

Methods and Materials to Improve the Durability of Concrete Repairs

USACE Lock Maintenance Workshop
12 February 2015

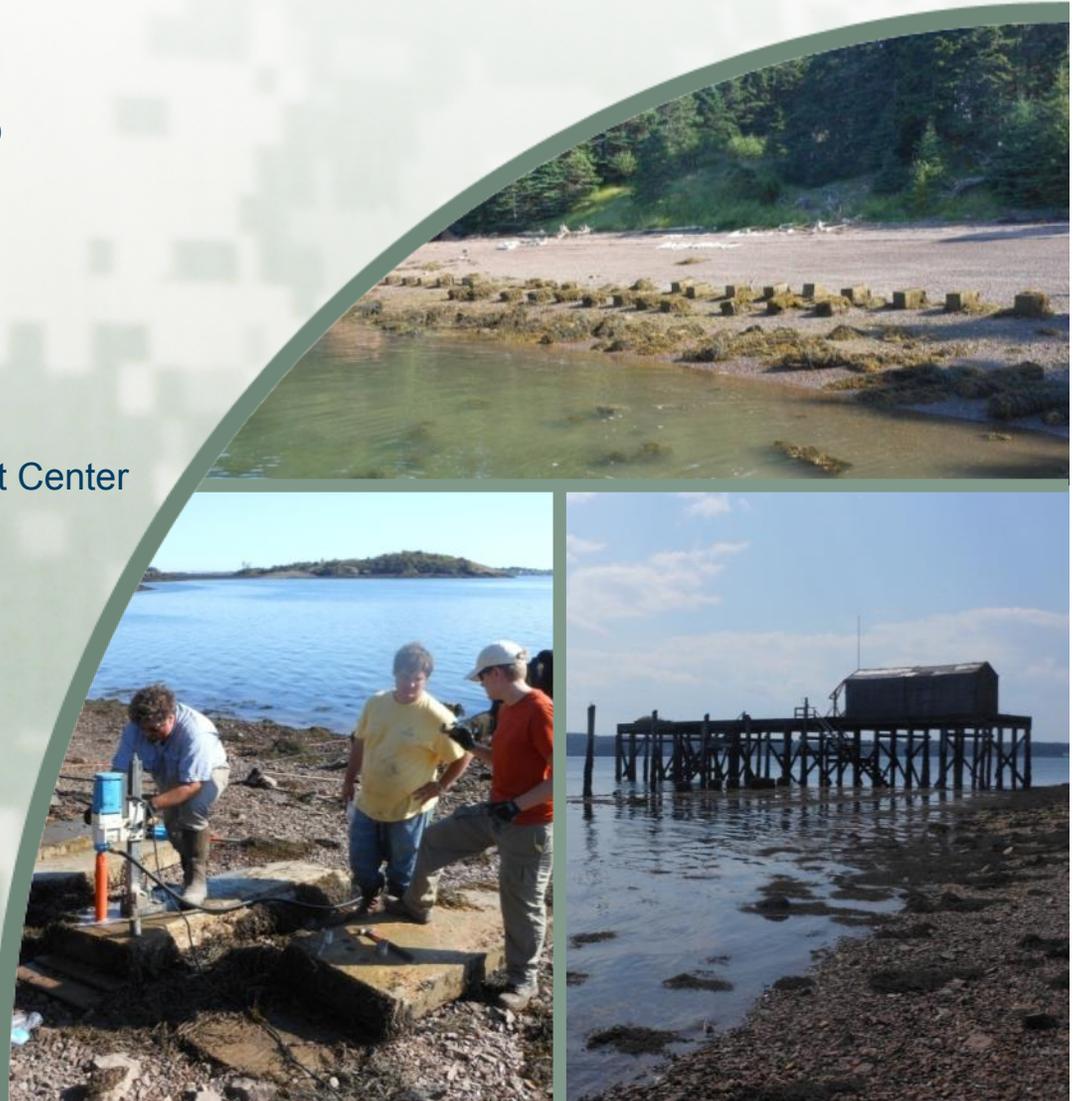
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Engineering Systems and Materials Division
Geotechnical and Structures Laboratory
U.S. Army Engineer Research and Development Center

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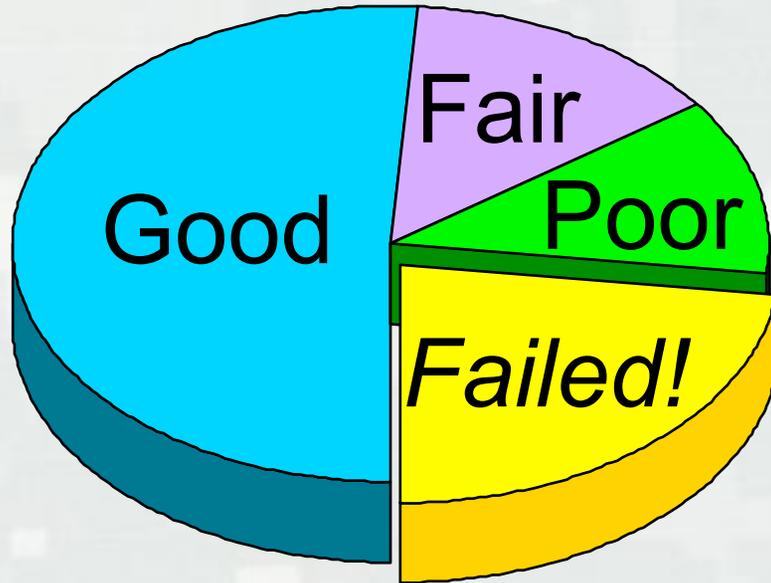


Agenda

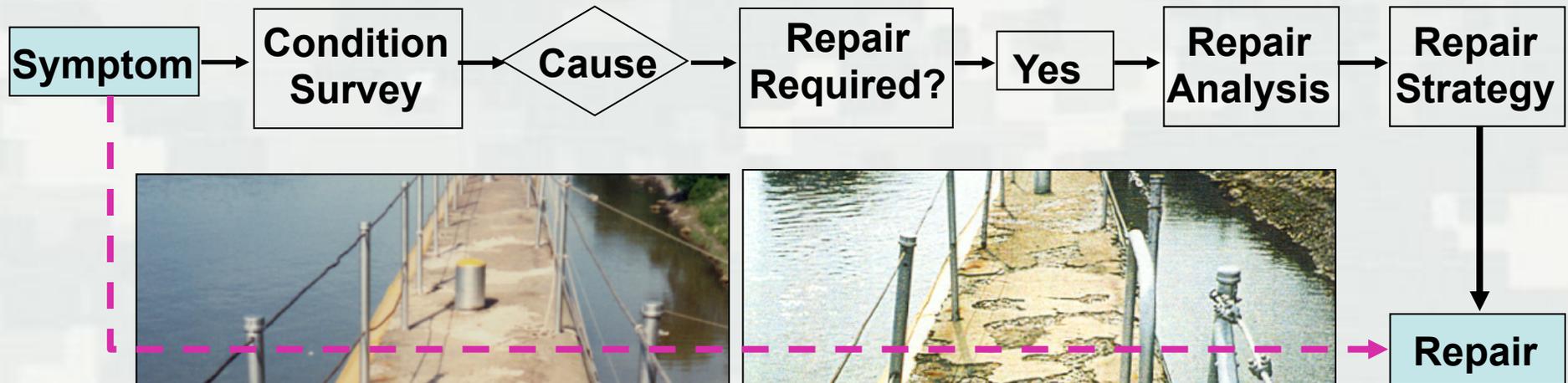
- Systematic Repair Process
- Typical Deterioration
- Repair Material Considerations
- Long-Term Field Durability
- Current Laboratory Research
- Future Research
- Related Research and Reachback Capabilities



What Is The Need? Poor Repair Performance



Systematic Concrete Repair Process

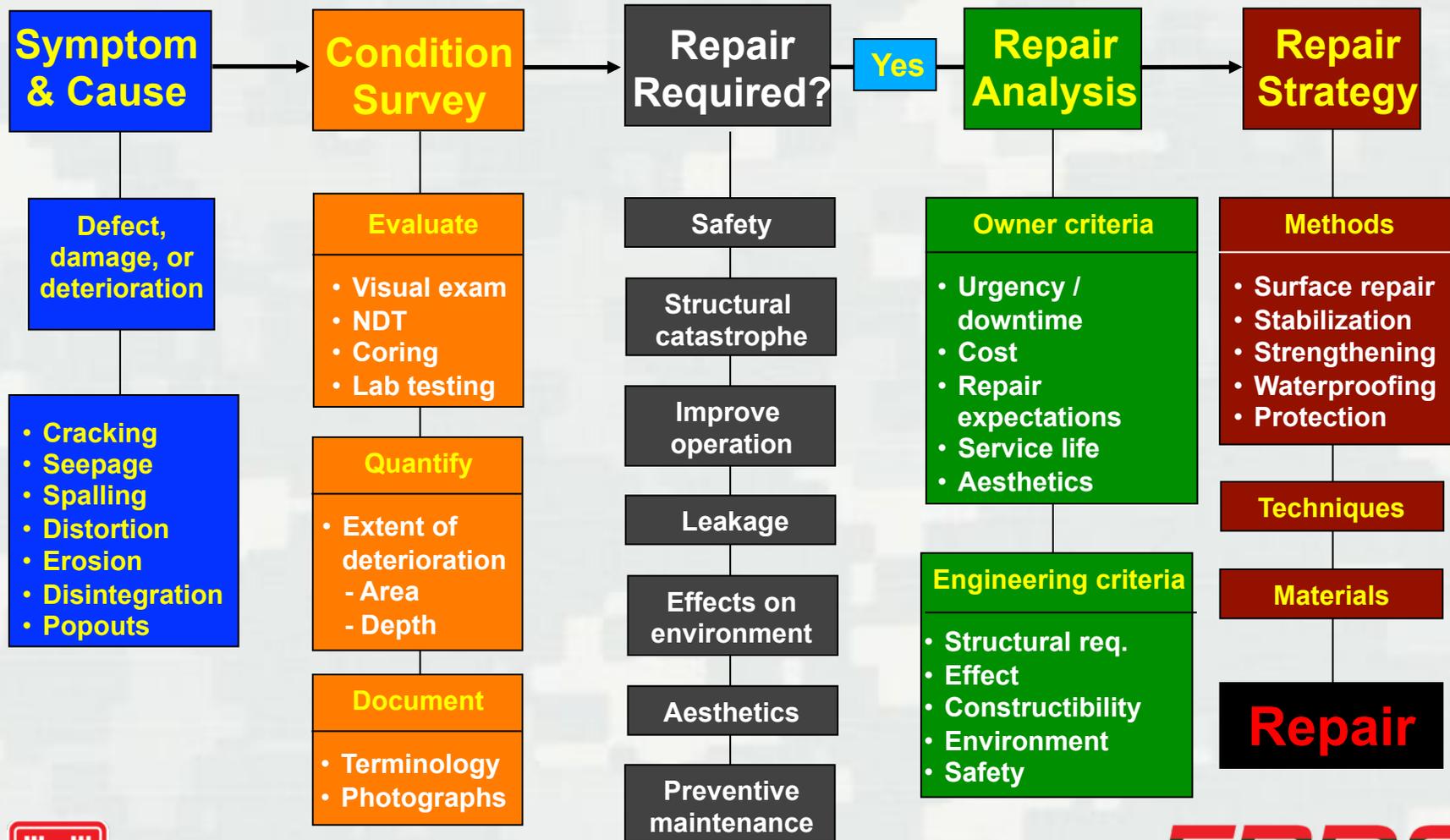


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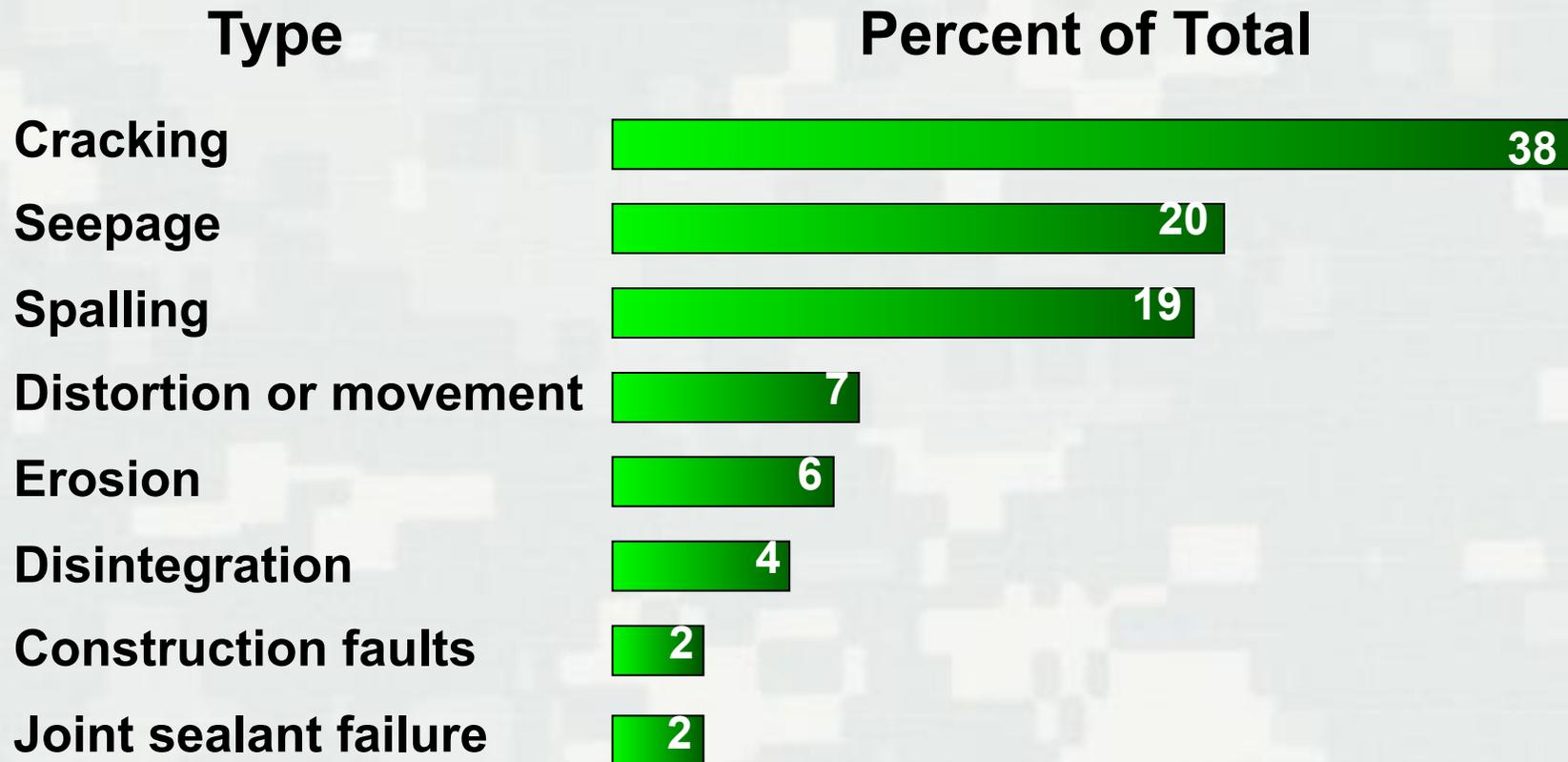


(After Emmons 2002) Innovative solutions for a safer, better world

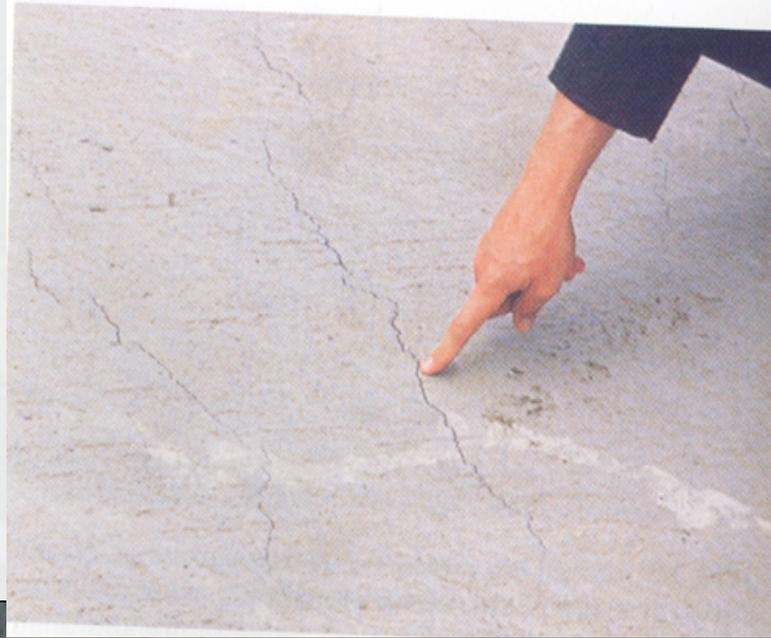
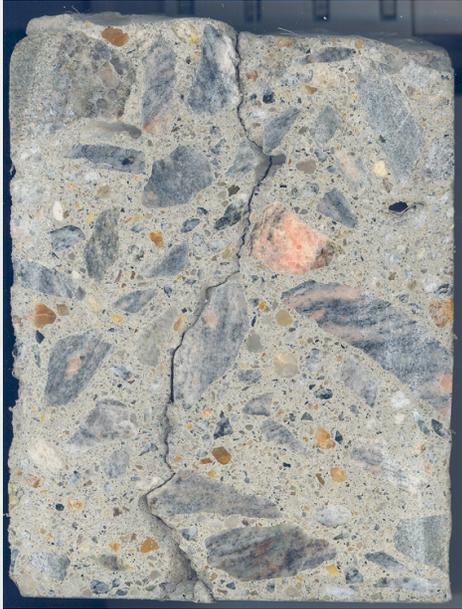
Concrete Repair Process



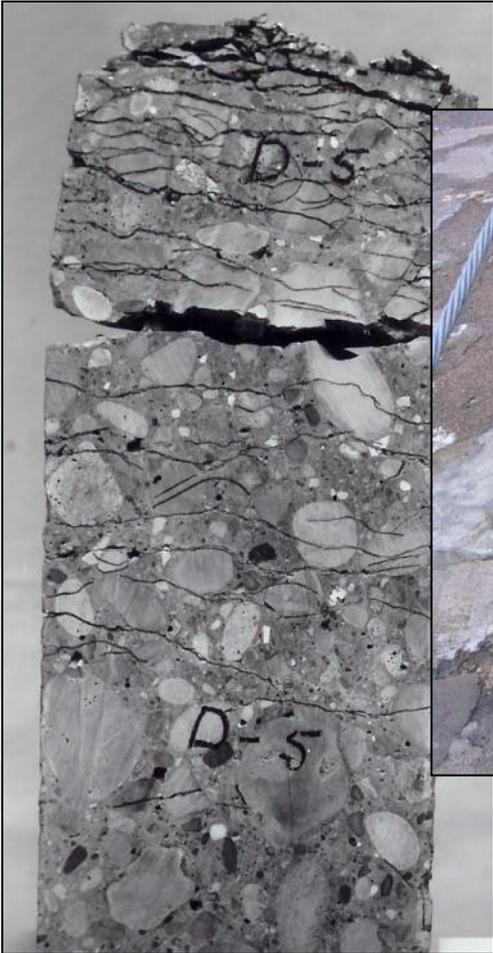
Symptoms of Concrete Deterioration & Distress



Shrinkage-Induced Cracking



Freezing & Thawing



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Primary *Causes* of Concrete Deterioration & Distress

Corrosion



- Destruction of a metal by a chemical, electrochemical, or electrolytic reaction within its environment
- Resulting expansion causes cracking, spalling, and delamination of concrete cover



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Reactive Aggregate Alkali-Silica Reaction (ASR)



- In its simplest form, ASR can be visualized as a two-step process
 - Alkali + Silica = Gel Reaction Product



Gel Reaction Product + Moisture = Expansion

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Cause of Deterioration? Combined?



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Issues with repairs...



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**We know how to make durable
concrete for repair of structures.**

**Issues still exist with methods but
there is good guidance available.**

**Issues with dimensional stability and
shrinkage-induced cracking remain!**

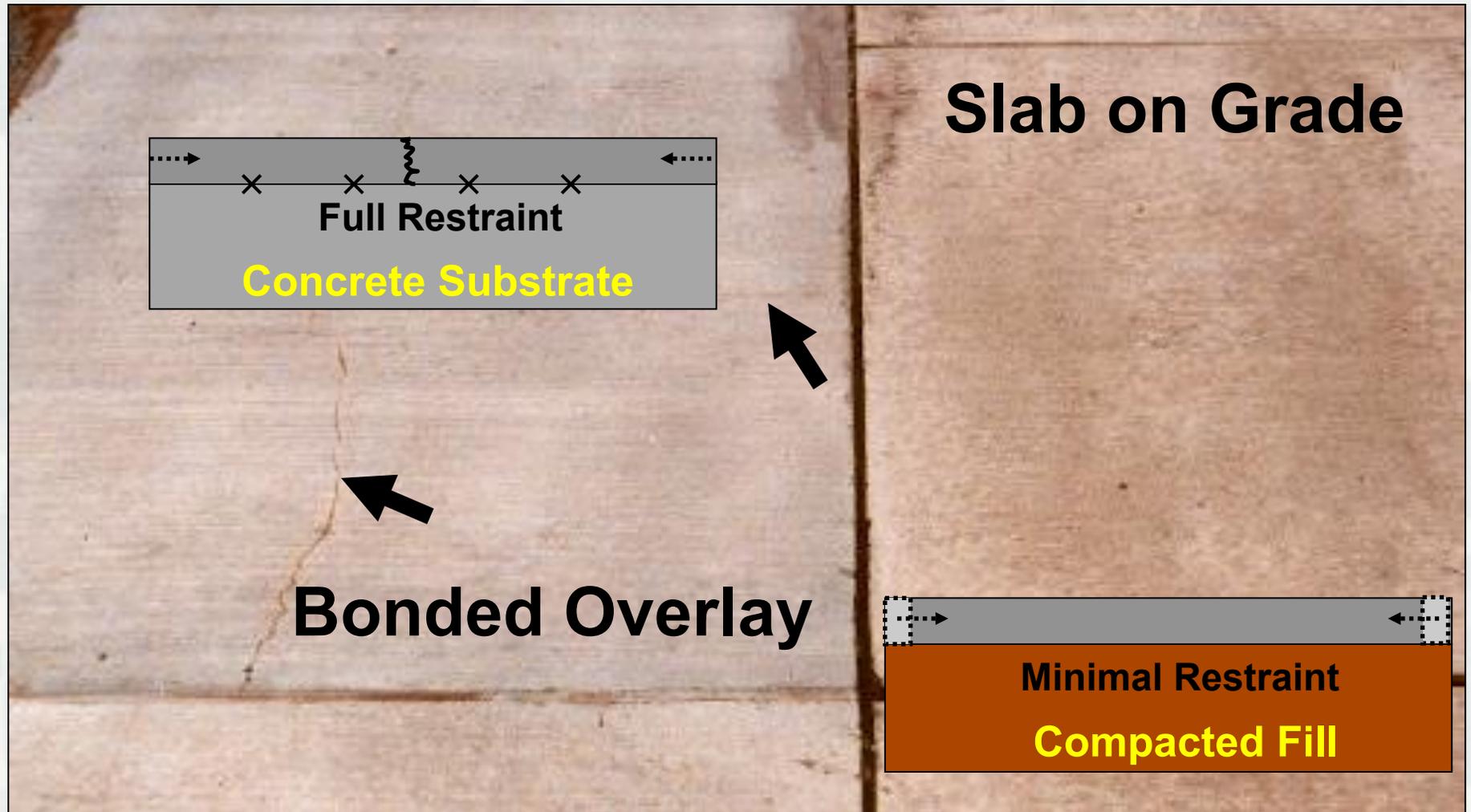


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Cracking Resulting from Restraint



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Map or Pattern Cracks

Restrained Shrinkage of Repair Materials

**4-in. Thick
Concrete
Overlays**



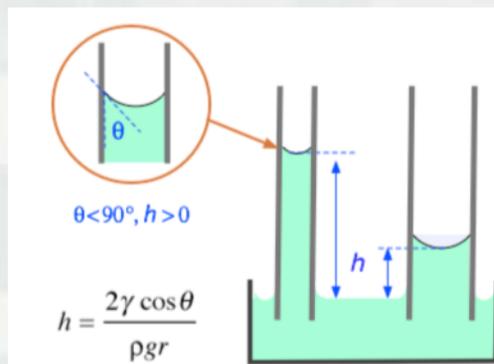
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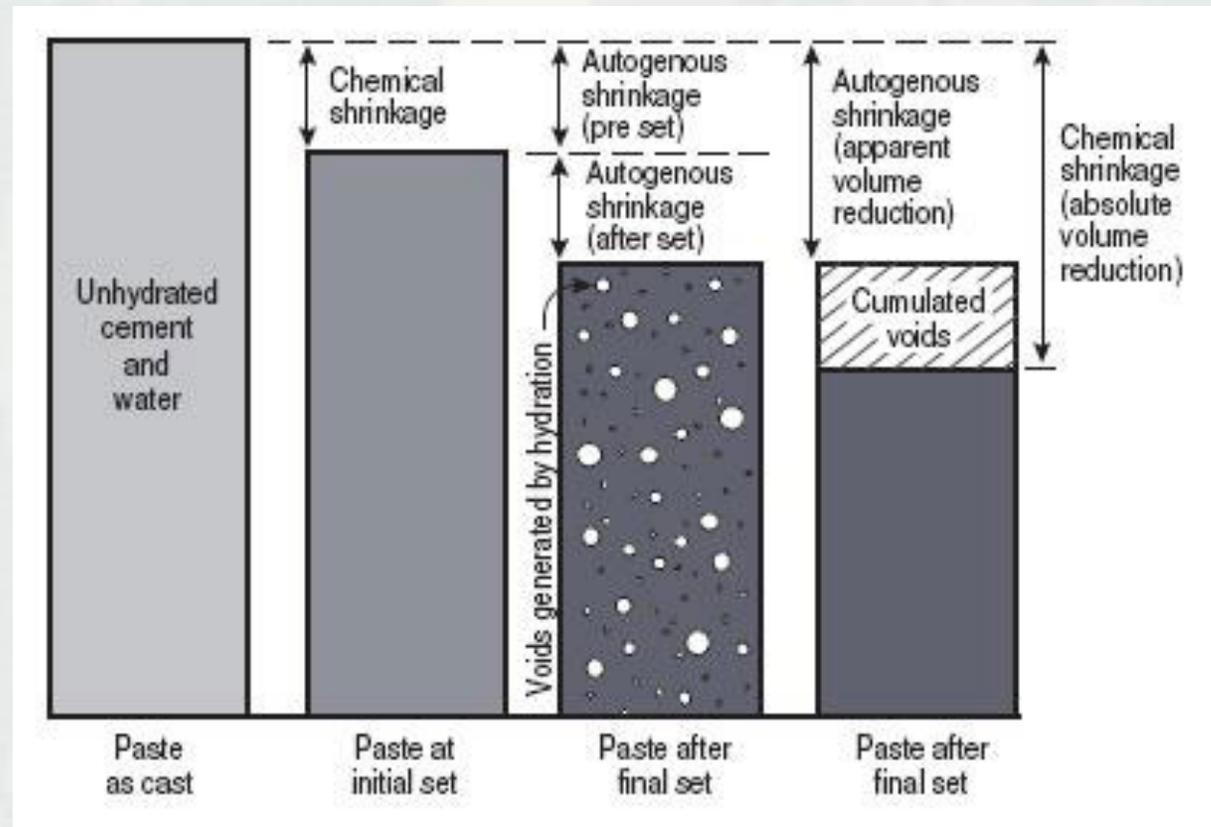
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Types of Concrete Shrinkage

- Chemical
- Autogenous
- Drying



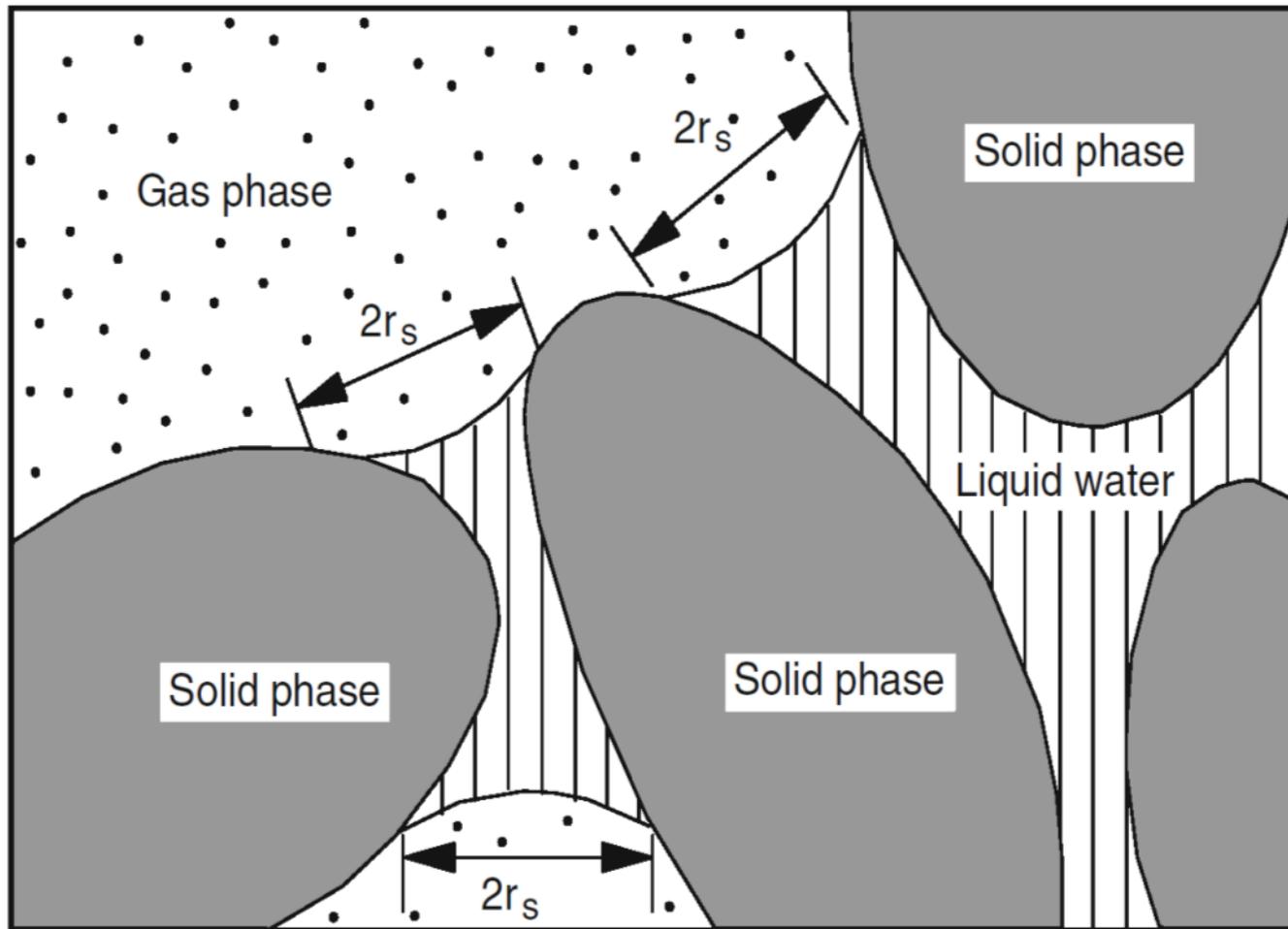
h = elevation of the liquid (m)
 γ = surface tension (N/m)
 θ = contact angle (radians)
 ρ = density of liquid (kg/m^3)
 g = acceleration of gravity (m/s^2)
 r = radius of tube (m)



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Drying Shrinkage in Concrete



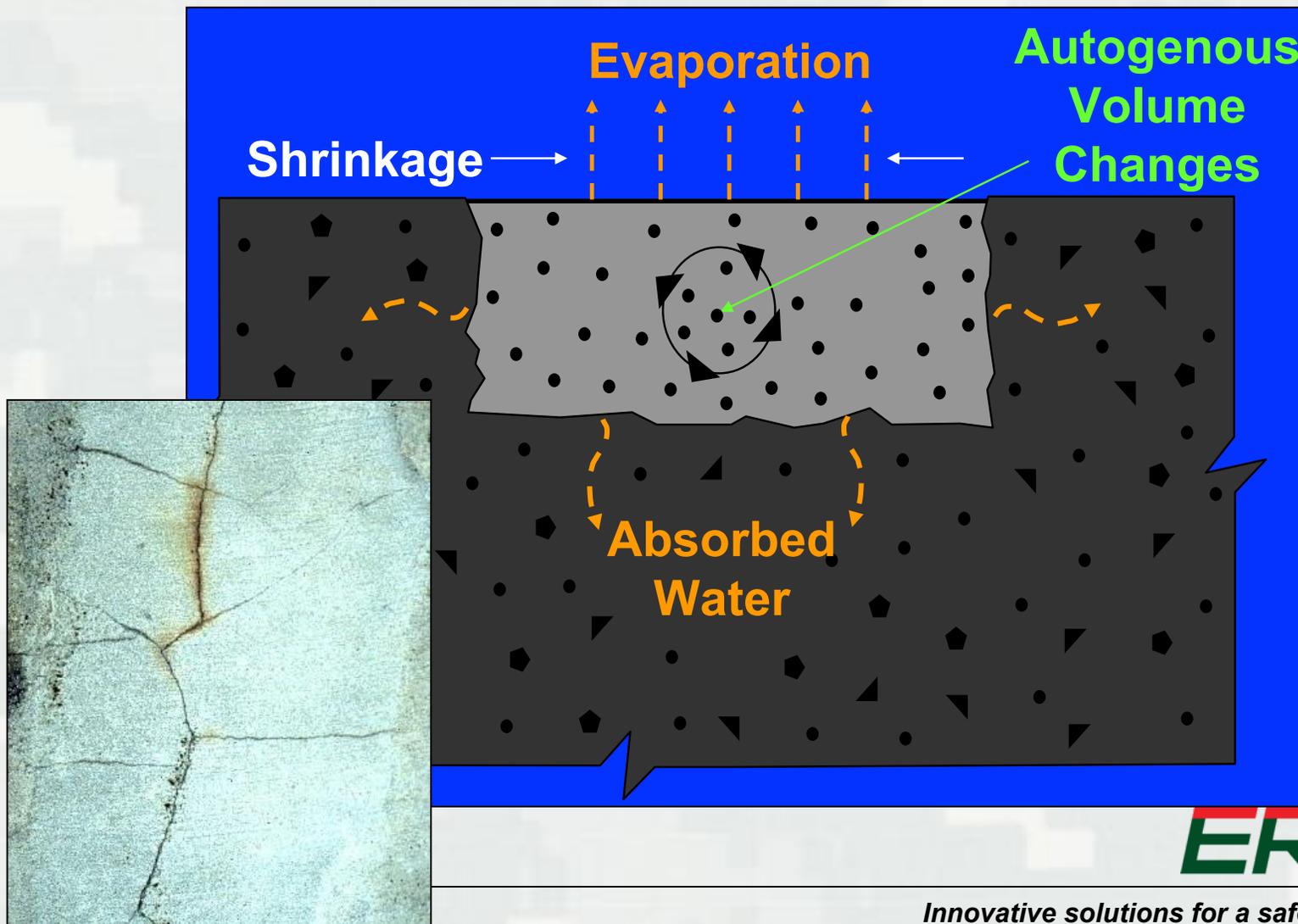
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Drying Shrinkage

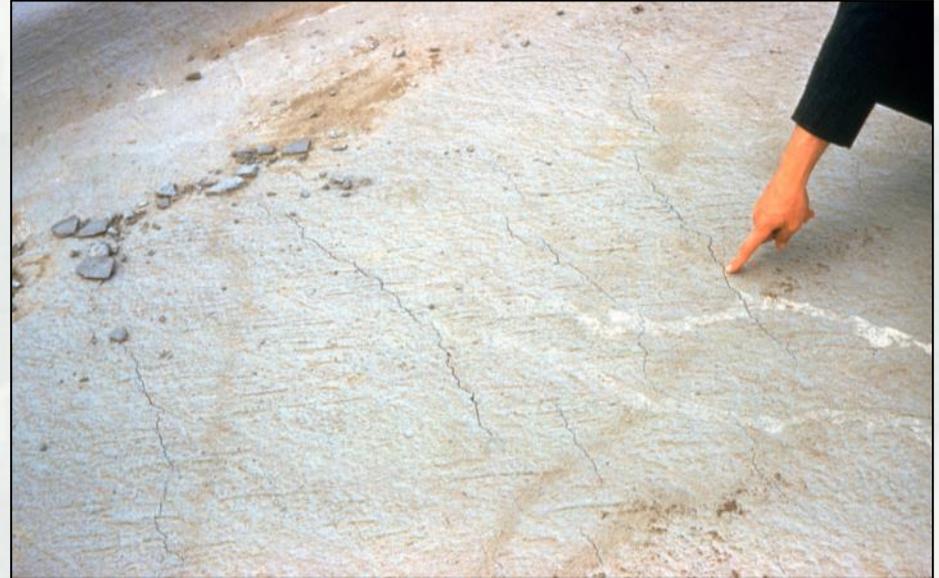
Moisture Loss



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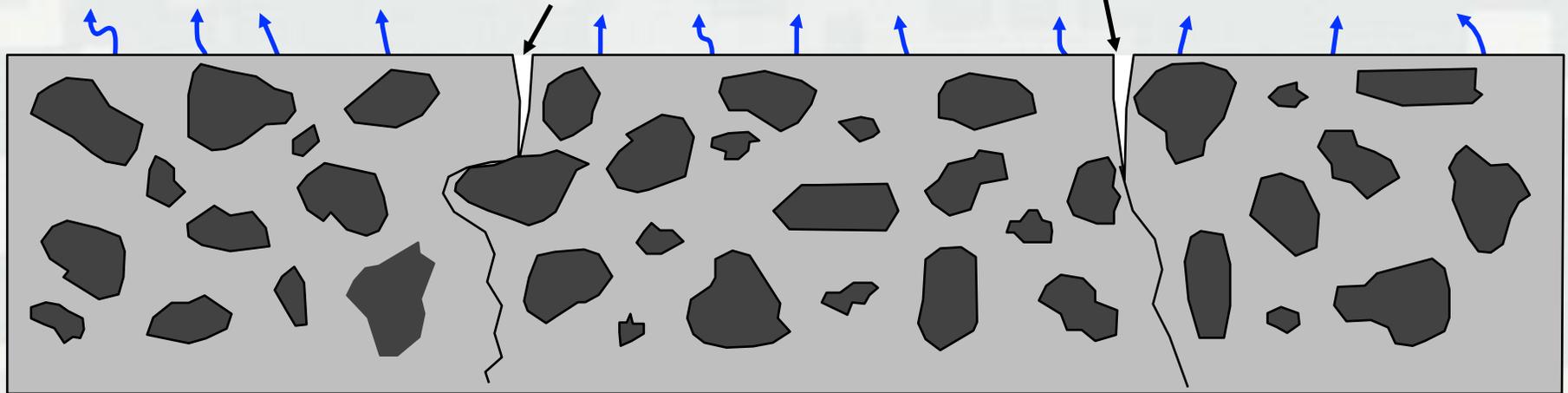
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Shrinkage-Induced Cracking



Water Loss Through Evaporation

Shrinkage Cracks



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Current Repair Material R&D Efforts

- Horizontal concrete surfaces of USACE navigation structures are subjected to significant weathering and deterioration that can result in spalling, scaling, and increased surface roughness along with erosion in underwater locations.
- Collaborators: USACE St. Paul District, Rock Island District (INDC), Omaha District, and U.S. Bureau of Reclamation Technical Service Center.
- Project activities:
 - ▶ Follow-up on long-term durability studies of repair materials.
 - ▶ Identify best practices for methods for repairs.
 - ▶ Study novel shrinkage reducing admixtures and fiber combinations.
 - ▶ Multi-scale investigation of durable repair applications.



Site Visits to Inspect Deterioration

- Site visits to USACE Districts:
 - ▶ St. Paul District – Inspection of structures along the upper Mississippi River which have horizontal concrete distress or have been repaired.
 - ▶ Information gained on repair process (concrete removal techniques, surface preparation requirements and capabilities), current repair materials used, and material availability considerations.



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Site Visits to Inspect Deterioration

- Site visits to USACE Districts:
 - ▶ Rock Island District – Inspection of Lock and Dam 13, 14, and 15.
 - ▶ Sites of different types of horizontal concrete repairs.
 - ▶ Information gained on repair process (concrete removal techniques, surface preparation requirements) and recommended best practices. Main takeaway is that the unbonded repairs performed significantly better with little cracking.
 - ▶ Report completed summarizing periodic inspection of repairs.



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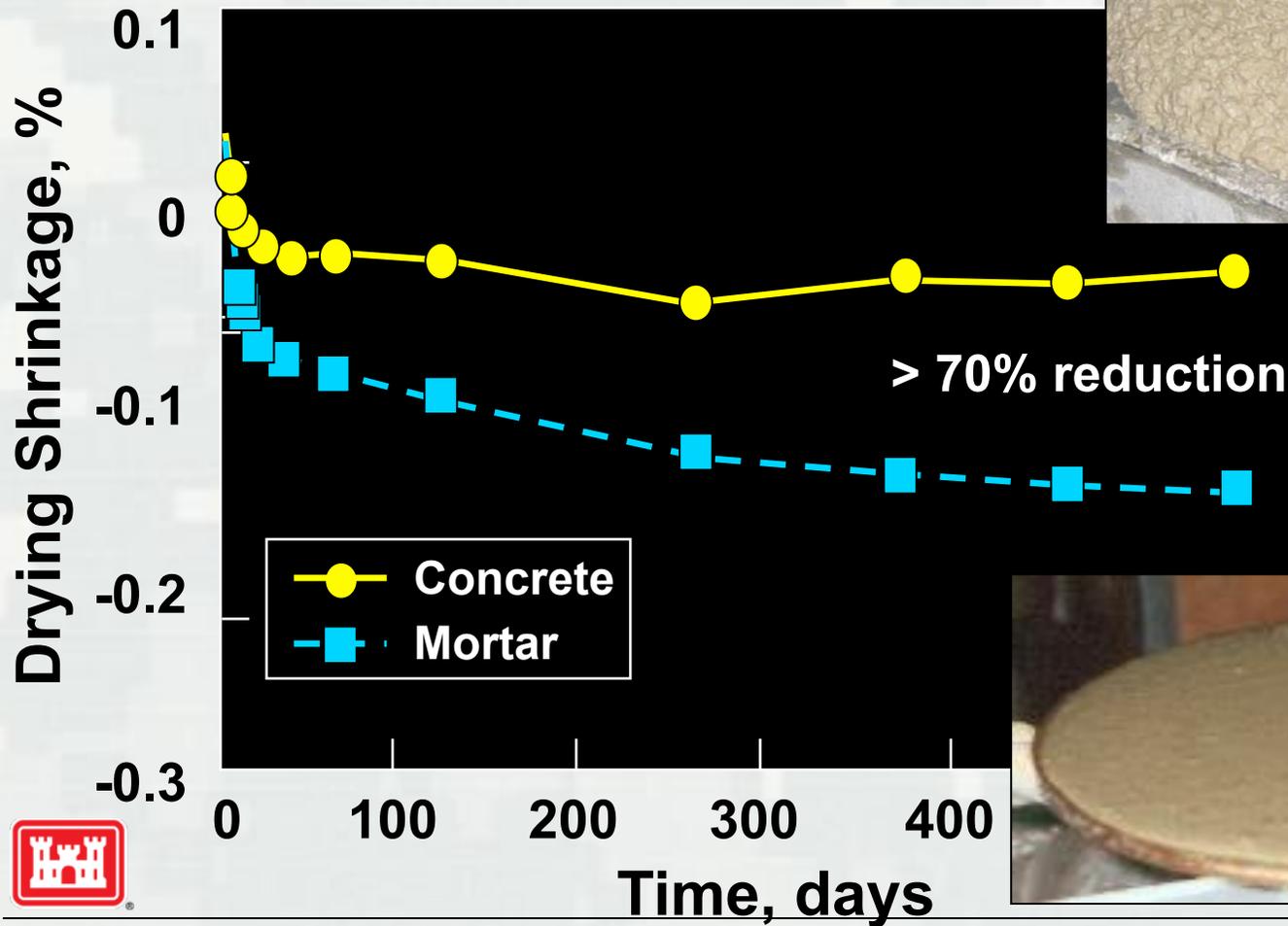
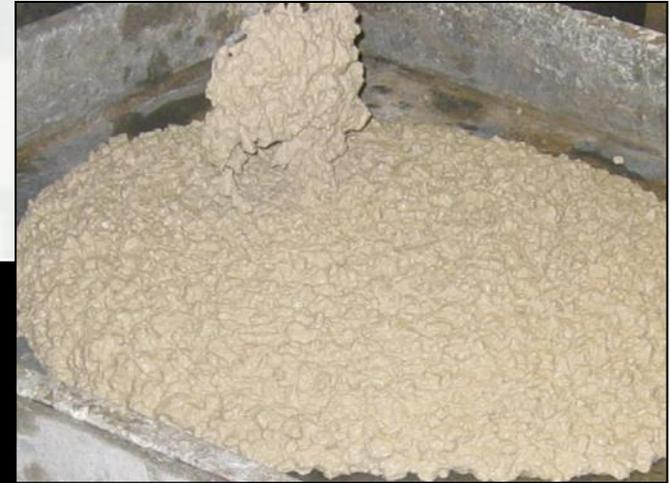
How can we mitigate this type of cracking of repair materials?

- Well proportioned concrete with dense aggregate gradation. **FIRST STEP!**
- Minimize shrinkage effects cause by cement and cementitious materials...difficult.
- Properly cure the concrete!
- Materials to minimize shrinkage...SRAs
- Materials to minimize cracking...fibers

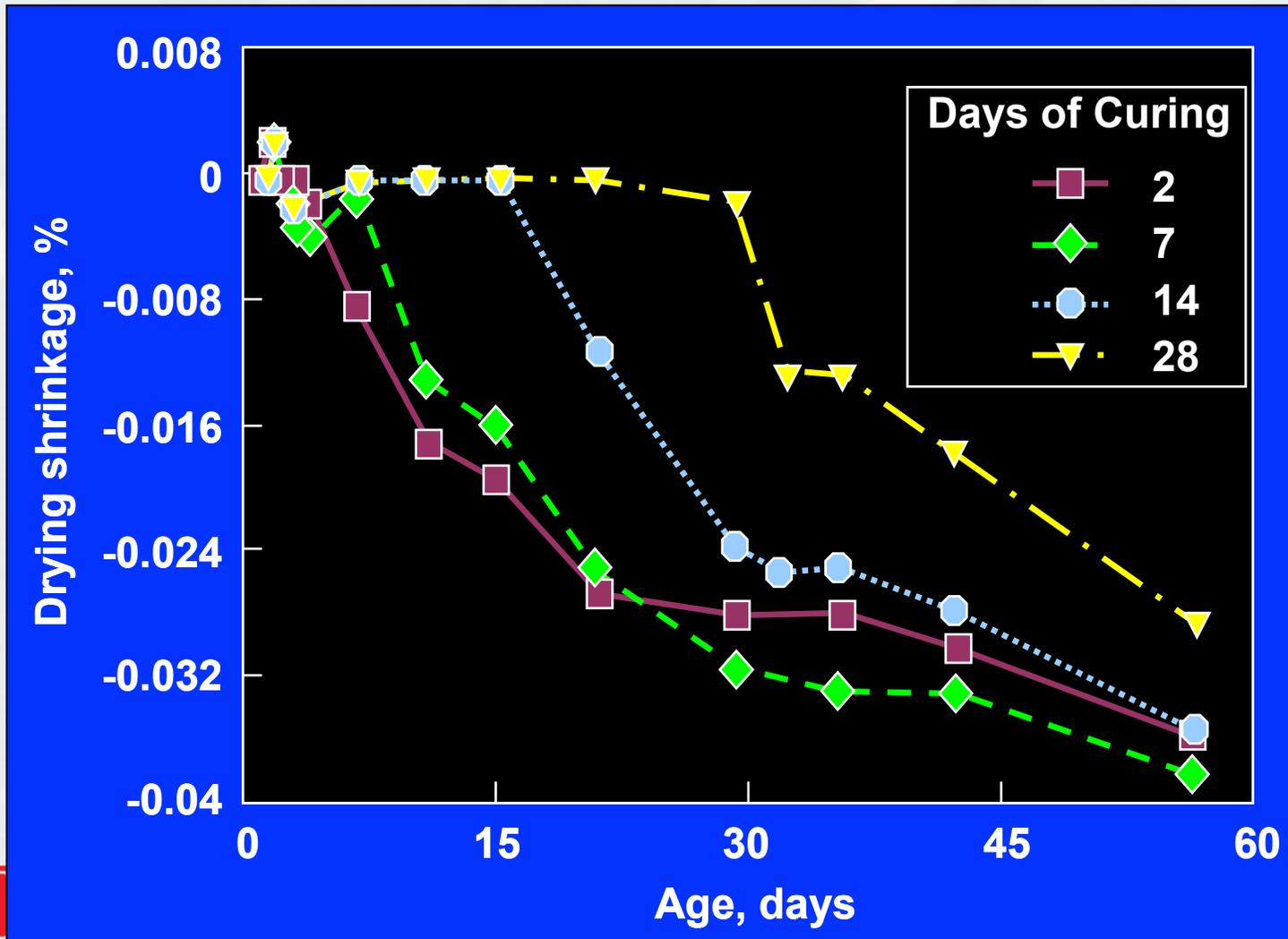


Drying Shrinkage

Effect of 3/4-in. Aggregate



Effect of Curing on Shrinkage Early Age



Treat Island REMR “Thin Repair” Slabs

- Ten repair slabs placed in 1995 as part of REMR “Thin Repair” project.
- Polymer modified, shrinkage reducing admixtures, rapid repair materials, alternative cements, etc...
- Not studied since completion of REMR.
- Samples retrieved for residual strength testing, petrographic, and chloride analysis.



~150 freeze/thaw cycles per year & two daily wet/dry cycles.

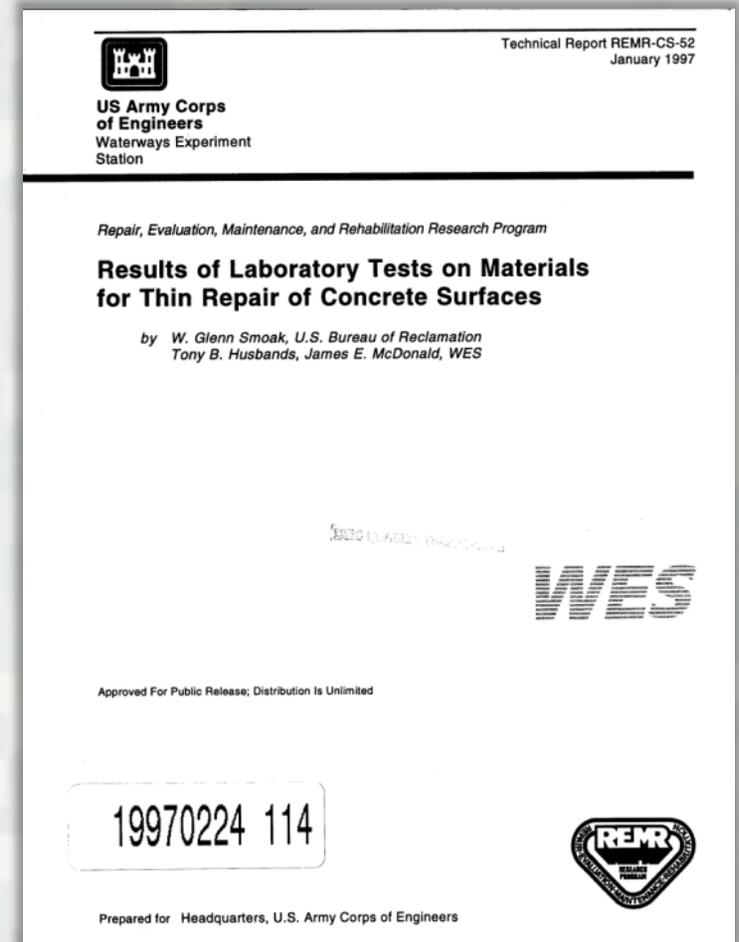
Treat Island Facility



REMR Thin Repair Slabs



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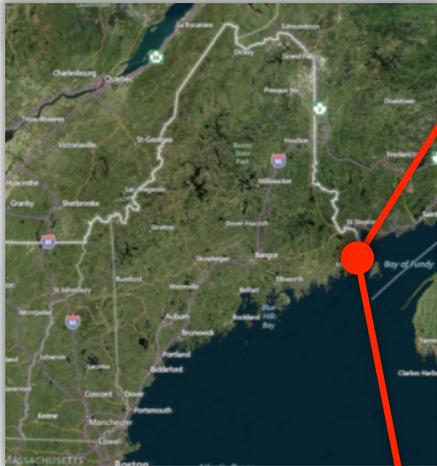


Report on laboratory testing. No report on field testing was generated.

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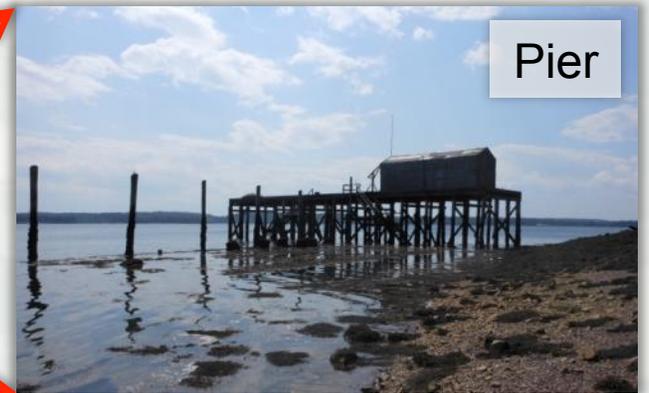
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Treat Island Natural Weathering Station – Facility Overview



100-160 freeze
thaw cycles per
year of exposure

Approx. 6.7m
(22ft) tidal
elevation change



Treat Island located in the Bay of Fundy
near Eastport, ME, USA.



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Treat Island Natural Weathering Station – History

- Site started in 1936 in conjunction with USACE plans to develop hydropower in the Bay of Fundy.
- Multiple historically-significant concrete-related field durability research programs:
 - Effect of w/c.
 - Air entraining admixtures.
 - Corrosion inhibitors.
 - Effect of size/thermal mass.
 - Fiber-reinforced concrete.
 - Polymer-modified concrete.
 - Roller-compacted concrete.
 - Reactive powder concrete.
 - Supplementary cementitious materials.
 - Prestressed concrete.
 - High-performance concrete.
 - Very-high-strength concrete (predecessor to UHPC).
 - Effect of aggregate size and properties.
 - Many others...



Field and Laboratory Investigations

- Higher strength repair materials with lower permeability (e.g., with silica fume addition) were in good condition
- Rapid repair materials were more susceptible to cracking and delamination following placement.
- Fiber reinforcement significantly improved crack resistance.
- Polymer modified systems exhibited increased surface scaling.



Scaling of polymer modified material

Good quality repair material



Cracking of rapid repair material



Samples used for strength testing and characterization



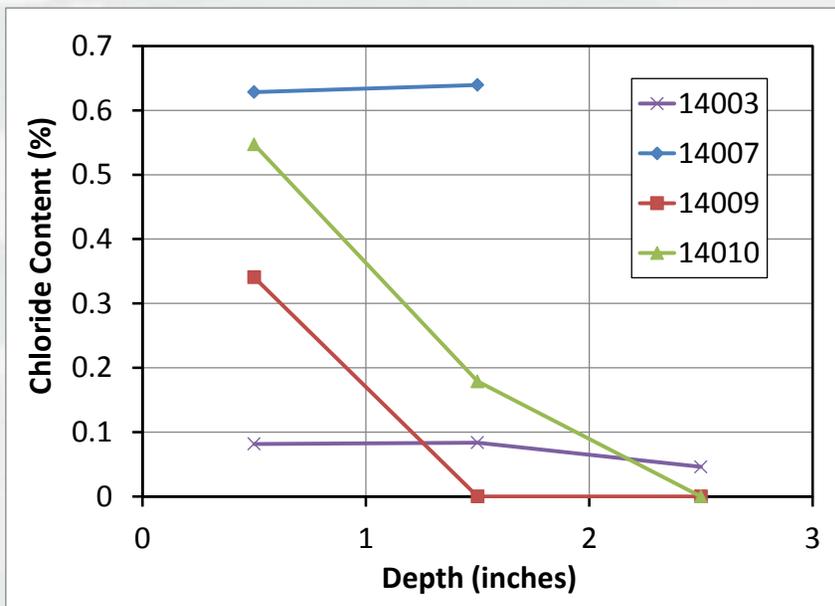
Results of Laboratory Investigation

Mechanical Properties:

- All materials that had not rubblized exhibited acceptable compressive strengths of 4,000-10,000psi.
- Higher strength materials with lower permeability exhibited less deterioration.

Chloride Penetration:

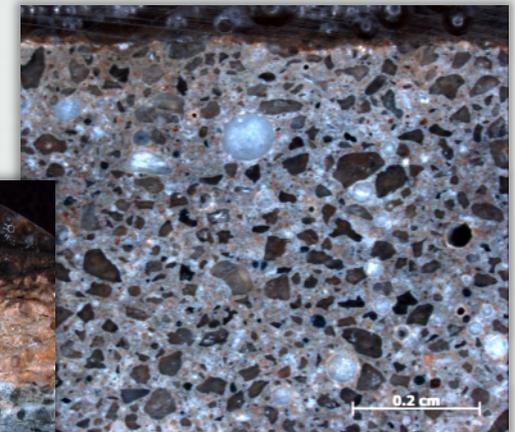
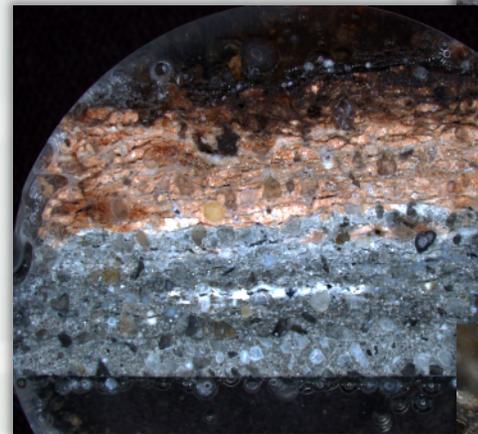
- Polymer modified and higher strength materials exhibited reduced chloride penetration at cover depths.



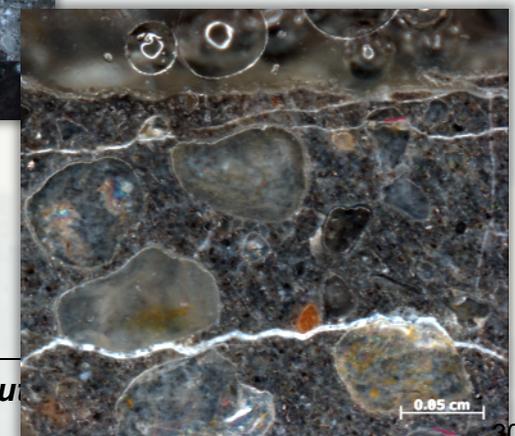
Microstructural Characterization:

- Petrographic analysis was conducted on samples prepared from three depths of the slabs: top, middle, and bottom.
- Total of 33 samples analyzed.

Surface scaling /
chemical attack.



Near-surface
delaminations and
microcracks



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Material Selections and Testing

- Key properties and relevant materials for testing identified:
 - ▶ Dimensional stability (shrinkage, thermal expansion / contraction)
 - ▶ Mechanical properties (strength, strength development, bonding)
 - ▶ Durability (chloride permeability, freeze/thaw resistance)
 - ▶ Fabrication ease
- Main requirement for horizontal concrete repairs is sufficient bond strength, mechanical properties, and minimal shrinkage that can lead to early-age cracking.
- Materials selected for initial testing round:
 - ▶ Shrinkage reducing admixtures including conventional chemistries and advanced chemistries that combine surface tension modifiers with an expansive component to minimize shrinkage.
 - ▶ Polymeric fiber reinforcement (polypropylene fibers).
 - ▶ Others...



Shrinkage Reduction Studies

- Initial testing performed on mortar bars to “dial in” shrinkage reducing admixture dosage rate:
 - ▶ Three dosage rates of each shrinkage reducing admixture used
 - ▶ Standard and modified test used (28d wet curing vs. 24hr wet curing)
 - ▶ Control samples were also tested to serve as a baseline
 - ▶ Total of 180 mortar samples produced and tested



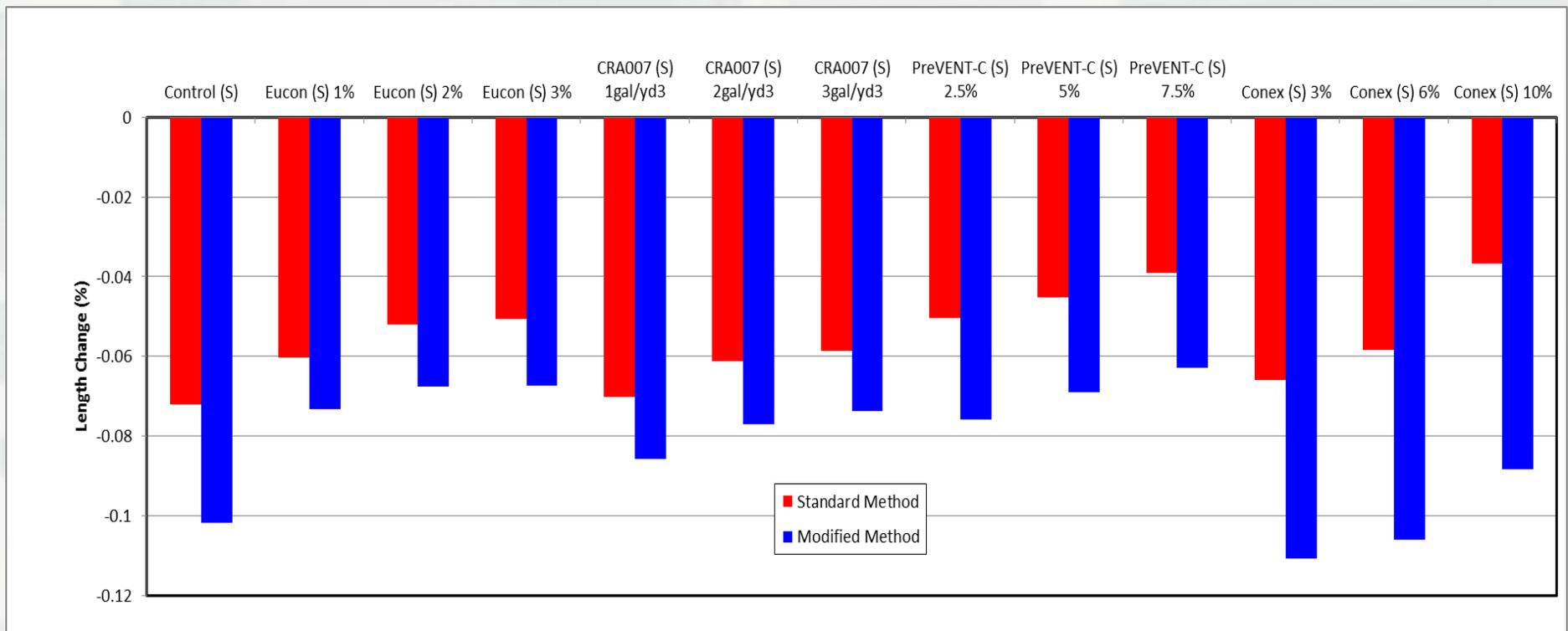
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Shrinkage Reduction Studies

- Shrinkage reduction reported by manufacturers of shrinkage reducing and compensating admixtures not achieved.
- Modified testing (i.e., curing) does influence results.

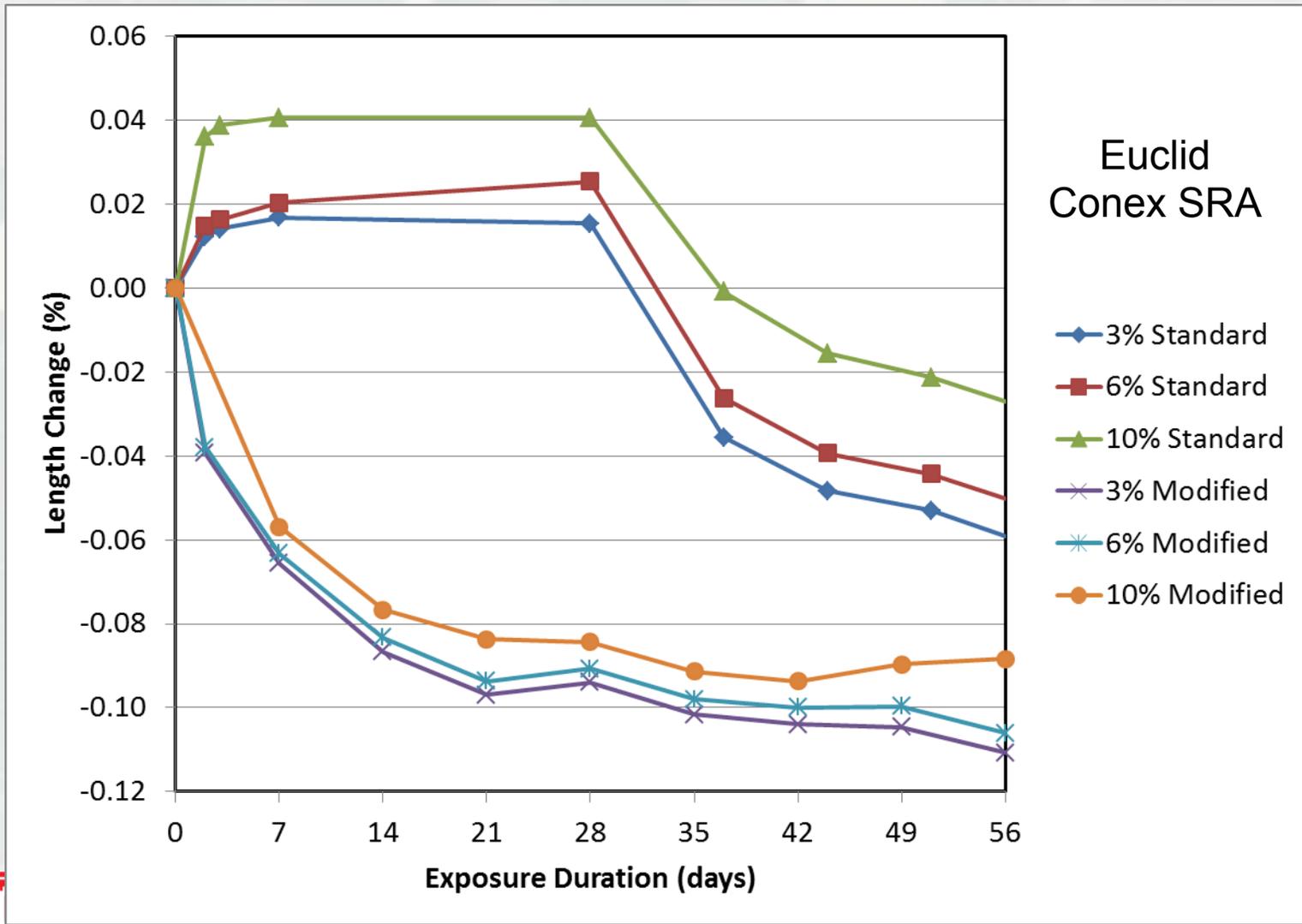


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Sub-par Performance of SRAs



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Scaling Up to Concrete

- Identified best-performing SRAs and dosage rates from studies on mortars to be used in concrete studies
- Combinations of SRAs, expansive components, and fibers
 - ▶ Control
 - ▶ 2% Eucon (basic SRA)
 - ▶ 7.5% PreVENT-C (advanced SRA)
 - ▶ 2% Eucon + Komponent (basic SRA + expansive admixture)
 - ▶ 1% ZP305s steel fiber reinforcement
 - ▶ PP fibers 1lb/yd³ polymeric fiber reinforcement
- Target air content of 6% for all materials
- Subjected to various concrete tests

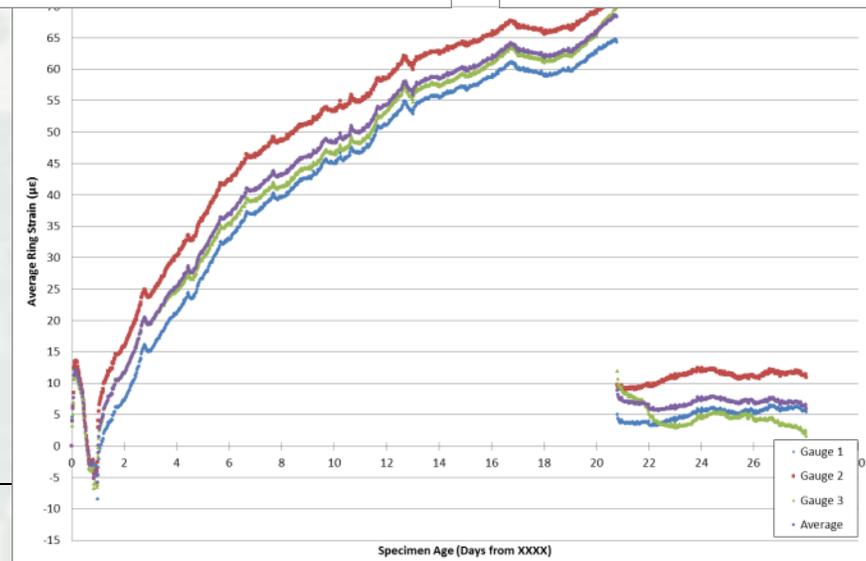
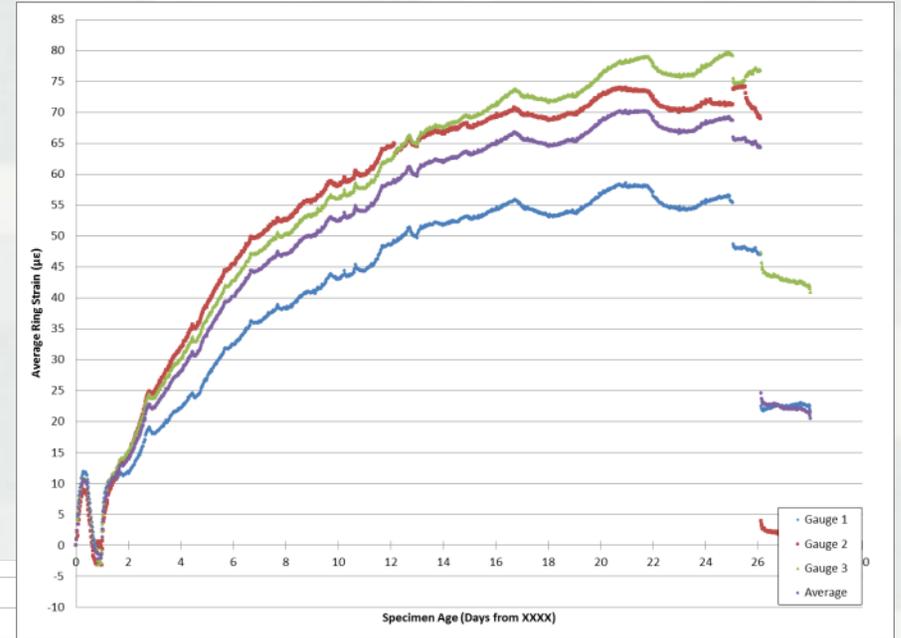
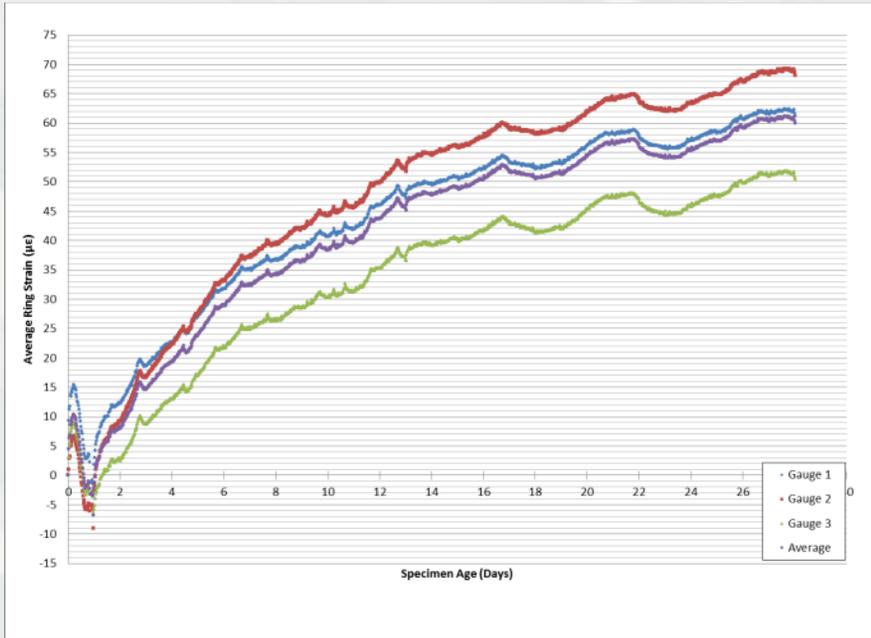


Scaling Up to Concrete

- Extensive trial batching to study admixture interactions
- Typical concrete tests for mechanical properties
- Length change (C157) and restrained shrinkage (C1581)
- Additional durability testing for freeze/thaw, chloride permeability, bond, elastic modulus, CTE, etc.



Example Shrinkage Ring Results



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Test Slabs for Laboratory-Scale Repairs

- Fabricated twelve concrete slabs to be used for simulated horizontal concrete repairs.
- Mildly reinforced (#4 bars at 12" centers each way) with 5,000 psi concrete (similar to most CW structures).
- Repairs will be performed with various bonding conditions and materials with measurements of shrinkage and cracking.



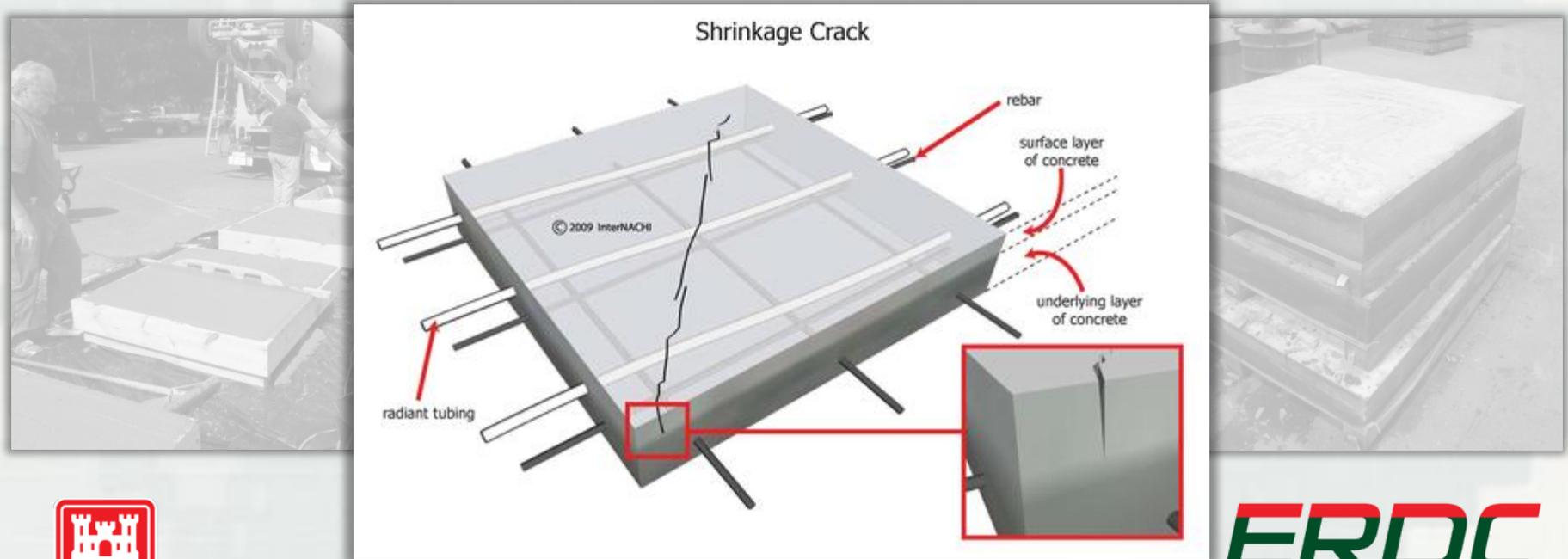
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Research Activities During FY15

- Publish technical report on forensic evaluation of existing horizontal concrete repair materials and survey of field demonstration sites at Rock Island and St. Paul Districts.
- Prepare and publish technical report on testing of materials for horizontal concrete repairs (e.g., shrinkage reducing admixtures).
- Two journal papers: one on shrinkage reducing admixtures and a second of the forensic investigation.
- Laboratory testing:
 - ▶ Shrinkage potential testing using restrained shrinkage test ASTM C581
 - ▶ Study shrinkage reducers, fibers, and internal curing concrete samples
 - ▶ Additional concrete testing on final mixture proportion
- Laboratory simulated repairs:
 - ▶ Conduct horizontal concrete repairs using twelve test slabs
- Field demonstration project at Lock and Dam 5 (MVP)



A couple other topics...



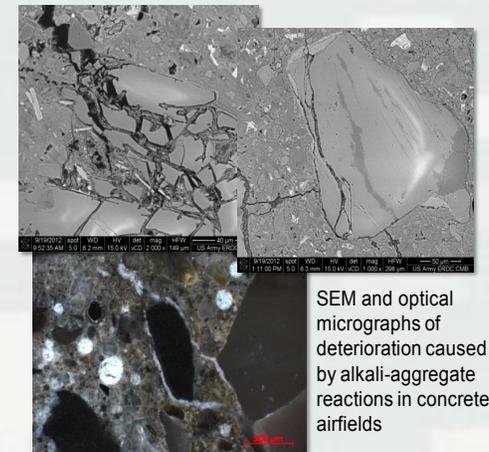
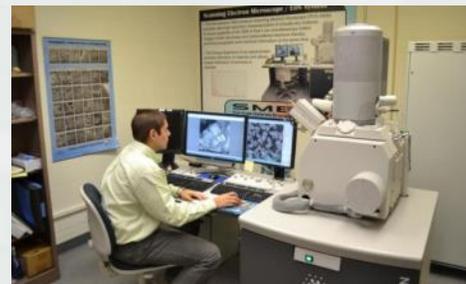
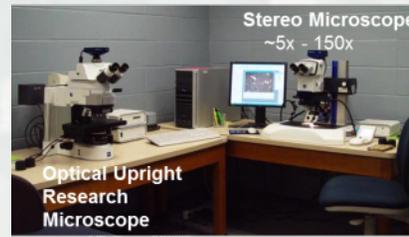
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Forensic Investigation Reachback Capability

- We have developed a unique forensic investigation capability
- Supporting USACE Districts, AFCEC, NAVFAC, NPS, USBR, DOE, and many others.
- Capabilities:
 - Concrete petrography
 - Chemical, mineralogical, and durability testing
 - Metallography
 - Failure analysis
 - Corrosion testing
 - Geochemistry
 - NDE



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Thank you!

Questions?

For questions:

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