ERDC Materials R&D for Aging Civil Works Infrastructure

Tech Exchange Meeting – ERDC Vicksburg

30 October 2014

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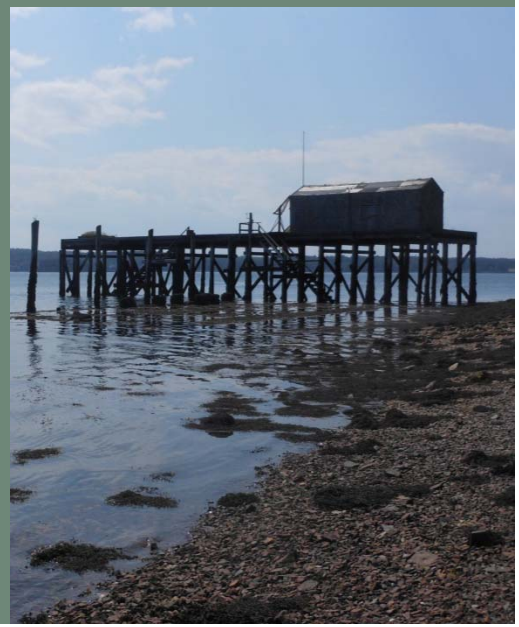

ERDC
Engineer Research and Development Center

US Army Corps of Engineers®

Agenda

- Materials R&D Needs
- Novel Materials for CW
- Field Demonstration
- Field Durability Testing
- Future Plans for Field Work
- Performance of Repair Materials
- New Admixtures for Minimizing Cracking in Repair Materials

U.S. Army Corps of Engineers Civil Works (CW) Infrastructure Assets:

- COASTAL NAVIGATION:
  - 1067 Navigation Projects
  - 19 Lock chambers
  - 13,000 miles of channels
  - 929 Navigation structures
  - 844 Bridges
- INLAND NAVIGATION:
  - 27 Inland river systems
  - 217 Lock chambers @ 171 sites
  - 12,000 miles of river channels
  - 692 Dams (75 are hydropower)

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  - 217 Lock chambers @ 171 sites
  - 12,000 miles of river channels
  - 692 Dams (75 are hydropower)

- 2,370 Million Tons of Goods Transported Annually
- $22.3 Billion in Average Annual Flood Damage Prevented
- 100 Billion Kilowatt Hours Per Year of Renewable Energy

State of U.S. Levees, Locks, and Dams

ESTIMATED 5-YEAR FUNDING REQUIREMENTS FOR
DAMS

Total investment needs
$12.5 BILLION

Estimated spending
$5.05 BILLION

Projected shortfall
$7.45 BILLION

Source: ASCE Report Card for America's Infrastructure

ESTIMATED 5-YEAR FUNDING REQUIREMENTS FOR
LEVEES

Total investment needs
$50 BILLION

Estimated spending
$1.13 BILLION

Projected shortfall
$48.87 BILLION

Source: ASCE Report Card for America's Infrastructure

ESTIMATED 5-YEAR FUNDING REQUIREMENTS FOR
INLAND WATERWAYS

Total investment needs
$50 BILLION

Estimated spending
$29.475 BILLION

Projected shortfall
$20.5 BILLION

Source: ASCE Report Card for America's Infrastructure

Operational Needs: Infrastructure R&D

Inadequate knowledge of the physics and monitoring of internal erosion (seepage and piping mechanics, monitoring) limits risk assessment and management.	High	High
Uncertainty (where and when) of surface erosion on embankments due to overtopping (prediction, mechanics, monitoring) makes breach modeling difficult. (look at NRCS work)	Moderate	High
There is limited ability to accurately predict hydrologic loadings beyond gage records (non-stationarity), particularly during extreme events	Moderate	High
There is limited understanding of transient seepage modeling (modeling vs reality)	Moderate	High
Current inspection and monitoring techniques for locks and gates do not effectively reveal imminent failure	Moderate	High
Corrosion detection and monitoring systems for steel components can be invasive and destructive to the steel components	Moderate	High
The limited process for predicting and quantifying consequences can adversely impact investment decisions	Moderate	High
There is a lack of awareness of materials and methods in which USACE is most heavily invested, which could help guide appropriate materials and construction research to improve efficencies	Low	High
There [illegible] RARG	[illegible]	[illegible]
There [illegible]	[illegible]	[illegible]
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There [illegible]	[illegible]	[illegible]
Develo [illegible] effecti [illegible] RARG	[illegible]	[illegible]
Shock [illegible]	[illegible]	[illegible]
Curren [illegible] degradeable (burlap)	[illegible]	[illegible]
Community response/consequences planning (warning, evacuation, EM, behavioral models, transportation models) is hampered by unpredictable human behavior	Moderate	Moderate
There is innadequate design guidance for downstream tainter gate temporary closure structures (Nav RARG)	Moderate	Moderate
Difficulty in predicting forces and projecting growth of levee breaches hampers ability to accurately model flood concequences (FRM RARG)	Moderate	Moderate
There is insufficient guidance or lack of technology for repair and replacement of in-structure waterstops (FRM RARG)	Moderate	Moderate
Monitoring and detection of concrete degredation (changes over time and magnitude) is either too invasive and destructive or ineffective	Low	Moderate?
Inability to accurately predict erosion of spillway rock foundations results in poor understanding of consequences and risk.	Low	Moderate
Methods to assess regional Met/Hydro conditions are inadequate	Low	Moderate
Current designs are not always satisfactory for controling scour at critical hydraulic structure - subaqueous interfaces	Low	Moderate
Design and implementation guidance for bearings (types, reliability) is inadequate	Low	Moderate
There is a lack of an integrated real-time seismic monitoring and notification system or approach	Low	Low
Hydraulic modeling for bridge decks under flood conditions is inadequate (hydraulic issue) (FRM RARG)	Low	Low

Corrosion, Concrete Repair, Steel Fatigue, Levee Breaching, Concrete Deterioration, Inspection Techniques, NDE…

Research Objectives

Problem Statement:

- Increasing maintenance and repair costs of aging USACE Civil Works infrastructure.
- Materials used for repair often do not meet logistic, durability, and serviceability requirements.
- Need for novel materials to improve the performance and resiliency of USACE mission critical Civil Works infrastructure.

ERDC's Infrastructure Materials

Longstanding ERDC research programs focused on development of novel materials for military infrastructure:

- Rapid setting and high early-age strength gain for concrete repair.
- Materials with improved corrosion, hardness, and abrasion resistance.
- Materials with reduced weight and cost.
- Advanced multi-functional coating materials.

A variety of materials have been developed and evaluated that can be rapidly transitioned for Civil Works applications:

- Ultra-high performance concretes
- Rapid concrete repair materials
- Many others… advanced coatings, advanced polymeric and metallic materials, self-sensing materials for structural health monitoring…

Novel Materials Approach

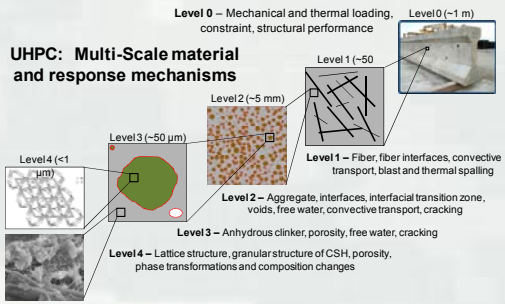
- **Novel materials from ME → CW:**

Advanced Cement-Based Materials
↓
Advanced Coating Systems
↓
Advanced Polymeric and Metallic Materials
↓
Self-Sensing Materials for Health Monitoring
↓
NOVEL MATERIALS

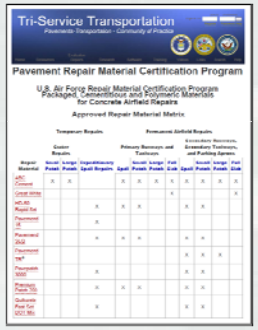
Example ERDC Novel Material Technologies

Ultra-High Performance Concrete

ERDC's modular protective system



Materials for Rapid Repair of Infrastructure



- **Collaborations across USACE:**

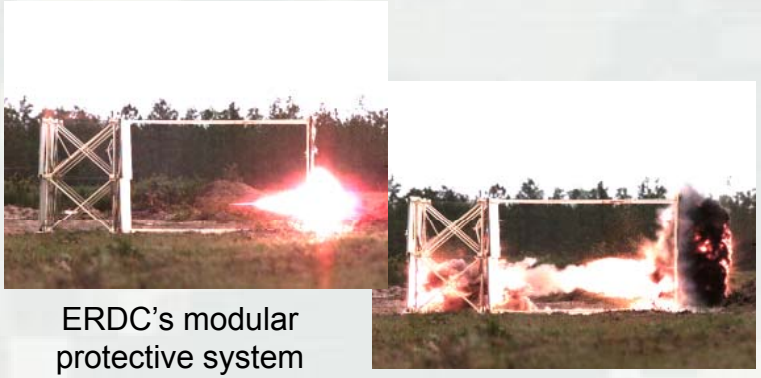
- **Other applications for both military and civilian facilities:**

ERDC

Ultra-High Performance Concrete (UHPC)

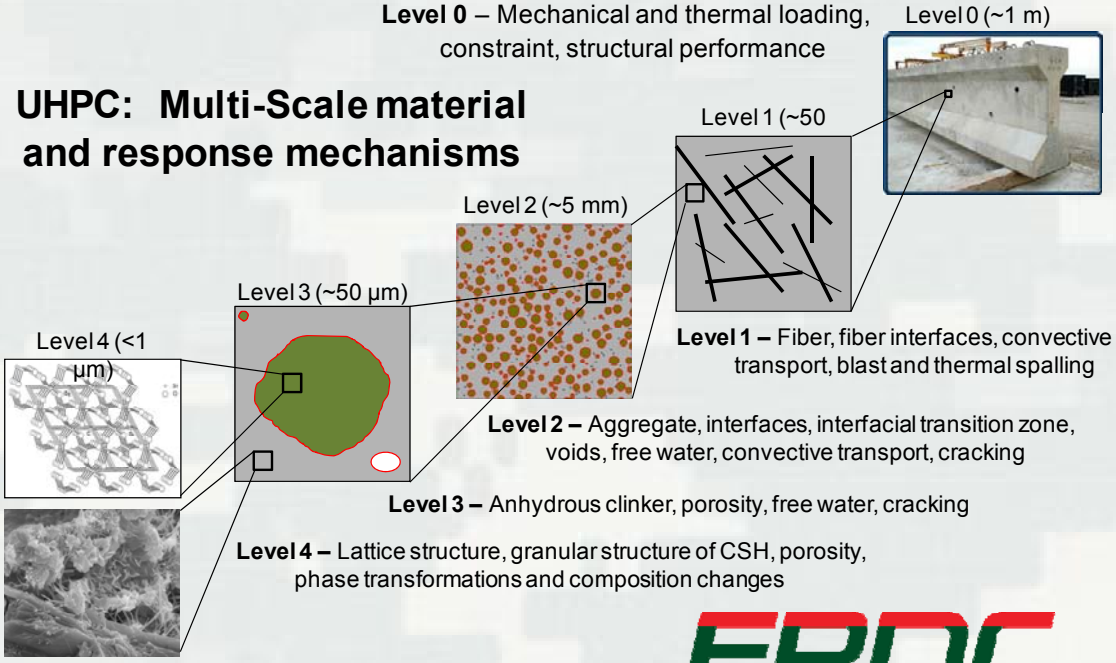
Three decades of R&D on development, characterization, modeling, and fielding of UHPCs:

- Primary focus on force protection.
- Strengths in excess of 200MPa / 30ksi
- High toughness with fibers
- High durability



ERDC's modular protective system

UHPC: Multi-Scale material and response mechanisms



Level 0 – Mechanical and thermal loading, constraint, structural performance

Level 1 – Fiber, fiber interfaces, convective transport, blast and thermal spalling

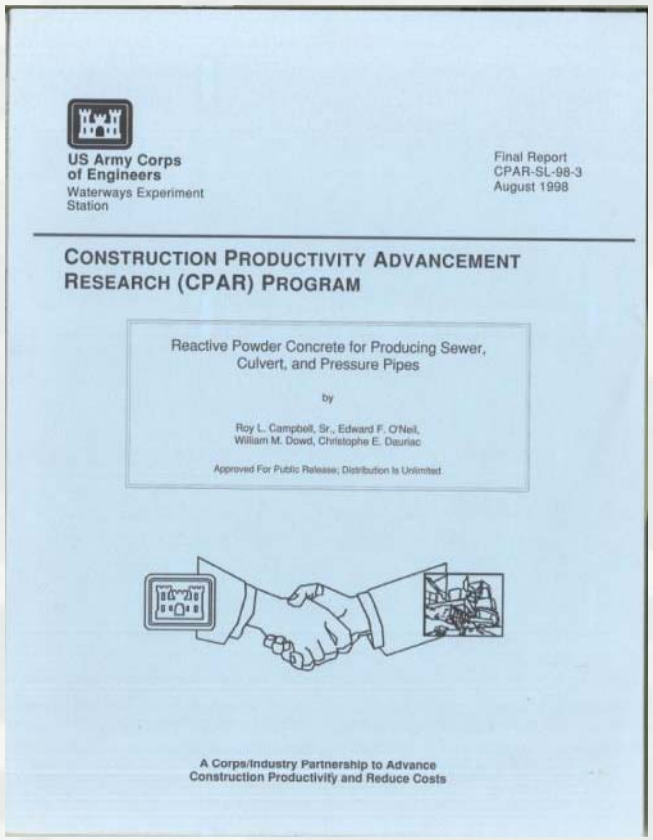
Level 2 – Aggregate, interfaces, interfacial transition zone, voids, free water, convective transport, cracking

Level 3 – Anhydrous clinker, porosity, free water, cracking

Level 4 – Lattice structure, granular structure of CSH, porosity, phase transformations and composition changes

History - WES/ERDC "RPC" Research

- Waterways Experiment Station (WES)
  - Now the Engineer Research and Development Center (ERDC)
- Construction Productivity Advancement Research Program (CPAR)
  - "Reactive Powder Concrete for Producing Sewer, Culvert, and Pressure Pipes," Campbell, O'Neil, Dowd, and Dauriac, CPAR-SL-98-3, August 1998 http://dodreports.com/pdf/ada354199.pdf
  - HDR Engineering (American "Partner" for Bouygues)



US Army Corps of Engineers
Waterways Experiment Station

Final Report
CPAR-SL-98-3
August 1998

CONSTRUCTION PRODUCTIVITY ADVANCEMENT RESEARCH (CPAR) PROGRAM

Reactive Powder Concrete for Producing Sewer, Culvert, and Pressure Pipes

by

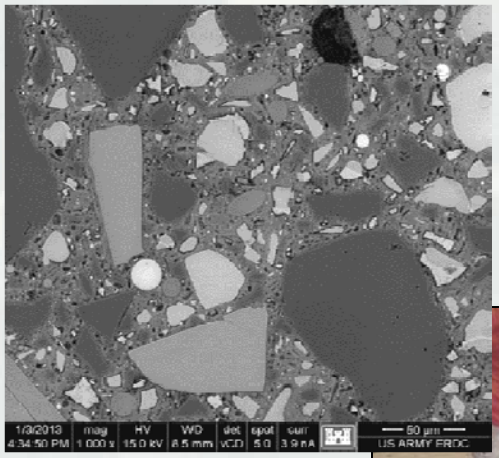
Roy L. Campbell, Sr., Edward F. O'Neil, William M. Dowd, Christophe E. Dauriac

Approved For Public Release; Distribution Is Unlimited

A Corps/Industry Partnership to Advance Construction Productivity and Reduce Costs

History WES/ERDC UHPC Research
Very-High-Strength Concrete - VHSC

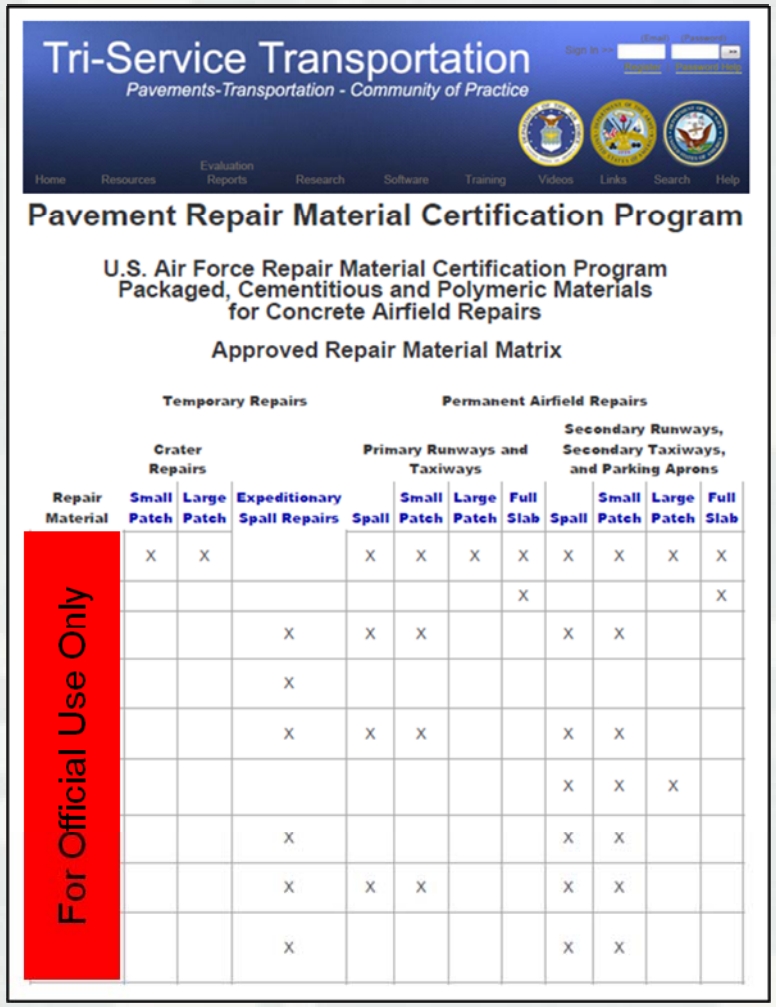
- "Local" materials used
- Not RPC, incorporating ASTM C 33 concrete sand
- Developed by Donald M. Walley and Billy Neeley
- Early/Mid 1990's
- **Mixture #247!**
- 200 MPa (29,000 psi) with steam curing at 190° F
- **Revolving-drum mixer truck used to produce!**
- **Lead to Cor-Tuf ®**



Rapid Setting Rapid Strength Repair Materials

Novel repair materials for airfield and pavement repairs in austere environments:

- Alternative binders: Ca-Al, Ca-S-Al, and other non-portland cement binders
- Controllable rapid setting
- Full strength in hours
- Ideal for contingency repair needs



Tri-Service Transportation

Pavements-Transportation - Community of Practice

Home | Resources | Evaluation Reports | Research | Software | Training | Videos | Links | Search | Help

Pavement Repair Material Certification Program

U.S. Air Force Repair Material Certification Program
Packaged, Cementitious and Polymeric Materials
for Concrete Airfield Repairs

Approved Repair Material Matrix

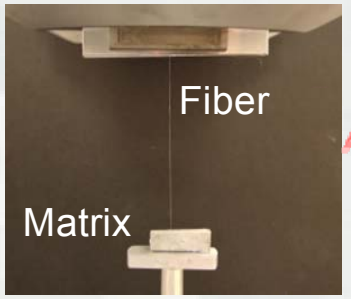
For Official Use Only

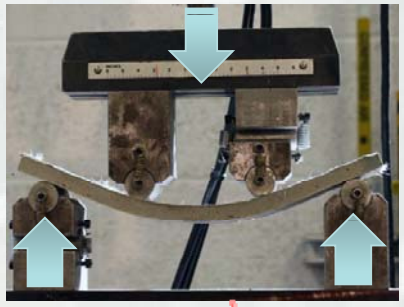
	Temporary Repairs			Permanent Airfield Repairs							
	Crater Repairs			Primary Runways and Taxiways				Secondary Runways, Secondary Taxiways, and Parking Aprons			
Repair Material	Small Patch	Large Patch	Expeditionary Spall Repairs	Spall	Small Patch	Large Patch	Full Slab	Spall	Small Patch	Large Patch	Full Slab
	X	X		X	X	X	X	X	X	X	X
							X				X
			X	X	X			X	X		
			X								
			X	X	X			X	X		
								X	X	X	
			X					X	X		
			X	X	X			X	X		
			X					X	X		

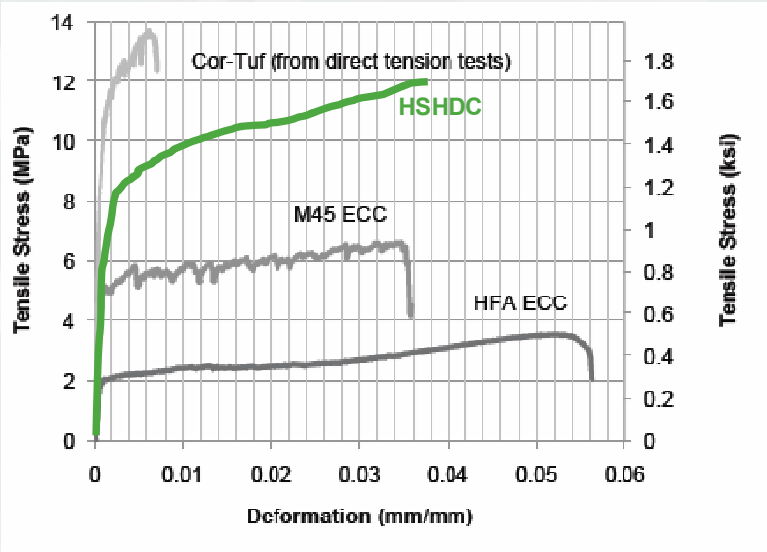
BUILDING STRONG®

Innovative solutions for a safer, better world

High Strength, High Ductility Concrete







- HSHDC
- Engineered Cementitious Composite (ECC) designed to maximize energy dissipation from weapons effects in protective construction.
- Revolutionary Ultra High Performance Concrete (UHPC) with very high strength and ductility
- Extreme resiliency to severe loading conditions due to:
  - Strength ~ 7x conventional concrete
  - Ductility ~5-10x other UHPC's
  - Strain hardening response

Example Material Need – Armoring Systems

Damage and failure of armoring in navigation lock structures:

- Steel armor plates embedded in common impact areas of lockwalls and guidewalls in inland navigation structures.
- Frequently impacted and damaged by vessels.
- **Often go unrepaired due to logistic impact on navigation!**

Armor plate damage at miter gate recess at Newt Graham L&D (Tulsa District)

Requirements:

- Rapid setting and strength gain grout or mortar to prevent long shutdown for armor repairs.
- High strength, toughness, and impact resistance.

Laboratory-Based Repair Studies

Various materials used to repair/retrofit mock-ups of armoring systems for laboratory-scale strength testing.

- Control of typical non fiber-reinforced portland cement-based grout.
- Calcium sulfoaluminate (Ca-S-Al) cement-based grout with addition of steel fiber reinforcement.
- Fiber-reinforced ultra-high performance concrete with no high temperature steam curing applied (logistic constraint).

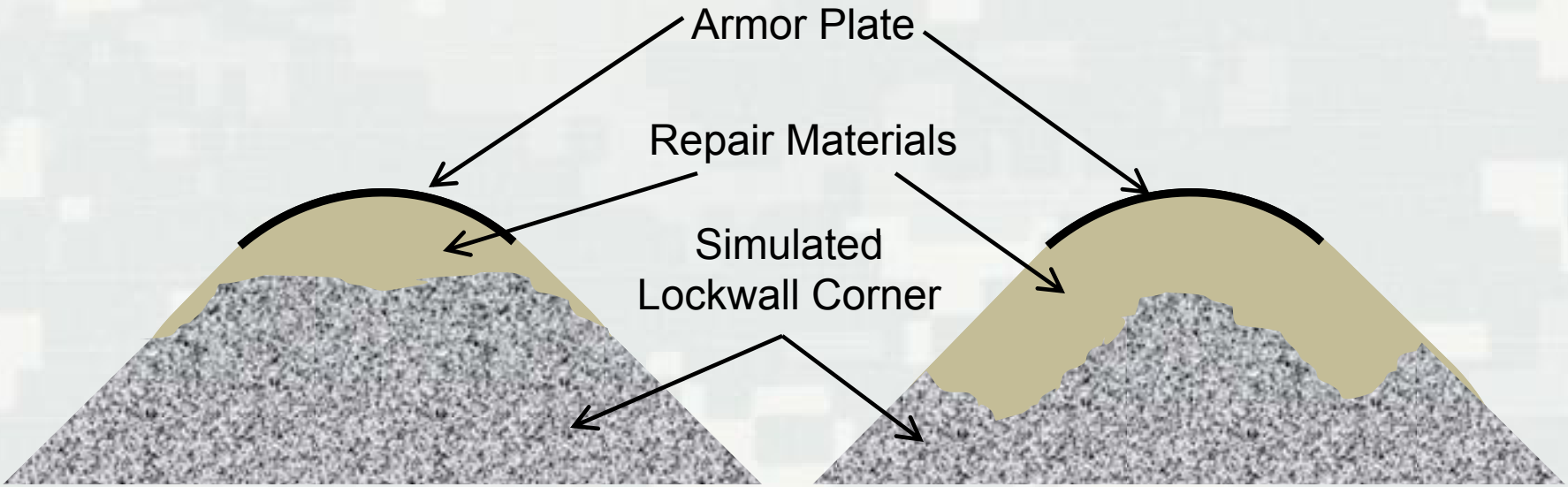
		Normal Repair Without Fibers	Good Cavity Without Fibers	Normal Repair With Fibers	Good Cavity With Fibers	Good Cavity With Fibers and No Armor Plate
Material	Portland Grout	X				
	Ca-S-Al Grout	X	X	X	X	
	UHPC				X	X

Cor-Tuf ®

Repair Cavity Geometries Investigated

Two repair cavity geometries:

- Typical repair cavity with roughened impacted / damaged surface.
- Ideal repair cavity with loose / friable concrete removed and no feathered edges at perimeter of repair area.



Typical repair of damaged surface.

Ideal repair cavity w/o feathered edges.

Fabrication of Test Specimens

Production of all test specimen blocks:

- Production of 5,000 psi fiber-reinforced concrete mock-up of armoring.
- Once concrete mock-up reached 28d, repairs were made.

Concrete for test specimens.

Placement of mock-ups for repair application.

Placement of UHPC into repair cavity

Completed test specimen

Laboratory-Based Testing

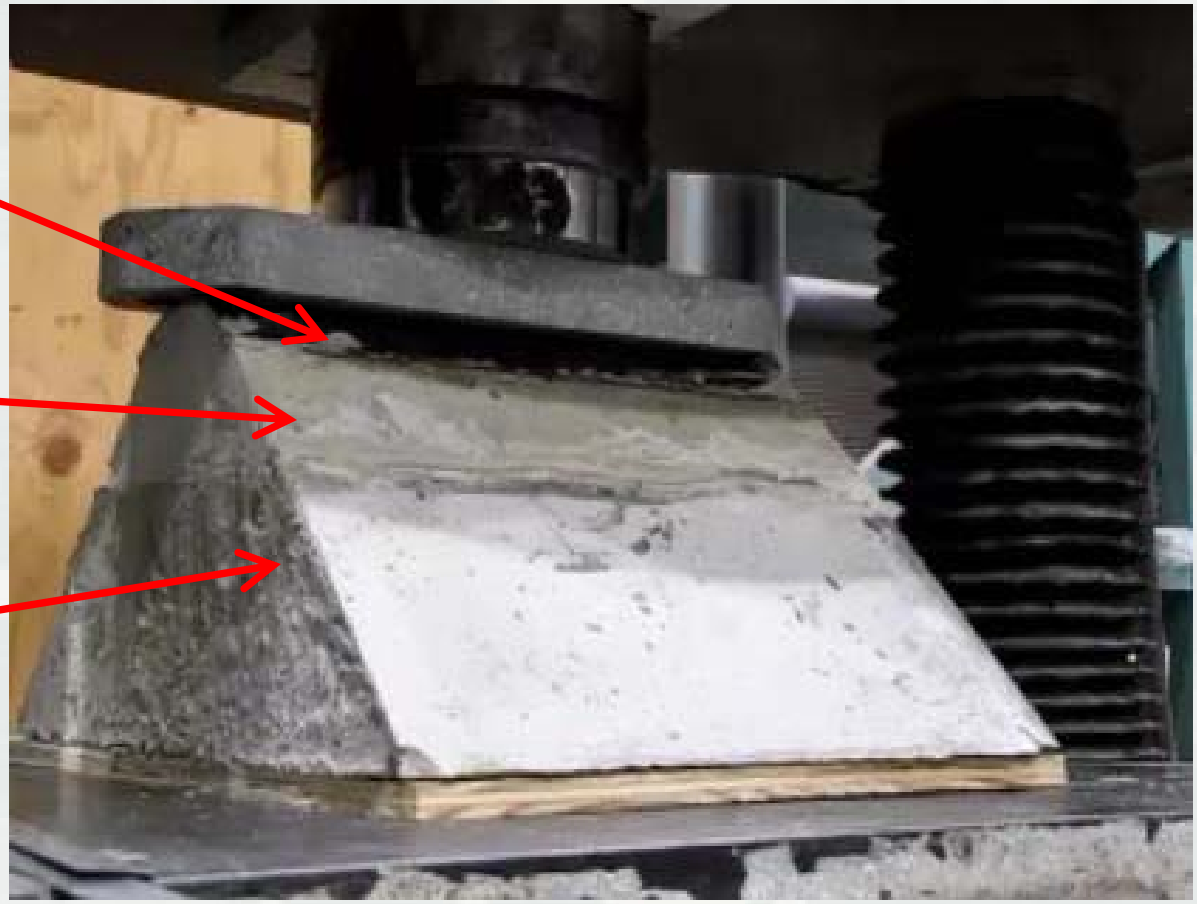
Testing of trial mock-up of armor plate repair:

Armor Plate

Repair Material

Simulated Concrete Lockwall Corner

Displacement rate similar to velocity of vessel impact.



Before Testing

Laboratory-Based Testing

Testing of trial mock-up of armor plate repair:

Armor Plate

Repair Material

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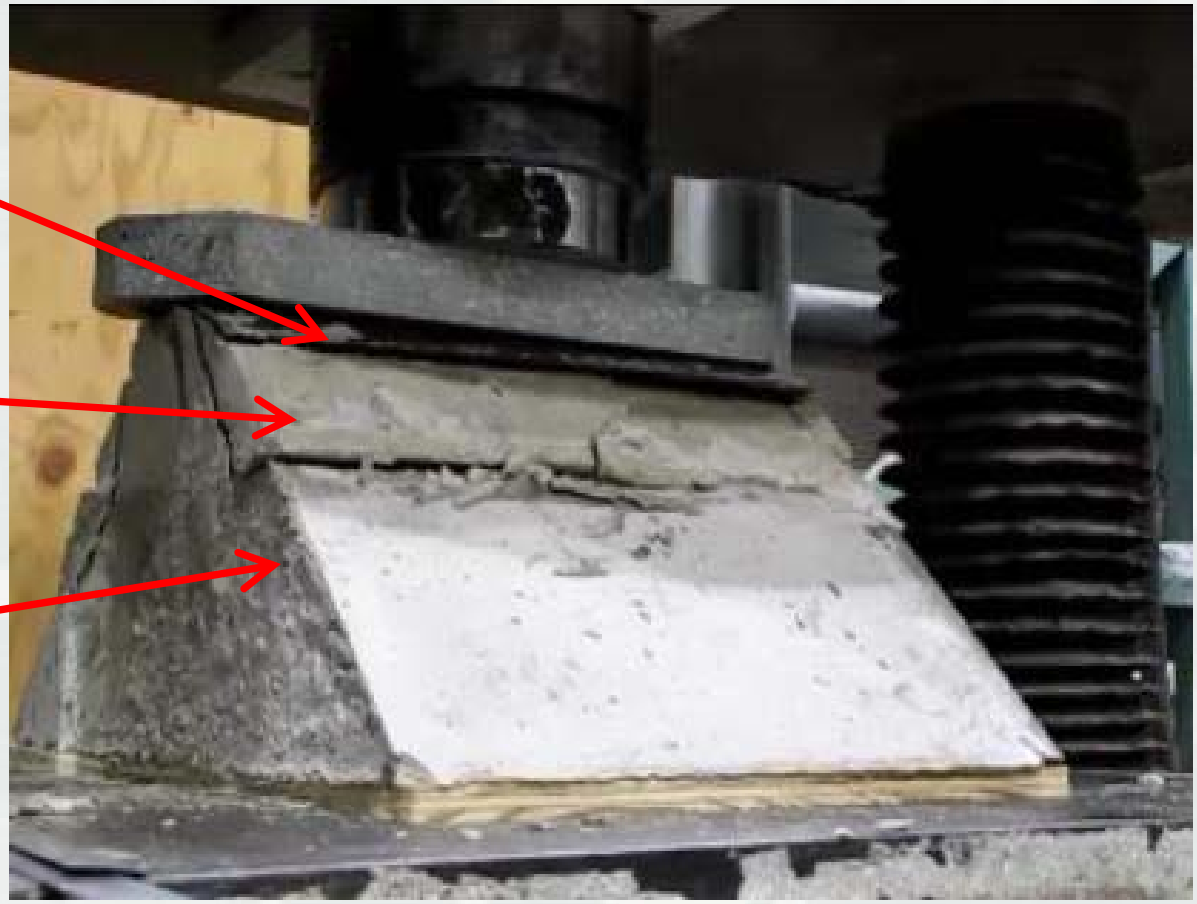


After Testing

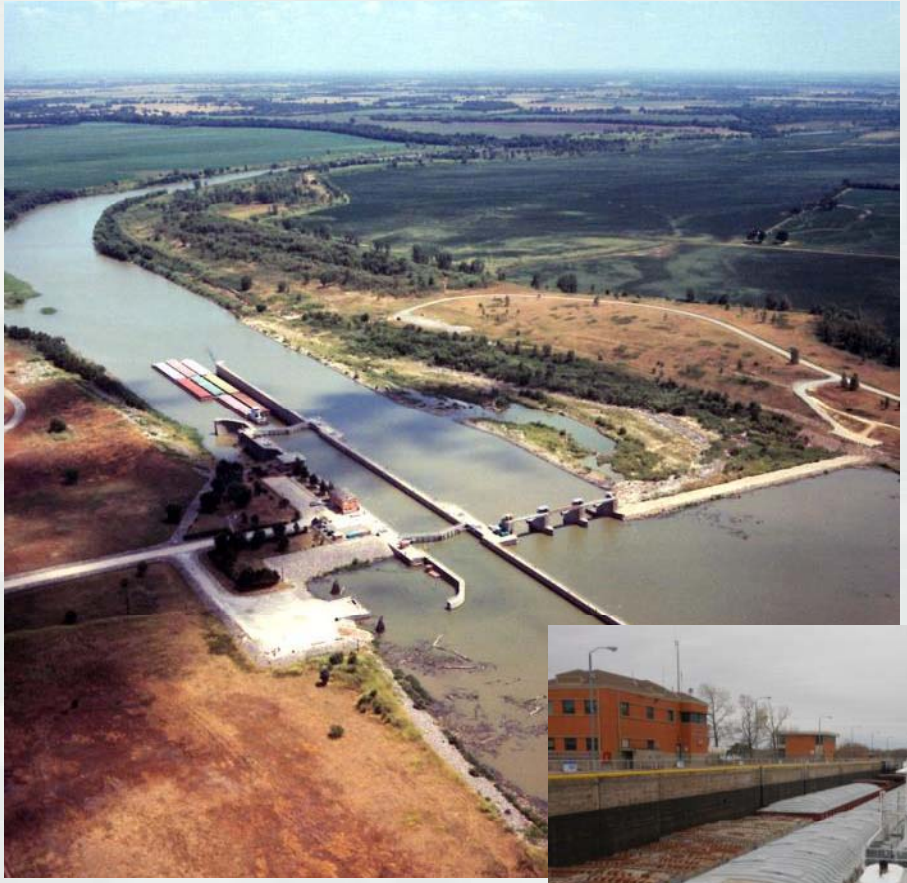
Key Results of Laboratory Testing

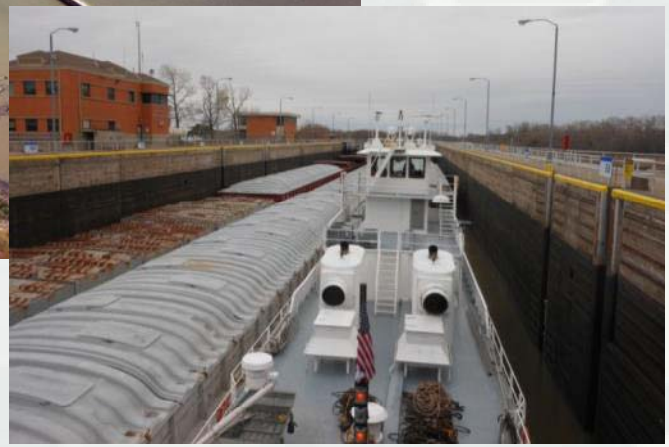
- Portland cement-based grouts:
  - Failure occurred at approximately 130 kips with extensive spalling of the repair material.
- Ultra-high performance concrete:
  - Increase in load carrying capacity to 200 kips (a 50% increase).
  - **NO** spalling or repair with presence of steel fiber reinforcement.
  - Samples without surface affixed steel armor plate exhibited similar load carrying capacities.
- Rapid repair materials:
  - Strengths similar to portland cement-based grout.
  - Removes logistic constraints for repair!

Without steel fiber reinforcement.

With steel fiber reinforcement.

Newt Graham Lock and Dam

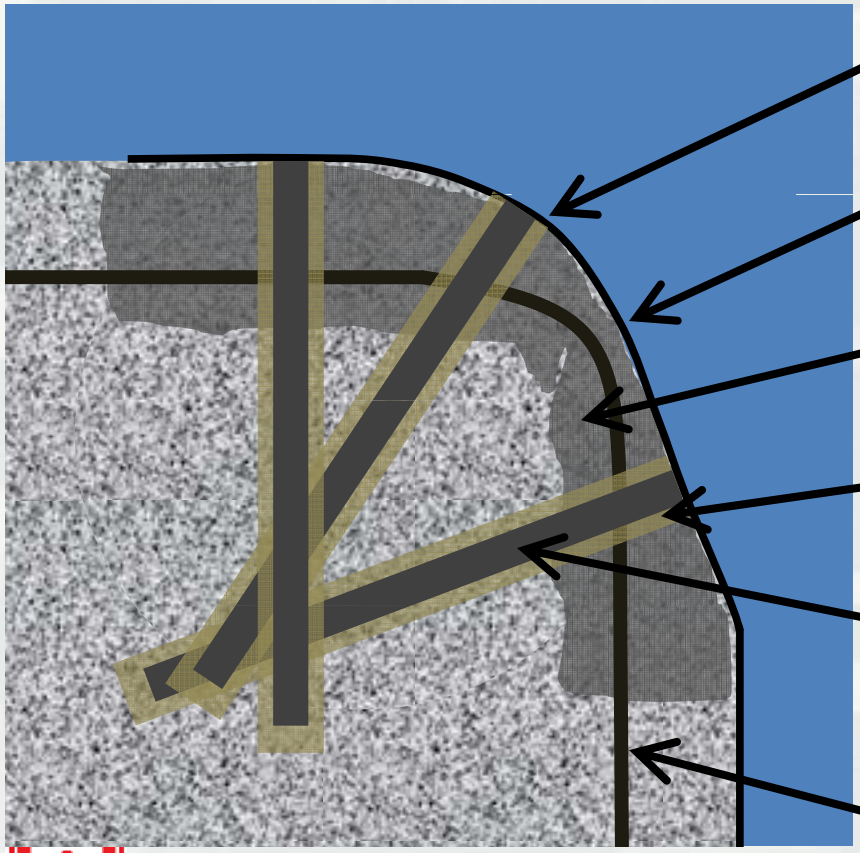




- Located on Verdigris River
- East of Tulsa, OK
- 1,630 ft. long
- Combined earthfill and concrete gravity dam
- Single-lift lock chamber
  - 110-ft by 600-ft long
  - 21-foot lift

Concepts for Repair

- Example concept for repair of wall armor systems that incorporates sloped approach to wall recess.



Armor

Gradual slope

Repair Grout

Epoxy-Filled Drill Hole

Steel Anchor Rod
Welded to Armor Plate

Rebar

From the Lab → to the Field

Field demonstration project using ultra-high performance concrete and other repair materials:

- Conducted at Newt Graham Lock and Dam.
- Project completed with assistance of USACE Tulsa District OCT 2013.

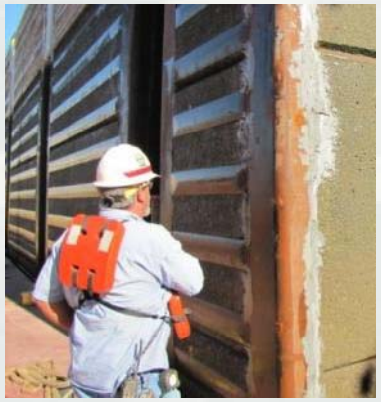
Newt Graham Lock and Dam near Tulsa, OK, USA.

Armor plate damage at Newt Graham Lock and Dam

From the Lab → to the Field

Demonstration of materials for armoring component repair:

- Ultra-high performance concrete
- Rapid repair materials
- Polymer-modified grouts
- Extended two-part epoxy
- Portland cement-based grout
- A test bed for repair materials…



Repair cavity prior to placement

Placement of UHPC

Consolidation via external vibration

Completed UHPC repair

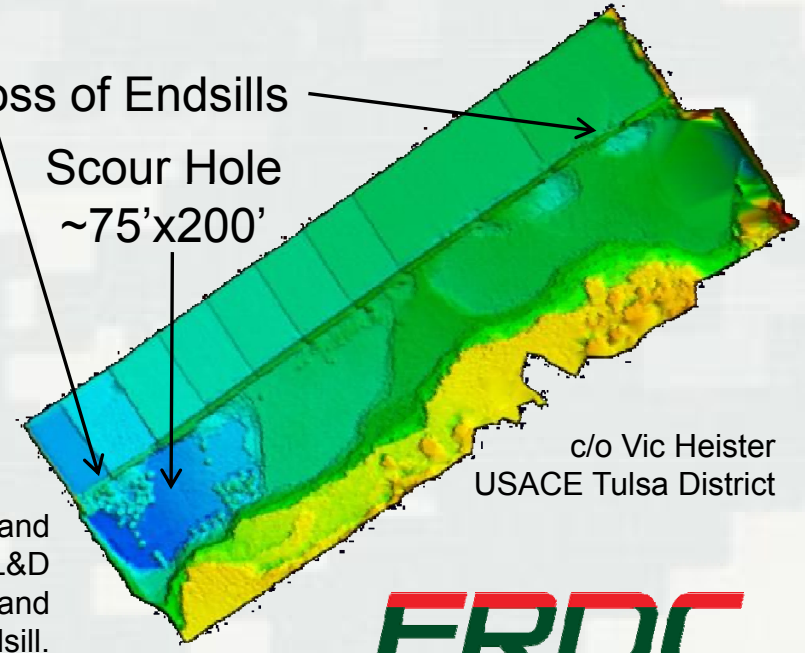
Future Focus: Underwater Repair/Retrofit

Novel materials for rapid underwater concrete repairs:

- Widespread issues with underwater scour / erosion / abrasion / impact / cavitation damage of concrete in USACE civil works structures.
- Dewatering for repair typically >$1-$10MIL and conducted along with other maintenance at 5+ yr periodic de-watering cycle.
- Can we use **UHPC** to improve the performance of these systems?

Requirements:

- Material with extremely high impact toughness (e.g., debris impact).
- Material with extremely high abrasion resistance.
- Potential for precast retrofit system.



c/o Vic Heister
USACE Tulsa District

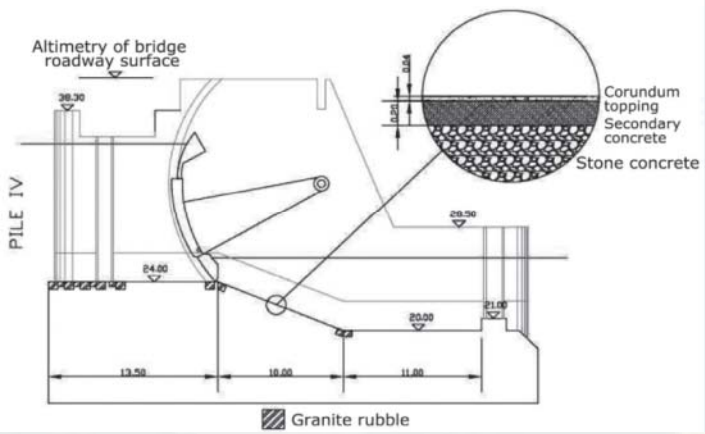
3D sonar scan of stilling basin and downstream riverbed at Webbers Falls L&D (Tulsa District) with extensive scour and erosion of stilling basin and endsill.

Underwater Repair/Retrofit – Feasibility has been Demonstrated!

Field demonstration by Lafarge of UHPC for repair of stilling basin / spillway in dam:

- Area of structure subjected to significant abrasion from high velocity debris-rich flows.

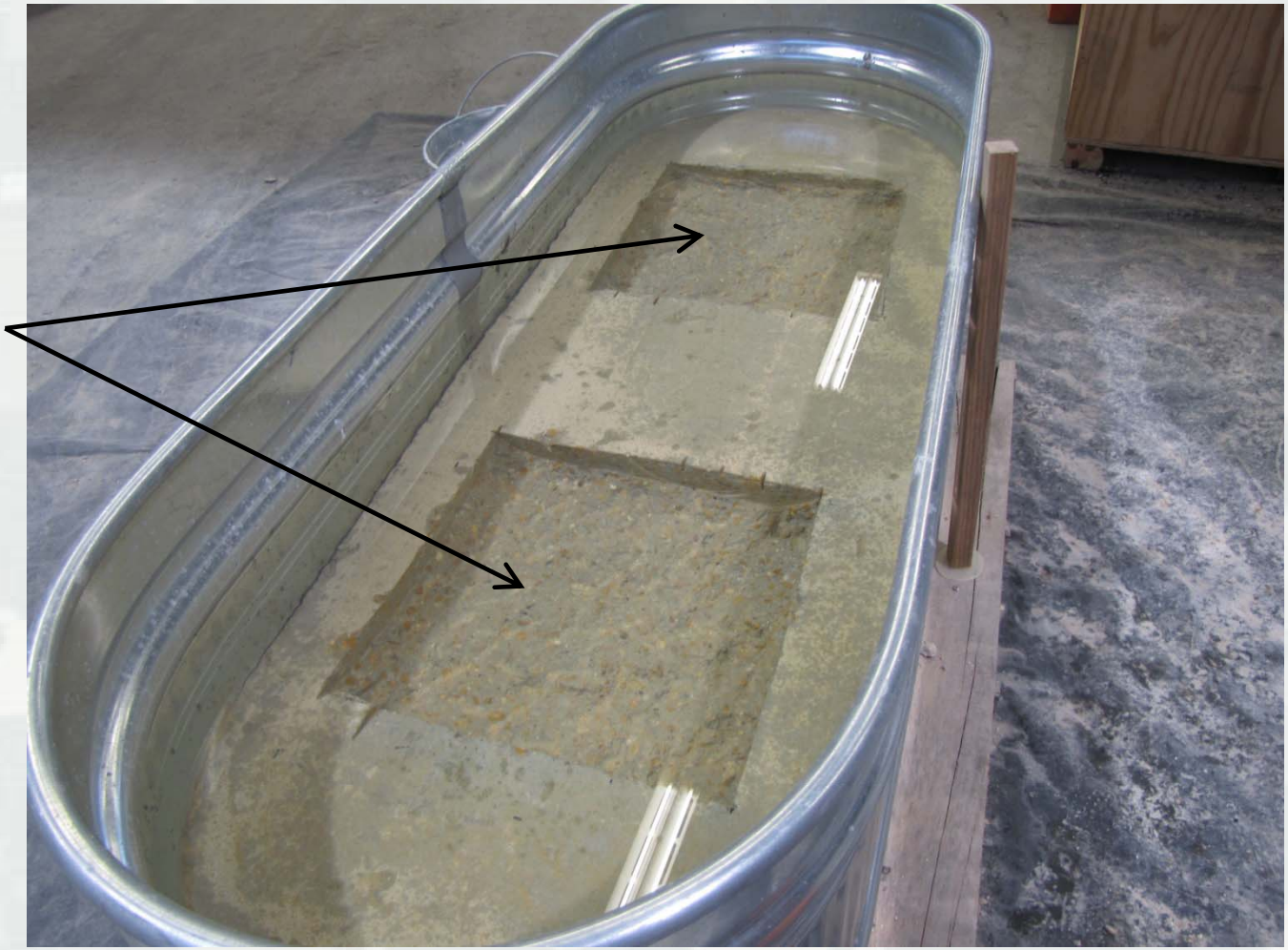
Thanks to Gaston Doiron of Lafarge for this information.



Details on spillway retrofit.

Tubs before underwater placement

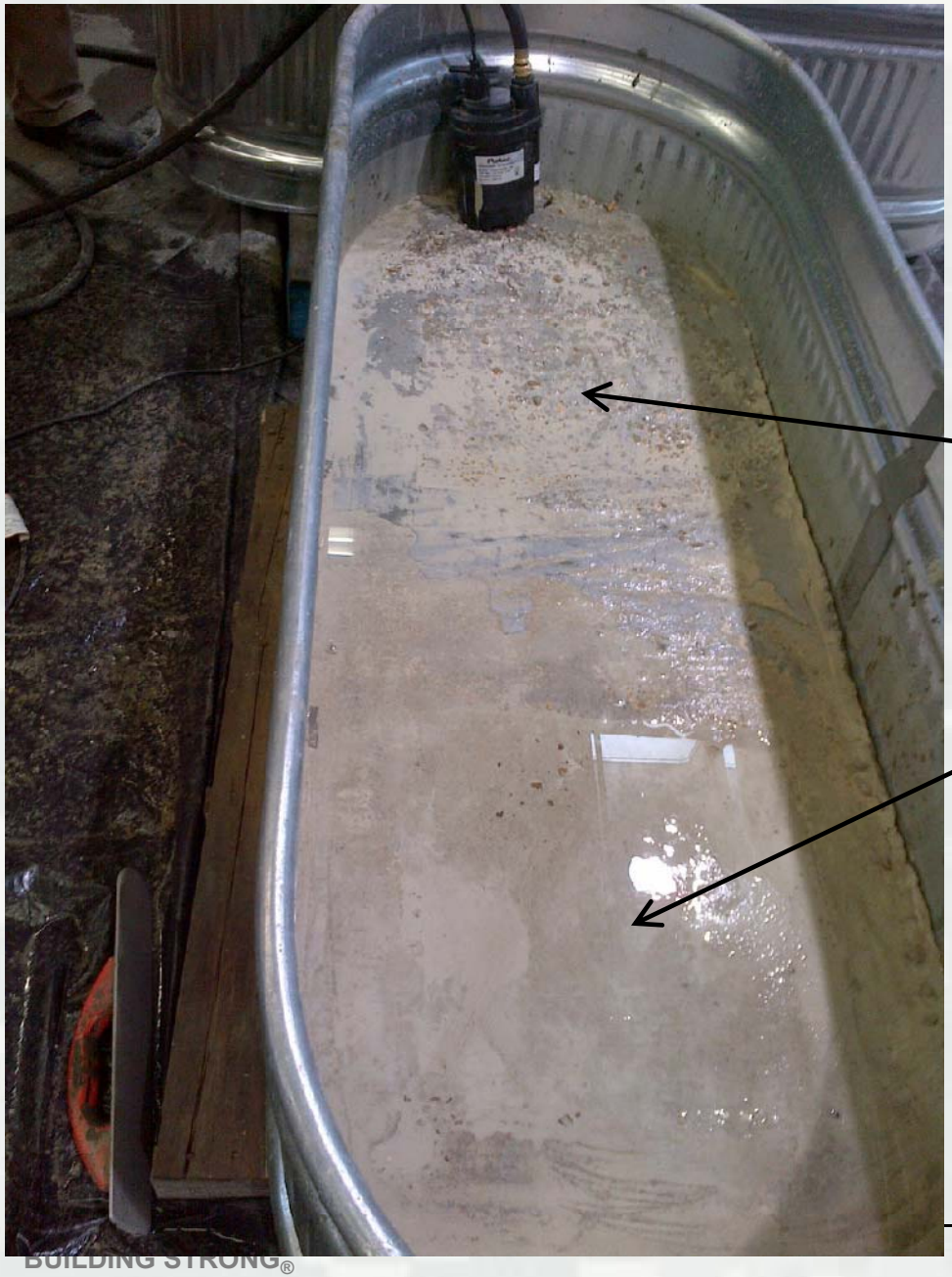
Underwater Repair Cavities



Placements

Moving Water Placement

Stagnant Water Placement Using Tremie Pipe



Placement in Stagnant Water

Portland Cement-Based Concrete Repair

Rapid Repair Material

Good quality repair with adequate infilling of the repair cavity and no evidence of shrinkage cracking and debonding from repair cavity.

Placement in Moving Water

Portland Cement-Based Concrete Repair

Rapid Repair Material

Additional washout with moving water. Washout still minimal with rapid setting material as the quick set time minimized exposure to moving water.

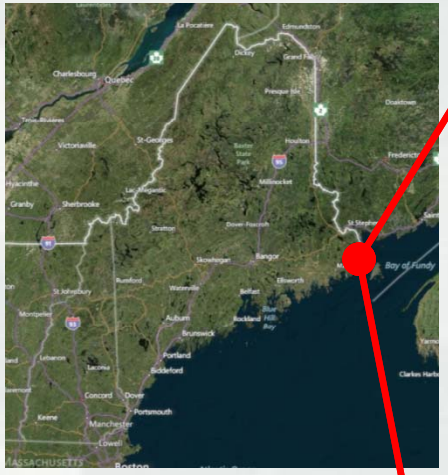
Placement in Moving Water

Planning for additional laboratory work in FY15 and field demonstrations that coupling underwater imaging techniques and underwater rapid repair materials…

Rapid Repair Material

Additional washout with moving water. Washout still minimal with rapid setting material as the quick set time minimized exposure to moving water.

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.

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…

Treat Island Natural Weathering Station – Recent Changes

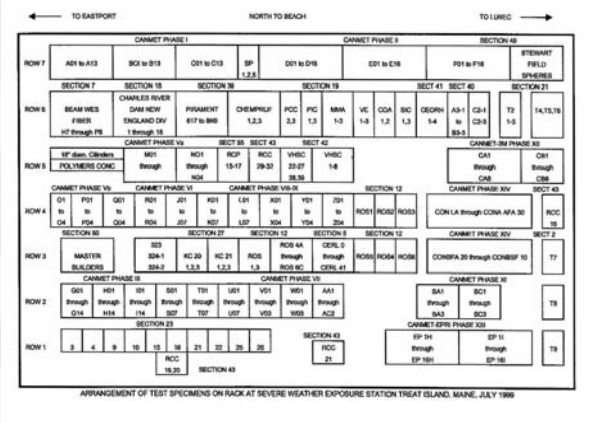
- Previously supported by USACE HQ with multiple collaborations with industry, government, and academia.
- Change in long-term funding lines in mid 2000s.
- Resulting lack of funding and supposed mission relevance lead to disrepair and lack of monitoring.

Treat Island Natural Weathering Station – Facility Upgrades FY13/14

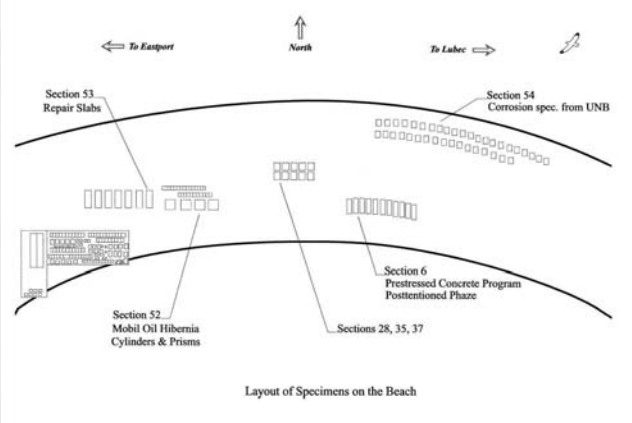
- New funding obtained in 2013 to support facility upgrades and new research.
- Repairs to pier and approach stairways
- Upgrades to storage bldg.
- Shifting specimens to new portion of mid-tide wharf.
- Preparations for upgrade(s) to mid-tide wharf.

Ongoing Research Projects

- Historical specimens from various USACE projects
- UNB specimens
- FHWA – ASR
- Many others…



Previous specimen map for mid-tide wharf.



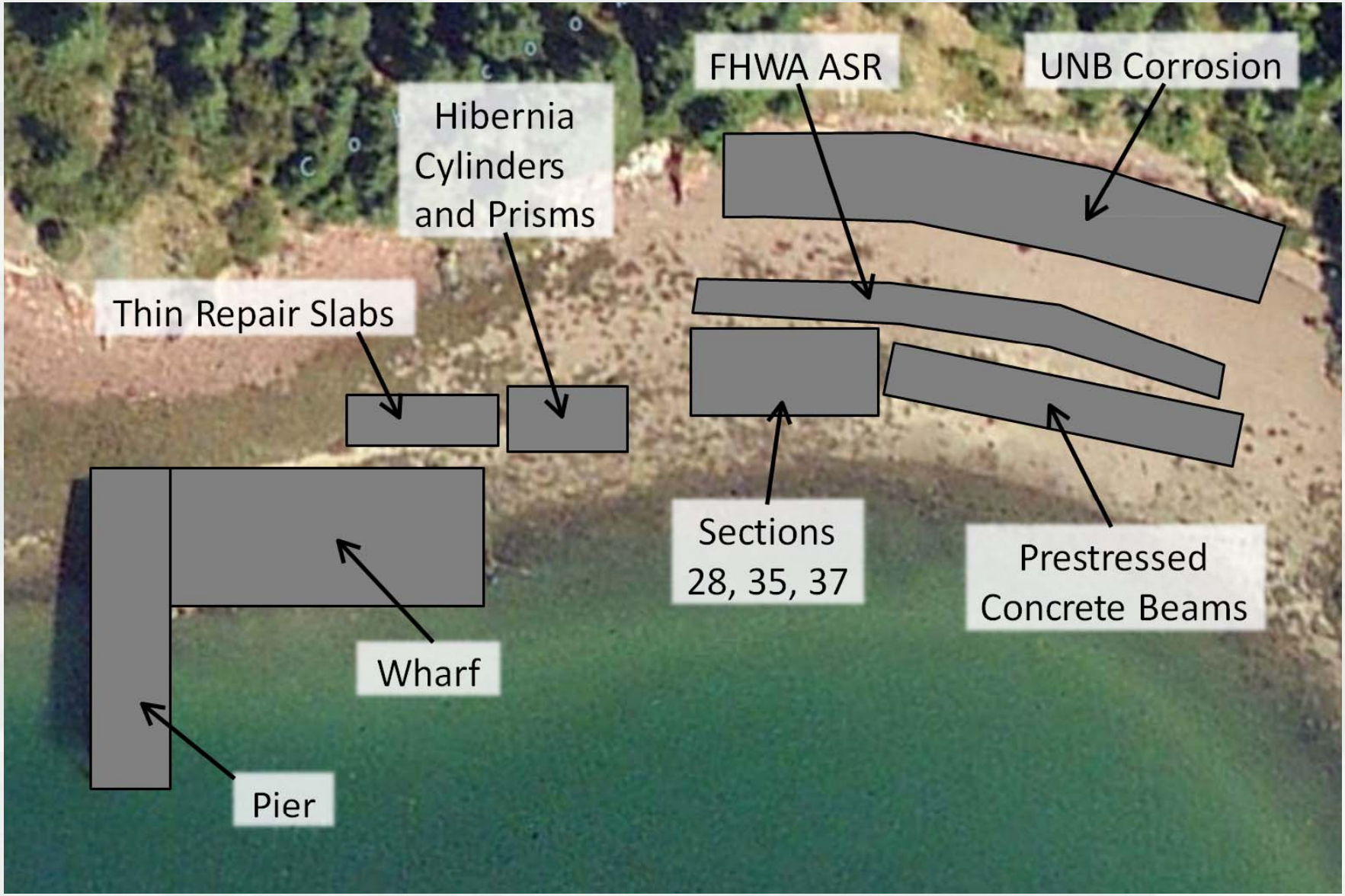
Previous specimen map for beach area.

PROGRAMS

Arrangement of Specimens on Exposure Rack	
Dickey Lincoln Dam (New England Division)	Rack - Row 6 Section 21
Lock Wall Repair Durability Program (REMR)	Rack - Row 1 Section 23
Kansas City District Aggregate Program	Rack - Row 3 Section 27
Master Builders, Scaling, Corrosion Inhibitors and Concrete Freezing and Thawing Resistance	Rack - Row 3 Section 50
CRREL/VTT Cooperative Study of Durability of High-Strength Concrete	Rack - Row 6 Section 40
Winfield Lock and Dam Freezing/Thawing Beams	Rack - Row 6 Section 41
Specimen Size - Frost Effects Investigation	Rack - Rows 3 and 4 Section 12
Construction Engineering Research Laboratory Fibrous Concrete	Rack - Row 3 Section 5
Waterways Experiment Station Fibrous Concrete	Rack - Row 6 Section 7
Concrete-Polymer Materials	Rack - Row 6 Section 19
CPAR - Modified Sulfur Concrete (Chempruf)	Rack - Row 6 Section 39
CPAR - High-Performance Blended-Cement System (Pyrament)	Rack - Row 6 Section 39
Charles River Dam - Smelt Brook Location Protection Project	Rack - Row 6 Section 18
Reactive Powder Concrete (RPC) in a Marine Environment	Rack - Row 5 Section 55
Roller-Compacted Concrete (RCC)	Rack - Rows 1, 4, 5 Section 43
Very High-Strength Concrete (VHSC)	Rack - Row 5 Section 42
Stewart Field Spheres	Rack - Row 7 Section 49
Natural Resources Canada - Durability of Concrete in Marine Environment	Rack - See Rack Map
Layout of Test Specimens on Beach	
Prestressed Concrete Program - Posttensioned Phase	Beach - Half-Tide Level Section 6
Quality Aggregate Investigation	Beach - Half-Tide Level Section 35
Maximum Size of Coarse Aggregate Program	Beach - Half-Tide Level Section 37
ExxonMobil - Hibernia Reference Cubes and Cylinders	Beach - Half-Tide Level Section 52
Thin Repair Concrete Slabs	Beach - Half-Tide Level Section 53
UNB Corrosion of Steel in Concrete	Beach - High-Tide Level Section 54

Home | Programs | Rack Maps | Keywords

Current Site Plan



An Example Projects

- Studies on Ultra-High Performance Concretes

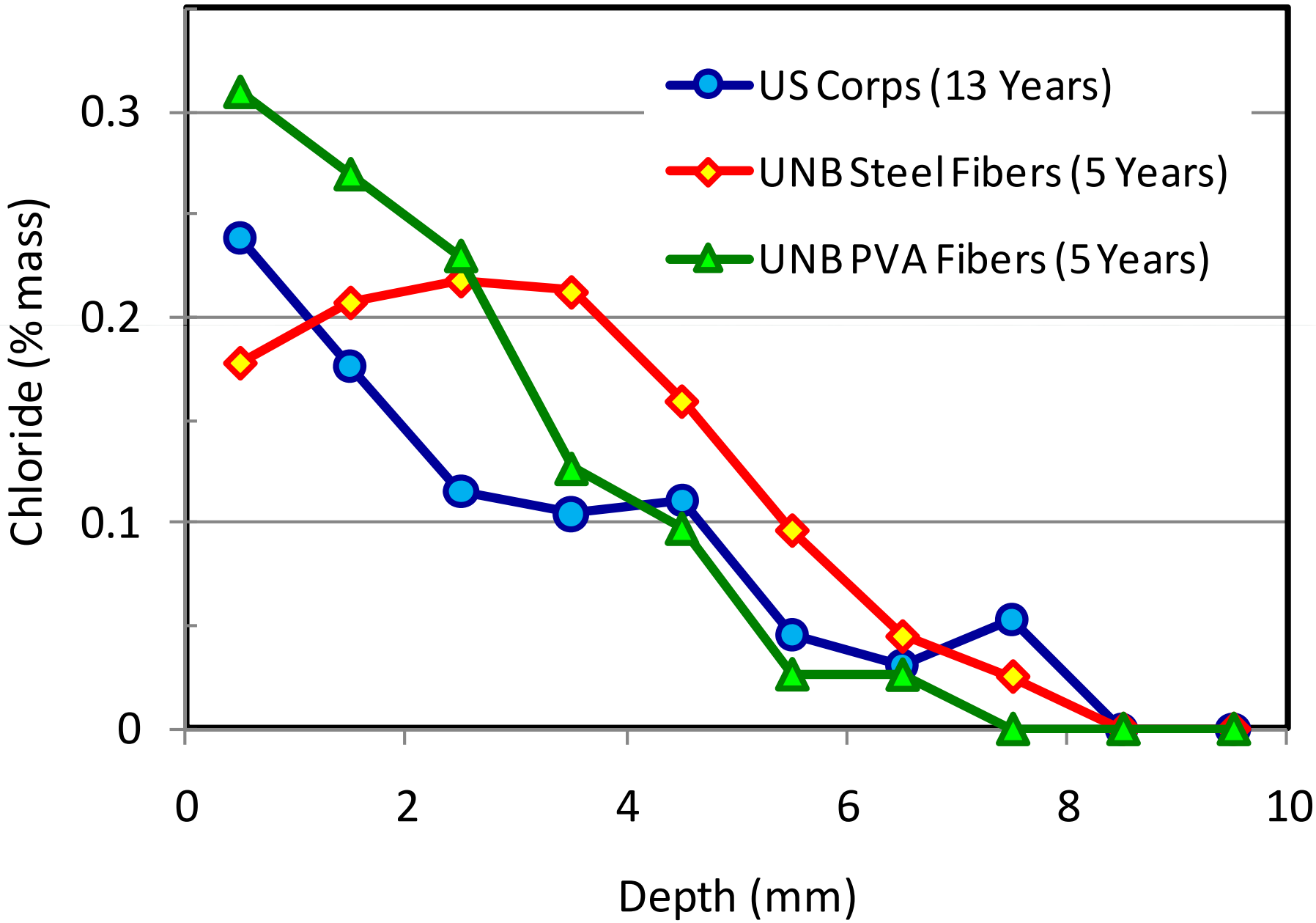
- In 2006 – Rebar at 10-mm (3/8-inch) cover removed from one of the 10-year-old beams (# 960017)
- This same specimen was retrieved for coring and testing at UNB in 2009
- Remaining specimens moved to high-tide level to ensure sufficient oxygen for corrosion

Three beams (6 x 6 x 21 in.)

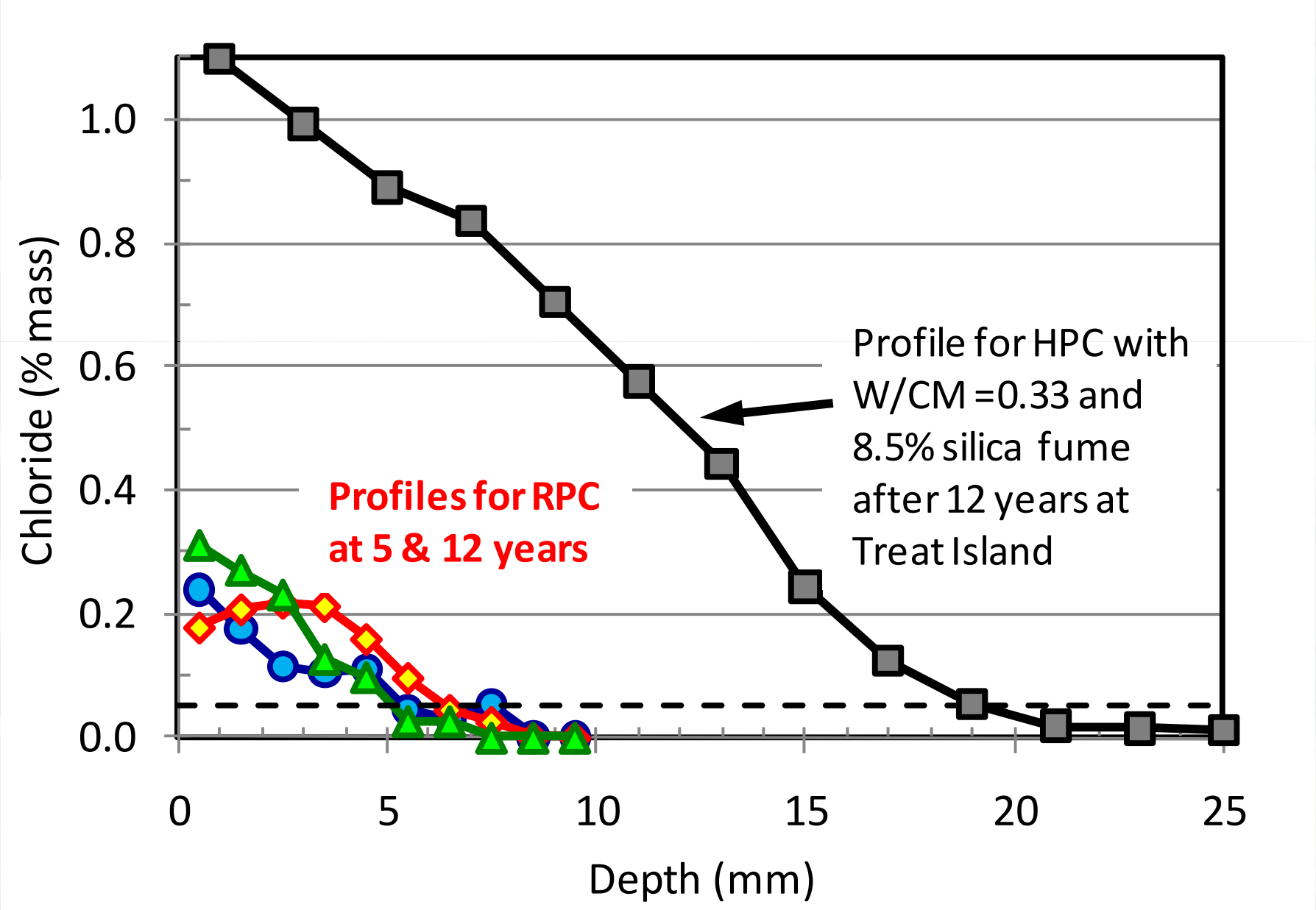
960015 – 25 mm cover
960016 – 19 mm cover
960017 – 10 mm cover

Cover over #4 (13 mm) steel rebar

Chloride Permeability of UHPCs



Chloride Profiles: RPC versus HPC

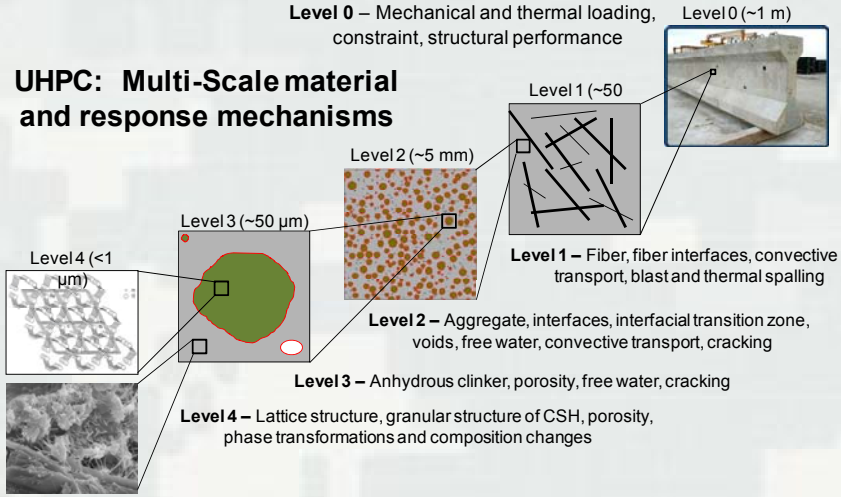


New Research Initiated in 2013 on Emerging Materials

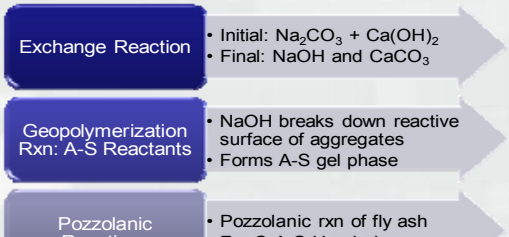
- Field exposure specimens of eight materials placed: UHPCs, geopolymer concrete, rapid repair materials, and OPC control.

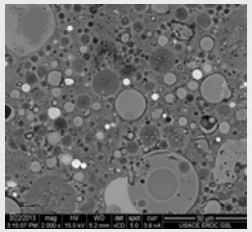
Materials for Rapid Repair of Infrastructure

Ultra-High Performance Concrete



Geopolymer Concrete





Soil solidified with alkali-activated mixture using slag

New Research Initiated in 2013 on Emerging Materials

Photographs after one year of exposure

UHPC – Cor-Tuf®

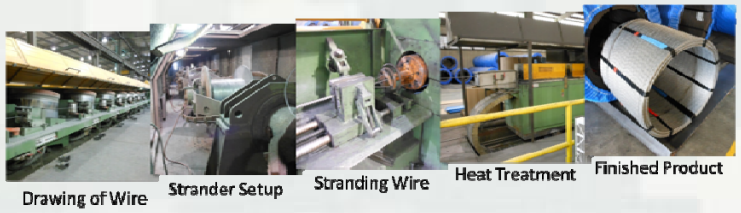
Rapid Hardening Concrete Material

Slag Based Geopolymer

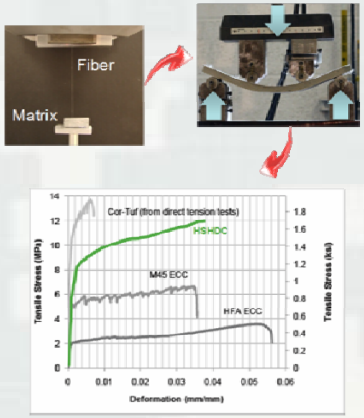
New Research Initiated in 2014 on Emerging Materials

- New series of samples exposed.
- Stainless steel prestressing strand (2205 and 2304)
- Enamel coated reinforcing steel
- High-strength high-ductility concrete for military applications
- High-strength lightweight concrete for offshore wind platforms
- Along with control samples for each material type

Corrosion-Resistant Prestressing Steels



High Strength, High Ductility Concrete



- HSHDC
- Engineered Cementitious Composite (ECC) designed to maximize energy dissipation from weapons effects in protective construction.
- Revolutionary Ultra High Performance Concrete (UHPC) with very high strength and ductility
- Extreme resiliency to severe loading conditions due to:
  - Strength ~ 7x conventional concrete
  - Ductility ~5-10x other UHPC's
  - Strain hardening response

Future R&D Work at Treat Island

- Repair Materials:
  - Continue studies on repair materials for extreme environments
  - Rapid repair materials
  - Additives for repair materials including new shrinkage reducing admixtures, novel fiber reinforcement
- Green Binders:
  - Alkali-activated cements
  - Rapid hardening cements (CSA, CAC, others)
  - Belite cements
  - Carbonating cement systems for CO_2 binding
- Other R&D Needs:
  - Influence of milling / profiling of concrete on durability
  - Durability of concrete with hydration control admixtures

Collaboration Opportunities

- Cooperative R&D Agreements (CRADAs) for producers, consultants, other R&D laboratories and Educational Partnership Agreements (EPAs) for academic institutions are available to collaborate on work at Treat Island.

- Please contact Dr. Robert Moser (ERDC-GSL) (robert.d.moser@usace.army.mil) for inquiries.

Horizontal Concrete Repair Materials

- 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 scour and erosion in underwater locations.
- Products: survey of field performance of test slabs at Treat Island and Rock Island District L&Ds, research on novel shrinkage reducing admixtures, Technical Report in review.
- Collaborators: USACE St. Paul District, Rock Island District (INDC), Omaha District, and U.S. Bureau of Reclamation Technical Service Center.

FY14 Completed Products

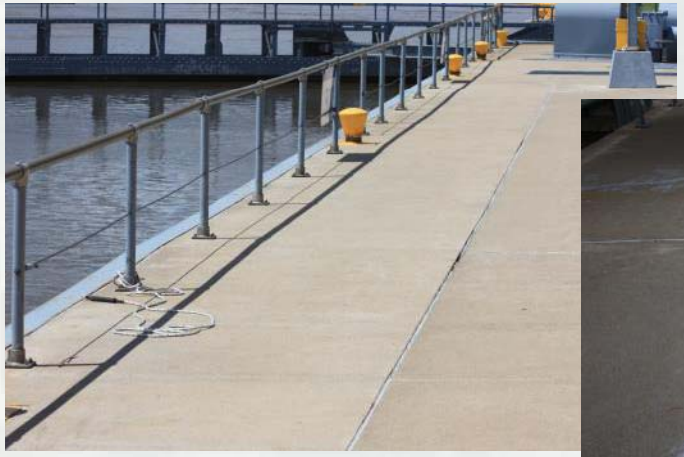
- Forensic investigation of “thin repair” slabs at the Treat Island Natural Weathering Station:
  - Ten horizontal concrete repair slabs placed during REMR program in mid 90s.
  - Field durability testing of variety of repair materials.
  - Petrographic analysis of the concrete and chloride permeability testing.
  - Providing guidance for current repair material selections.
- Site visits and inspections of District repair projects:
  - St. Paul District horizontal concrete repair projects.
  - Rock Island District horizontal concrete repair projects that include different bonding conditions, concrete types, and fiber reinforcement.
  - Literature review and report prepared based on field inspection and review of periodic inspection reports to assess repair material performance.
- Technical Report currently in review:
  - Results of Treat Island durability study
  - Results of literature review of other horizontal concrete repair materials and placement techniques.
- Coordination with external collaborators (e.g., USBR and Districts)

FY14 Activities: Field Investigations

- 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.

FY14 Activities: Field Investigations

- 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.

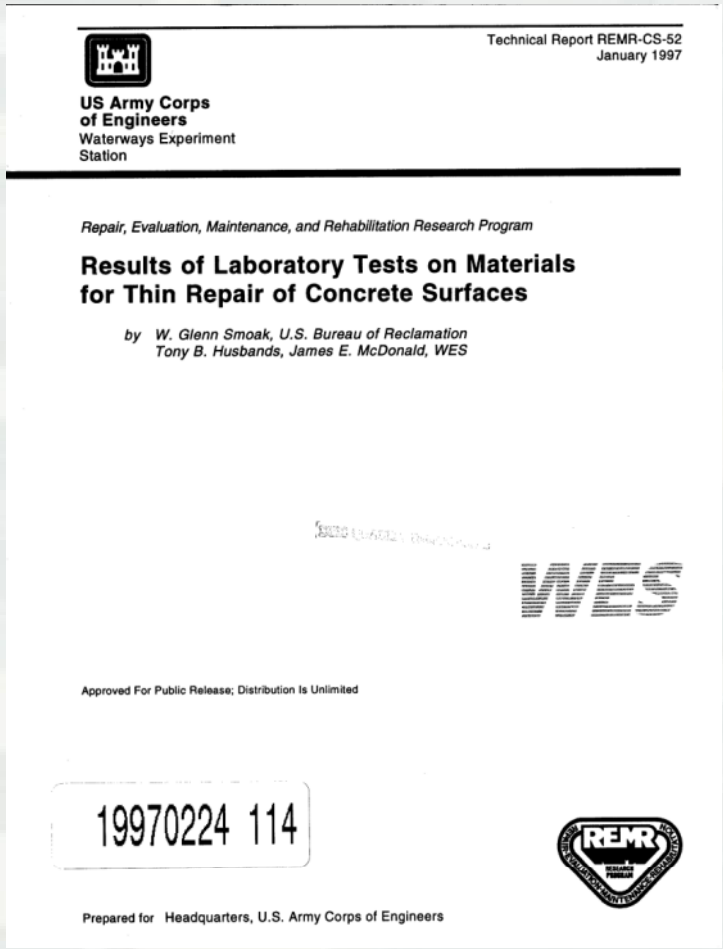


Treat Island REMR "Thin Repair" Slabs

- 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.

Treat Island Facility

REMR Thin Repair Slabs



Technical Report REMR-CS-52
January 1997

US Army Corps of Engineers
Waterways Experiment Station

Repair, Evaluation, Maintenance, and Rehabilitation Research Program

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

by W. Glenn Smoak, U.S. Bureau of Reclamation
Tony B. Husbands, James E. McDonald, WES

WES

Approved For Public Release; Distribution Is Unlimited

19970224 114

Prepared for Headquarters, U.S. Army Corps of Engineers

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

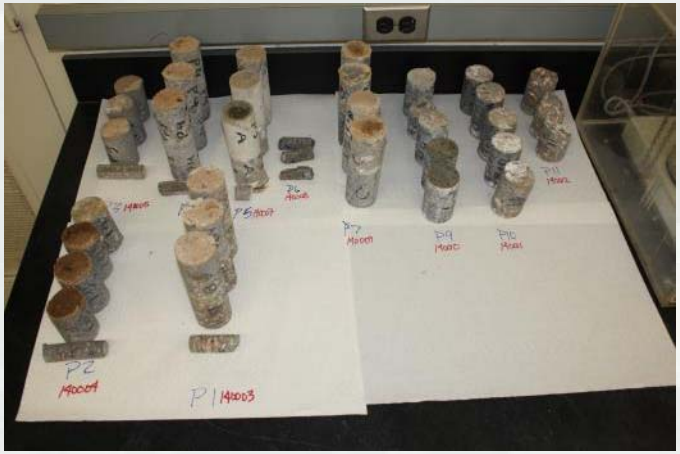
Field and Laboratory Investigations

- 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

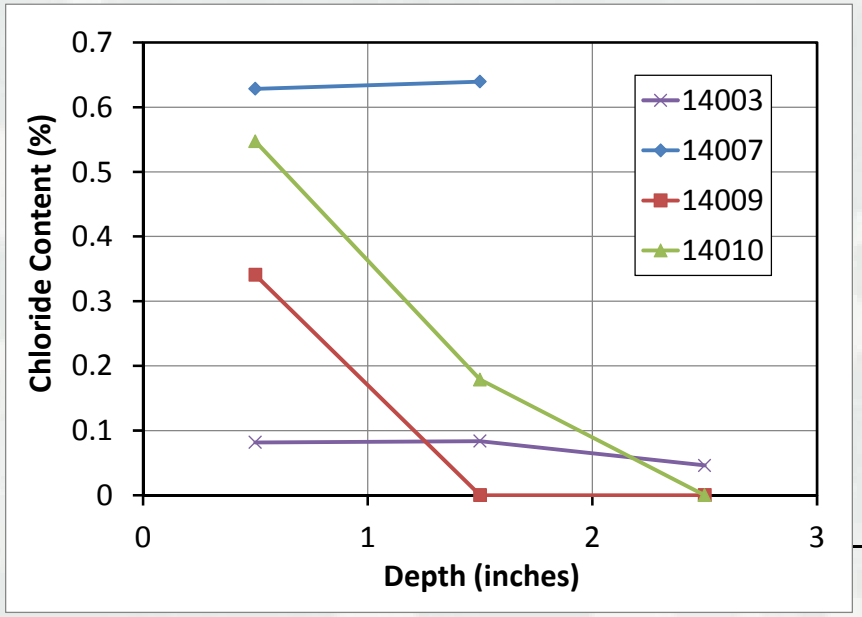
Results of Laboratory Investigation

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:

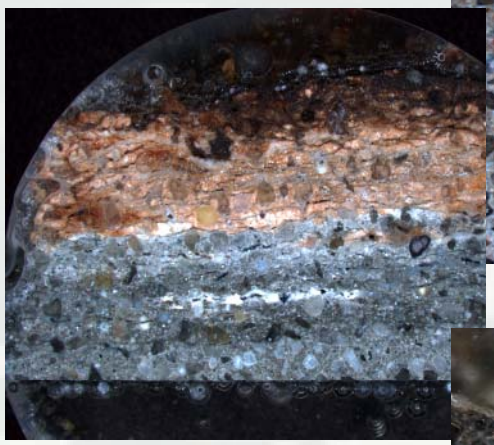
- Polymer modified and higher strength materials exhibited reduced chloride penetration at cover depths.

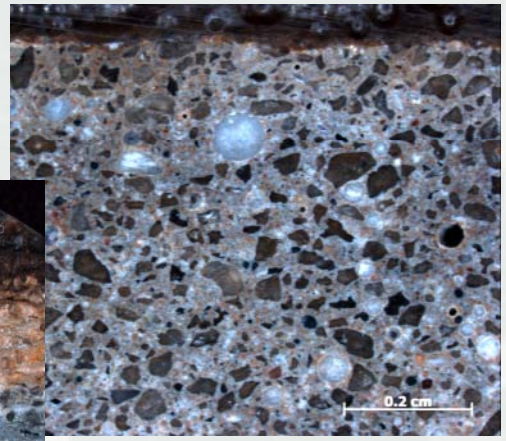


Microstructural Characterization:

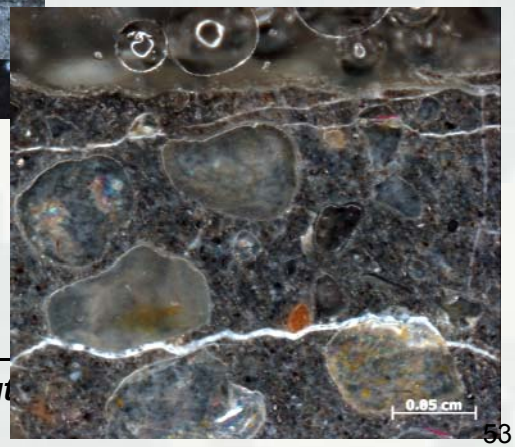
- Petrographic analysis was conducted on samples prepared from three depths of the slabs: top, middle, and bottom.
- Total of 33 samples analyzed.

Surface scaling / chemical attack.





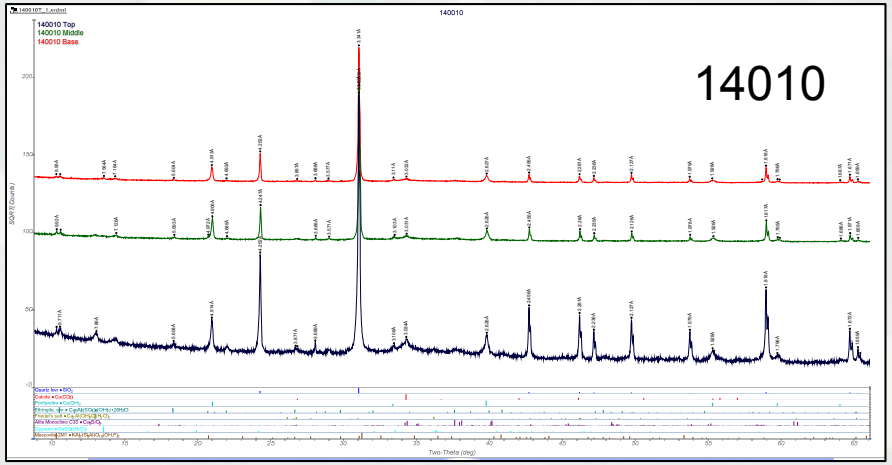
Near-surface delaminations and microcracks

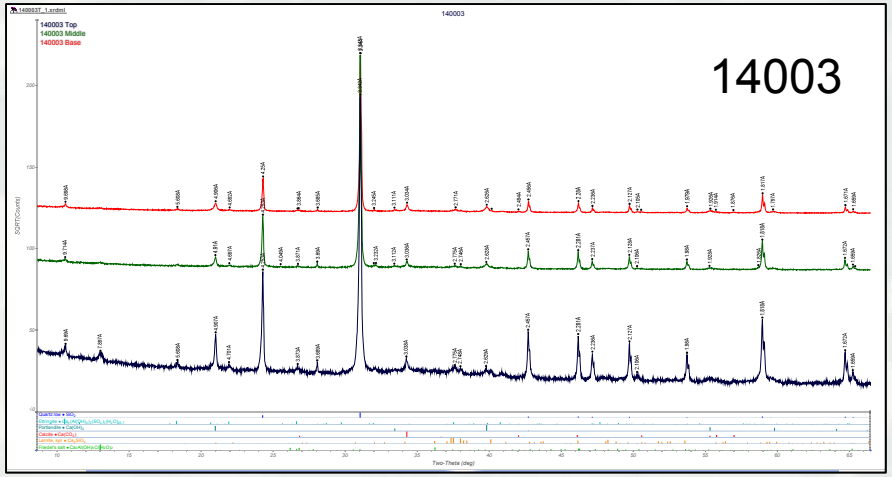


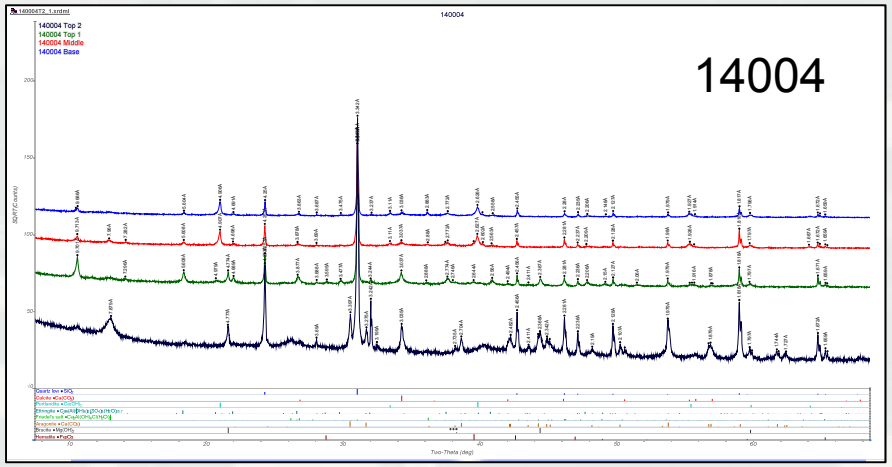
Results of Laboratory Investigation

Mineralogical Characterization:

- Samples from the top, middle, and bottom of the slabs were analyzed using quantitative X-ray diffraction.
- Anticipated phases were observed in each sample and no strange phases were observed related to deterioration.
- Exposure related phase observed was Friedel's salt near the surface.





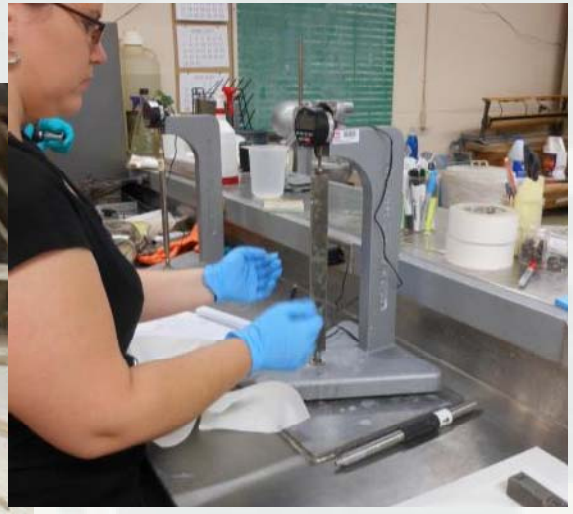


Material Selections and Testing

- 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.
  - Polymeric fiber reinforcement (polypropylene fibers).
  - Internal curing with lightweight aggregates.

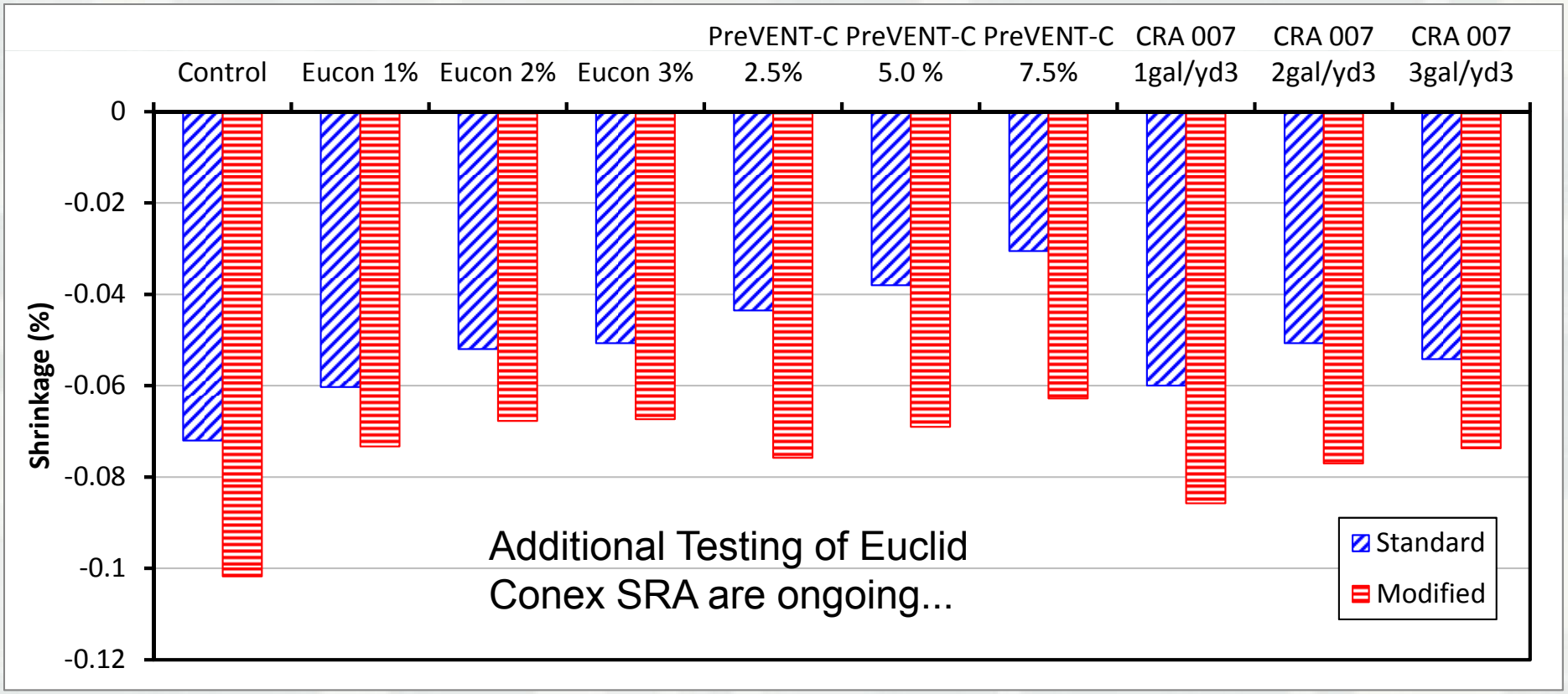
Shrinkage Reduction Studies

- 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



Shrinkage Reduction Studies

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



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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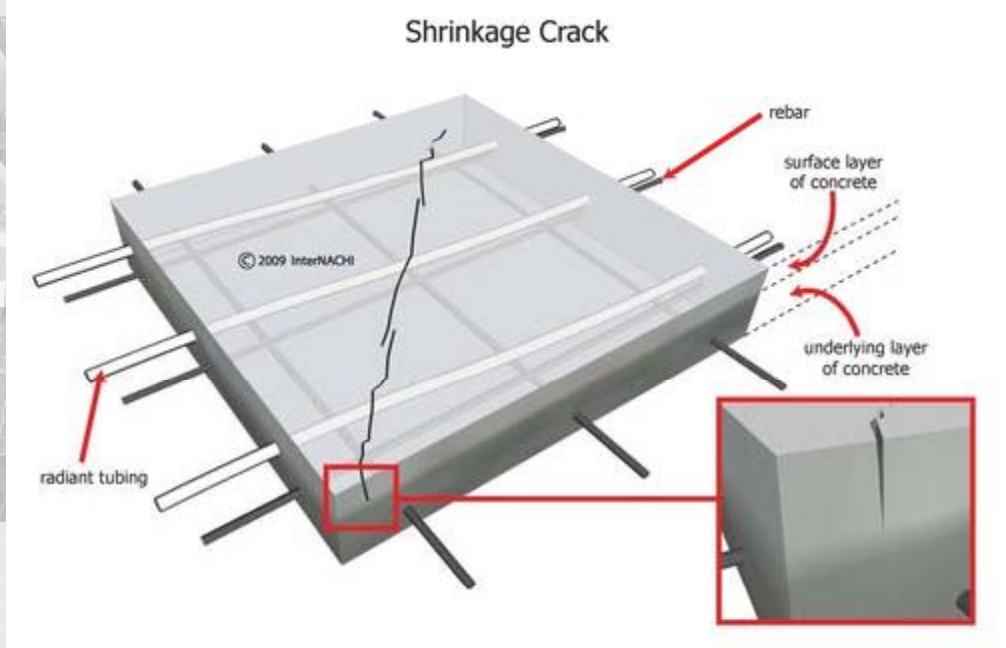

FY15 Proposed Activities

- 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)

Thank you!

Questions?

For questions:
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