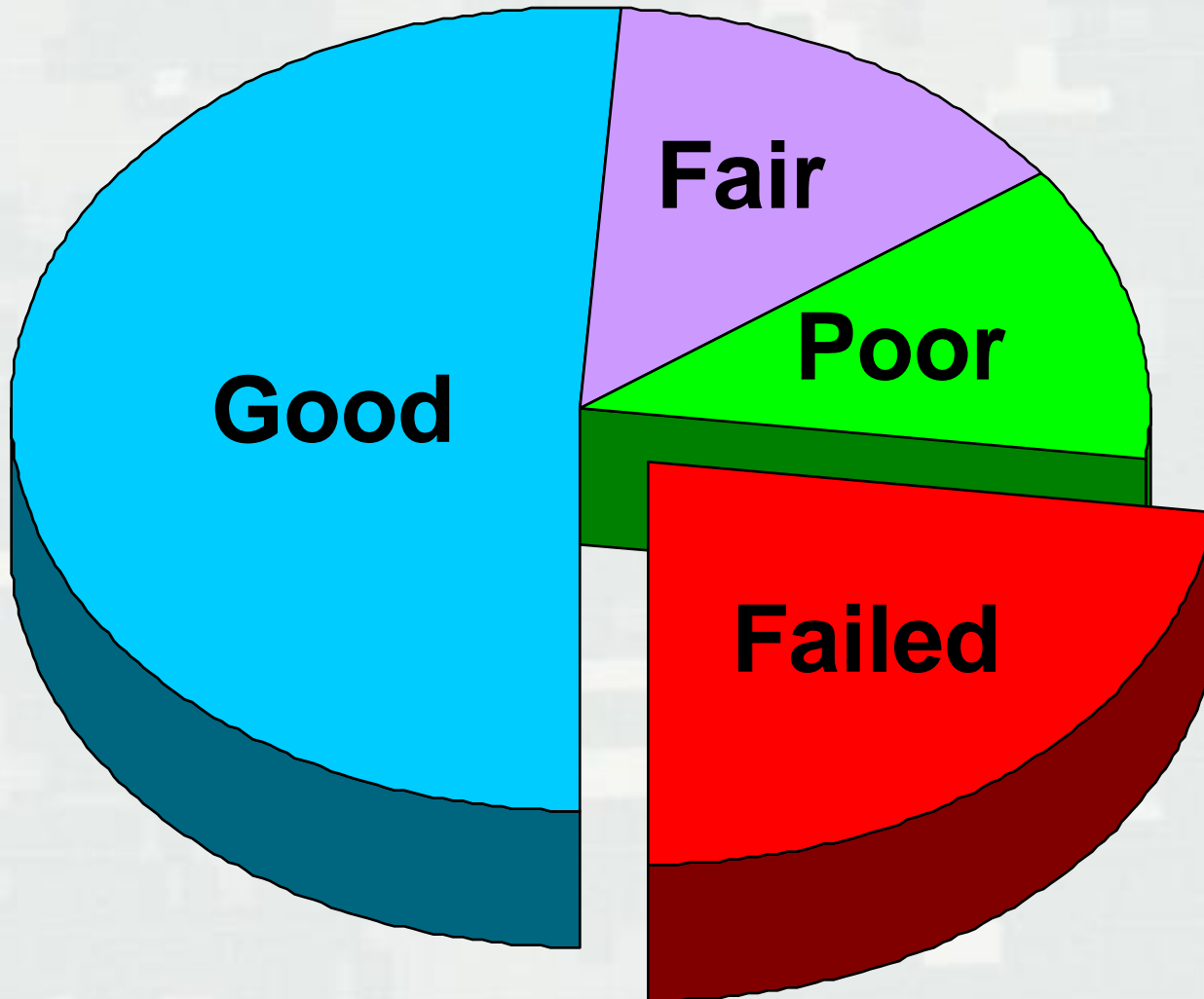
Severe Exposure Conditions

Ohio River



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.**”

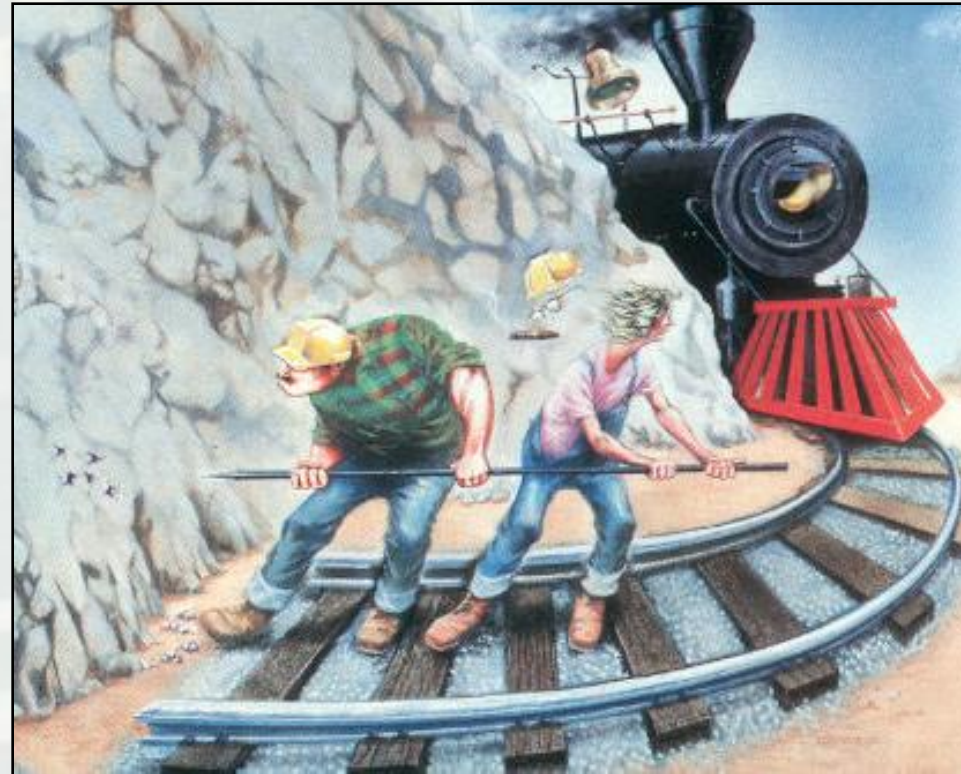
“Once the criteria are known, it will often be found that more than one material can be used with equally good results. Final selection of the material or combination of materials must then take into account the **ease of application, cost, and available labor skills and equipment.**”

(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)

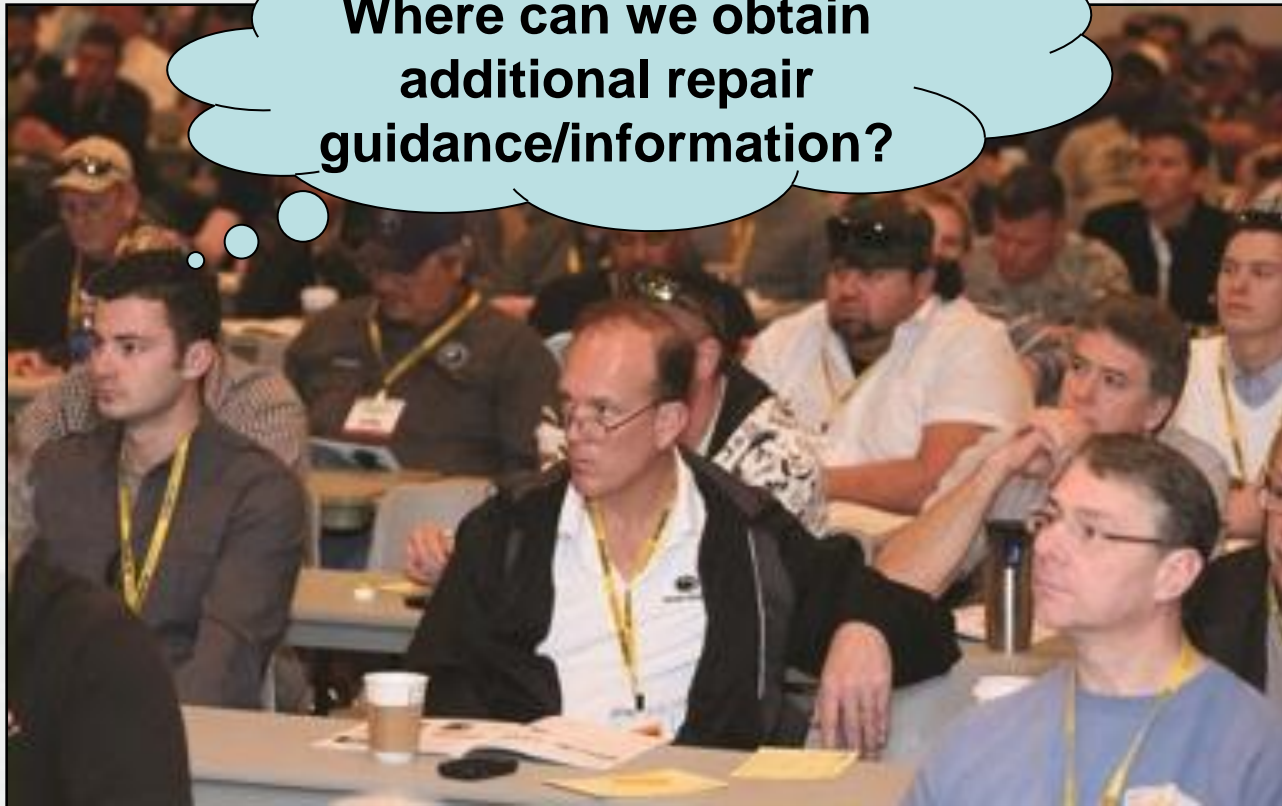
Relationship of Repair Material (R) to Concrete Substrate (C)

Property

Compressive Strength	$R > C$
Slant-Shear Bond	$R > C$
Modulus of Elasticity	$R \geq C$
Thermal Expansion/Contraction	$R \leq C$
Unrestrained Shrinkage	$R = C$

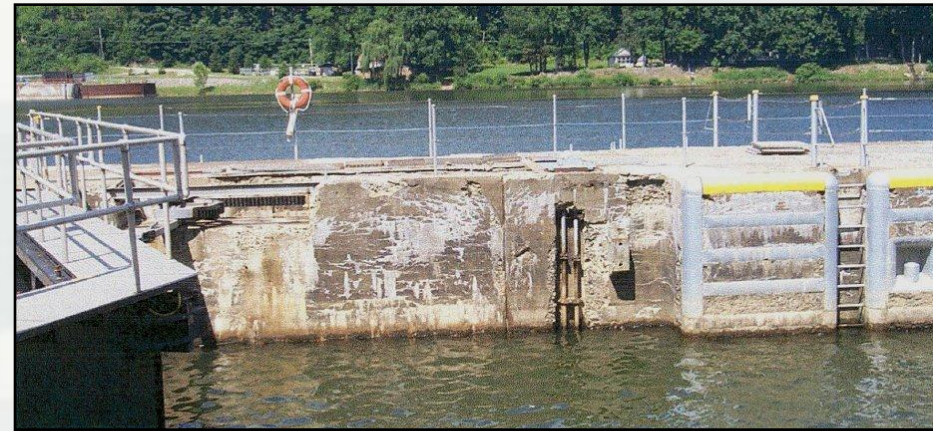
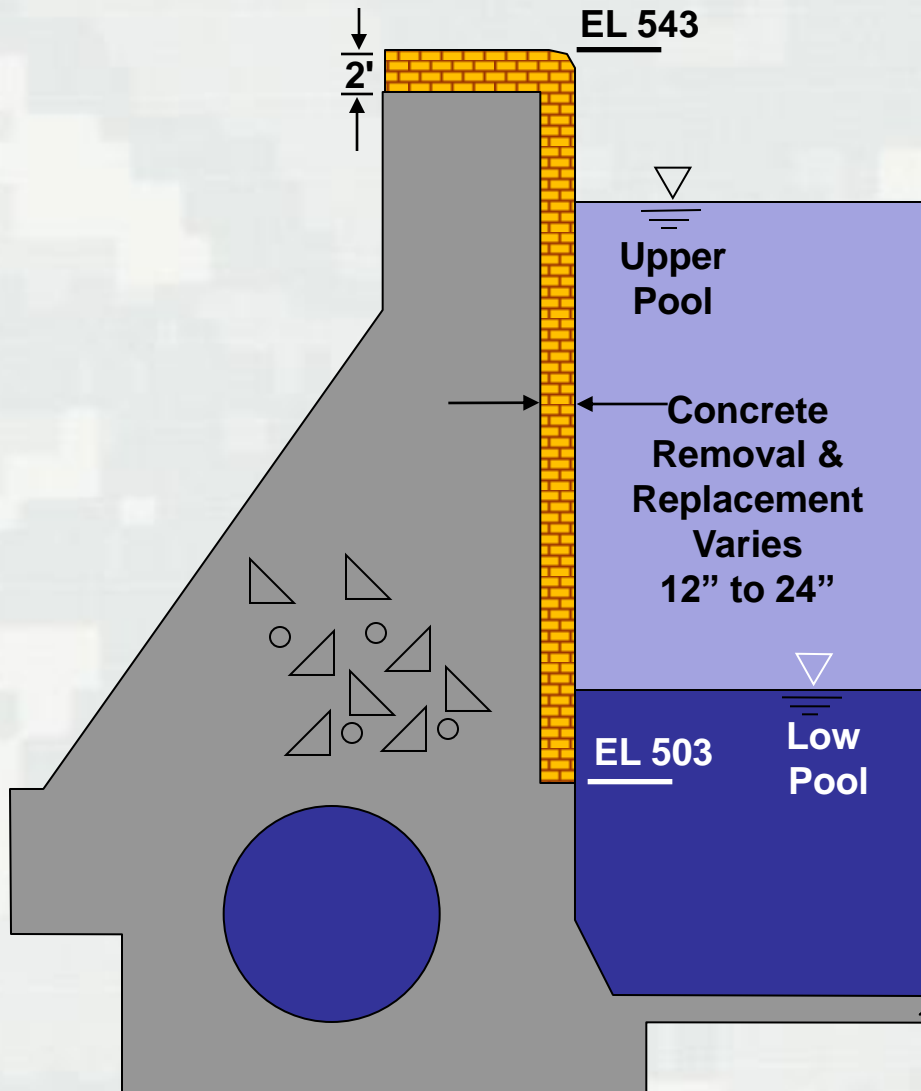
World of Concrete – Jan 1988

Jim Warner Concrete Repair Seminar



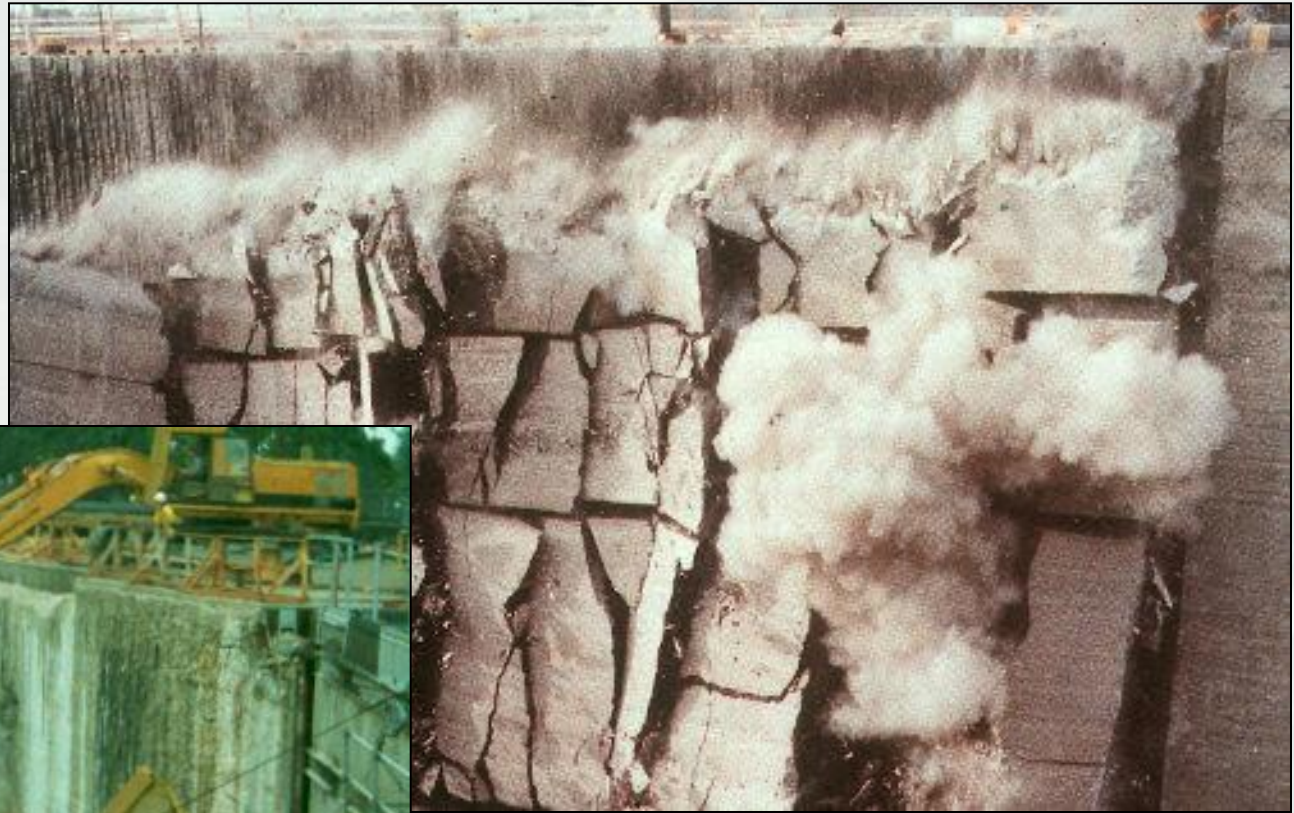
**International Concrete Repair Specialists
Naperville, IL May 1988**

Typical Lock Wall Rehabilitation



Deteriorated Concrete Removal

Secondary



Primary

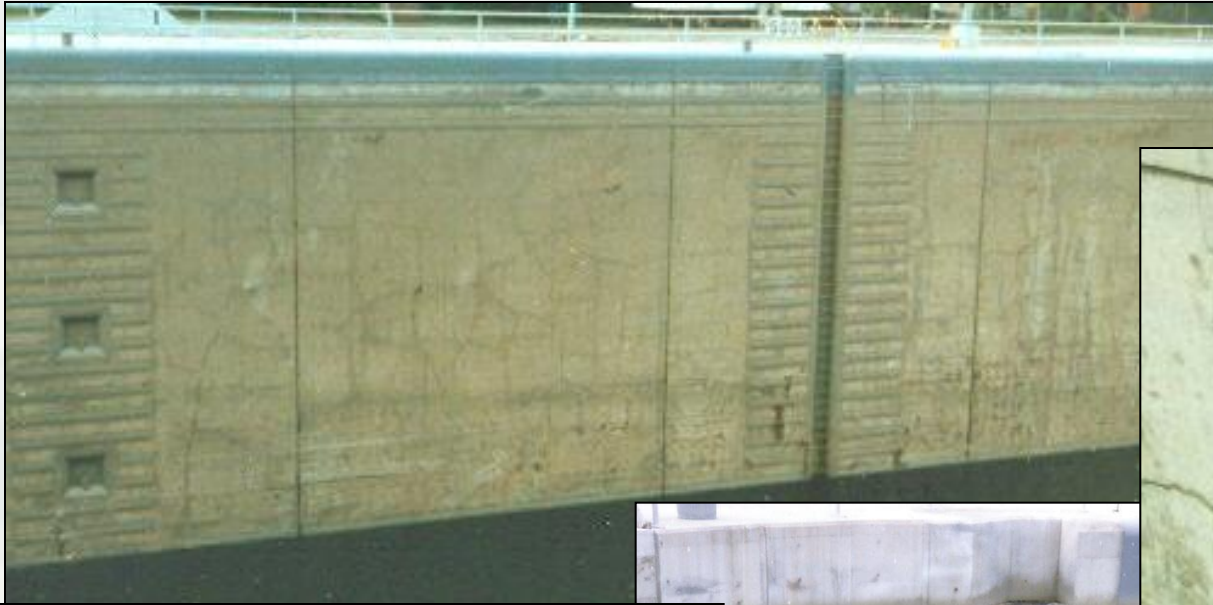
Surface Preparation



Cast-In-Place Concrete

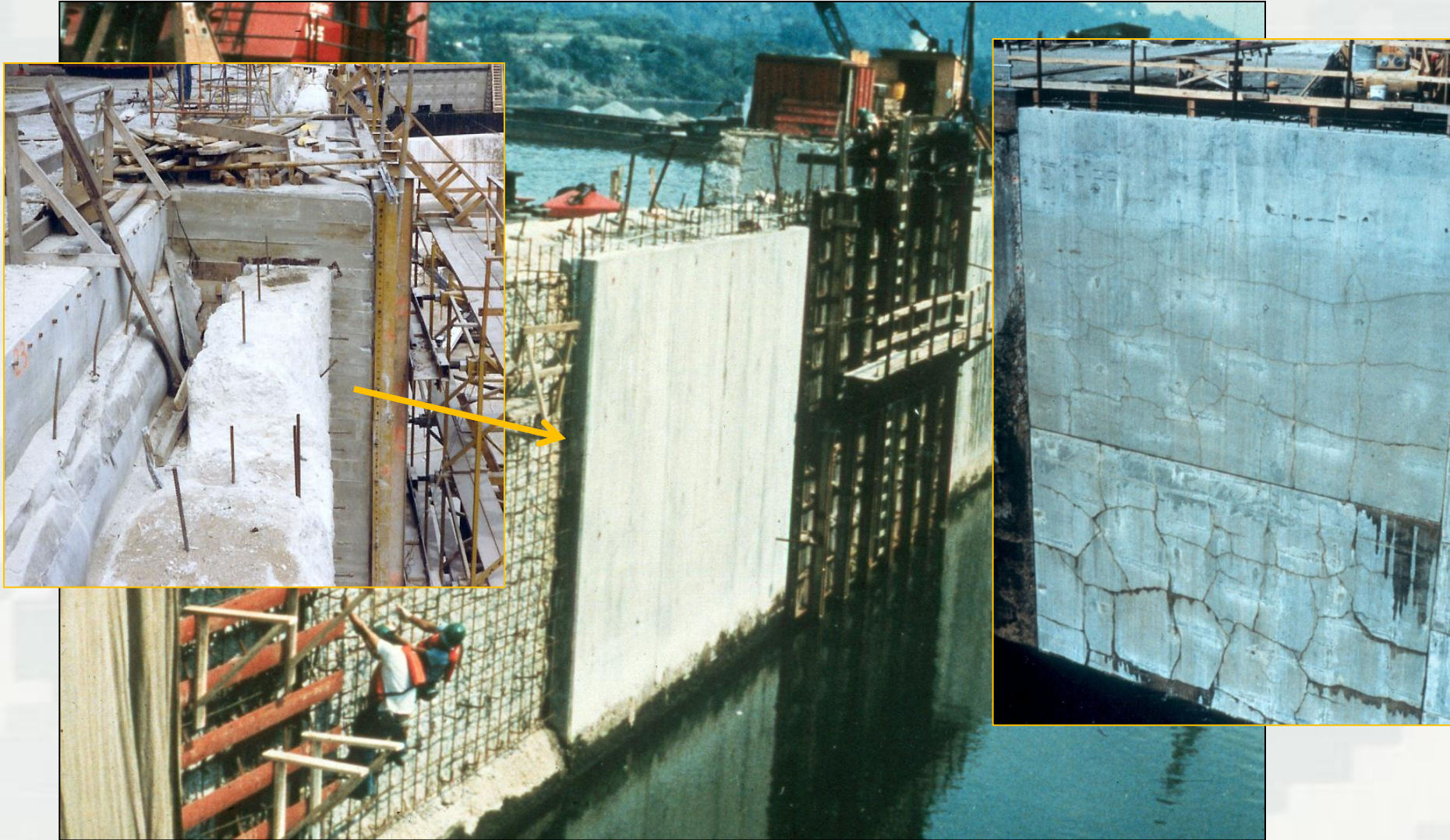


Concrete Cracking

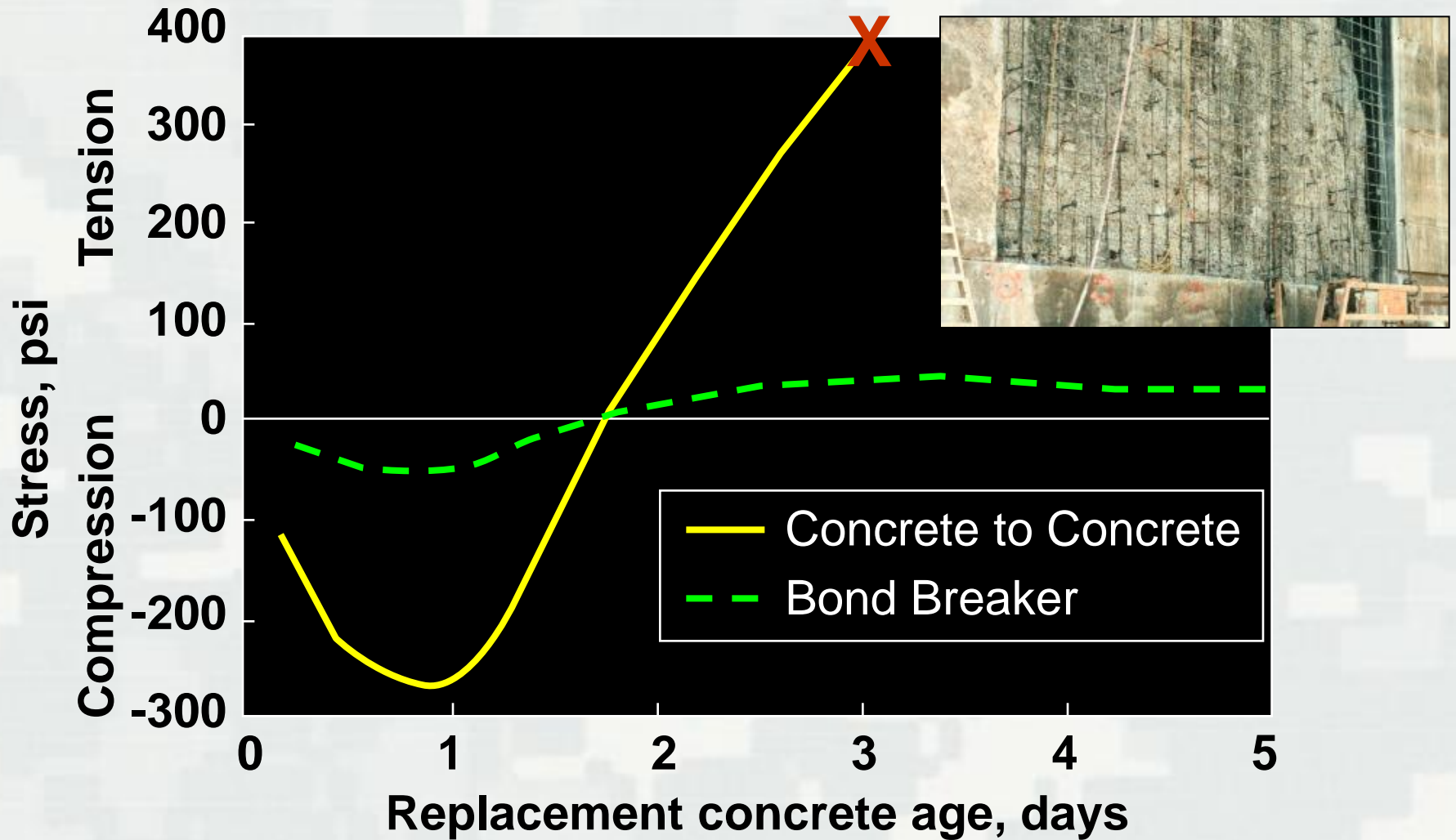


Lock Wall Rehabilitation

Restrained Contraction



Effect of Restrained Contraction



Effect of Restrained Contraction

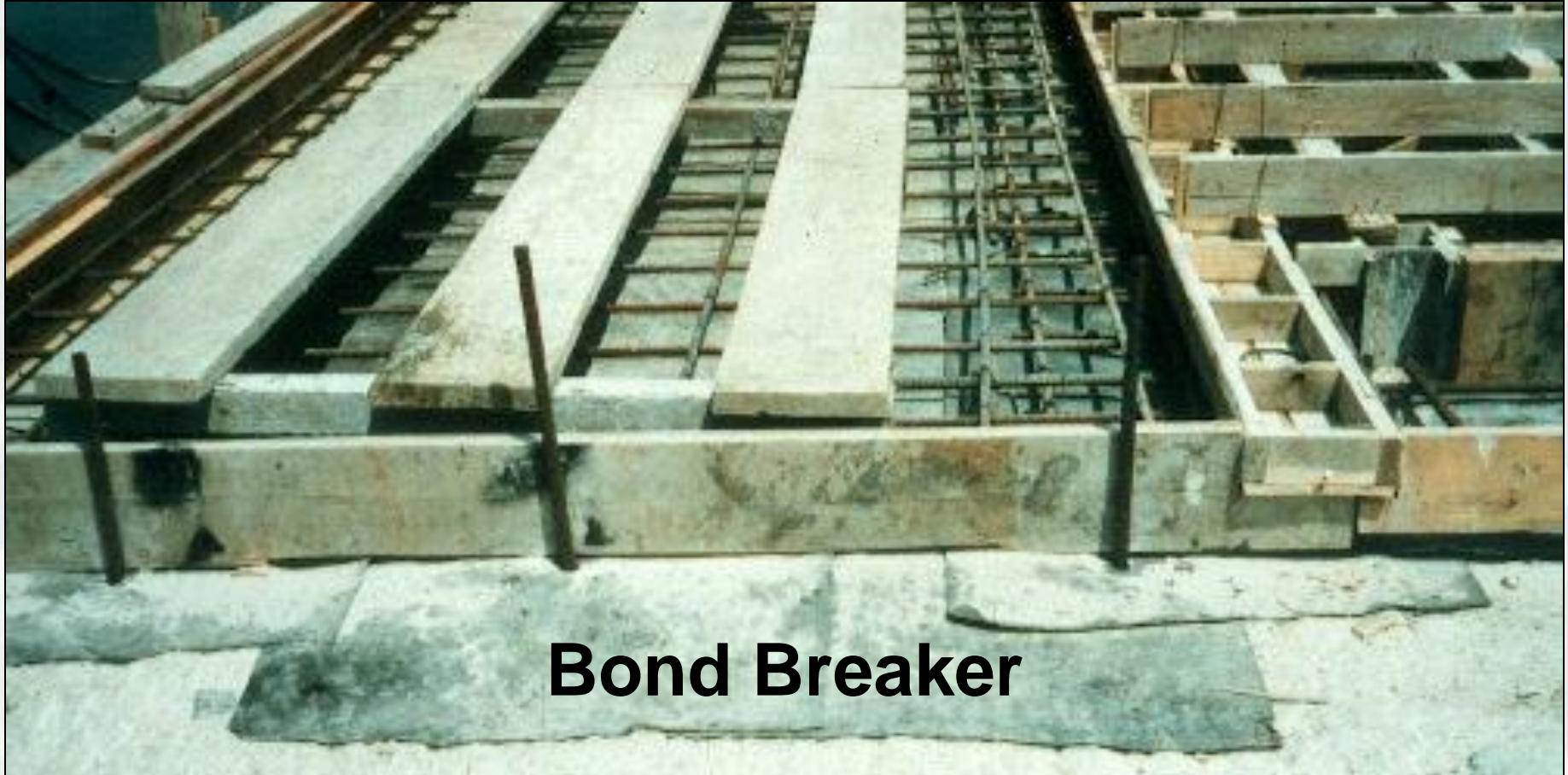
**Overlay
Cracking**



**New Construction
No Cracking**

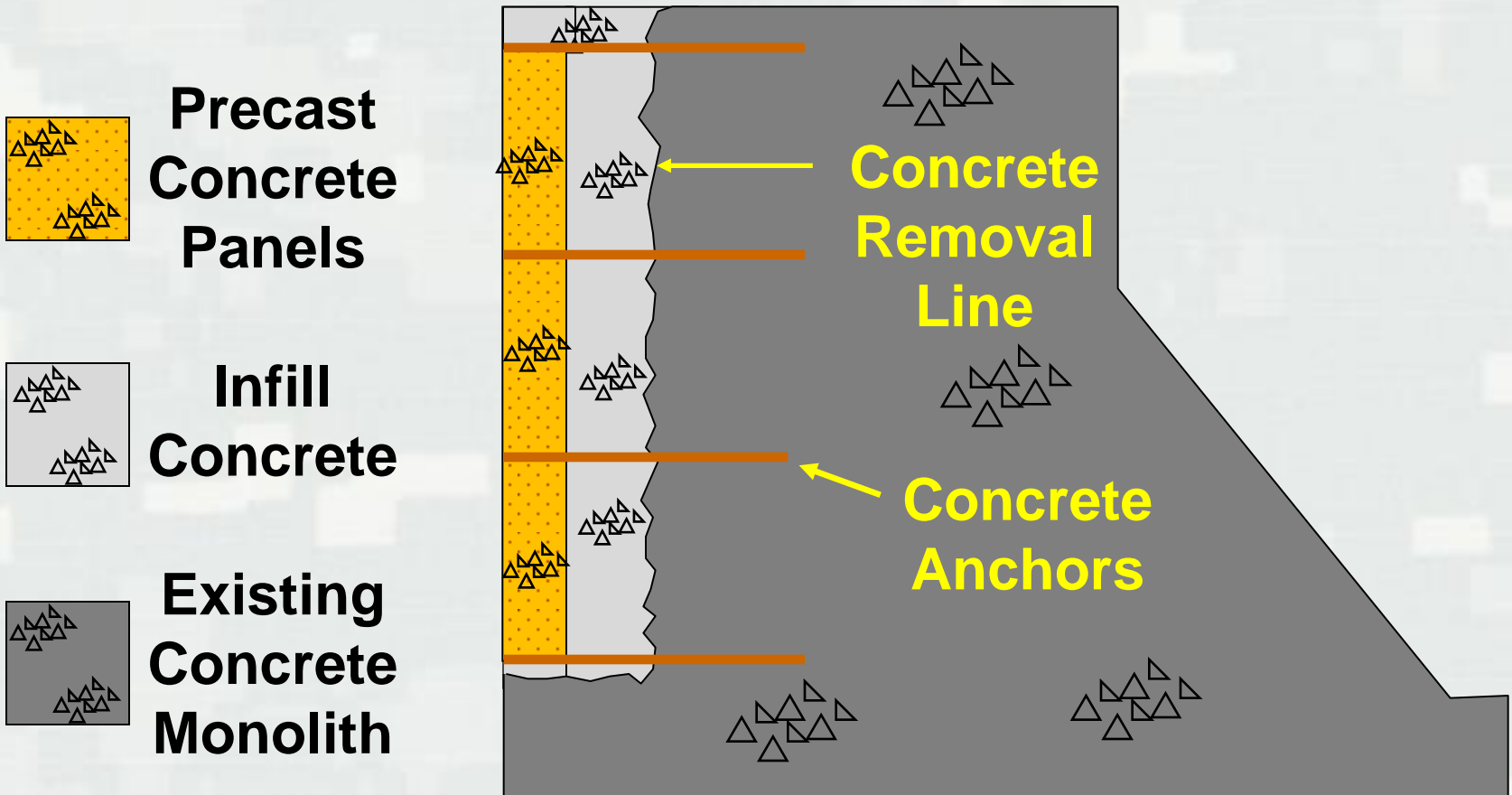
Brandon Road Dam

Bond Breaker Eliminated Cracking



Bond Breaker

Precast Concrete Stay-in-Place Forming System





Cast-in-Place



Precast

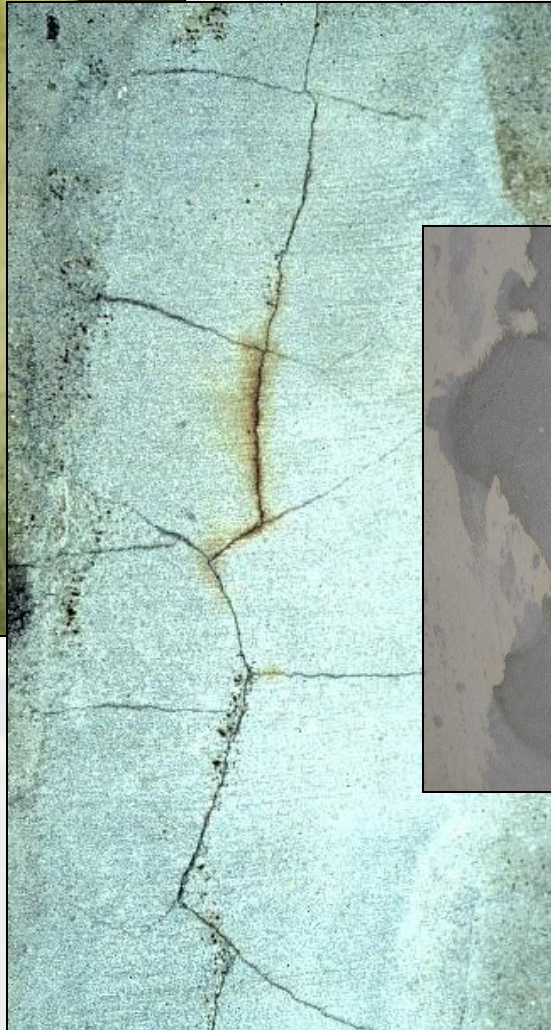
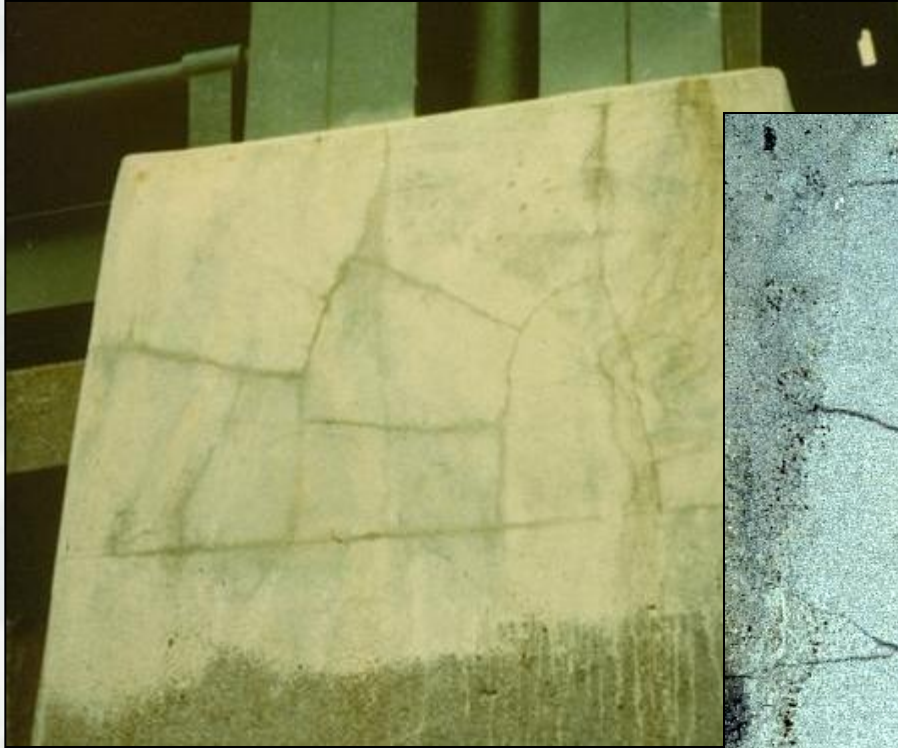
Precast Vs. CIP

Troy Lock

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

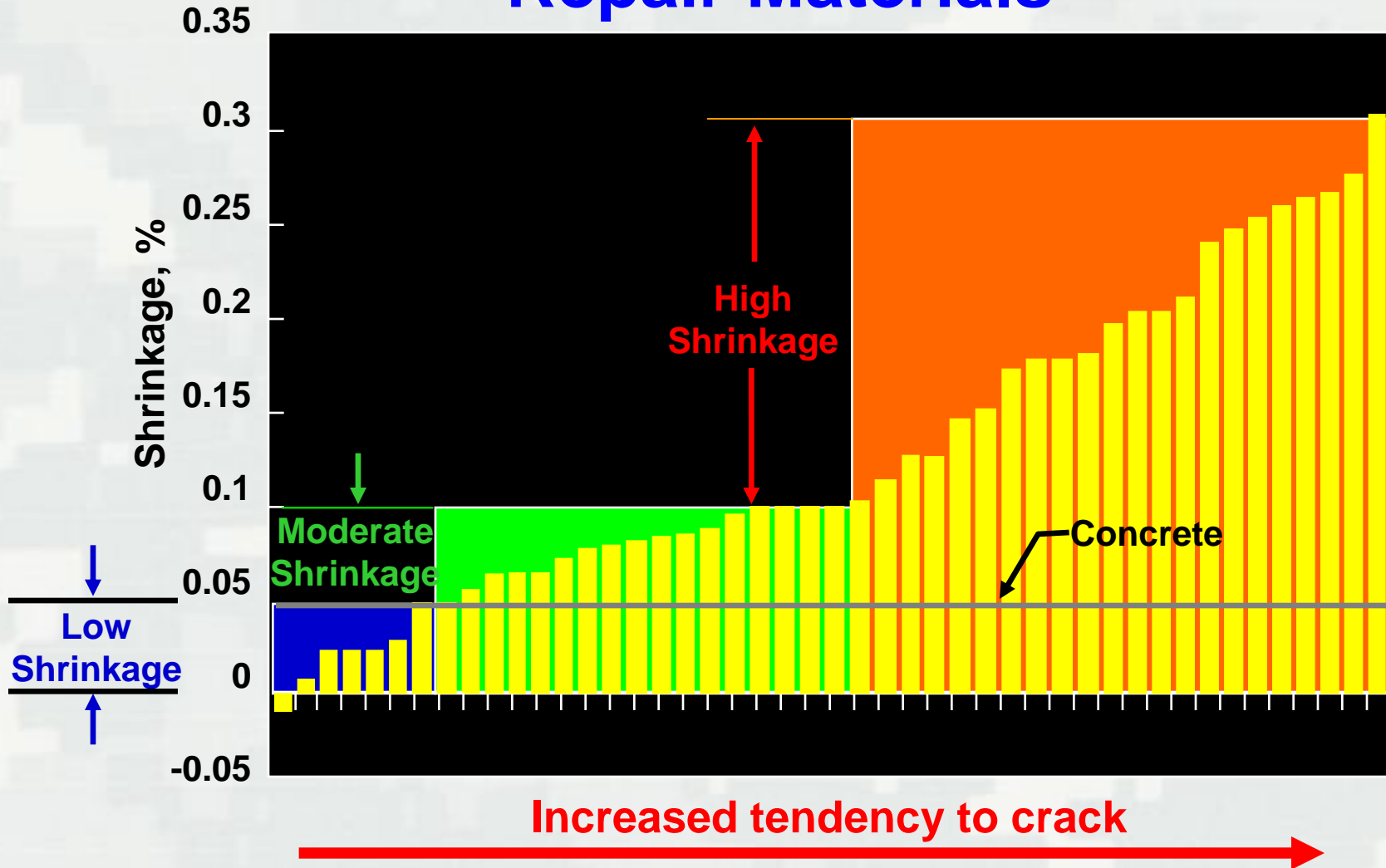
Effect of Restrained Contraction

Small Repairs



Shrinkage Test Results

Repair Materials



After Gurjar & Carter (1987)



**US Army Corps
of Engineers**
Waterways Experiment
Station

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

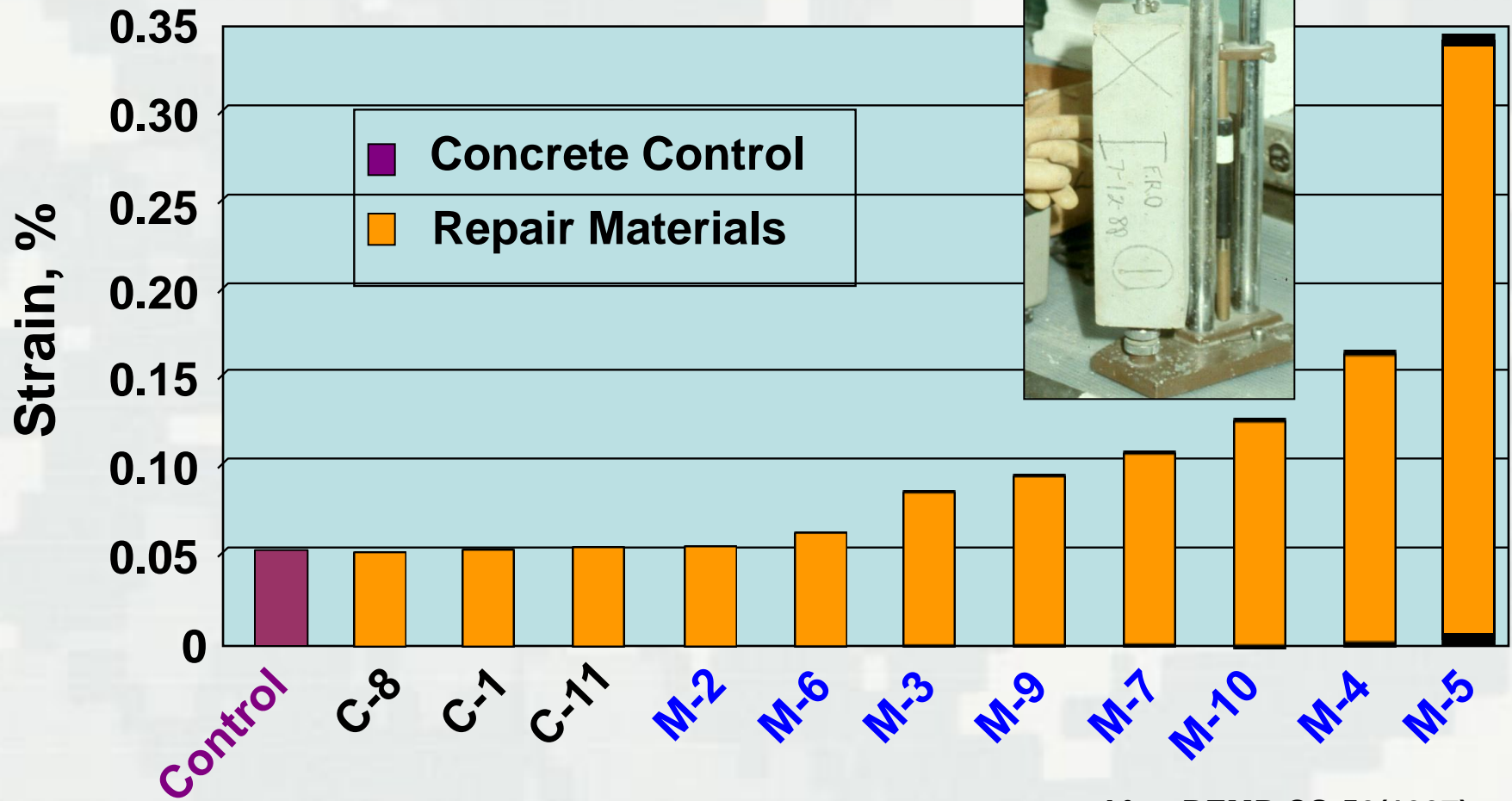
Repair, Evaluation, Maintenance, and Rehabilitation Research Program

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



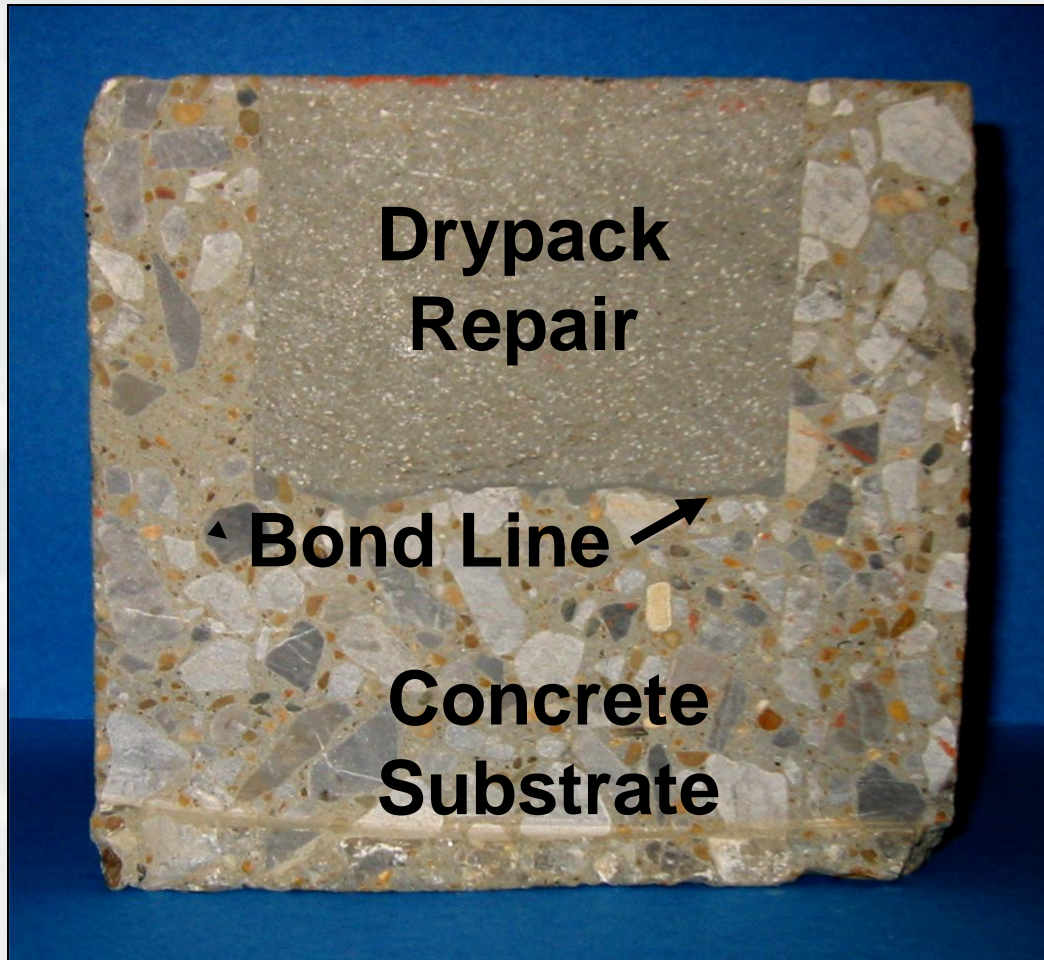
Drying Shrinkage Test Results

28 Days



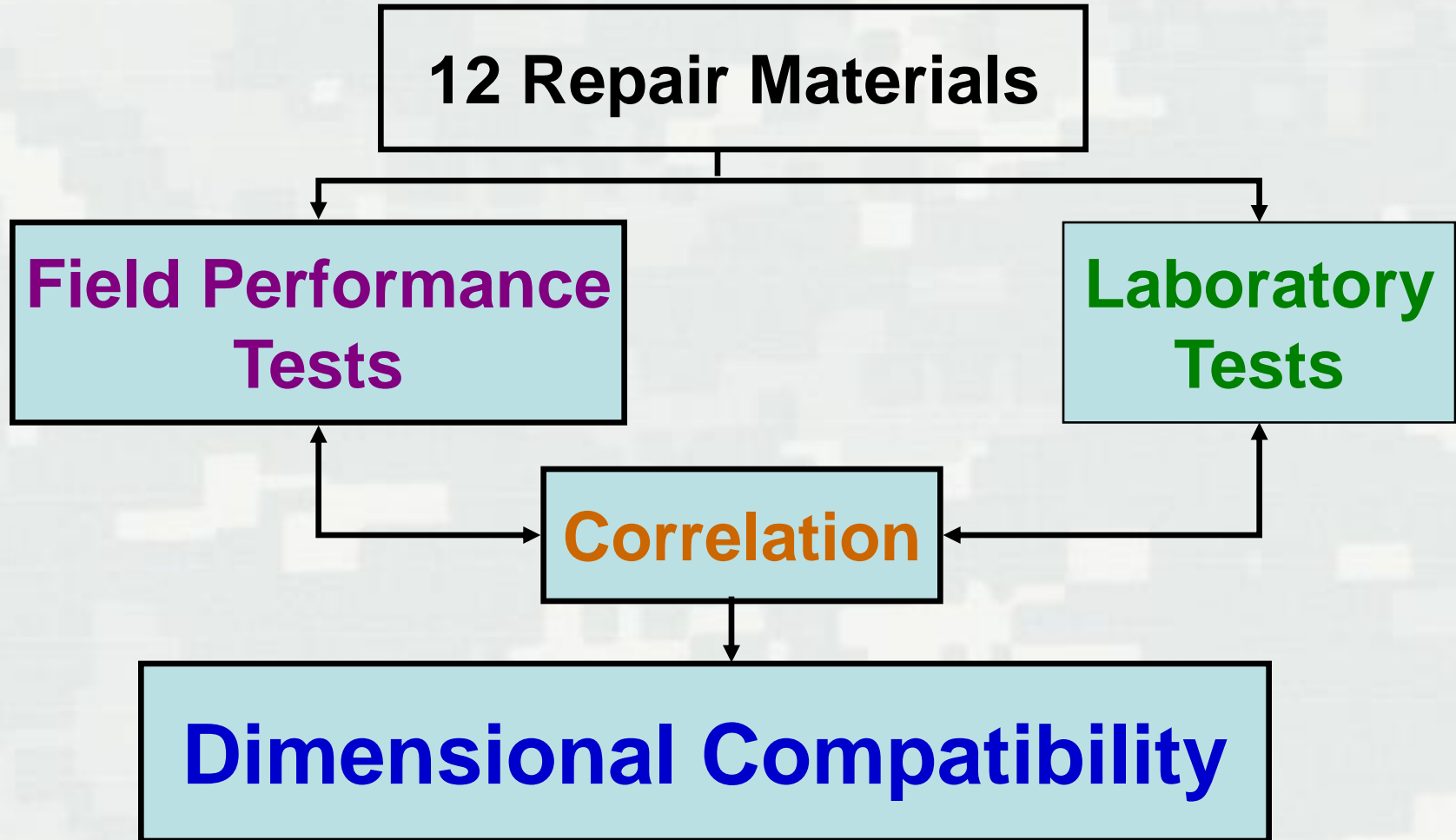
After REMR CS-52(1997)

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



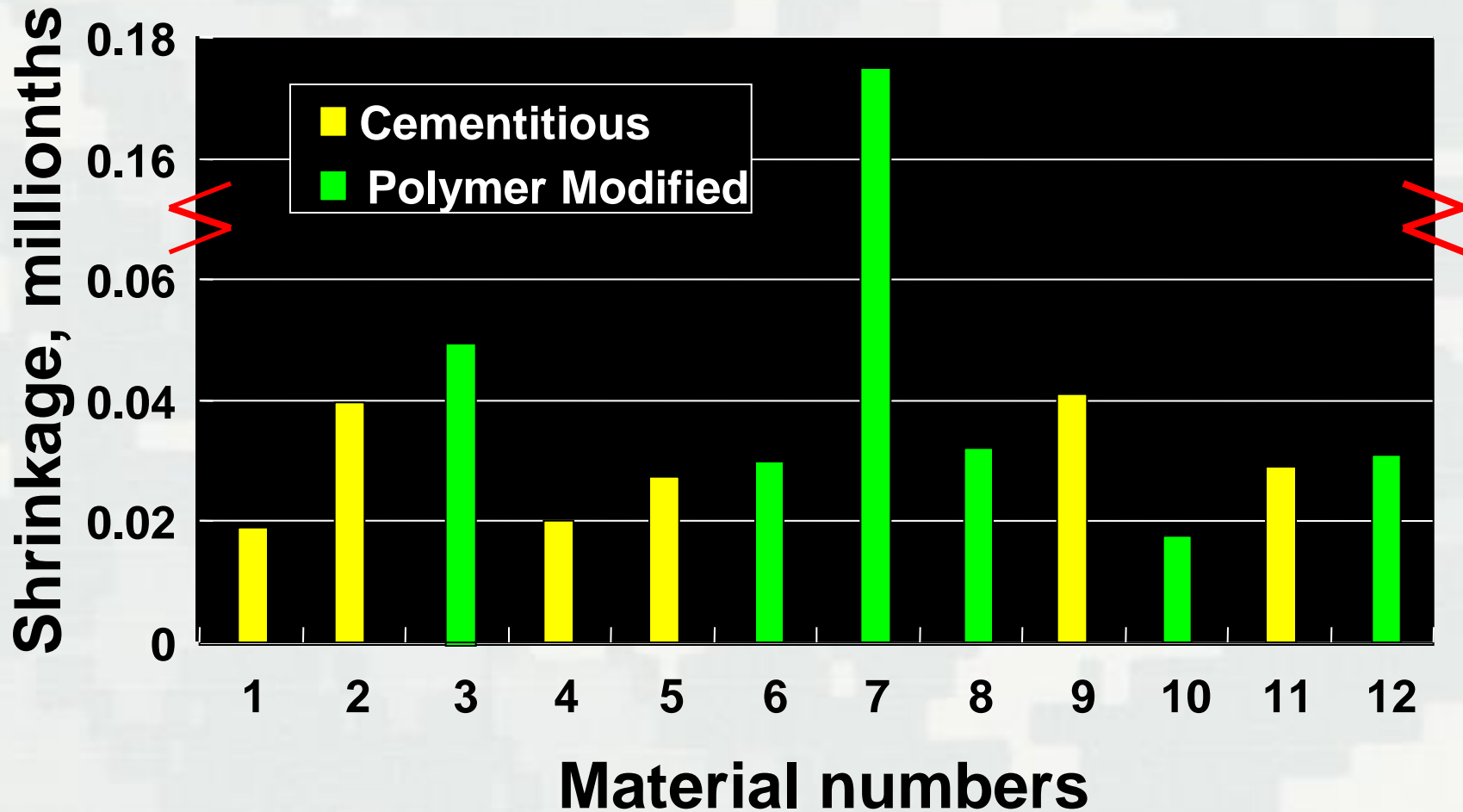
6 - Satisfactory

2 - Marginal

4 - Unsatisfactory

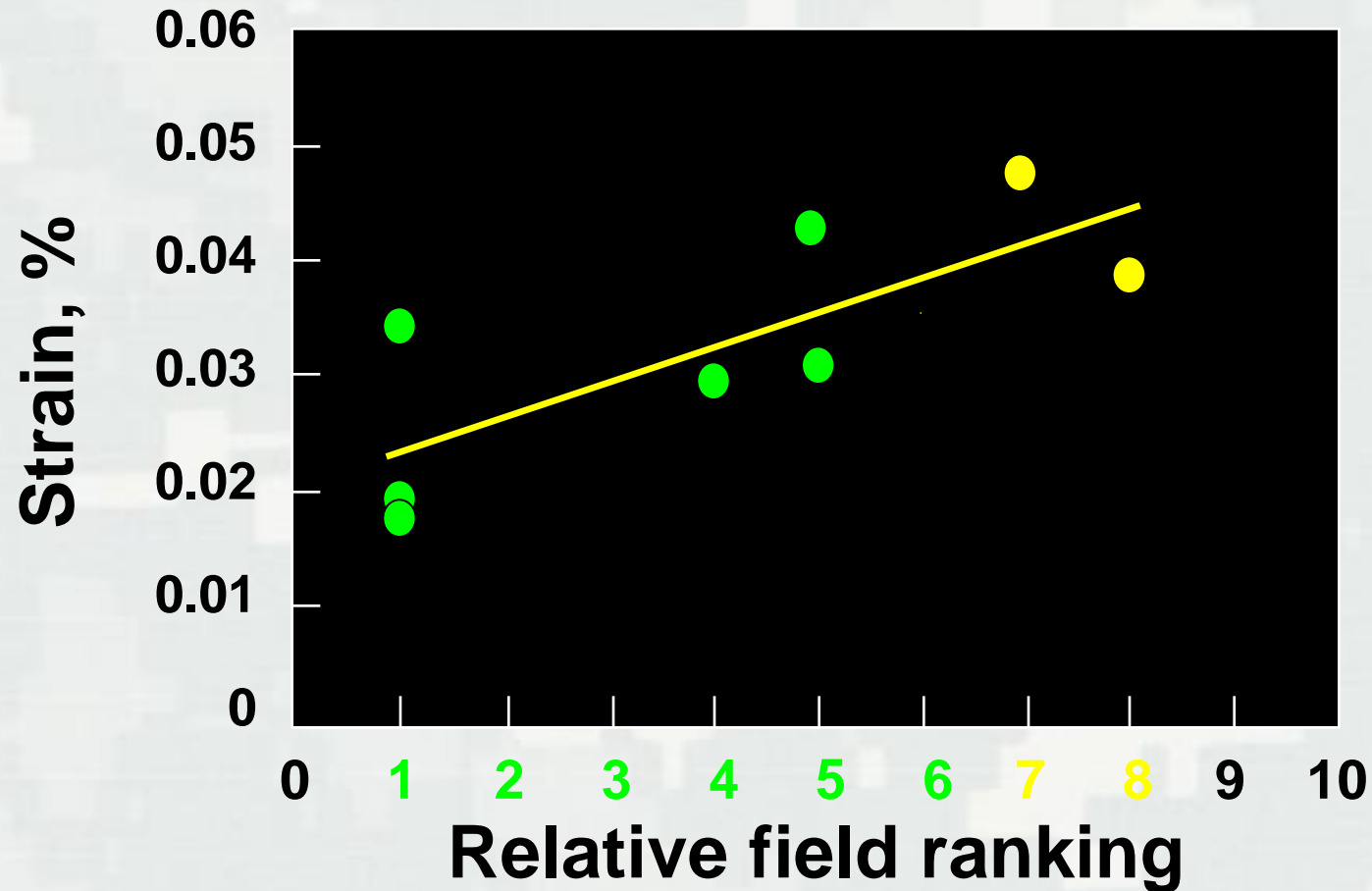
Drying Shrinkage

50% RH, 28-Days Age



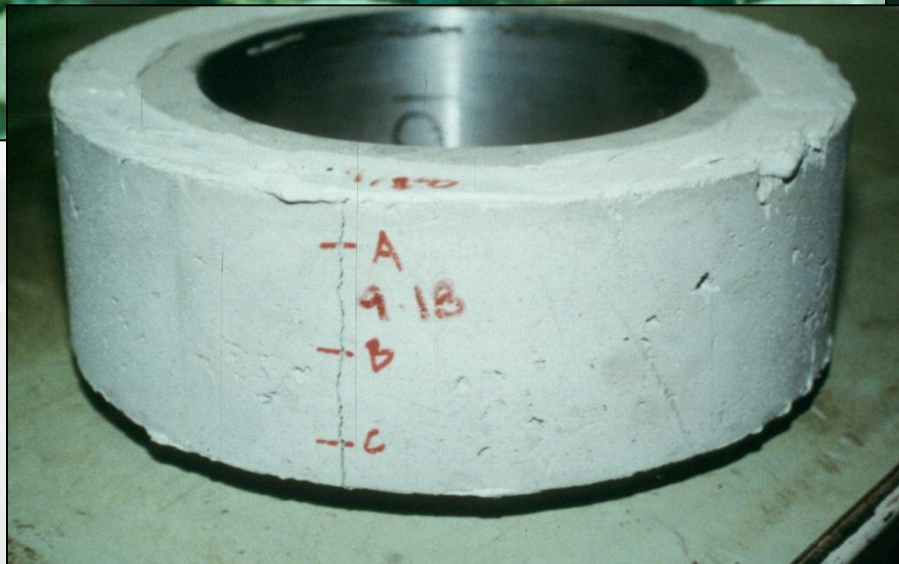
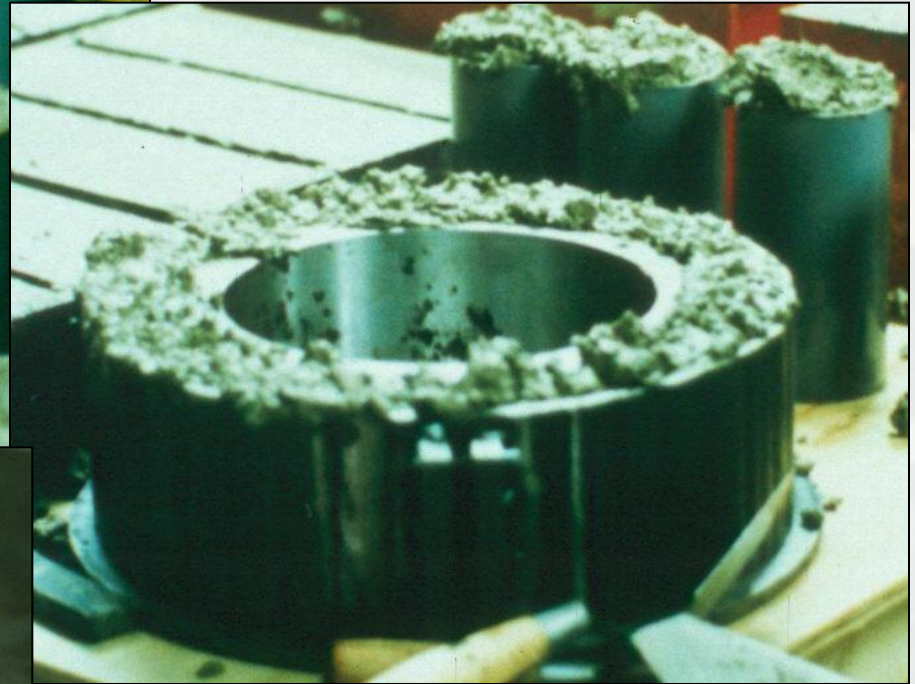
28-Day Shrinkage & Field Performance

Acceptable Materials



Restrained Drying Shrinkage

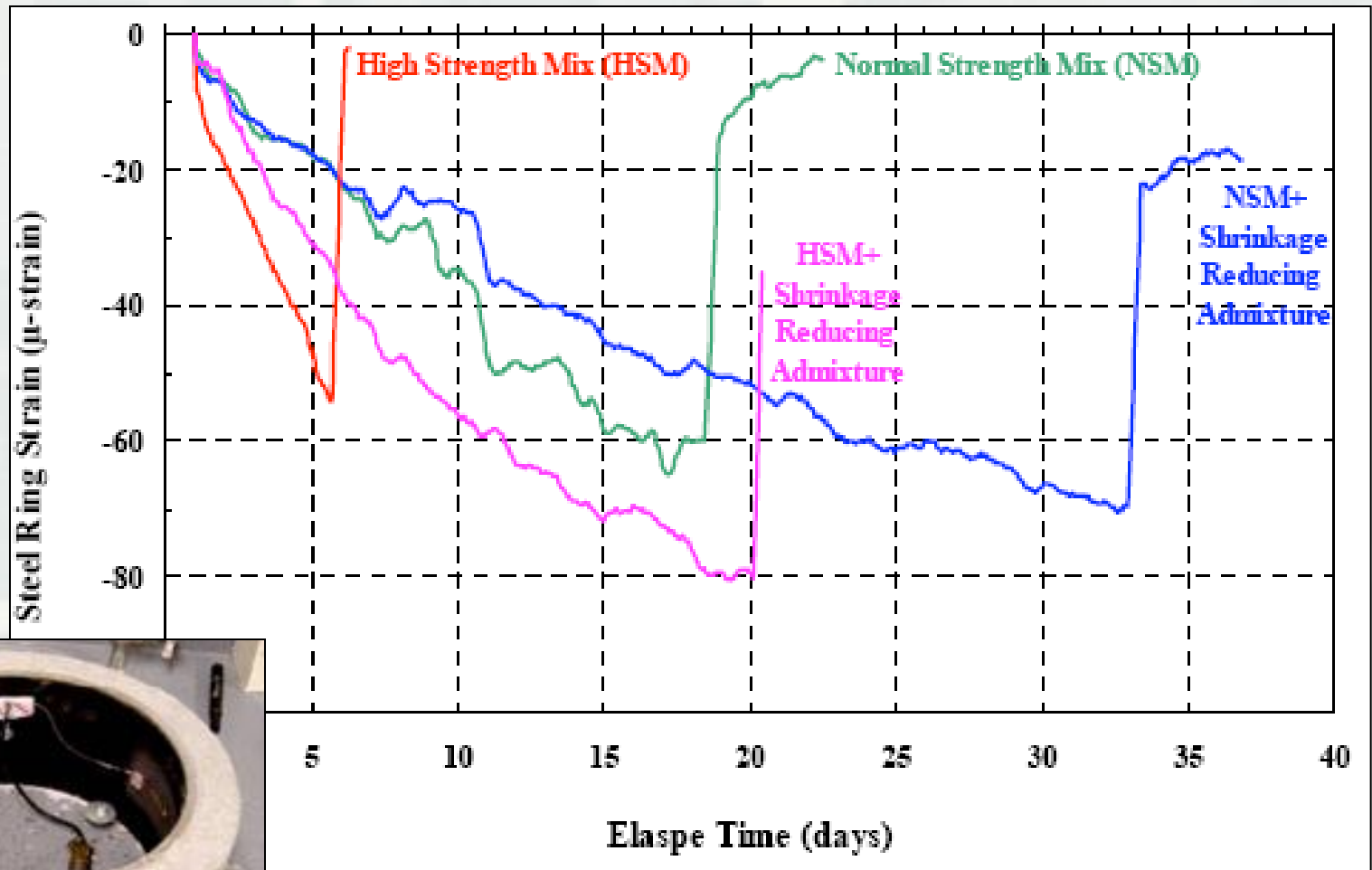
Ring Test
10 of 12 Cracked



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

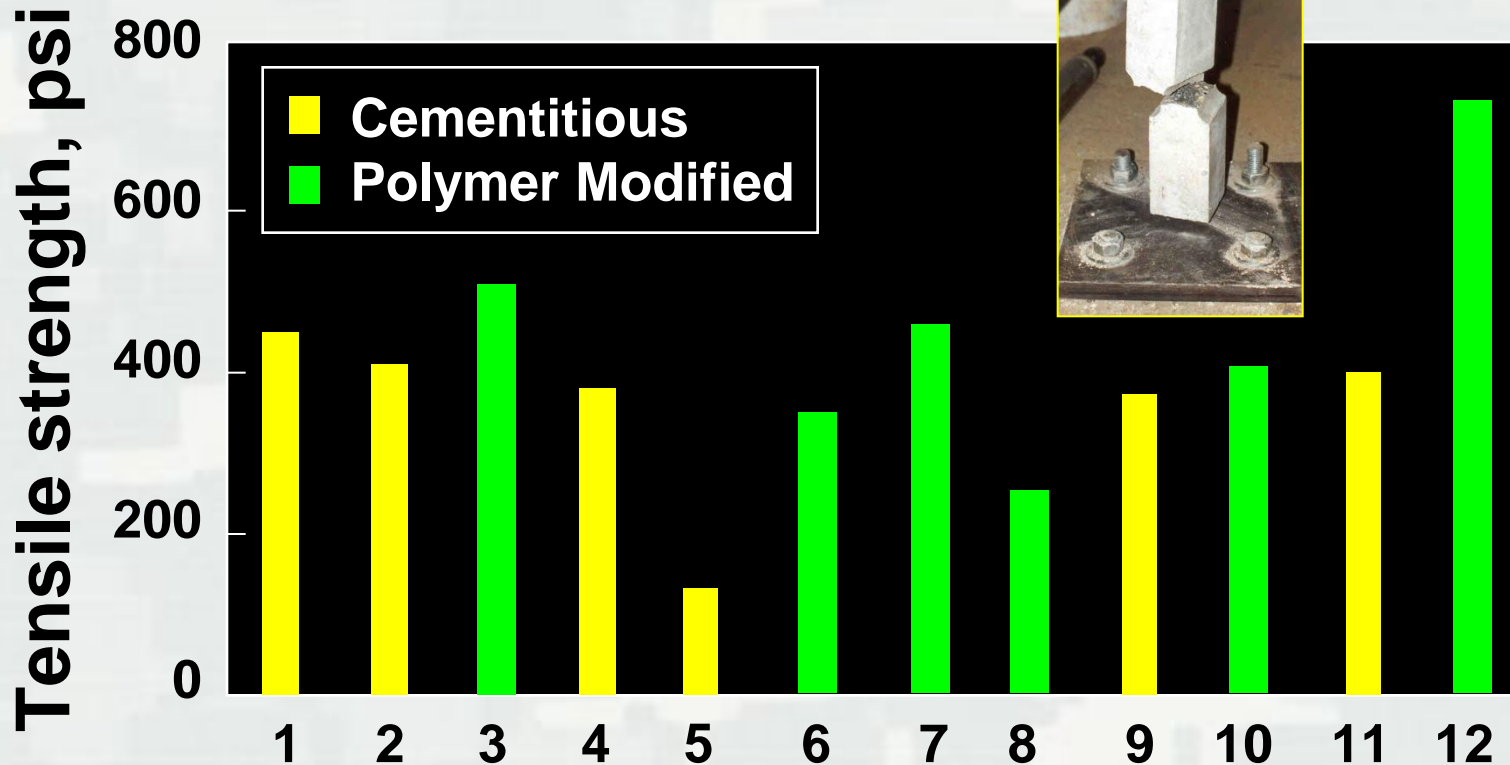
Restrained Shrinkage Test

ASTM C1581-04



Tensile Strength Test Results

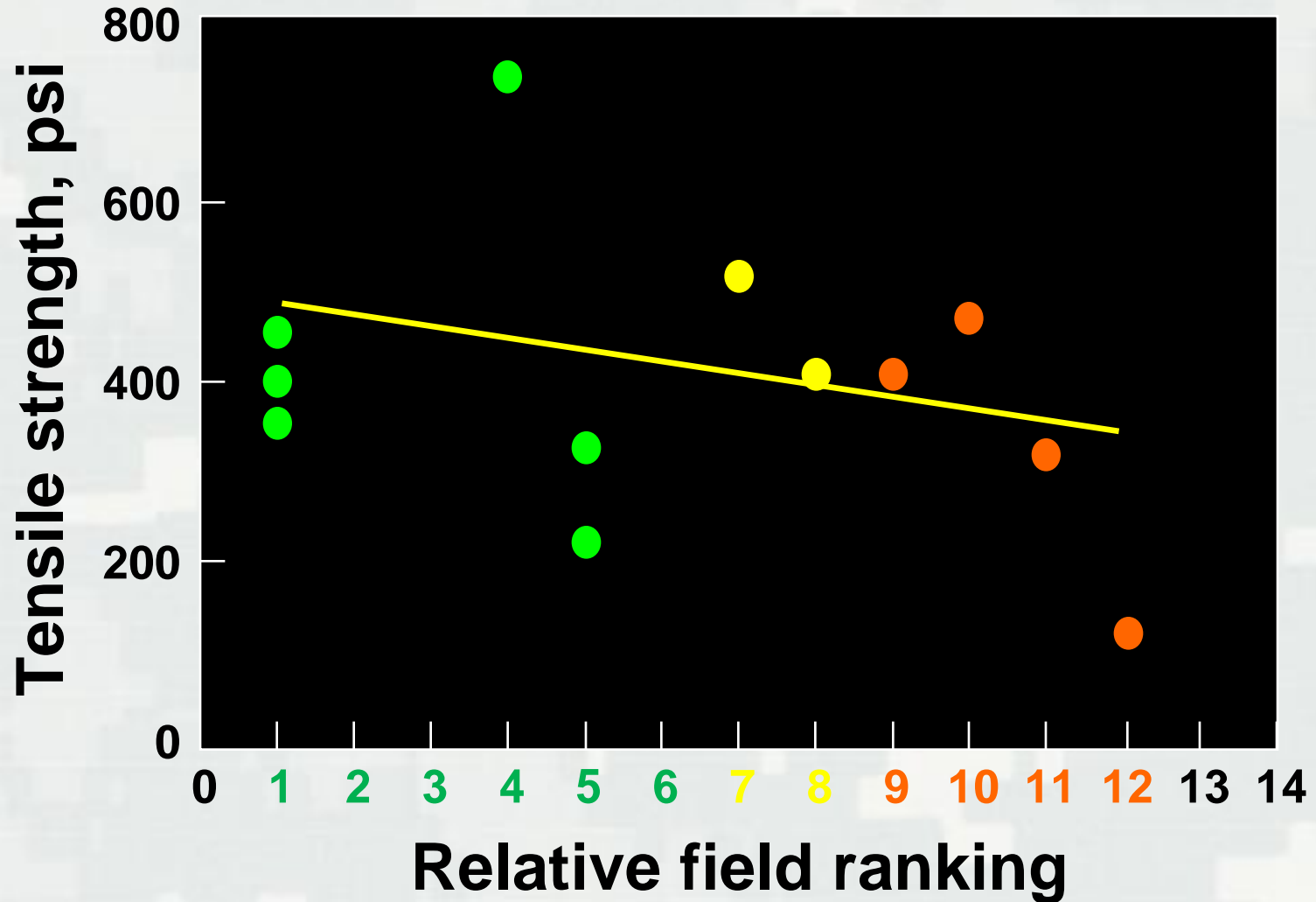
28-Days Age



Range: 90-740 psi
Average: 390 psi

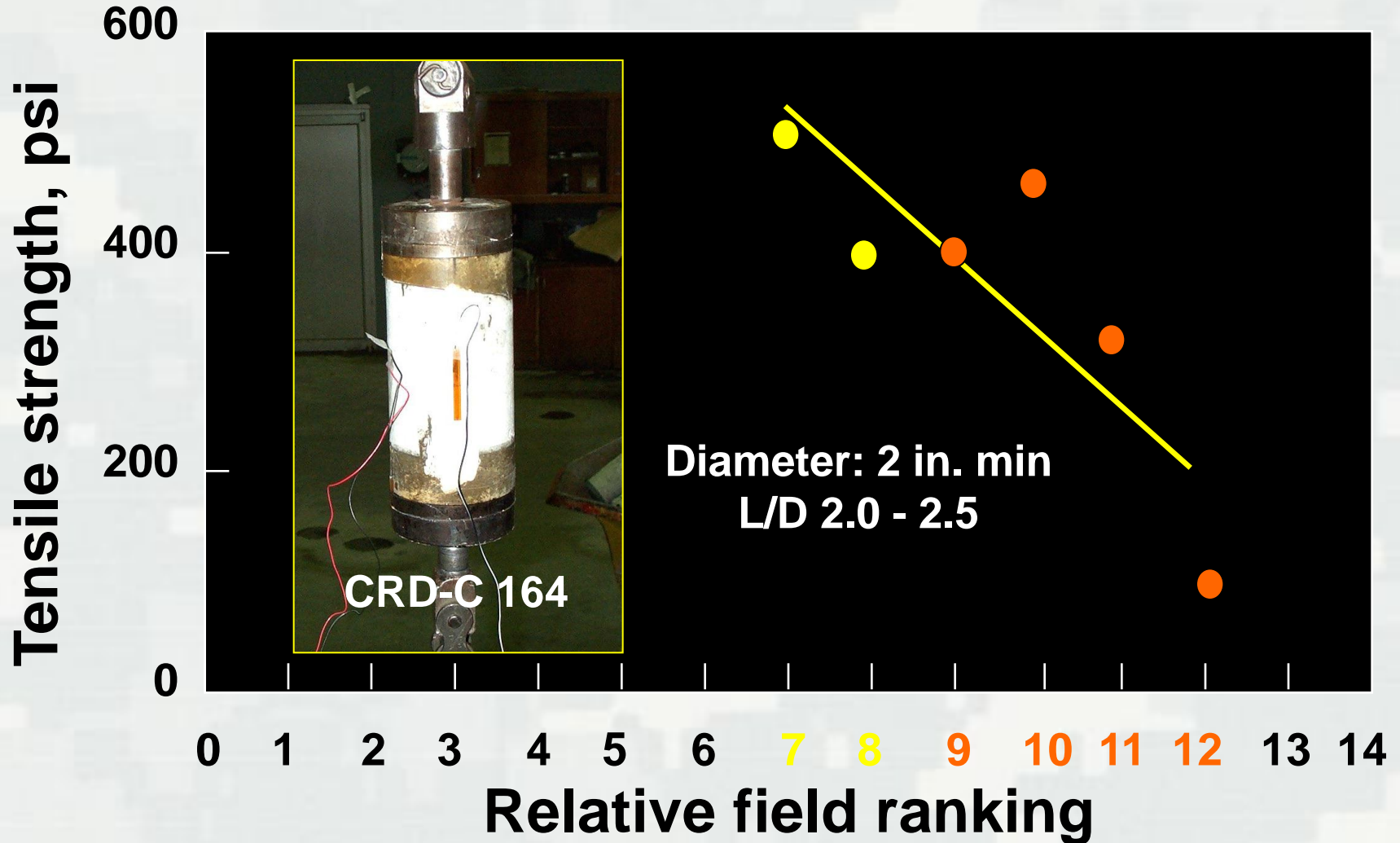
Material numbers

Overall Tensile Strength and Field Performance

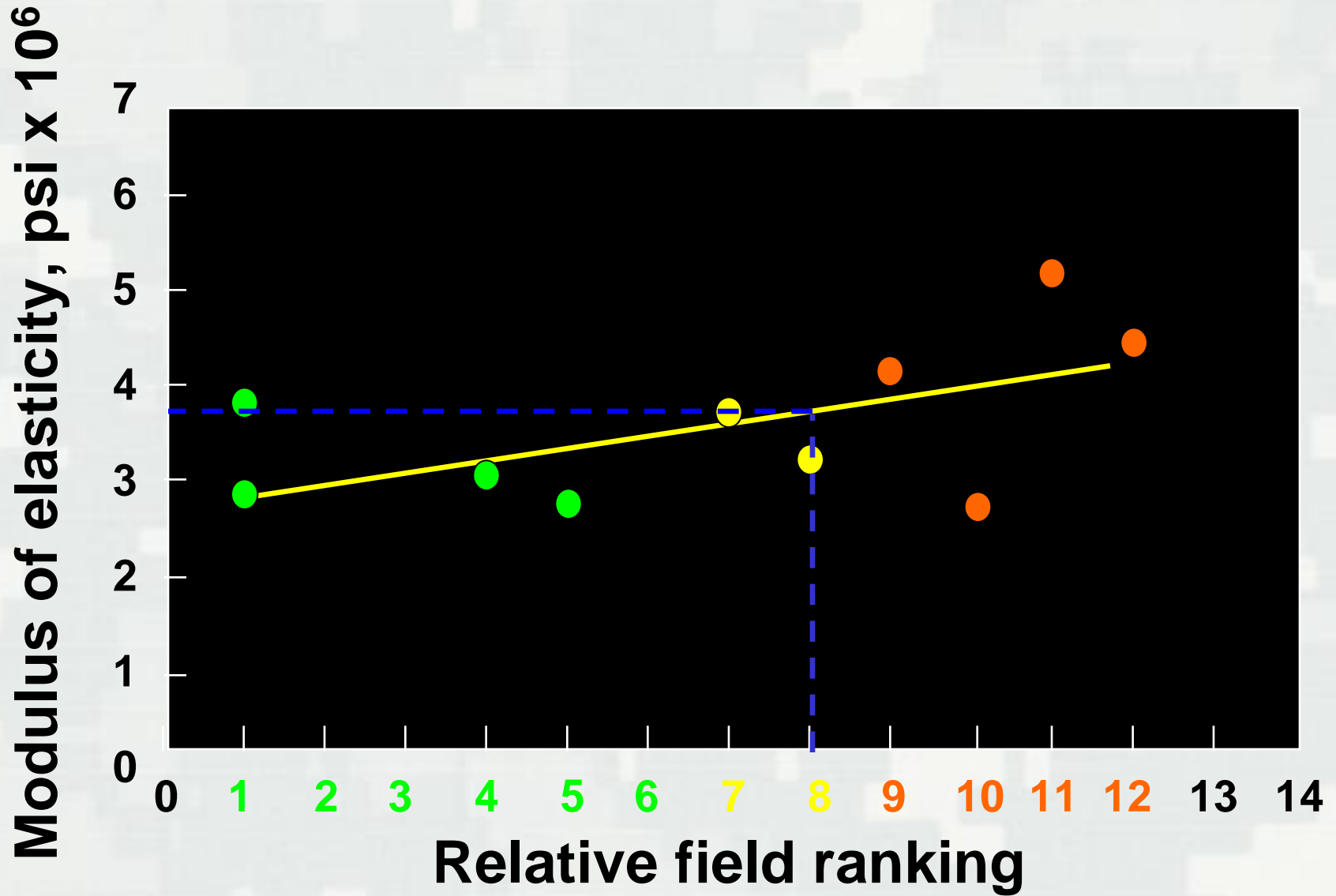


Tensile Strength & Field Performance

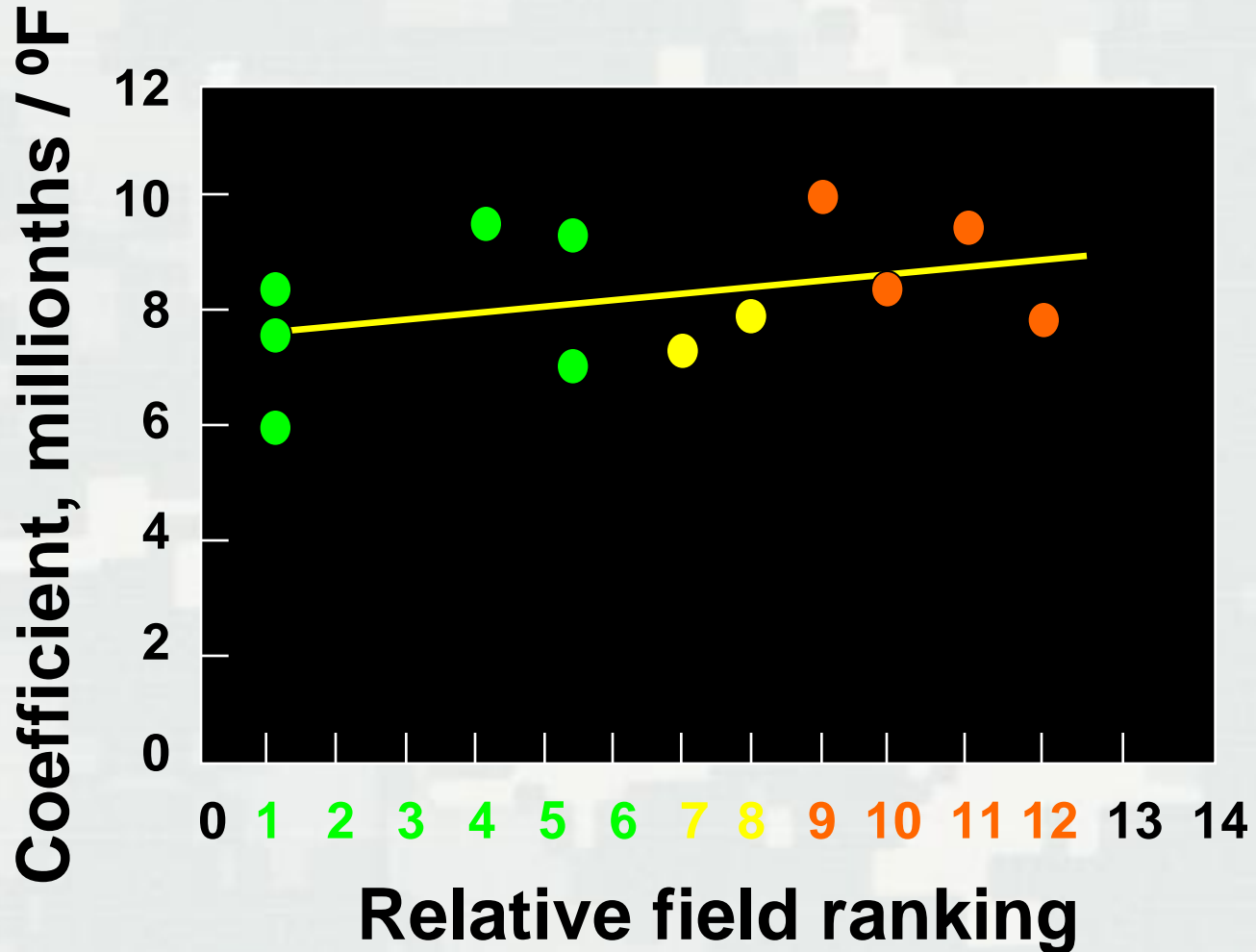
Marginal and Unsatisfactory Materials



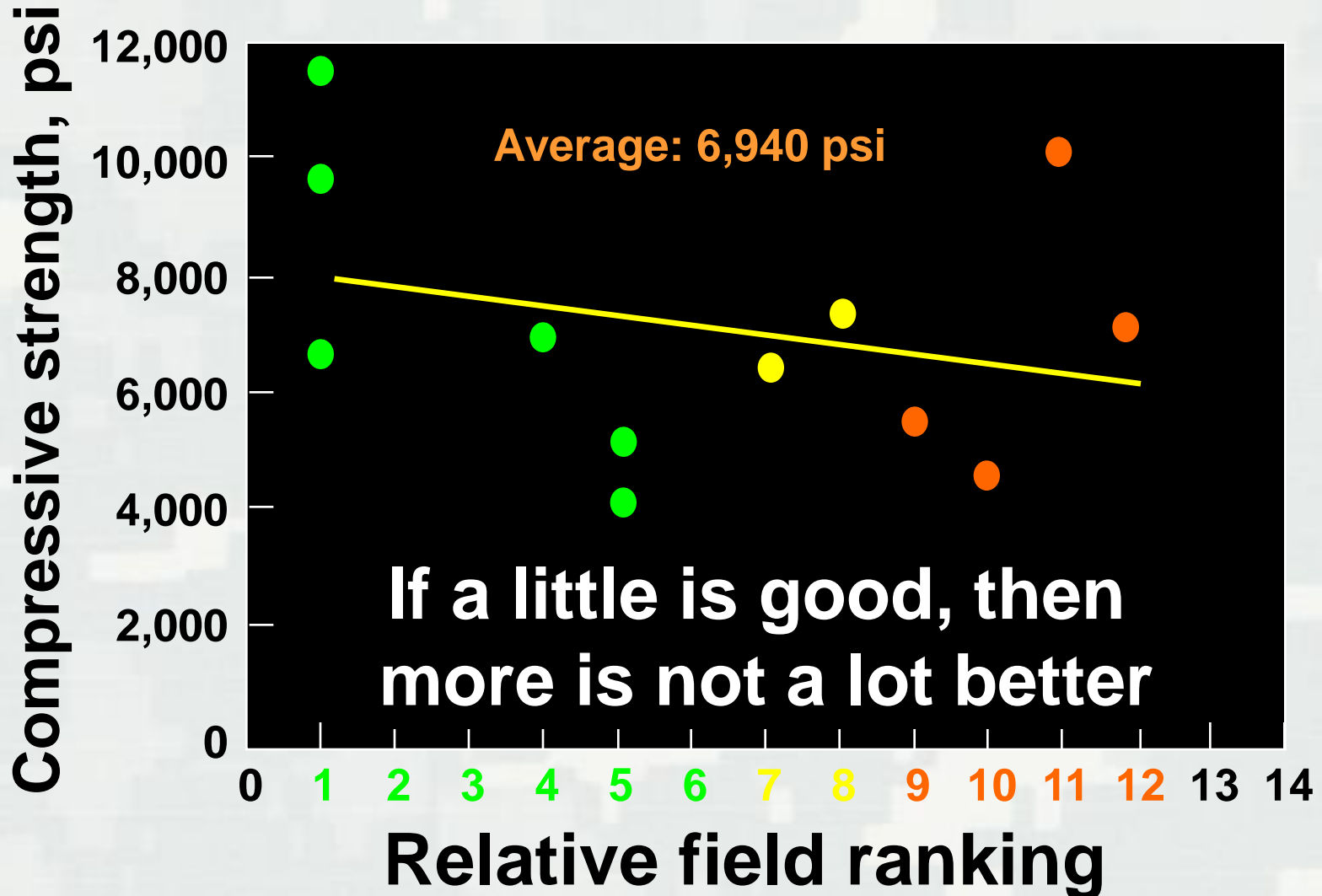
Modulus & Field Performance



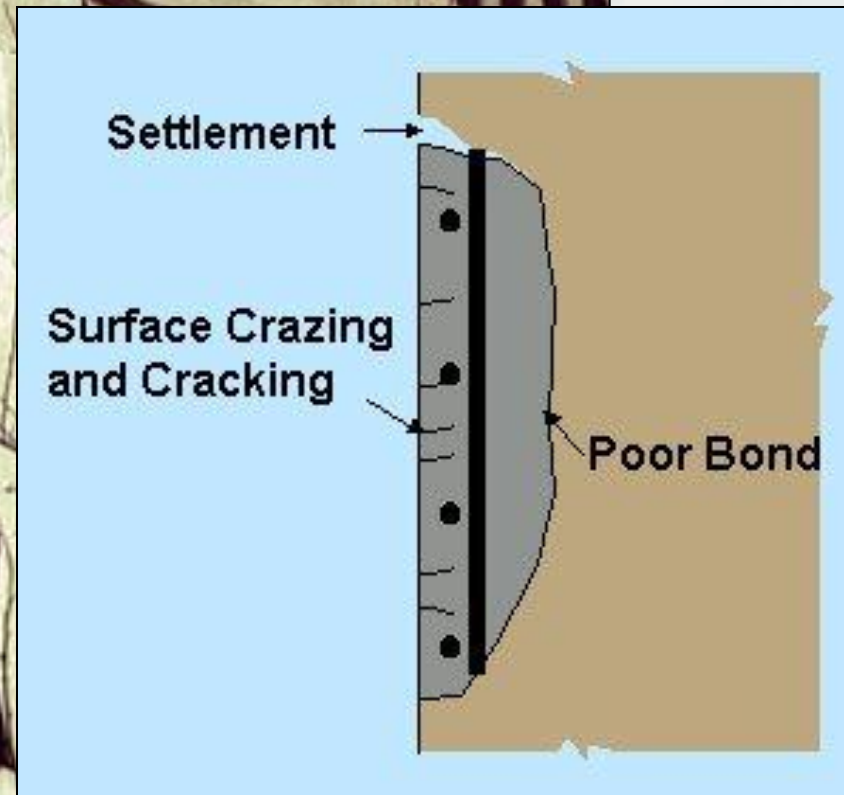
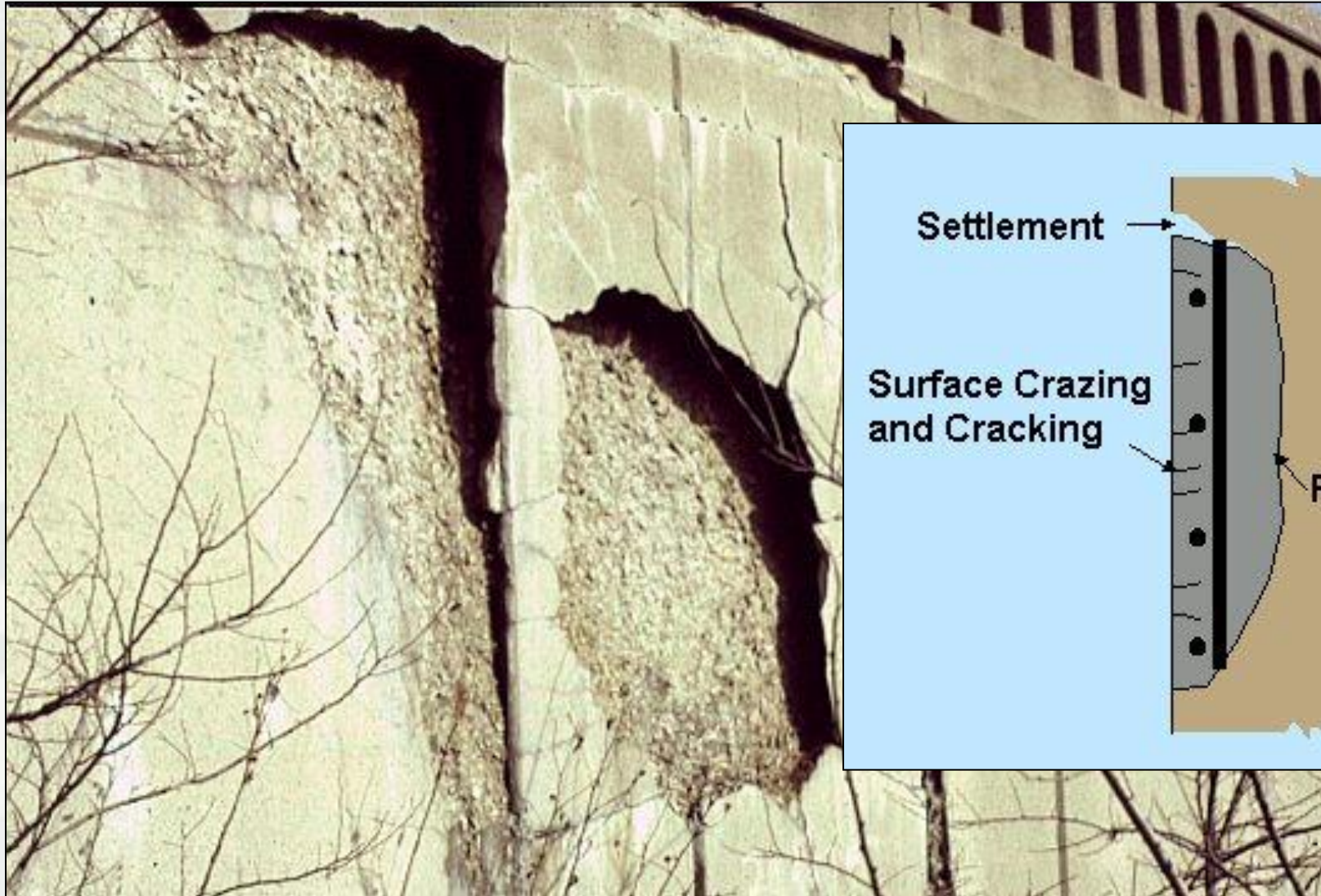
Overall Coefficient of Expansion and Field Performance



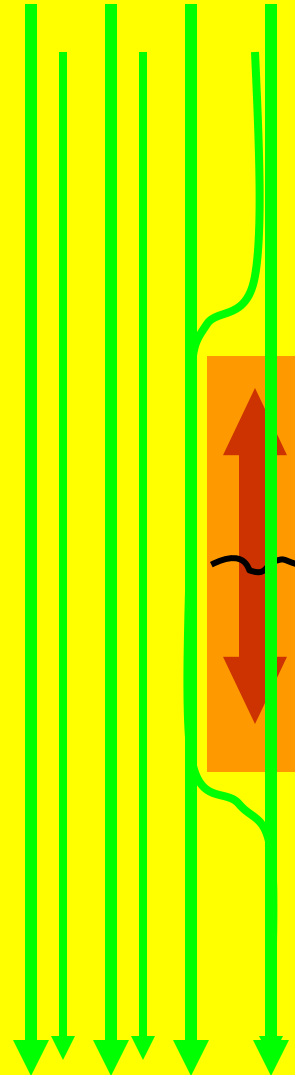
Compressive Strength and Field Performance



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*

<u>Property</u>	<u>Test Method</u>	<u>Requirement</u>
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,	Modulus of Elasticity	Thermal Coefficient	Drying Shrinkage		Ring Test	
		(>400)	(<3.5)	(<7)	28 Days	Peak	1 st Crack	Implied Strain
					(<0.04)	(<0.10)	(>14)	(<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,	Modulus of Elasticity	Thermal Coefficient	Drying Shrinkage		Ring Test	
		(>400)	(<3.5)	(<7)	28 Days	Peak	1 st Crack	Implied Strain
					(<0.04)	(<0.10)	(>14)	(<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)

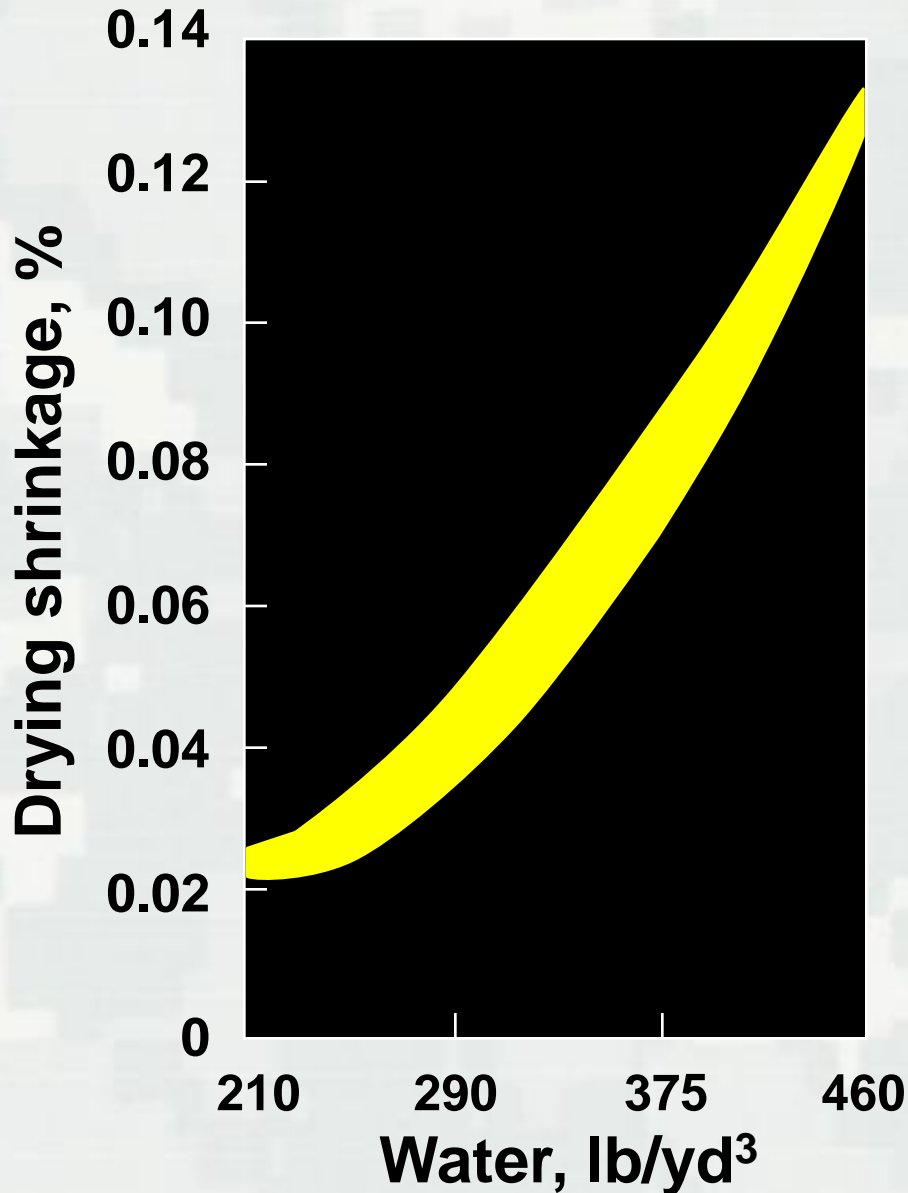
<http://acwc.sdp.sirsi.net/client/search/asset/1004732>

Field Rank	Mat'l No.	Tensile Strength, (>400)	Modulus of Elasticity (<3.5)	Thermal Coefficient (<7)	Drying Shrinkage		Ring Test	
					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%**

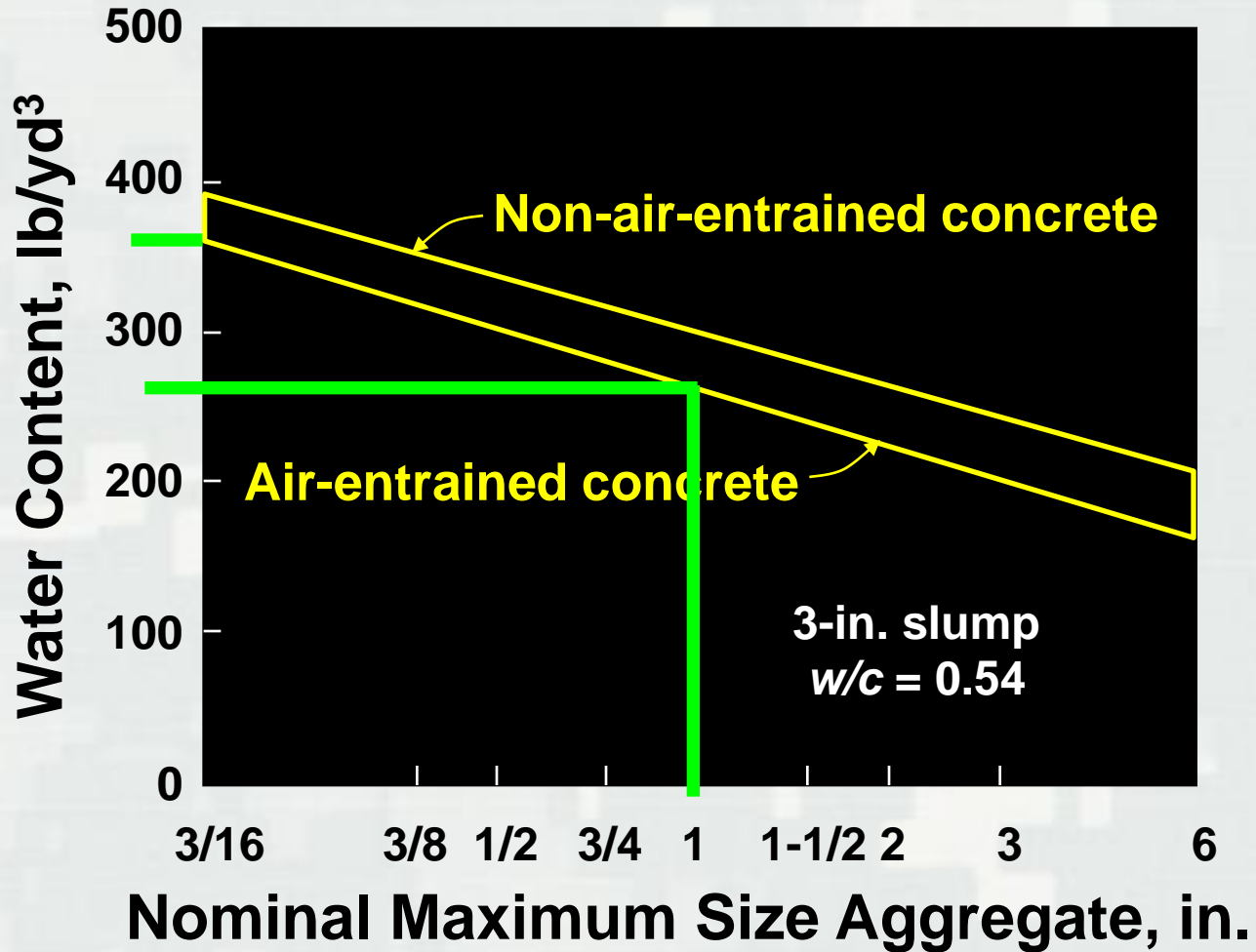
Minimizing Shrinkage Cracking



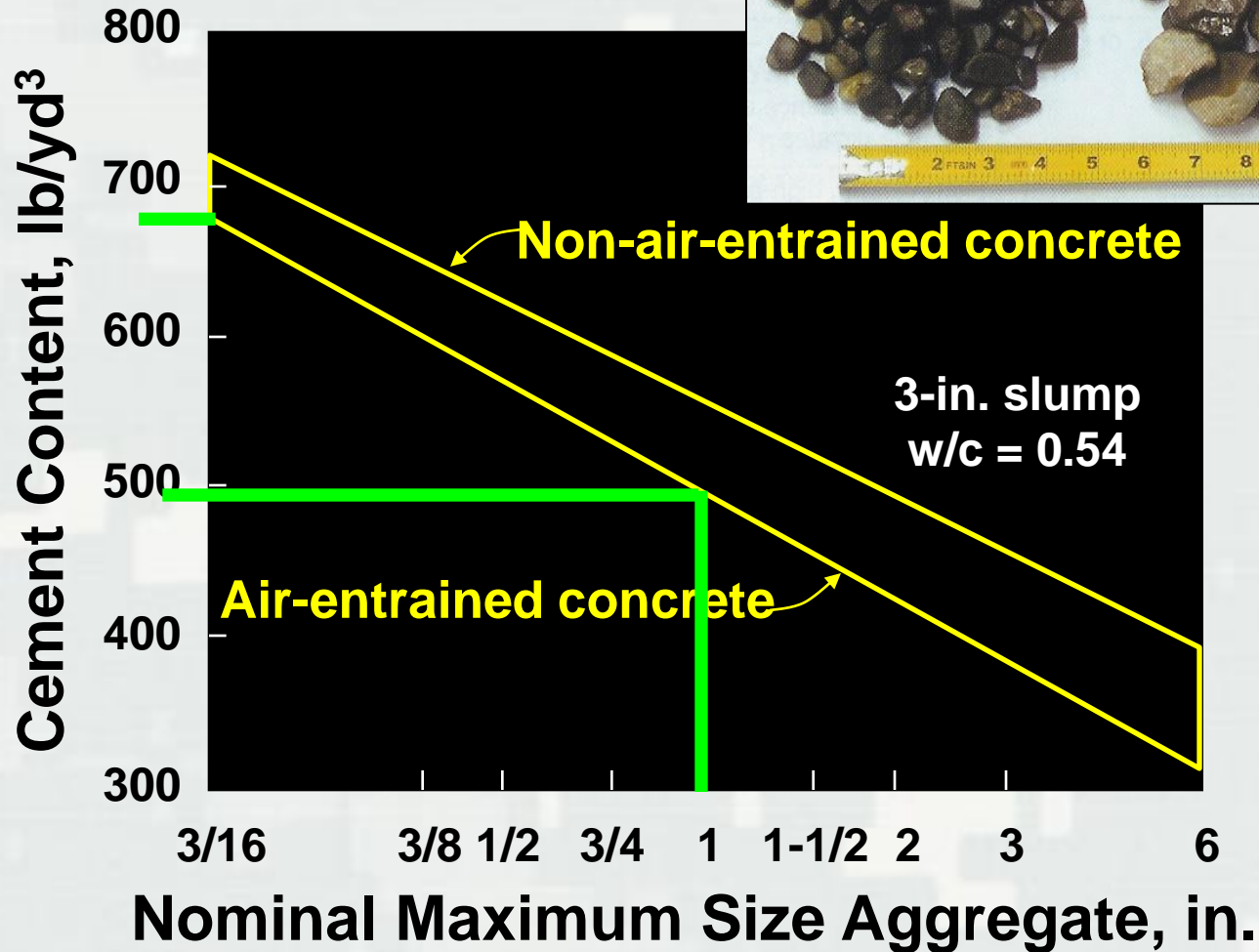
After PCA (2002)

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

Effect of MSA on Water Content



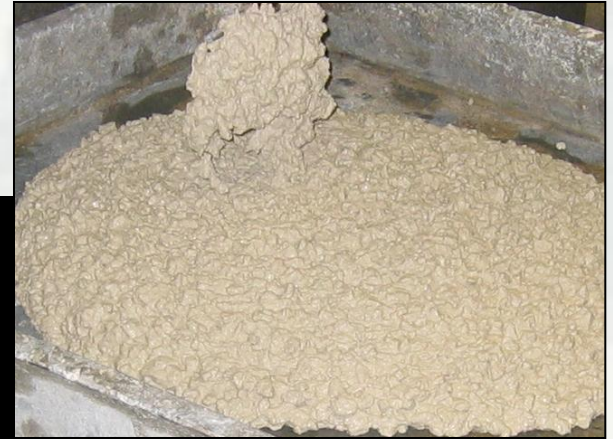
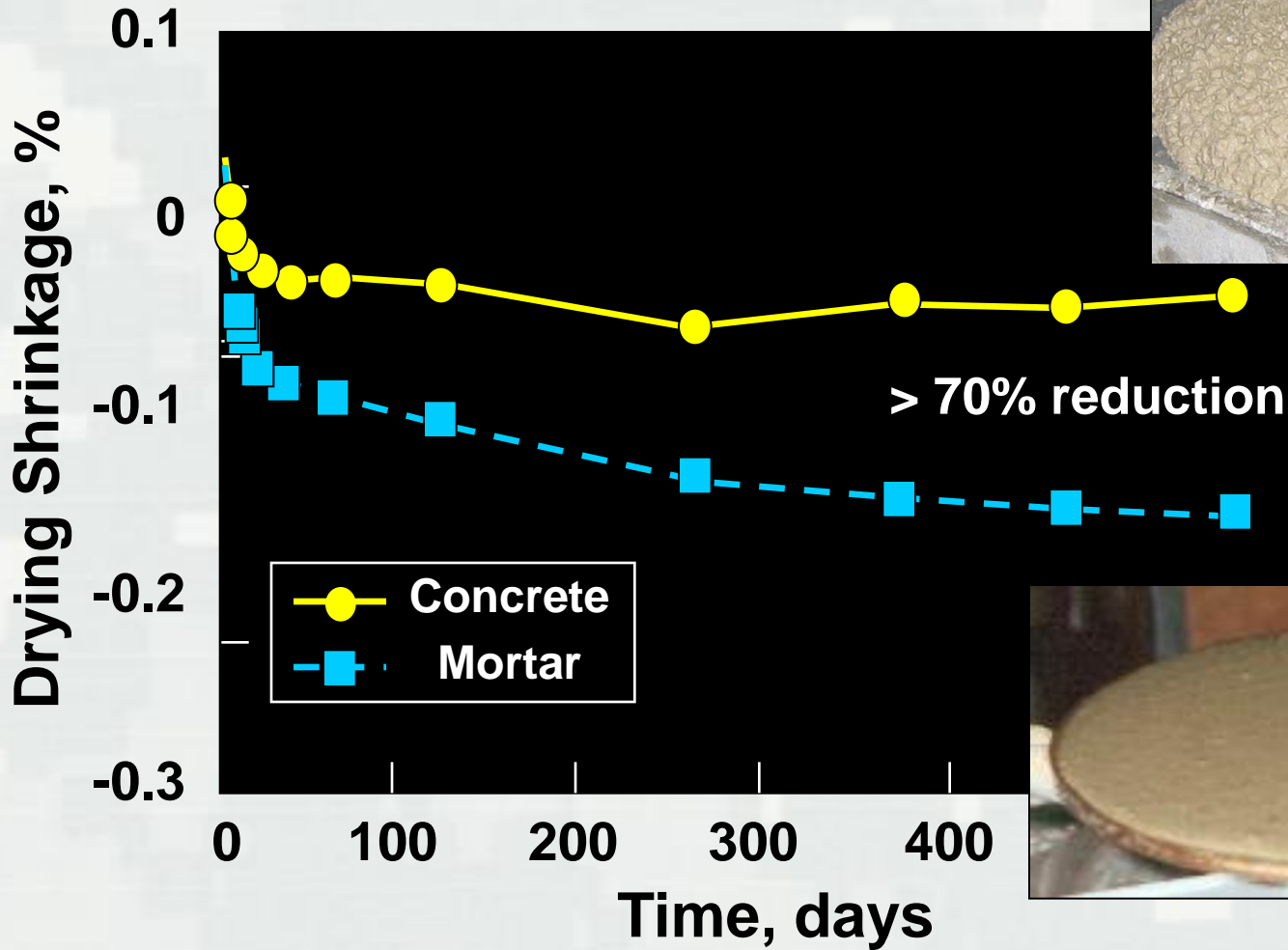
Effect of MSA on Cement Content



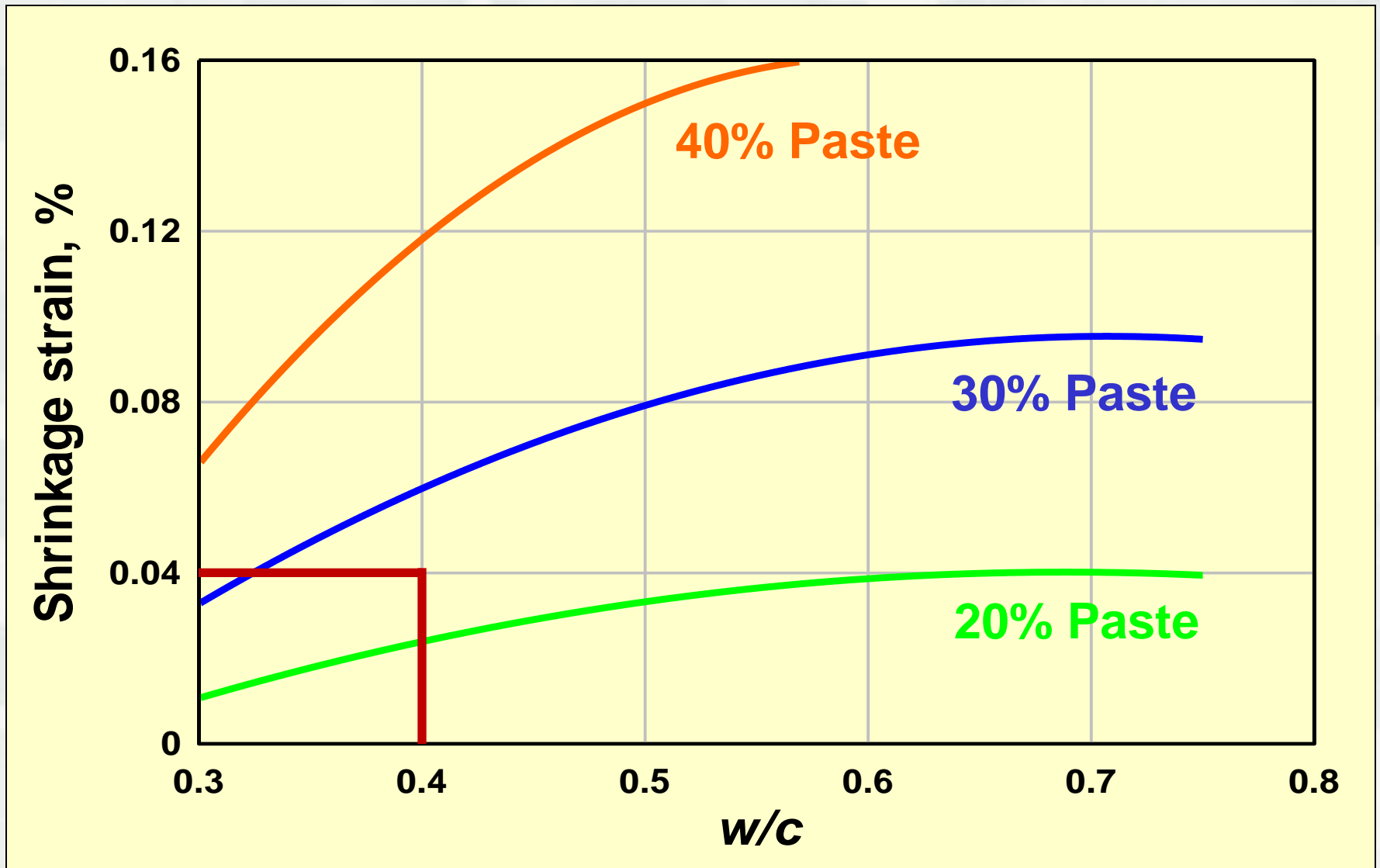
After PCA (2002)

Drying Shrinkage

Effect of 3/4-in. Aggregate

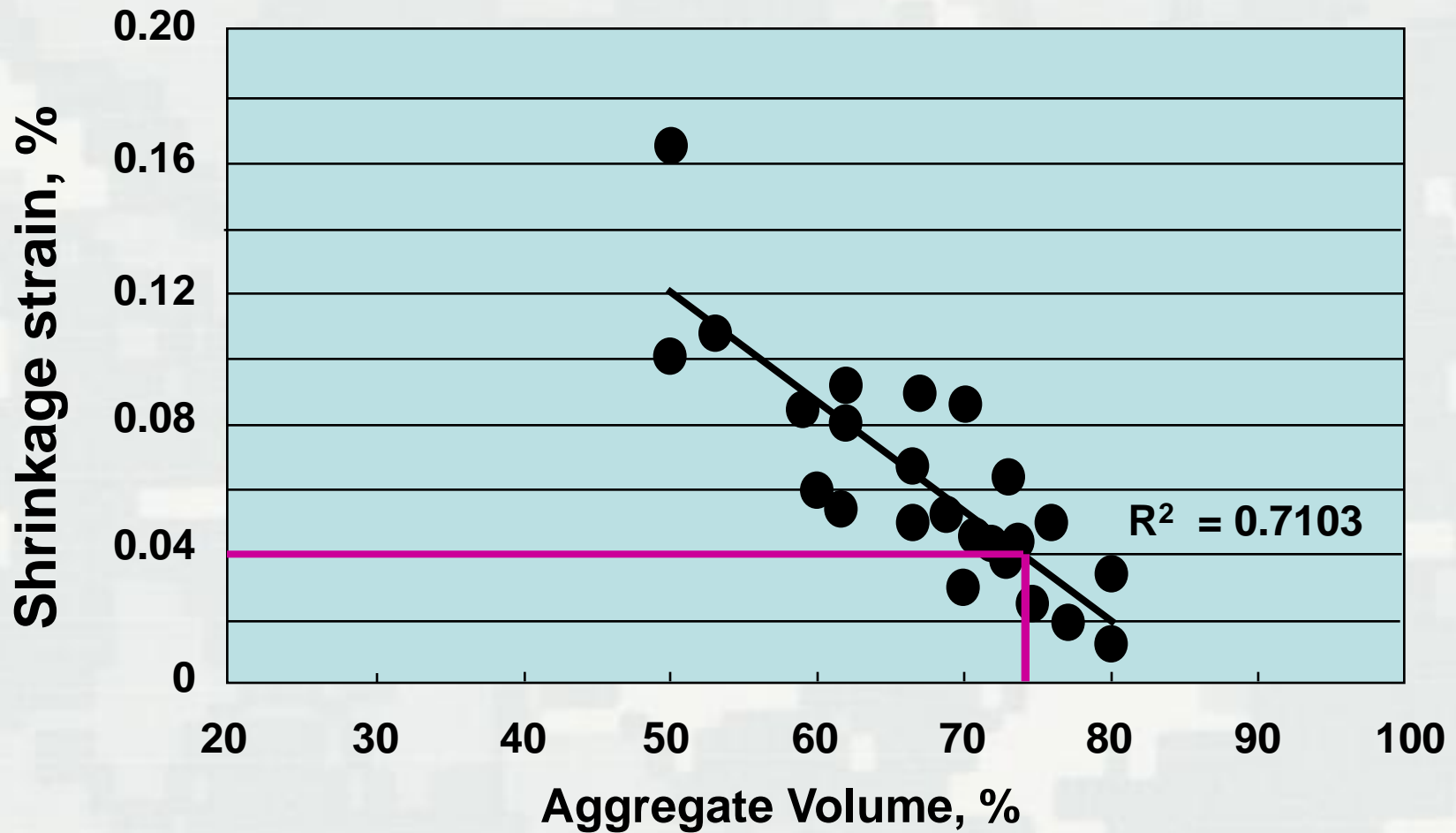


Paste Volume vs Shrinkage



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

$$R \geq C$$

Thermal Expansion/Contraction

$$R \leq C$$

Unrestrained Shrinkage

$$R = C$$

Nonstandard or modified test methods

No protocol for testing and reporting information

Lack of performance criteria

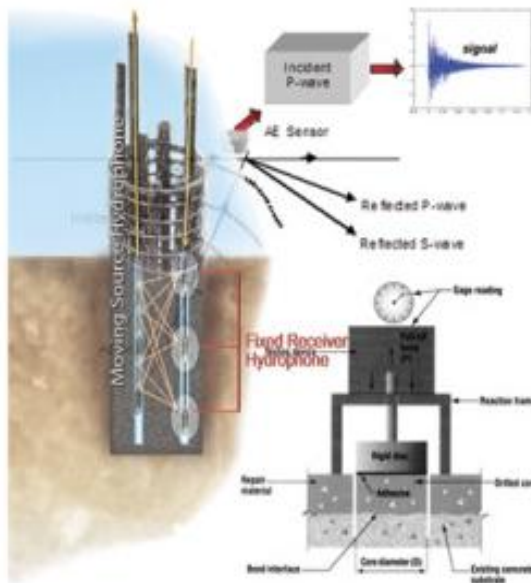
“We Have Come A Long Way”



TECHNICAL GUIDELINES

Prepared by the International Concrete Repair Institute

May 2009



Guideline No. 210.4-2009

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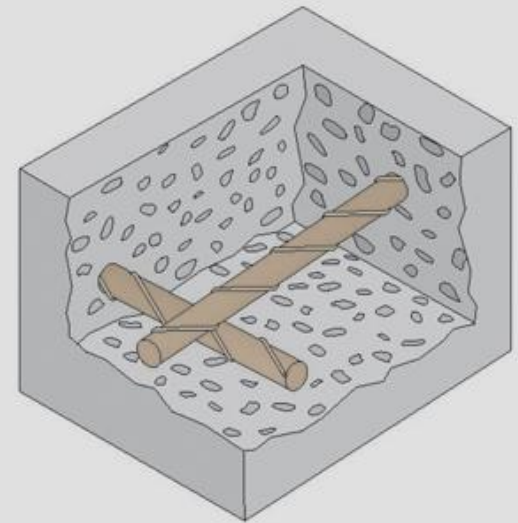
**Guide for Nondestructive Evaluation
Methods for Condition Assessment,
Repair, and Performance Monitoring
of Concrete Structures**



TECHNICAL GUIDELINES

Prepared by the International Concrete Repair Institute

December 2008



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

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**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 May 2009



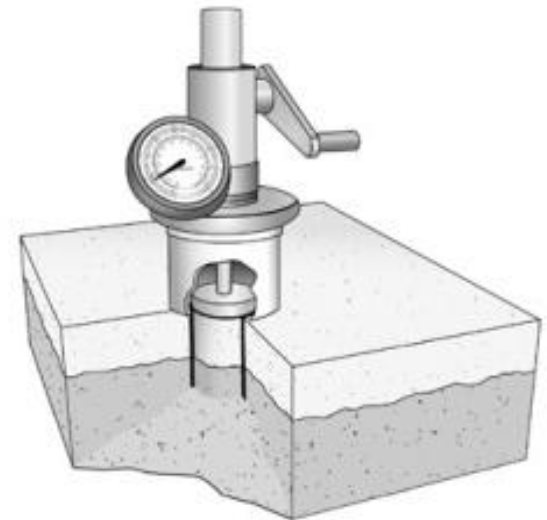
Guideline No. 320.2R-2009 (formerly No. 03733)
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Guide for Selecting and Specifying Materials for Repair of Concrete Surfaces



TECHNICAL GUIDELINES

Prepared by the International Concrete Repair Institute March 2004



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Guide to Using In-Situ Tensile Pull-Off Tests to Evaluate Bond of Concrete Surface Materials



TECHNICAL GUIDELINES

Prepared by the International Concrete Repair Institute

August 2012

[http://www.icri.org/PUBLICATIONS/](http://www.icri.org/PUBLICATIONS/PDFs/320.3R-2012.pdf)
[PDFs/320.3R-2012.pdf](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!