The 4th Biennial TRB-CMTS Conference: From Sail to Satellite: Delivering Solutions for Tomorrow's Marine Transportation Systems Conference, June 21-23, 2016, Washington, DC

Advanced Fiber Reinforced Polymer Composites for Corrosion Mitigation in Water Infrastructure

Ray Liang and GangaRao Hota

Constructed Facilities Center and NSF-I/UCRC Sponsored CICI

West Virginia University, Morgantown, WV 26506

Center for Integration of Composites into Infrastructure

US Army Corps of Engineers

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US NSF Industry/University Collaborative Research Center –

Center for Integration of Composites into Infrastructure (CICI)

- **NSF I/UCRC**
  - Develop long-term partnerships among industry, academe, and government;
  - Promote research and development programs of mutual interest, and
  - Enhance the intellectual capacity of the engineering workforce through the integration of research and education
- **CICI**
  - Established with a planning grant in 2008 and full grant in 2009 from NSF
  - Only I/UCRC focusing on polymer composites for infrastructure applications

CICI Mission

- To accelerate the adoption of polymer composites and innovated construction materials into infrastructure applications through collaborative research
  - Highway, railway and waterway
  - Buildings and housing
  - Pipelines
  - Utilities and energy industries

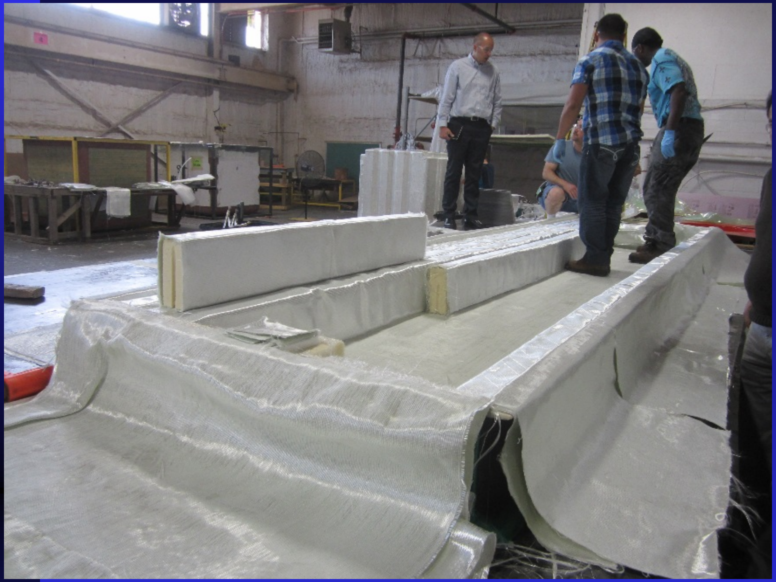
Types of Resins

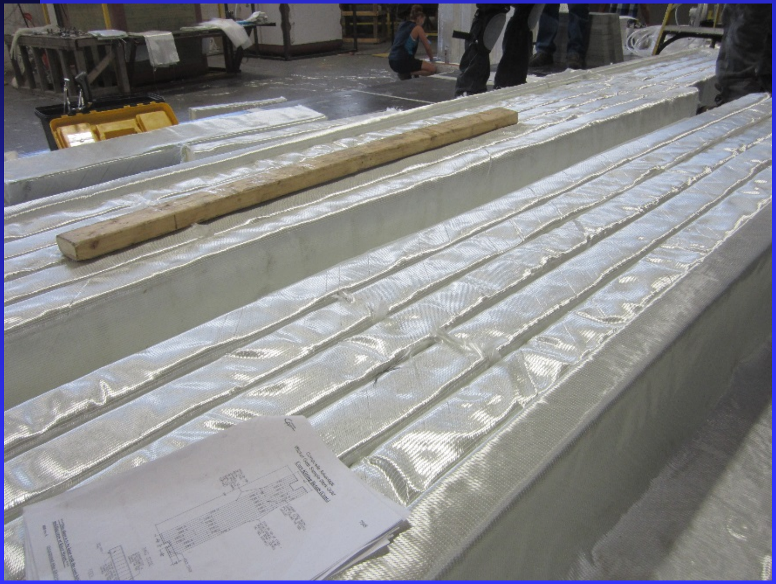
- Thermoplastic Resins
- Thermoset Resins
  - Inability to reshape due to cross-links.
  - Provide better bonding between the fibers and matrix.
  - Provide better creep resistance than thermoplastics.
  - Common thermoset resins
    - Polyester Resins
    - Vinyl Ester Resins
    - Epoxy Resins
    - Polyurethanes
    - Phenolic Resins

Manufacturing Methods for Composites

- Hand Lay-up
- Pultrusion
- Filament Winding
- Resin Transfer Molding (RTM)
- Sheet Molding Compound (SMC)
- Compression Molding
- Spray-up
- Vacuum Bag / Pressure Bag / Autoclave Molding
- Rotational Molding
- Bulk Molding Compound
- Injection Molding
- Others

Infusion





Composite Advantage

QA/QC of Manufacturing

- Good fiber wet-out
- Cure percent of resin
- Low void content
- High interlaminar shear strength
- Controlling shrinkage
- Cure cycle

Field Joint Failure, Leakage, De-bonding of Sandwich Panel

Photograph 2.4.1.4-2
End of ICI Panel. Note gap at field joint and water leaking from deck form hole.

De-bonding and no-Bonding in Pure Sandwich

Figure 9-8. No Adhesive Between Facesheet and Core Webs.

ir. Jan Peeters, 2015

Crushing of Webs in Pultruded Deck Plates

“60 Tonne Traffic” Effect on Pultruded Deck

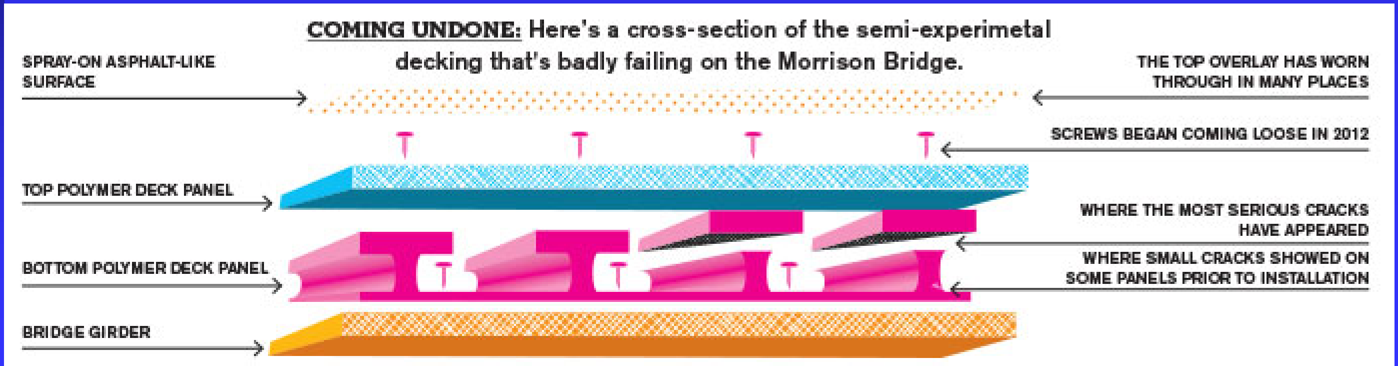
Field joint

Crack

‘Heay duty’ pultrusion deck panels: splitting under traffic loads

Achilles Heel of Pultrusions

- Extreme anisotropy
- Cracking and splitting along fibre direction



Thermoplastic Bridges: Risk of Fire

Recycled Thermoplastic Beams

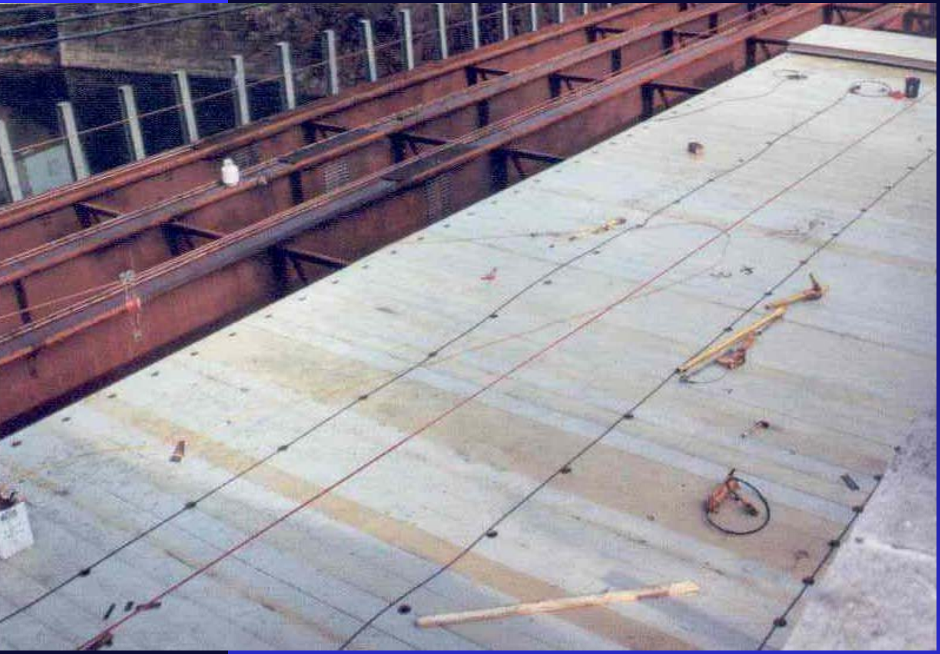
Extensive Studies of FRP Rebars

McKinleyville Bridge

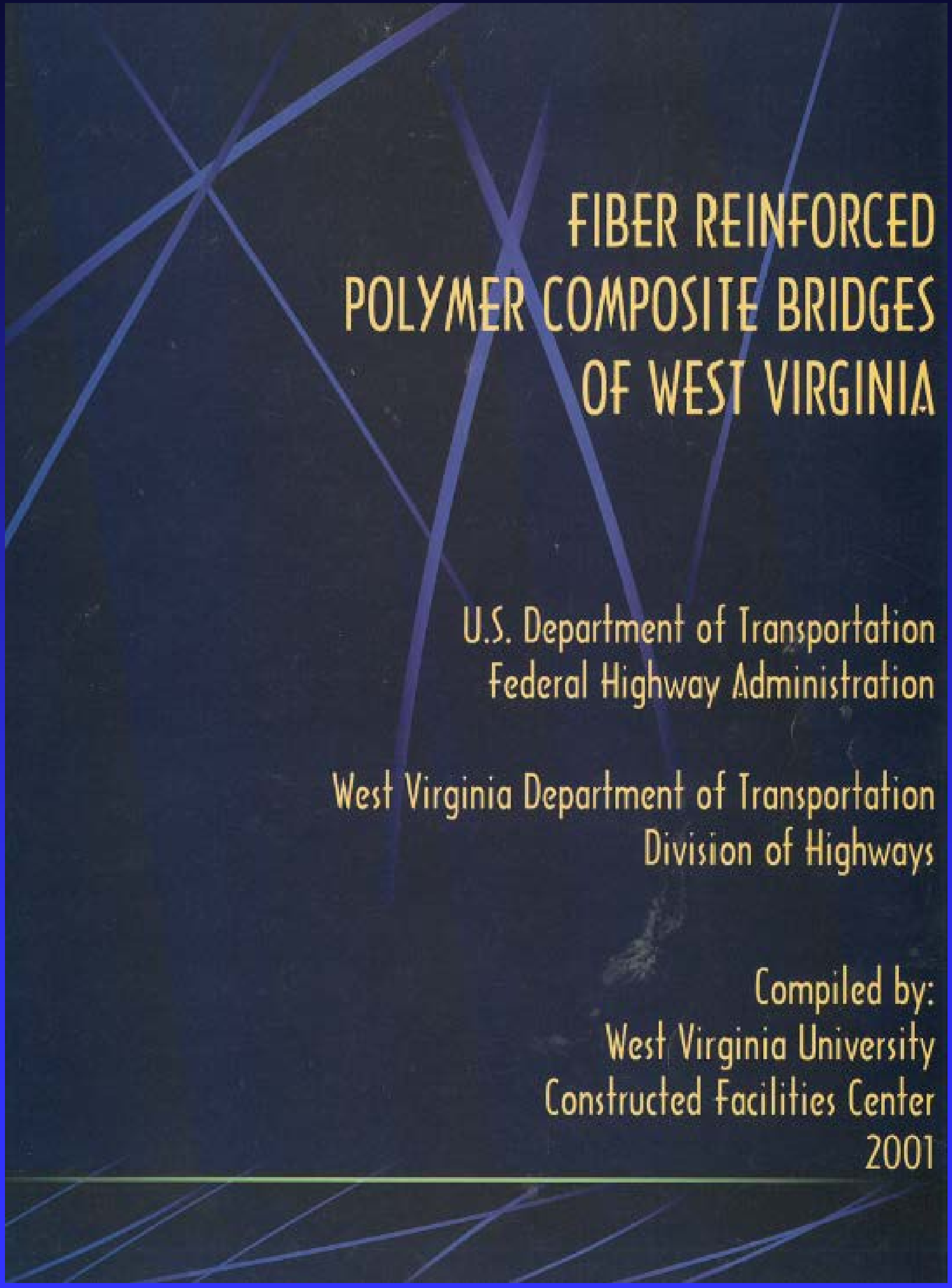
Highways & Bridges

FRP Rebar, WV Route 9, Martinsburg, WV

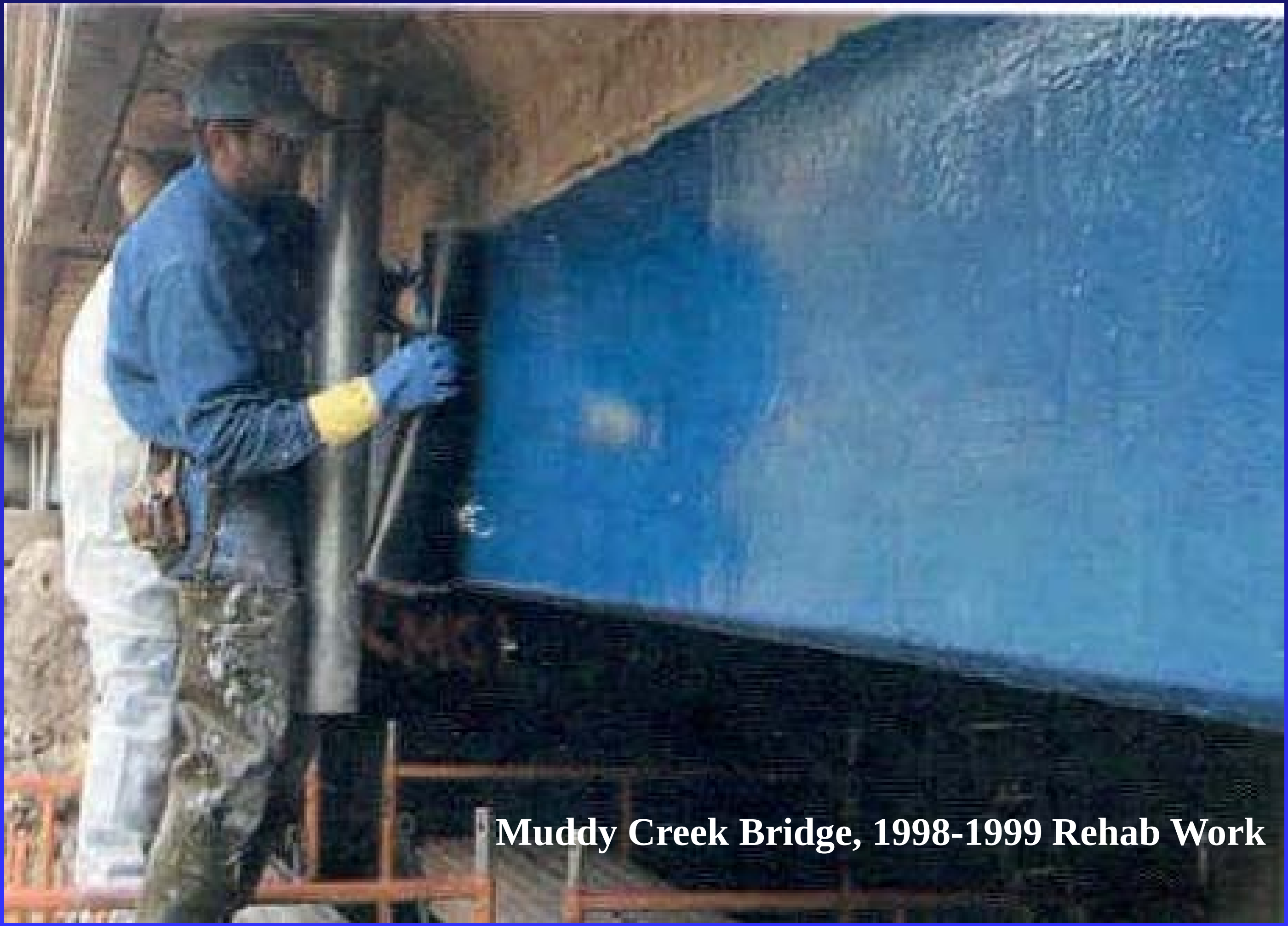
Highways & Bridges



Market Street Bridge – Wheeling, WV



Rehab of Highways & Bridges using FRP Wraps



Retrofitting of Railroad Bridges Using FRP Wraps, SBVR, Moorefield, WV (July 2010)

Durable FRP Gas Tank

Replacement of Single Shell Fuel Tank with Double Shell Tank

Utility Poles

- **$4 billion treated wood poles annually in US**

A 16” diameter FRP pole/pipe being tested at WVU- CFC Laboratory

Composite Turbine Blades for Wind Energy

Global market for wind turbines: $935 billion in 2020

As per Global Wind Energy Council,

China: 114 GW

US: 66 GW

Photo courtesy of Wikipedia

Pipelines

- Each year, ~1000 miles new natural gas pipelines go into service while ~1000 miles is replaced

Chimneys/Flues

- FRP composites are used in smoke stacks for pollution controls
- Large diameter FRP structures are needed

Cooling Tower

FRP Building

WVU-CFC designed, manufactured, and constructed the first FRP modular building in 1995 in collaboration with WV DOT (photos taken on Aug 27, 2009)

Rapid Housing

FRP composite home being erected at BRP Inc. manufacturing facility

FRP Sheet Piles and Pipe Piles

Long Beach, New York
Hurricane Sandy Repair and Protection (2013)

Credit: Creative Pultrusion

Composite Anti-Collision Bumper System for Bridge Protection

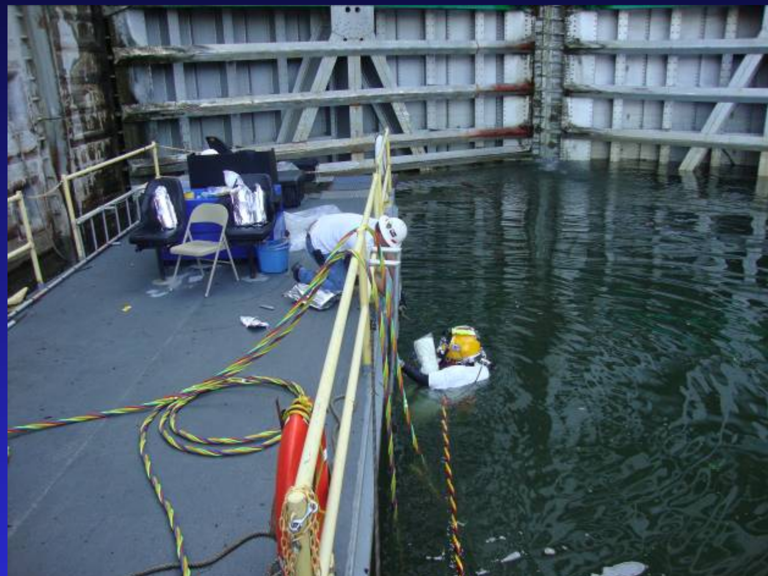
Credit : Nanjing Tech University

FRP Composites Demonstrations in Collaboration with US Army Corps of Engineers

Steel miter blocks were replaced with FRP Composite Miter Blocks

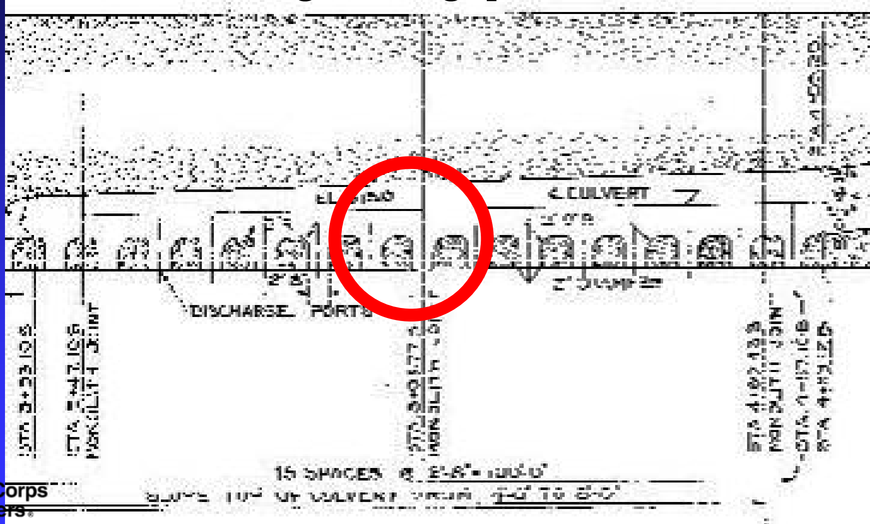
US Army Corps of Engineers

Repair Concrete Discharge Ports at Chickamauga Dam in Tennessee



Video monitoring of installation – subsequent diving inspection has shown the composite wrap to look like the day it was installed.

Schematic showing discharge ports in lock structure



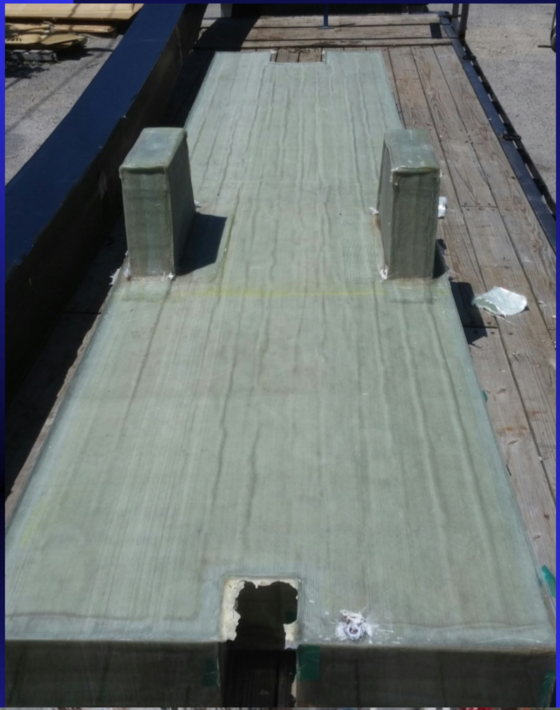
US Army Corps of Engineers

Recess Panels at Willow Island Locks and Dam, Ohio

Finished panels to be installed Summer 2016.

US Army Corps of Engineers

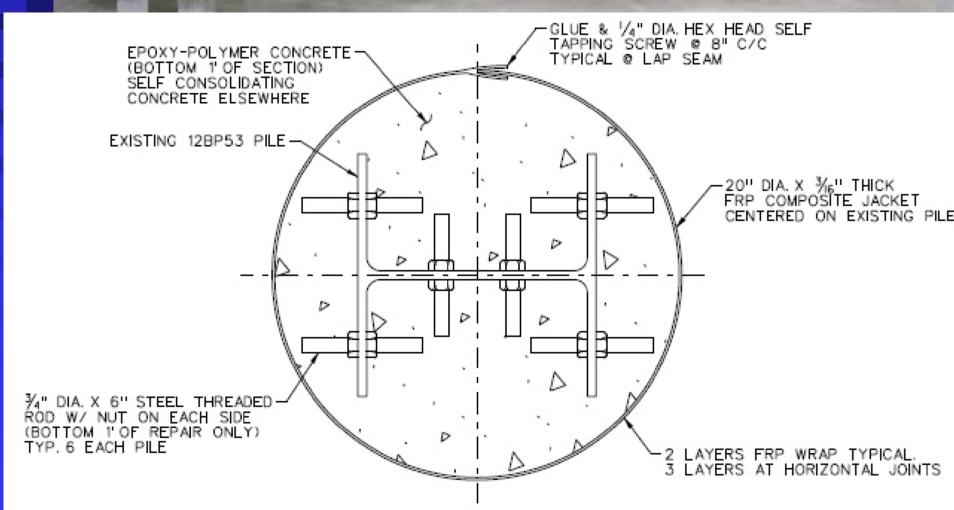
Fabrication, Evaluation and Field Installation of Composite Wicket Gates



Rehab of Corroded Steel H-Piles, East Fork Bridge, Huntington, WV

Another Full Presentation at this Conference: Rehabilitation of East Lynn Lake Bridge with Fiber Reinforced Polymer Composites

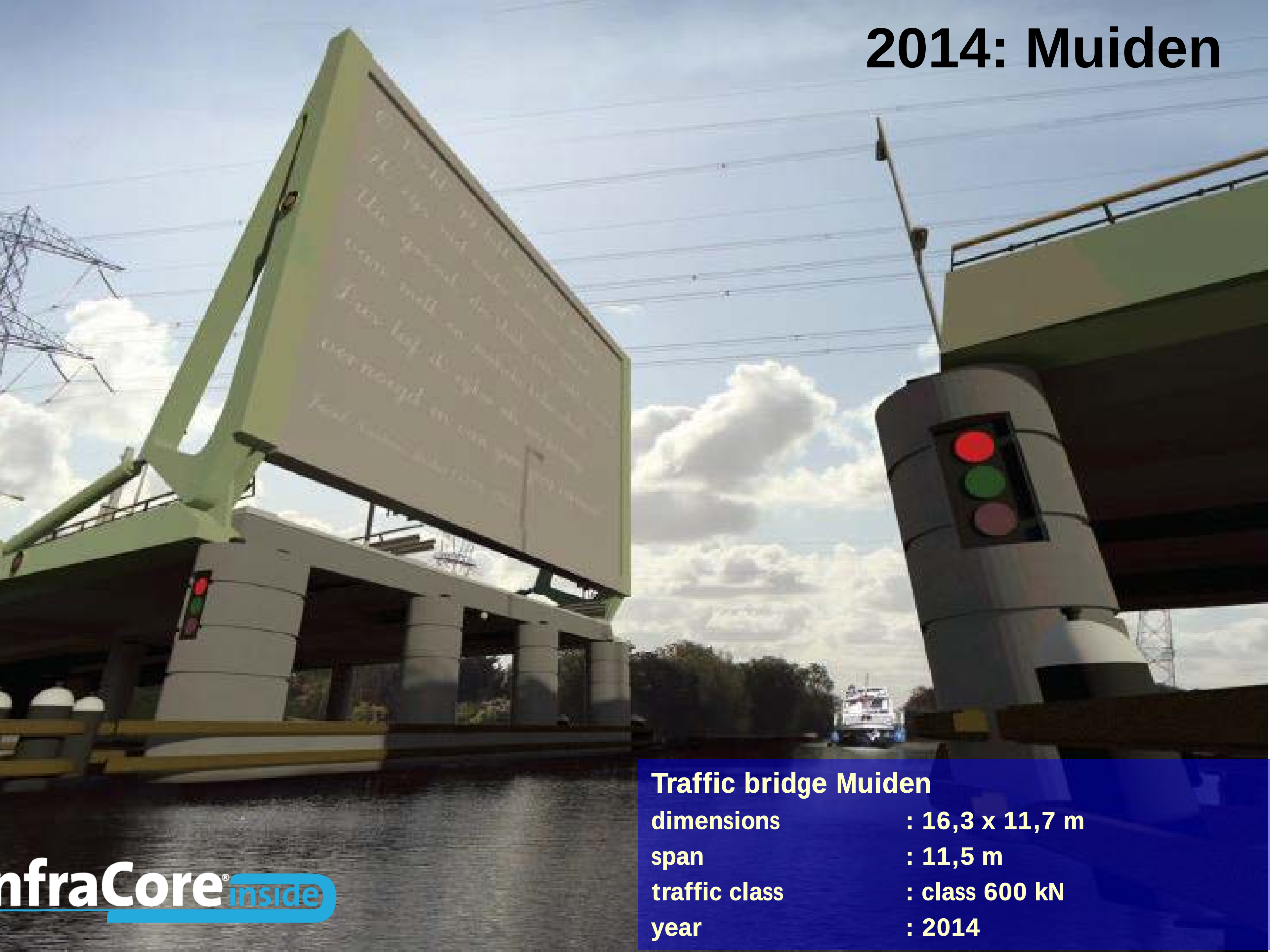
Bring load capacity back to original at 25% of traditional repair cost, with use of composite shell, wrapped, and then filled with SCC



Credit: USACE

Moveable Muiden Bridge with FRP

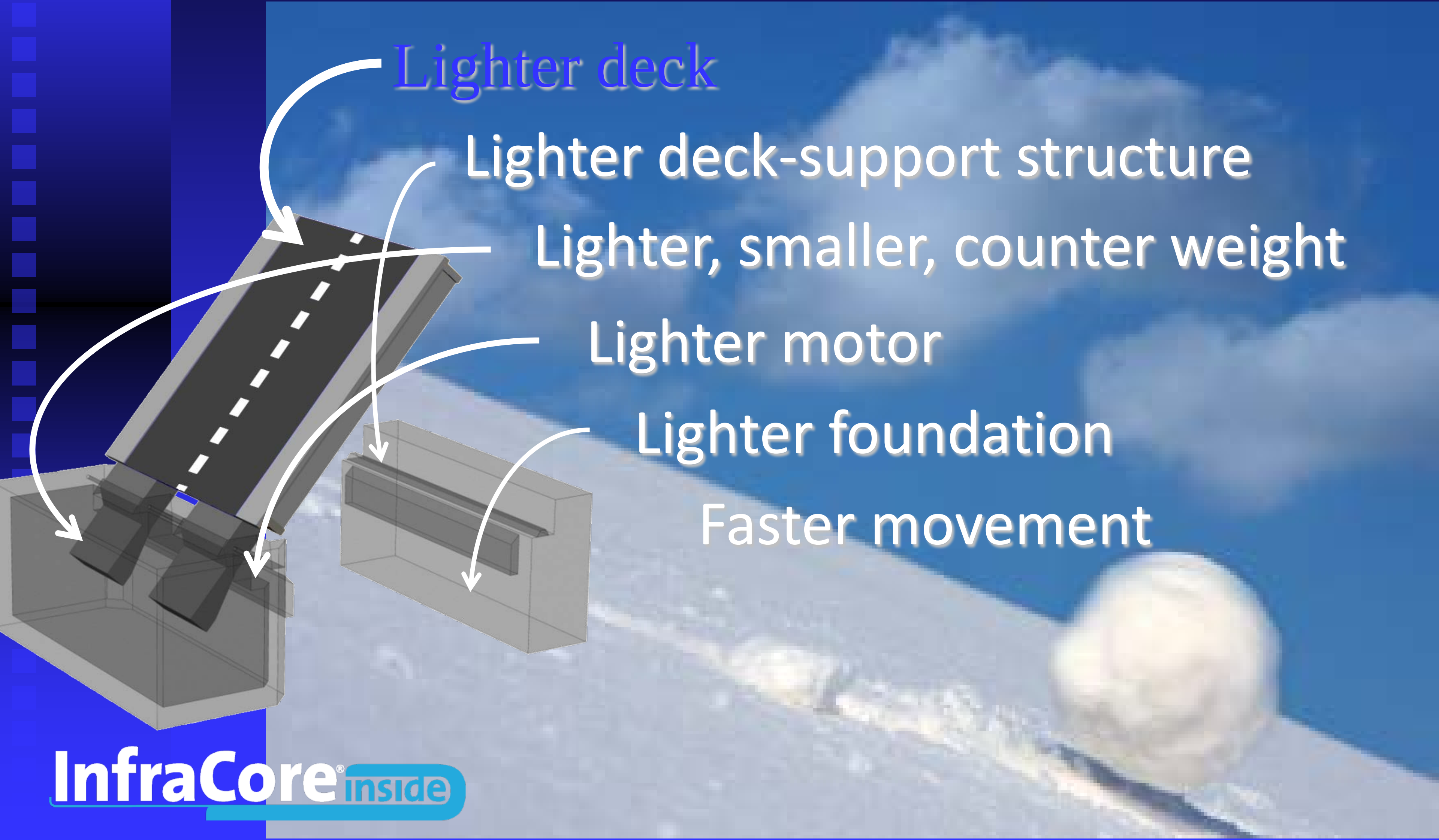
2014: Muiden



Traffic bridge Muiden

dimensions	: 16,3 x 11,7 m
span	: 11,5 m
traffic class	: class 600 kN
year	: 2014

Snowball-effect Moveable Bridges with FRP



InfraCore® inside

FRP Lock Doors

Werkendam

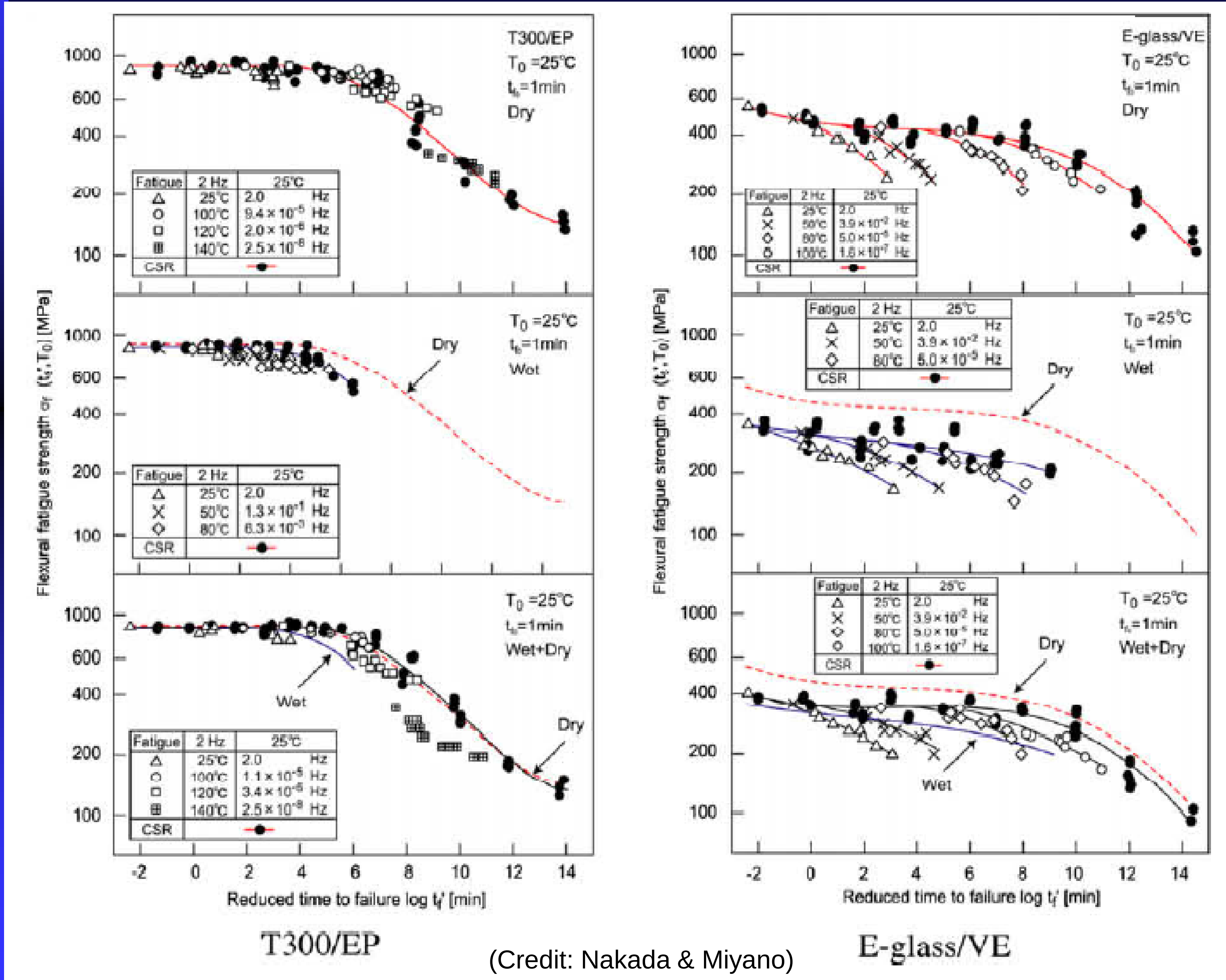
dimensions : 6 x 3m
year : 1999, 2005
principal : Bouwdienst RWS

InfraCore® inside

Factors Affecting FRP Durability

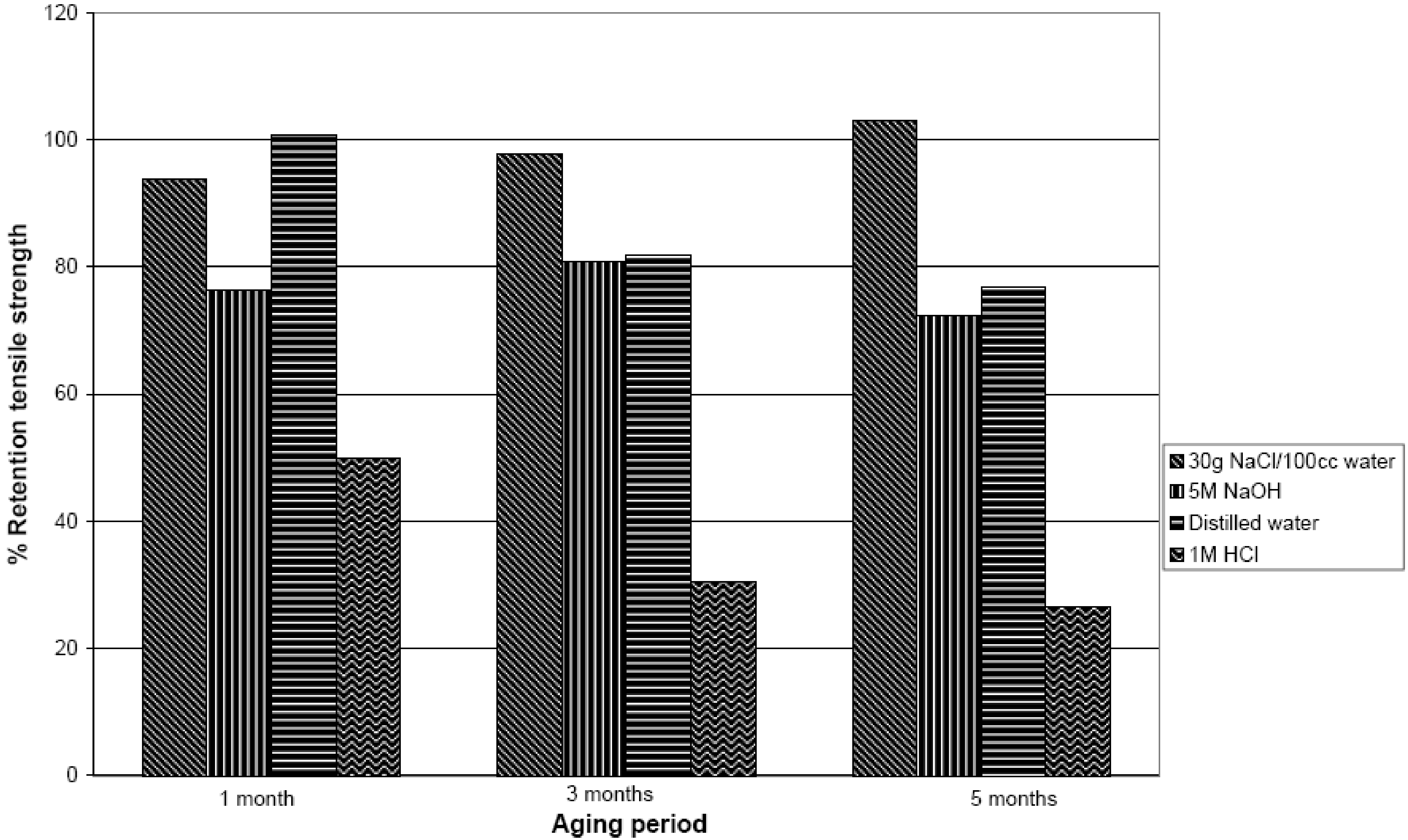
- Moisture including pH variation from 2 to 12
- Temperature influence including freeze-thaw
- Sustained loading and fatigue
- Fire responses (not an issue in hydraulic structures)
- Synergistic effects of above

Master curves of flexural fatigue strength for T300/EP and E-glass/VE in dry, wet and wet-dry environments



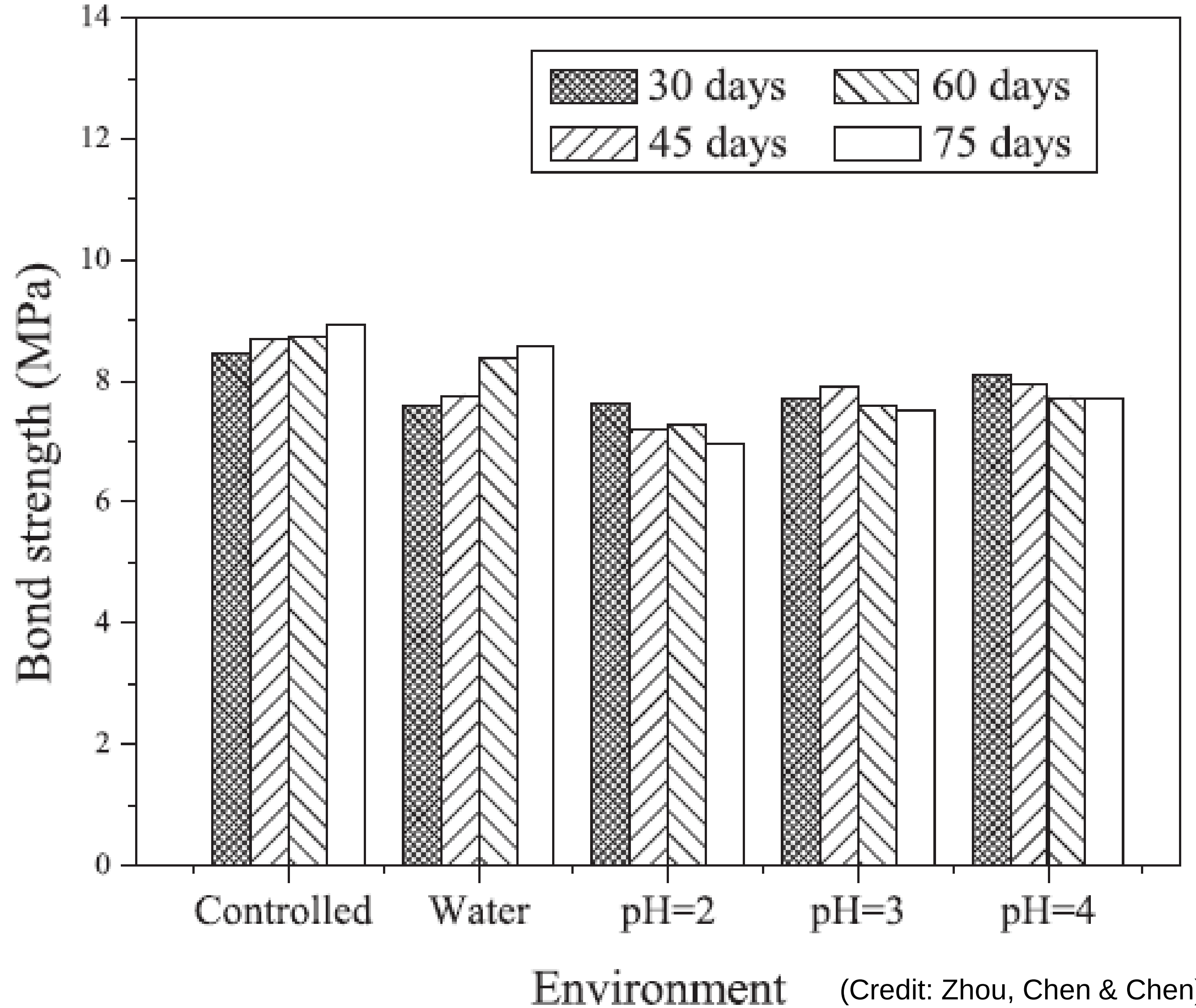
(Credit: Nakada & Miyano)

Comparison of percent retention of tensile strength of composite aged indifferent solutions at RT



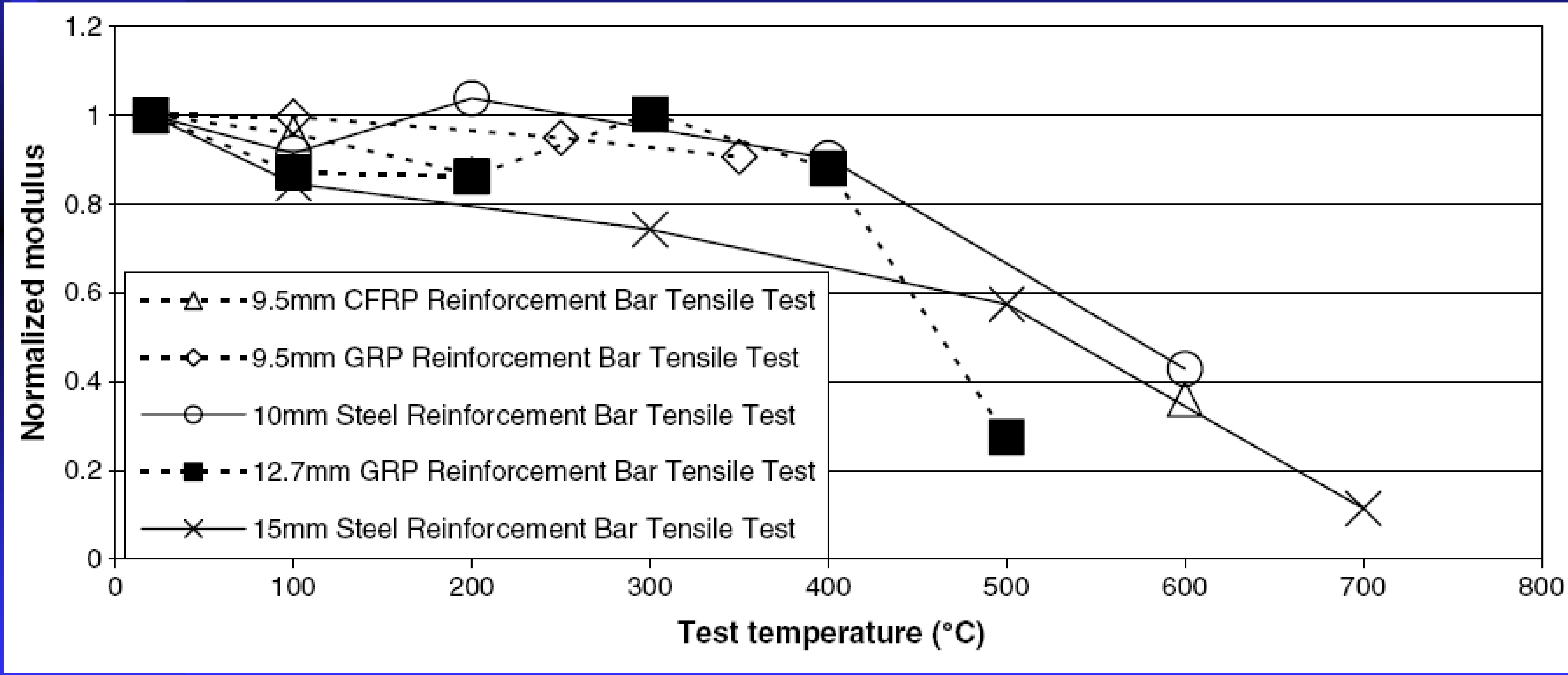
(Credit: Somjoy, Gangarao, Gupta)

Variation of bond strength of GFRP bars under tap water and acid solution



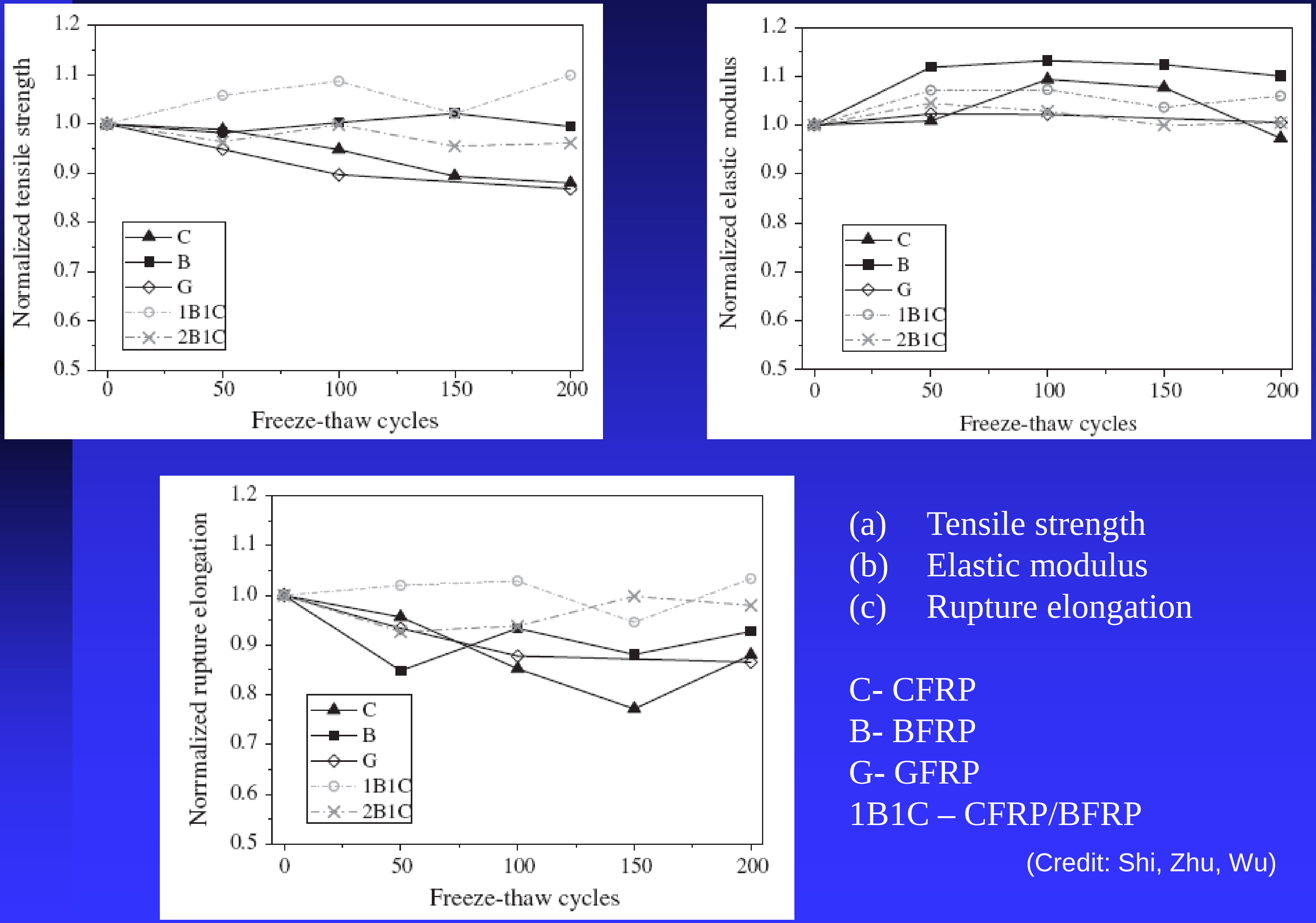
(Credit: Zhou, Chen & Chen)

Comparison of elastic modulus as a function of temperature for FRP and steel bars



(Credit: Wang, Wong, Kodur)

Normalized tensile properties of FRP composites versus freeze–thaw cycles

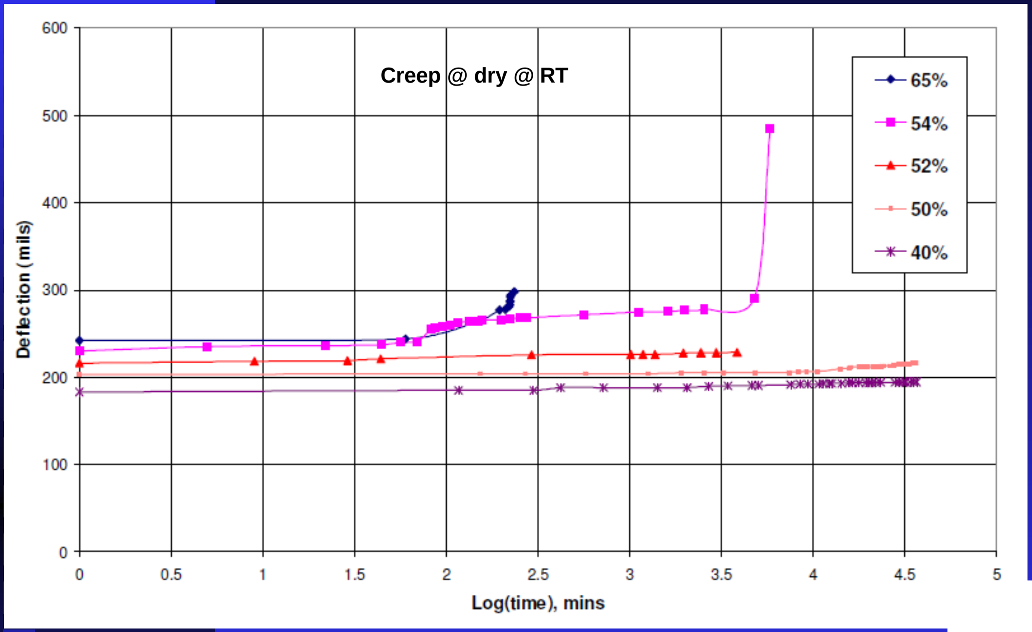


(a) Tensile strength
(b) Elastic modulus
(c) Rupture elongation

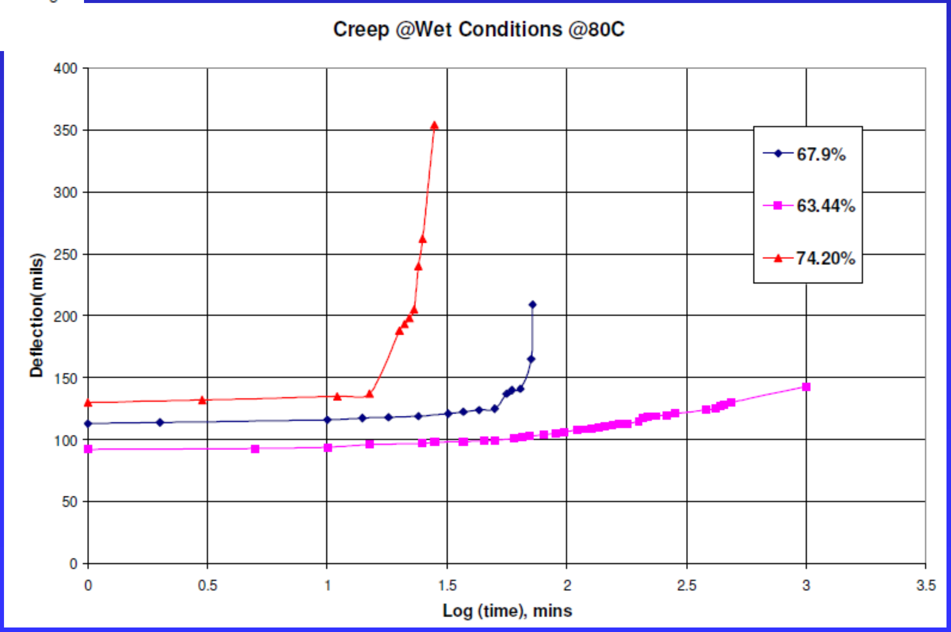
C- CFRP
B- BFRP
G- GFRP
1B1C – CFRP/BFRP

(Credit: Shi, Zhu, Wu)

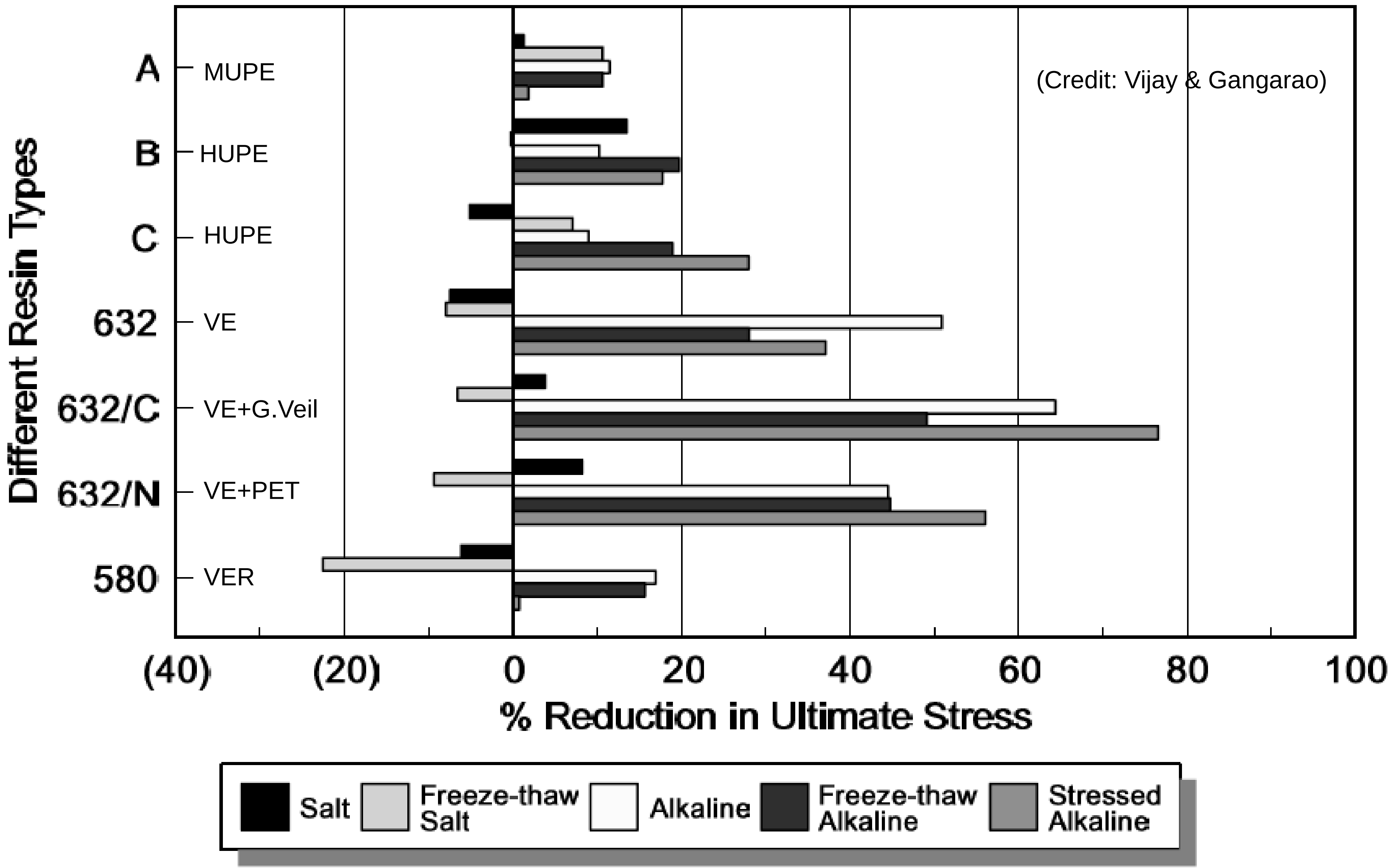
Creep responses of three point bending creep with constant loads



(Credit: Batra)



Variation of tensile strength in GFRP bars in different conditions



Strength reduction factor for FRP under coupled effects of sustained stress and environment

FRP type	Sustained stress level	Environment	Strength reduction factor	Data resource
Glass/vinylester	45%	60°C, deionized water, 139 days	0.43 (T)	Helbling and Karbhari[82]
	45%	40°C, deionized water, 500 days	0.44 (T)	
	30%	60°C, deionized water, 668 days	0.34 (T)	
Sand-coated GFRP bar	29%	60°C, pH = 13, 2 months	0.89 (T)	Debaiky et al.[60]
Glass/polyester and Glass/vinylester	30%	60°C, 2000 h	0.85–0.9 (T)	Miller[88]
Sand-coated GFRP bar	37%	RM, pH = 13, 6 months	0.51 (T)	Vijay et al.[14]
	27%	RM, saltwater, 8 months	0.73 (T)	
	40%	66°C, pH = 13, 4 months	0.15 (T)	
Sand-coated GFRP bar reinforced concrete	30%	250 cycles, −25 to 15°C, followed by 1,000,000 cycles at 1.5 Hz and 25% of stress level	0.77 (B)	Alves et al.[90]

Abbreviations: T: tensile strength; B: bond strength.

(Credit: Wang, et al)

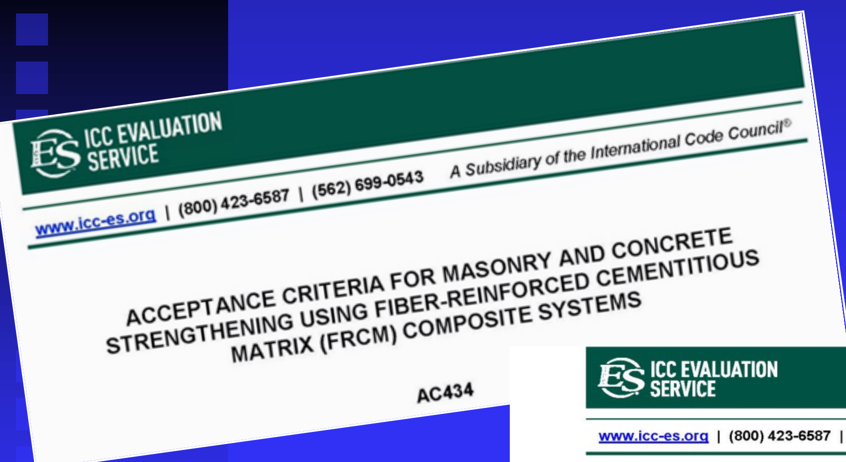
Summary of FRP composite durability responses

- H_2O including pH variation weakens strength more than stiffness
- Extreme acidity is more aggressive than alkalinity except for GFRP
- Although Fickian phenomenon is more popular, superposition of independent contributions of H_2O and creep are ok at higher temp.
- Temp. strongly affects H_2O absorption rate; thus FT needs evaluation
- Creep accelerates property degradation
- For design several strength reduction factors are suggested accounting H_2O, temp, pH, creep

Codes, Specifications and Guidance

- Construction industry relies on design codes and specifications, such as ACI 440.1R.03 & AASHTO LRFD Bridge Design Guide; ICC-ES AC434; and AC454

- New design code entitled, "Pre-standard for Load and Resistance Factor Design (LRFD) of Pultruded Fiber Reinforced Polymer (FRP) Structures" by ACMA-ASCE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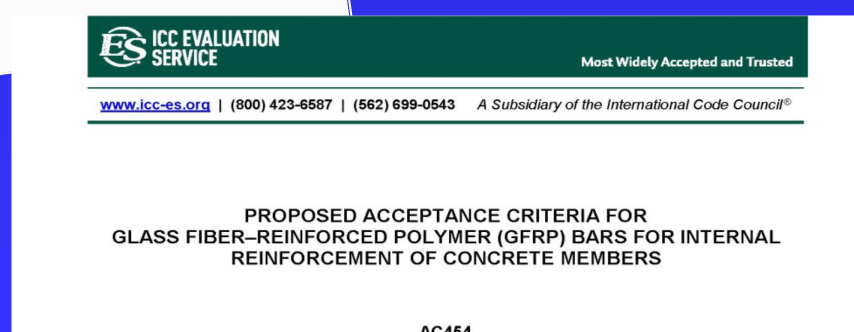
ACCEPTANCE CRITERIA FOR MASONRY AND CONCRETE STRENGTHENING USING FIBER-REINFORCED CEMENTITIOUS MATRIX (FRCM) COMPOSITE SYSTEMS

AC434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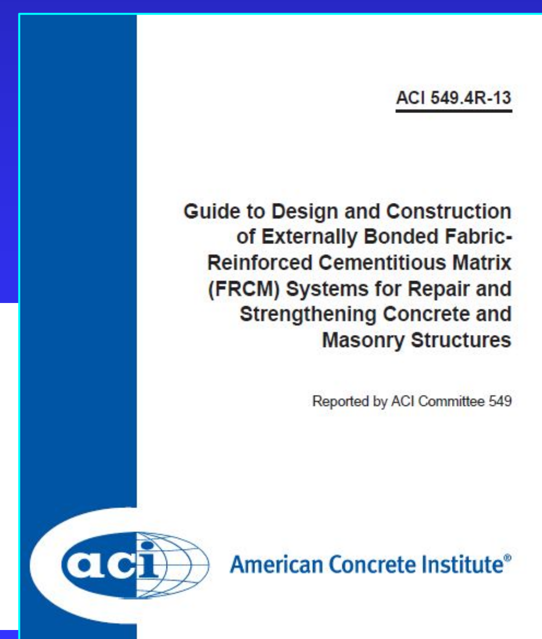
PROPOSED ACCEPTANCE CRITERIA FOR GLASS FIBER–REINFORCED POLYMER (GFRP) BARS FOR INTERNAL REINFORCEMENT OF CONCRETE MEMBERS

AC454

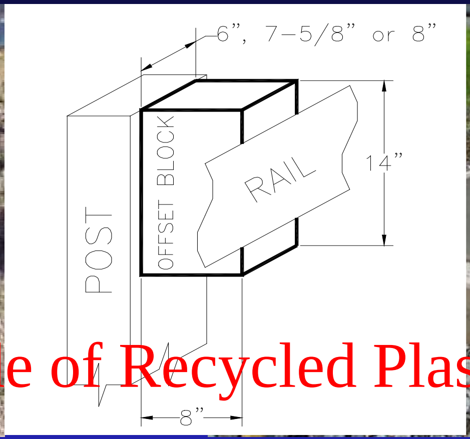

ACI 549.4R-13

Guide to Design and Construction of Externally Bonded Fabric-Reinforced Cementitious Matrix (FRCM) Systems for Repair and Strengthening Concrete and Masonry Structures

Reported by ACI Committee 549

American Concrete Institute®

Engineered Recycled Thermoplastic Composites



Offset Blocks Made of Recycled Plastic

Field Installation and Testing of Full Scale RR Ties Made with Recycled Polymer Composite Shell and Used Wood Tie as a Core

Conclusions

- Academia in cooperation with government and industry has made major strides with FRPs for infrastructure applications.
- With code acceptance, FRP composite materials will become an integral part of civil infrastructure including rehab of aging structures at 15-30% of conventional repair costs.
- Increased use of reliable and durable composite materials results in low maintenance, longer service life, and greener products, provided durability concepts are properly integrated in design.

Acknowledgement

- Many of the projects presented were carried out under NSF-IUCRC-CICI program as joint efforts among WVU-CFC, WVDOT, USACE, NSF, FHWA and Industries.
- East Lynn Bridge Rehab was honored with 2014 USACE Innovation of the Year Award and the 2014 Engineering Excellence Award of the Great Lakes and Ohio River Division of USACE.
- Many graduate students of WVU-CFC have participated in various projects.

Questions and discussions