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Innovative Materials for Repair and Retrofit of Civil Works Infrastructure

Lock Maintenance Workshop – 11 FEB 2014

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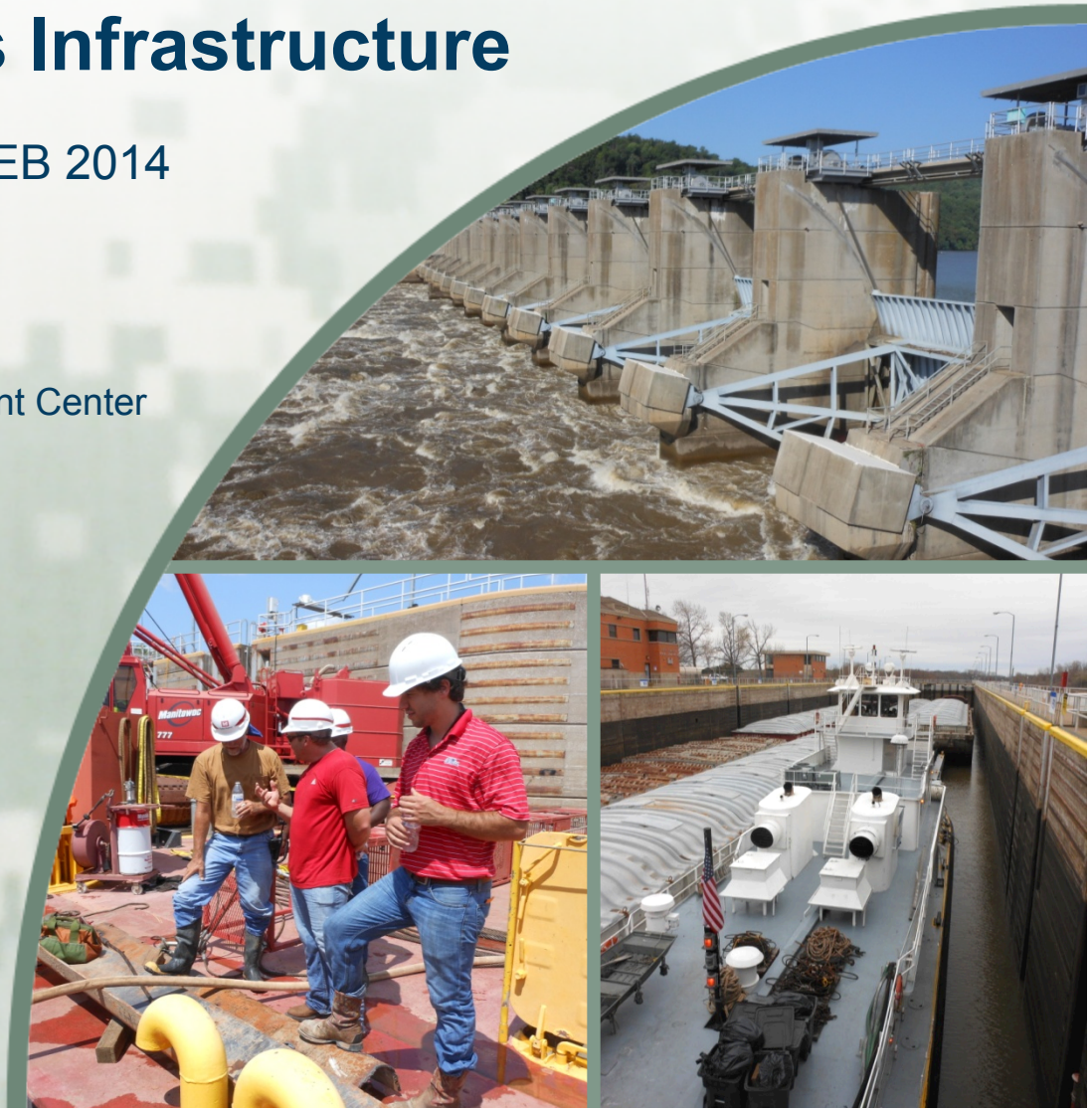

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Introduction

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.

Innovative 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:

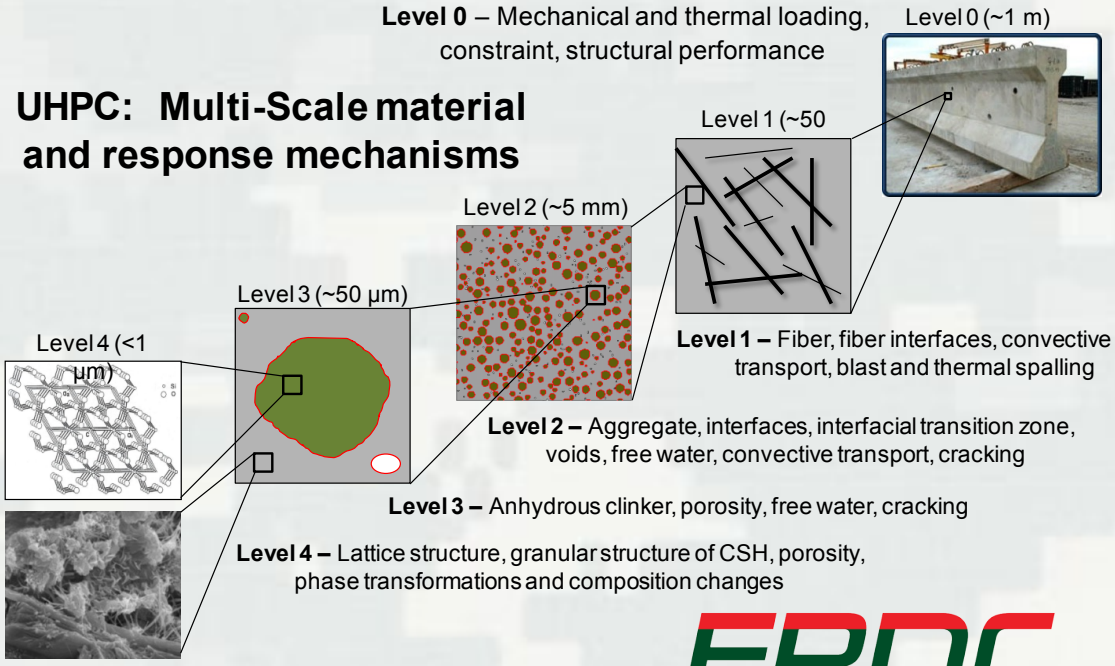
- Ultra-high performance concretes
- Rapid concrete repair materials
- Many others… advanced coatings, advanced polymeric and metallic materials, self-sensing materials for structural health monitoring…

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

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

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

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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

	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
For Official Use Only	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		
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ERDC

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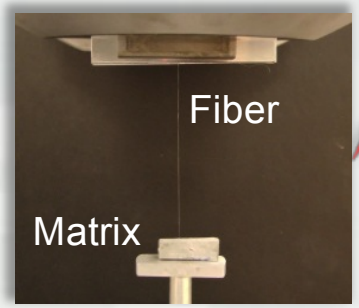
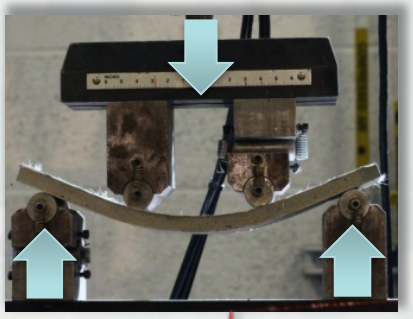
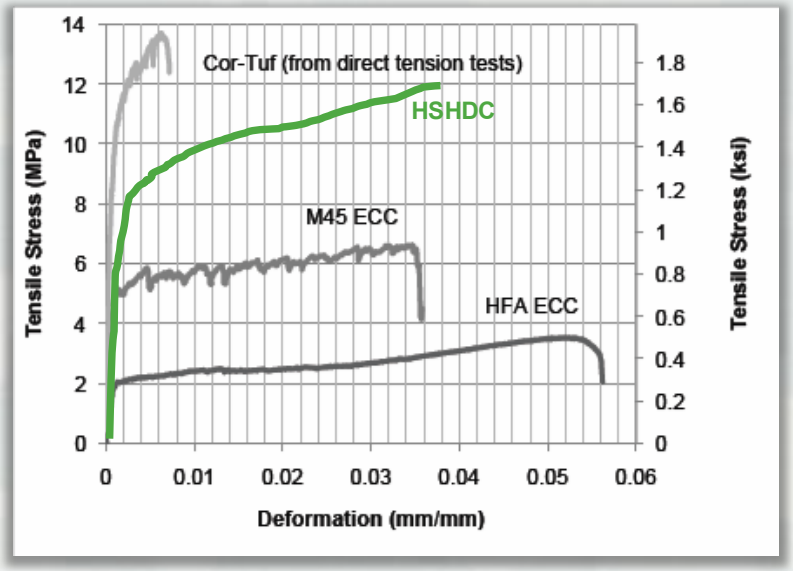






- HSHDC – Bendable concrete!
- Engineered Cementitious Composite (ECC) designed to maximize energy dissipation from weapons effects in protective construction.
- Revolutionary Ultra High Performance Concrete (UHPC) with very high strength and ductility
- Extreme resiliency to severe loading conditions 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 ®

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

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

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 SEP 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

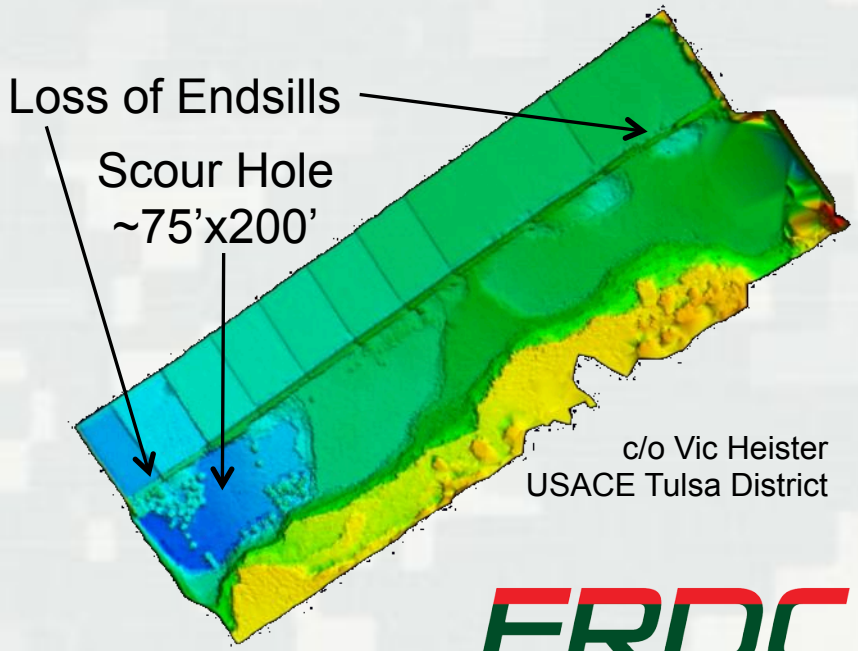
Future Focus: Underwater Repair/Retrofit

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 **novel materials** to improve the performance and durability 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.

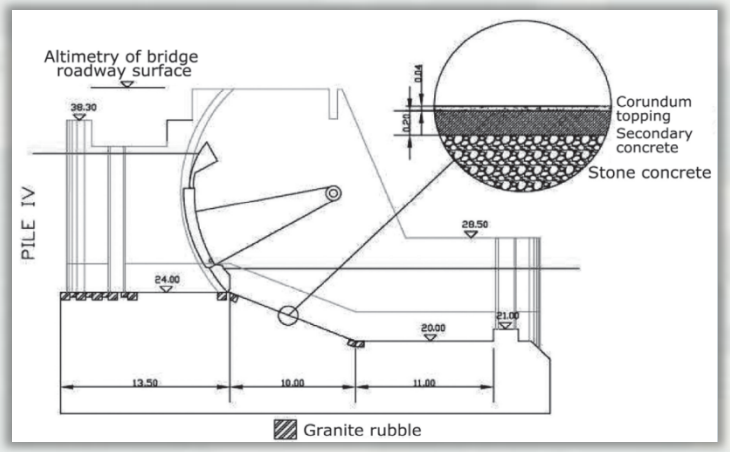


Underwater Repair/Retrofit – Feasibility has been Demonstrated!

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.

Summary

Can we leverage materials R&D to answer CW problems?

- Unique properties: high strength, high toughness, high stiffness, and, more recently investigated, high durability.
- Many applications under investigation for novel materials in USACE infrastructure, including Civil Works infrastructure.
- Extreme environments (sub zero to arid austere conditions)
- Standardized protocols for evaluation of material properties
- Many applications for military and civilian infrastructure.

Costs are high → but feasible for critical applications:

- Benefits often times far outweigh costs over long-term!
- Future work on retrofit of underwater repair applications.

NavSys: Concrete Repair Materials

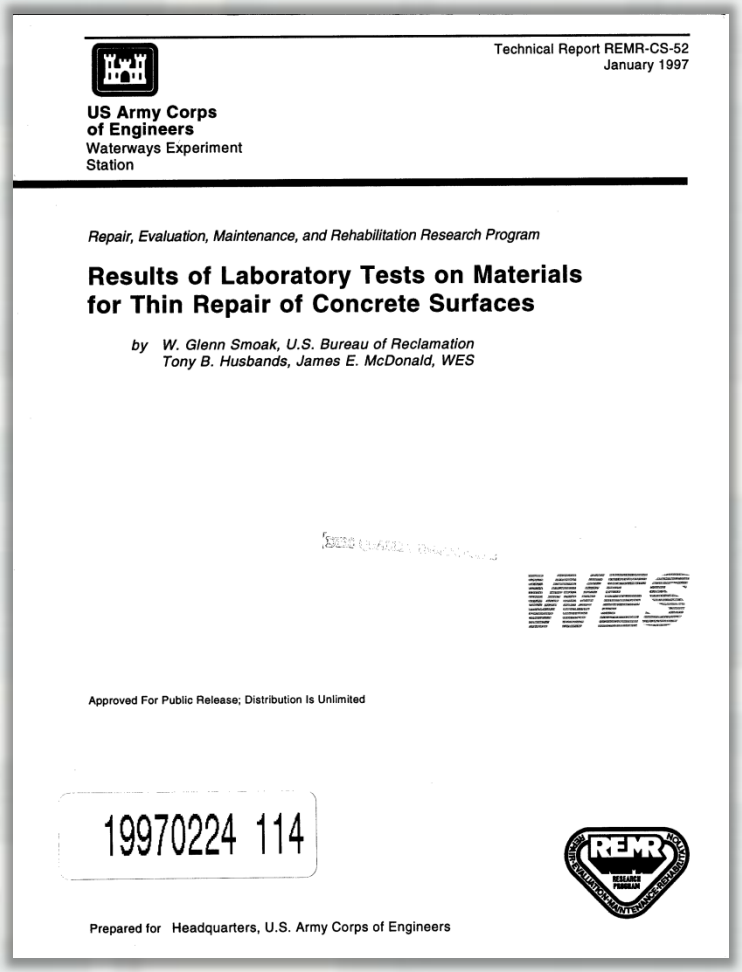
- Horizontal concrete surfaces of USACE navigation structures are subjected to significant weathering and deterioration that can result in spalling, scaling, and increased surface roughness along with scour and erosion in underwater locations.
- Evaluate existing guidance and follow-up on research initiated by REMR but not completed on repair materials.
- Develop standardized protocols to evaluate materials including structural performance and long-term durability.
- Calibrate protocols using various repair materials to consider relevant properties: set times, strength gain, shrinkage, freeze/thaw, abrasion, chloride permeability, etc.
- Develop and revise existing guidance related to concrete repair materials.
- Identify modifications to use in underwater applications.

Long-Term Durability of Repair Mats.

- Site visit to Treat Island Natural Weathering Station to assess condition of repair slabs placed in 1995.
- Eleven slabs fabricated with different repair materials: polymer modified, shrinkage reducing admixtures, rapid repair materials, alternative cements, etc…
- Not studied since completion of REMR.

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

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

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

Thank you!

Questions?

For questions:

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