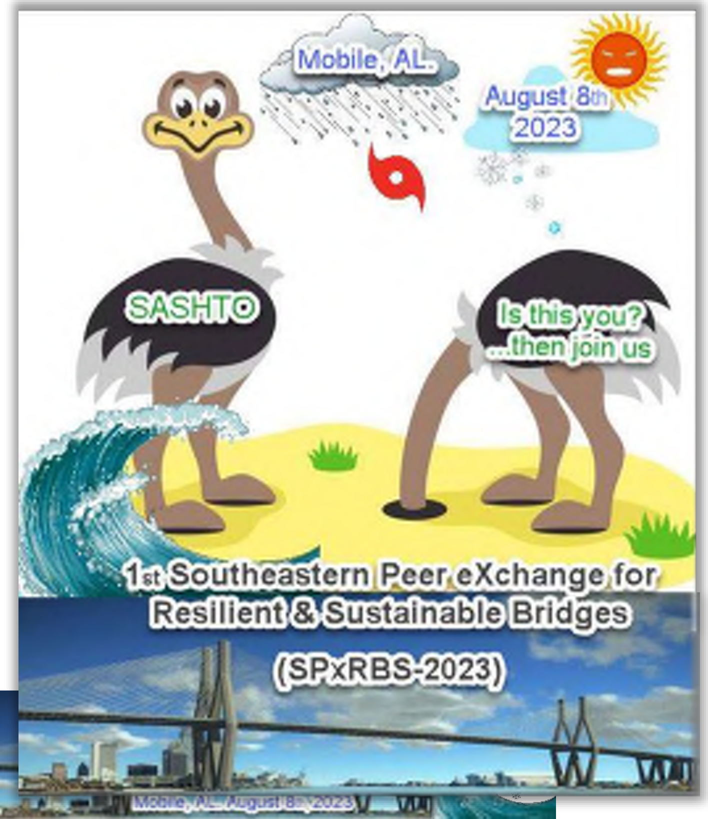
1st Southeastern Peer Exchange for Resilient & Sustainable Bridges – Part 1



Session 1 (12pm – 1:30pm):

- **Part 1**: Definitions & discussion of goals and commitments (24-minutes)
- **Part 2a**: Technical presentations of State of the Art in member states (30 minutes)
- **Part 2b**: Technical presentations of State of the Art in member states (30 minutes)

**** Breakout (120 minutes) ****

**** Coffee, Tea, Lemonade & Beignets 3:00-3:30pm ****

Session 2 (3:30pm-6:00pm)

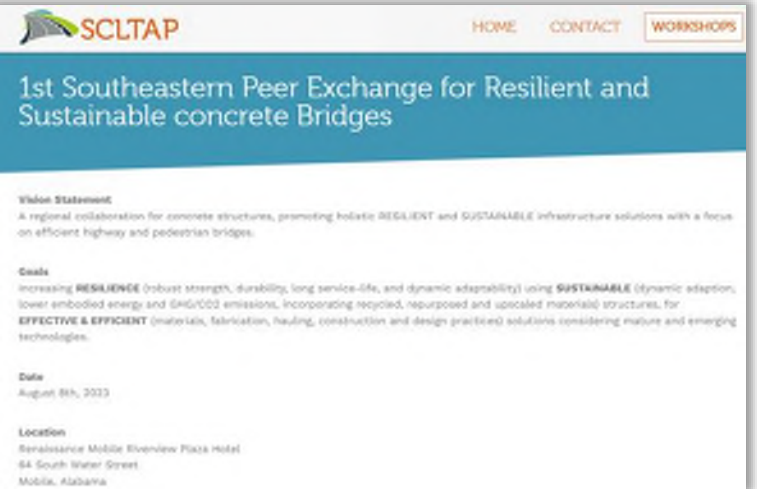
- **Part 3**: Technical presentations of Manufacturer & Materials Acceptance (60-min)
- **Part 4**: Technical presentation and discussion on Research Needs (30-min)
- **Part 5**: Technical presentation Open Topics (30-min)
- **Part 6**: Final Q&A, Wrap Up assignment of Follow-up Tasks and Champions. (20 minutes)

Session 1 : Introduction & Logistics (August 8th, 2023)

Logistics

- Please mute all phones.
- Fire Exit is to the left of the Bon Secour III room.
- Bathrooms to the right past the Escalators.

- The sessions will be recorded for archival purposes.
- Presentations will be made available in PDF format on the webpage:



https://www.scltap.org/spxrbs-2023/

Logistics

- Bathrooms to the right past the Escalators

- Meeting Room

Participants & Sponsors

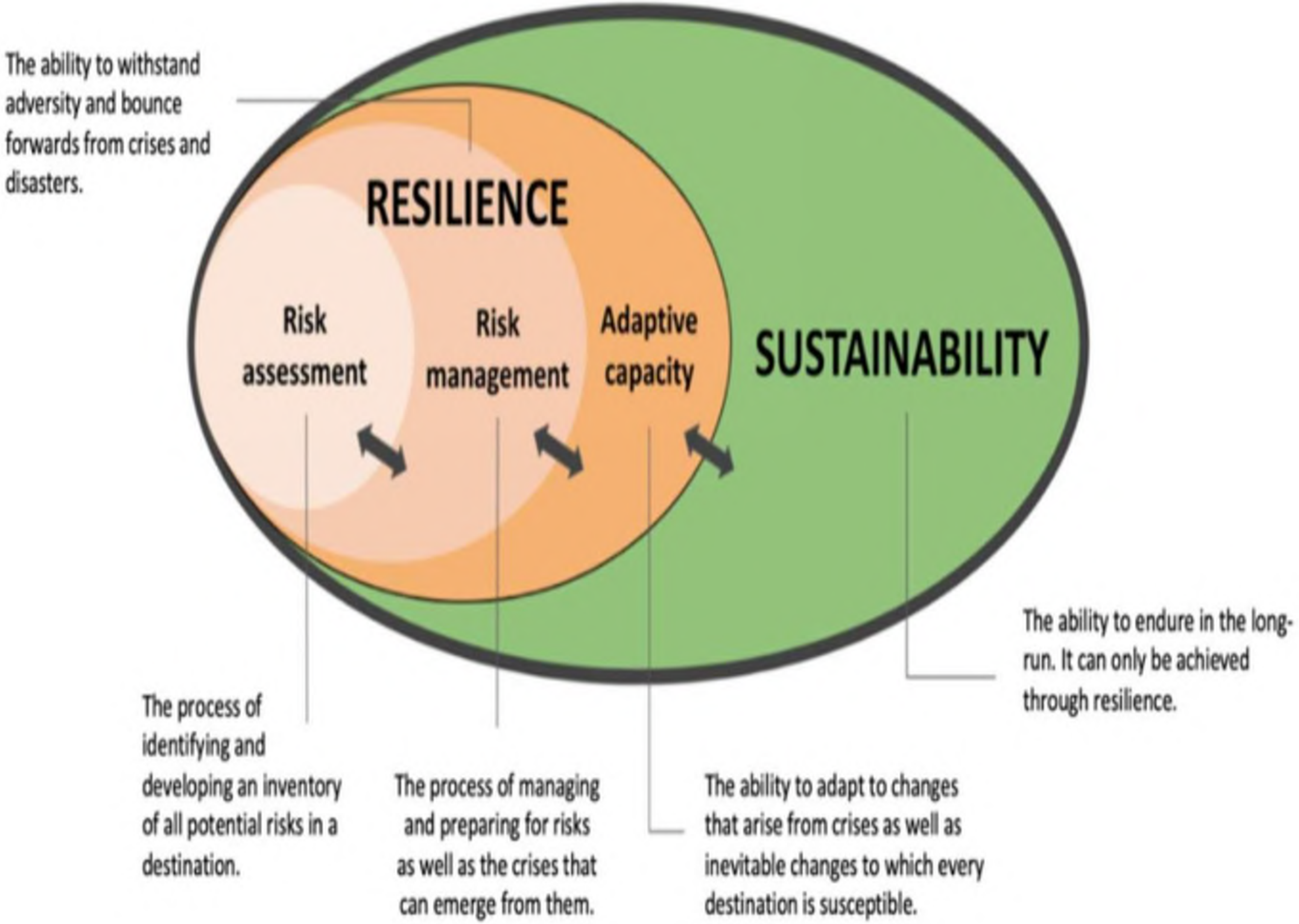
1st Southeastern Peer Exchange for Resilient and Sustainable Bridges

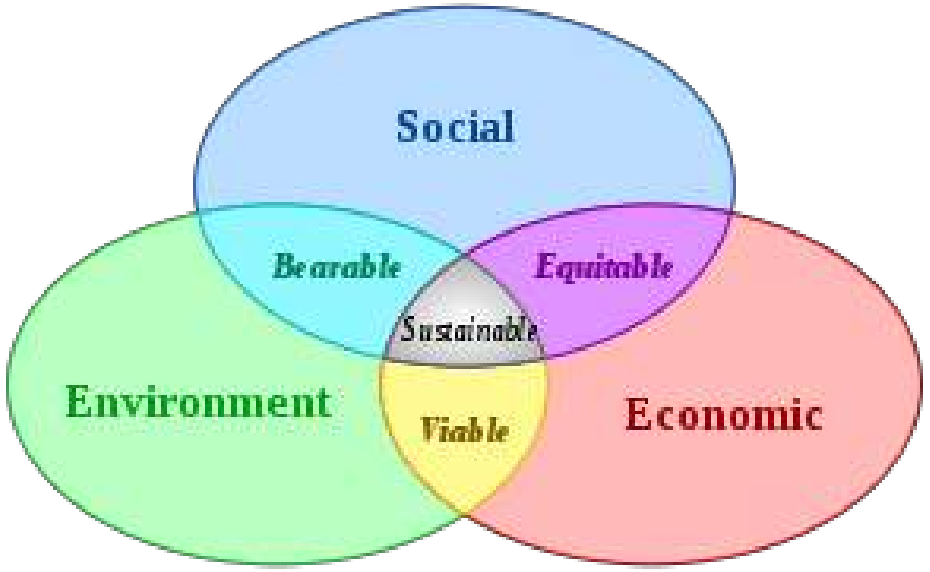
SPxRSB - 2023

Dr. Prasad Rangaraju, Clemson University
Steven Nolan, FDOT
Dr. Antonio Nanni, University of Miami

August 8th, 2023
Renaissance Mobile Riverview Plaza
Mobile, AL

Resilience and Sustainability





Sustainable development can only happen

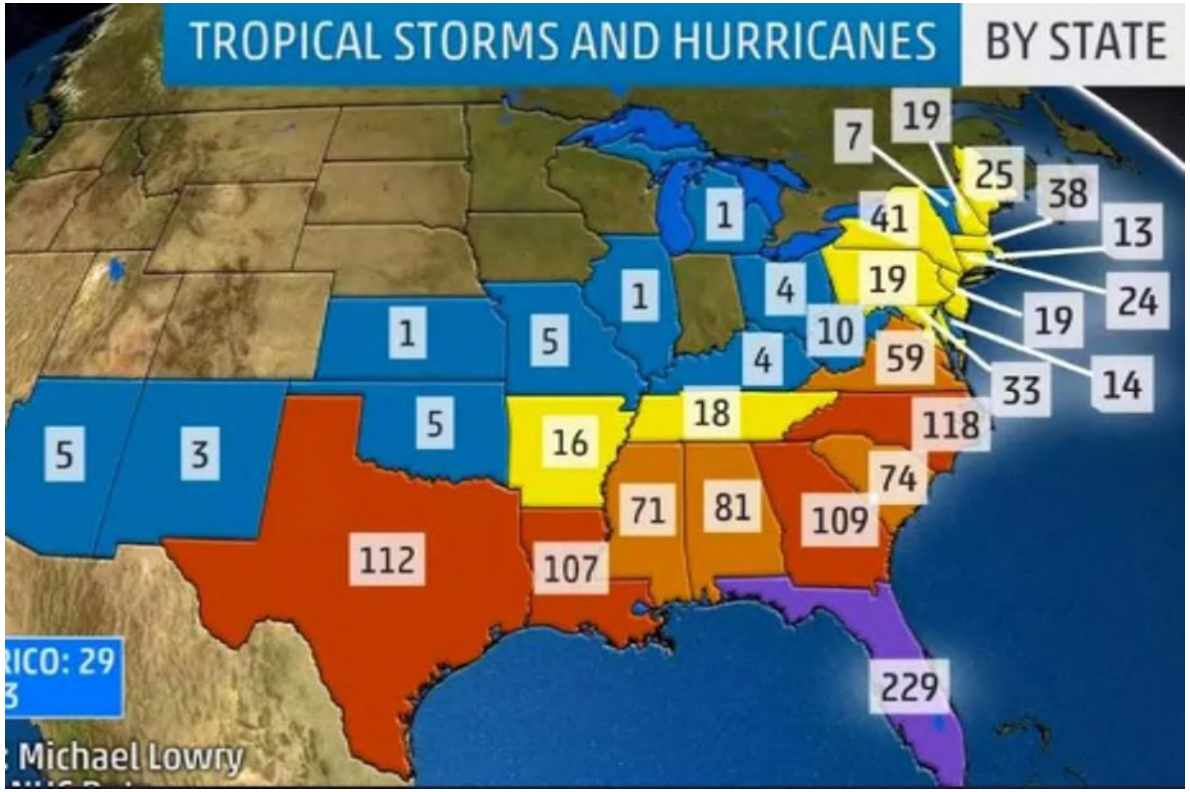
When all the three needs are met

In the context of Transportation Infrastructure…

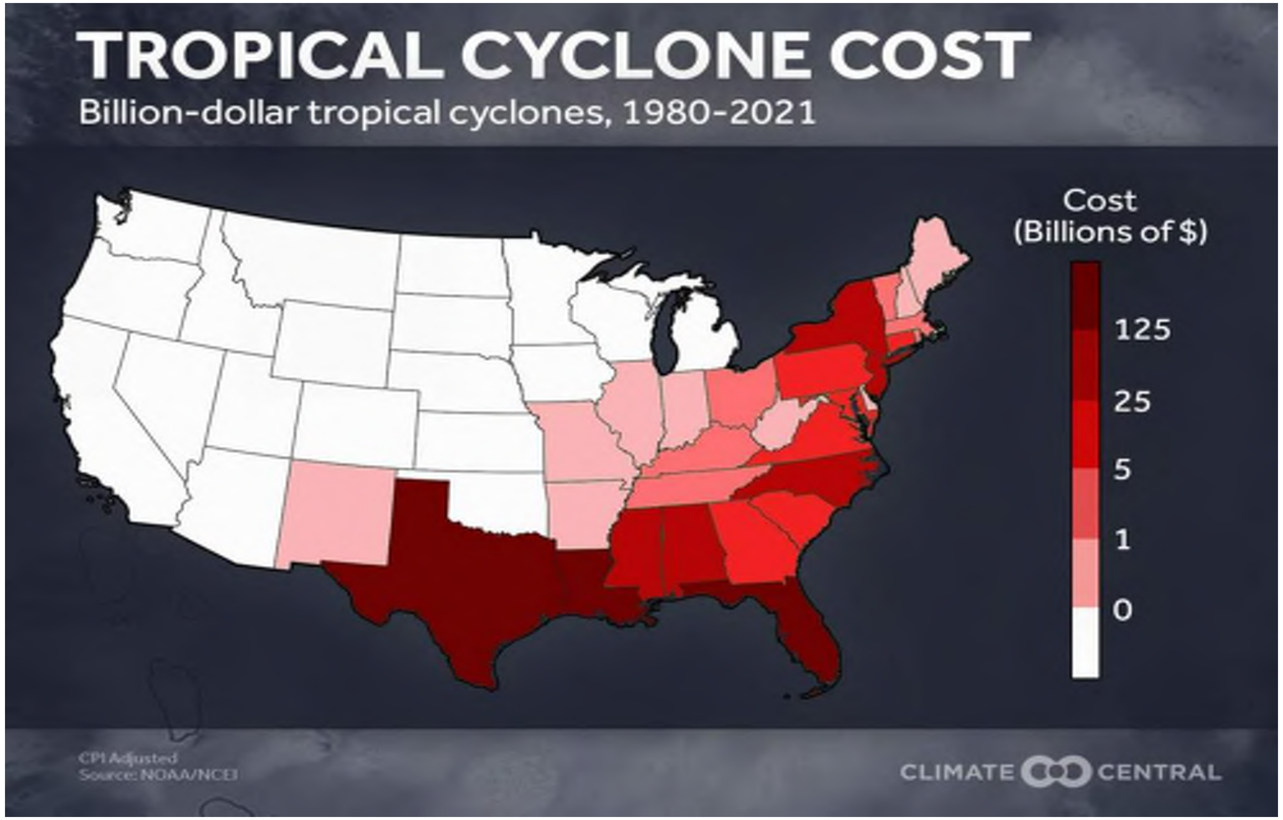
- Design and build structures with materials & technologies which ensure a **long service-life** with minimal maintenance, while doing so in an **environmentally, economically and socially responsible way**.
- **Environmentally responsible way**: 3Rs – reduce, reuse, recycle, all of which ultimately impact the use of **resources and the associated emissions (GHGs).**
- "Long service life" is synonymous with **durability,** which refers to the ability to resist damage imposed by both natural and man-made hazards and provide a level of serviceability that is acceptable.

Natural Threats (Shocks)

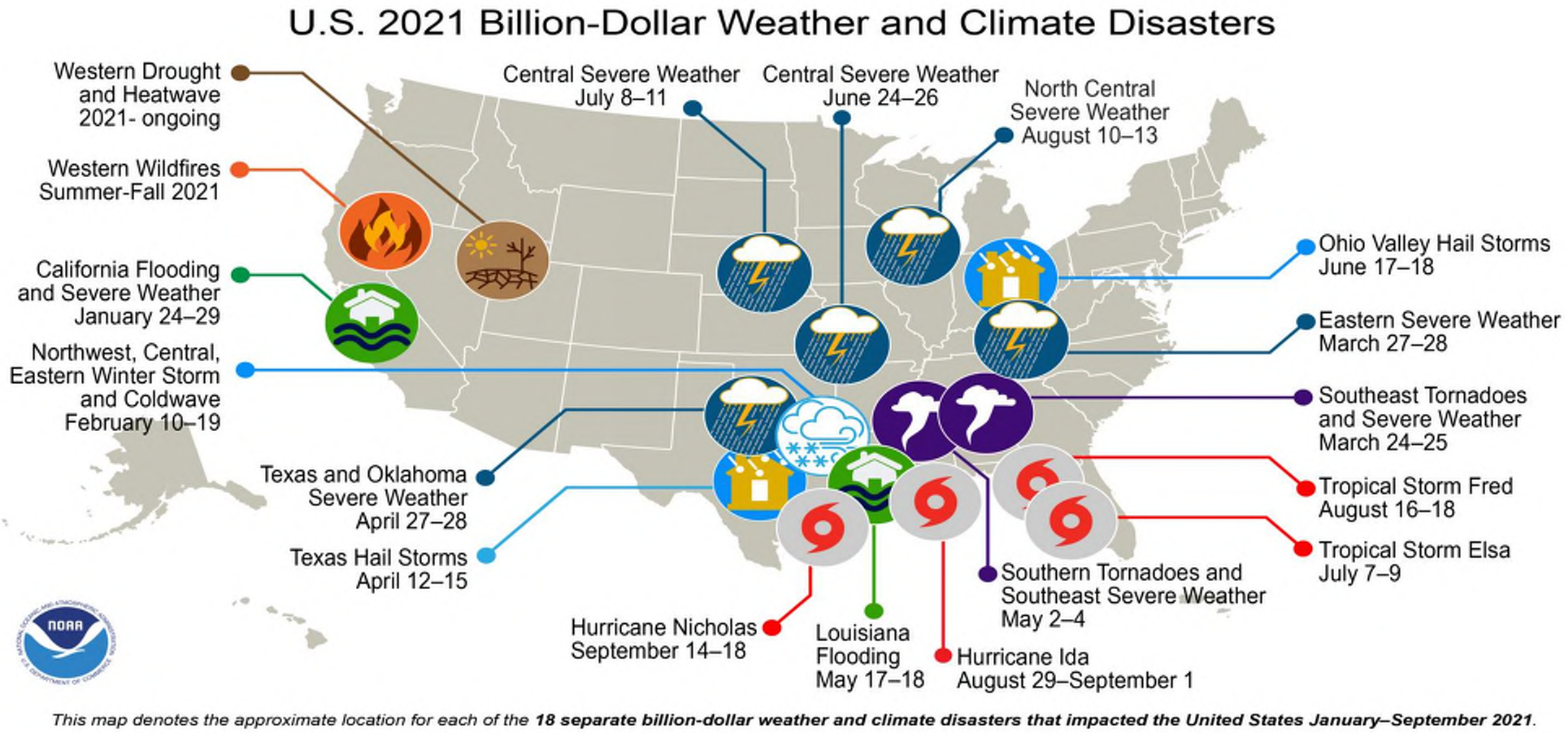
Frequency and Cost of Tropical Storms and Hurricanes



Yrs 1851 to 2020



Natural Disasters (2021)



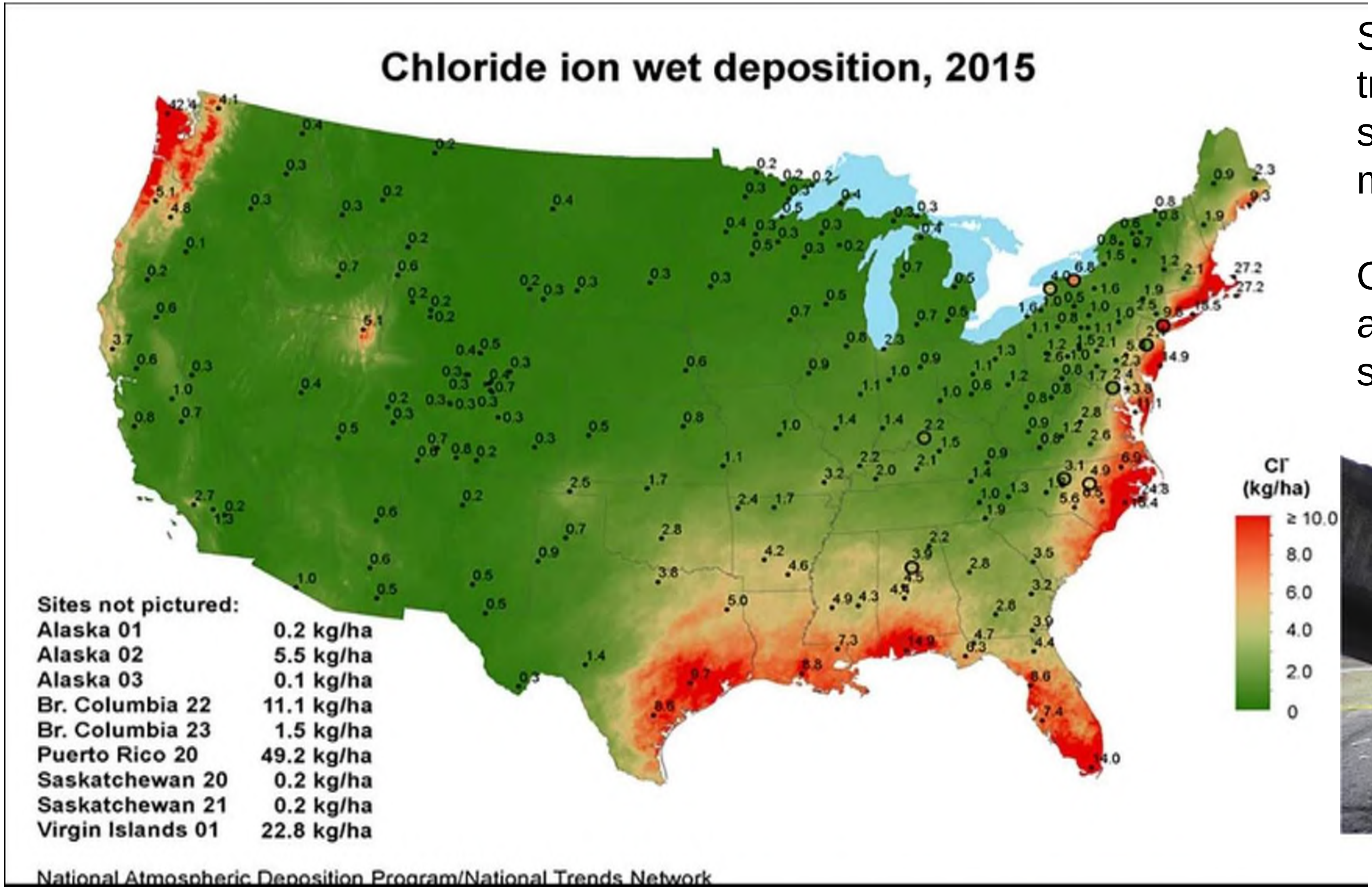
Resiliency of Bridges

Section of major Florida bridge wiped out by Hurricane Ian (2022)

Impact of Hurricane Katrina on Biloxi Bay Bridge on US 90 (2005)

https://nypost.com/2022/09/29/section-of-major-florida-bridge-destroyed-by-ian/

Marine Salt Spread Inland (Stress)



Salt chloride deposition map showing United States how far inland salt air affects these coastal areas. Courtesy of the National Atmospheric Deposition Program (NADP).

Salt-laden air from marine regions can travel as much as 50 miles inland, and in some unique cases to as much as 100 miles inland.

Other sources of salt such as deicers, and brackish waters can cause significant damage as well

© Pennsylvania Department of Transportation

Material-Dependent Resiliency and Sustainability Issues

- Chloride and carbonation induced corrosion of reinforcing steel
- Sulfate attack
- Alkali-aggregate reactions
- Abrasion
- Erosion and Cavitation
- Others

Solutions for Achieving Resiliency and Sustainability

- **New generation of reinforcement materials for concret infrastructure**
  - Fiber Reinforced Polymer (FRP): GFRP, CFRP, BFRP
  - Stainless steel reinforcement
  - Stainless-clad reinforcement
- **New generation of cementitious materials**
  - Portland Limestone Cement, LC3 Cement, Other Low Carbon Binders
  - Alternate Supplementary Cementitious Materials (SCMs)
  - Carbon Capture, Utilization and Storage (CCUS) Strategies
- **New generation of chemical admixtures**
- **Recycled aggregates**
- **Carbon Capture, Utilization and Storage (CCUS) Solutions**

PLC

Limestone Calcined Clay Cement LC3

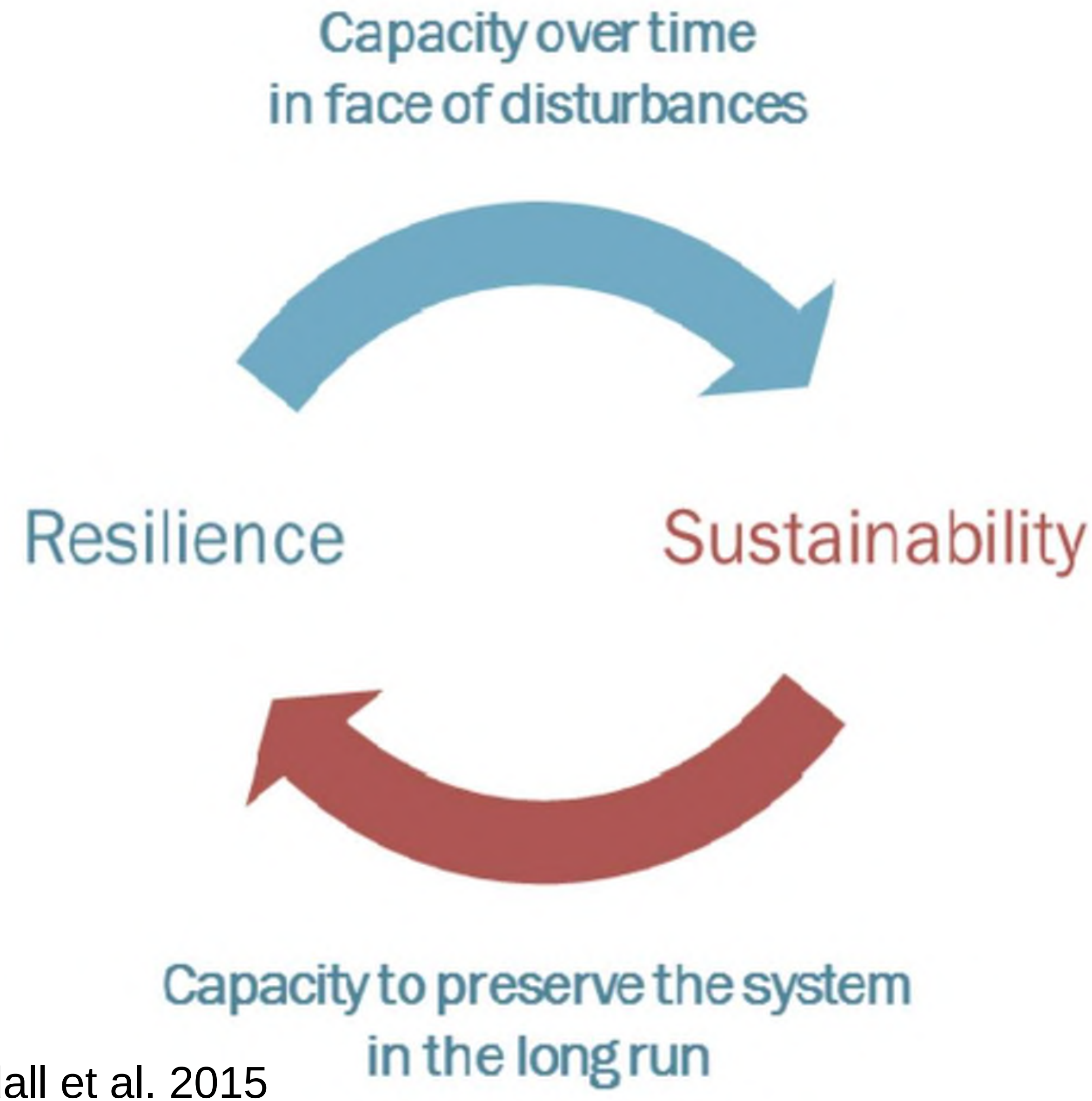
SMART CENTER
CLEMSON

Questions?

prasad@clemson.edu


Mobile, AL.
August 8th
2023
SASHTO
Is this you?
...then join us
1st Southeastern Peer eXchange for
Resilient & Sustainable Bridges
(SPxRBS-2023)

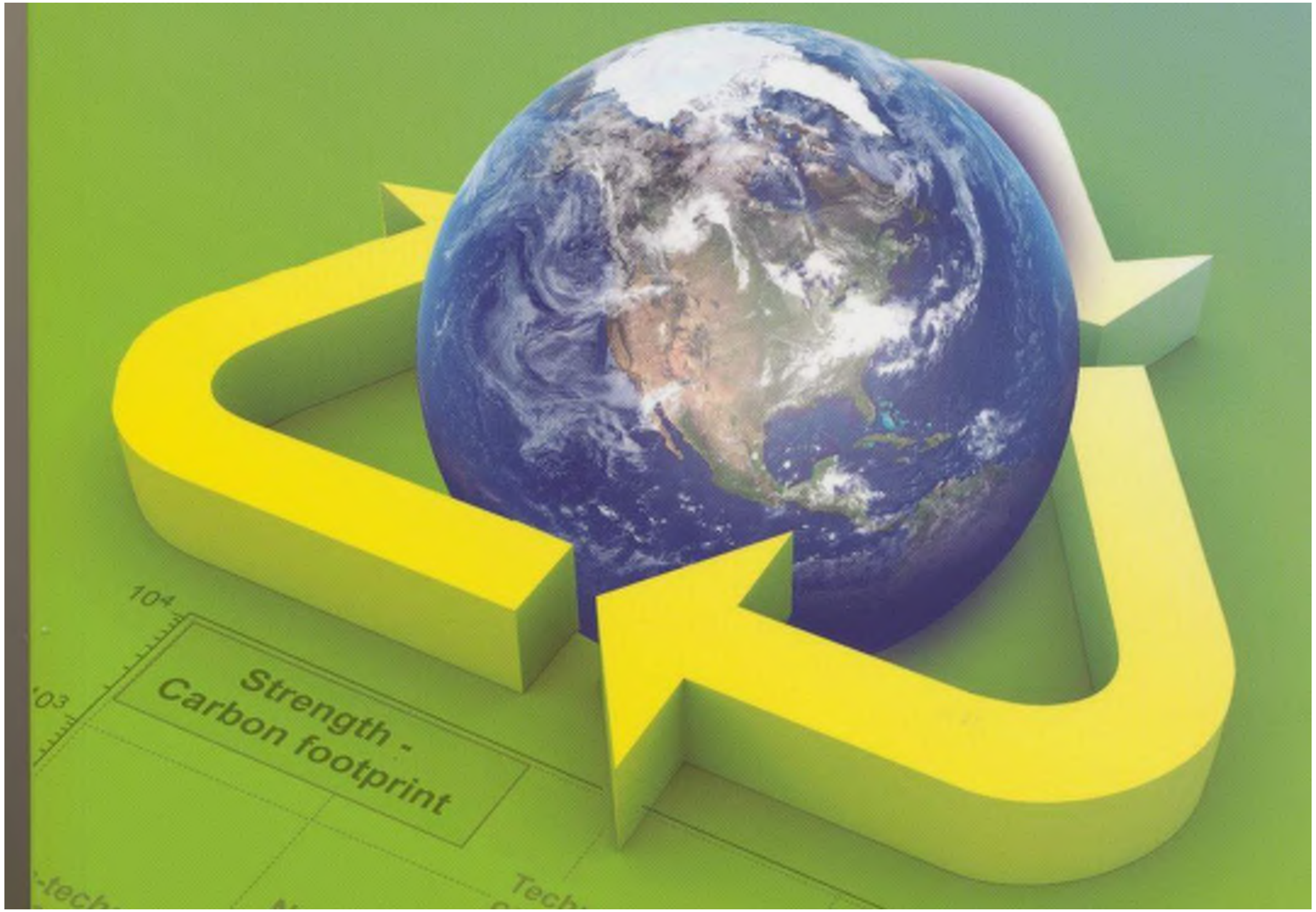
Resilience and Sustainability

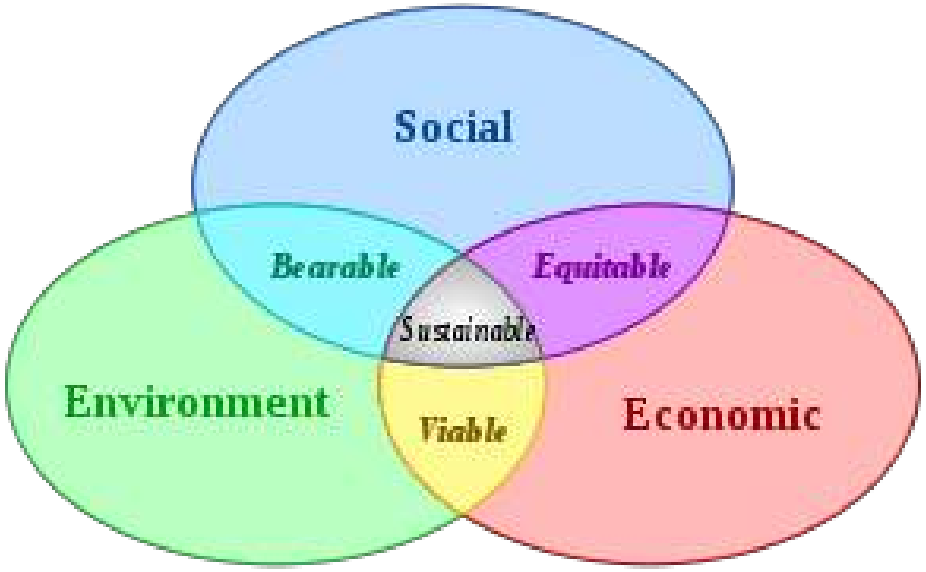


Tendall et al. 2015

- Resilience and sustainability are complementary concepts.
- Resilience is the ability to deal with adversity, withstand shocks, and continuously adapt and accelerate as disruptions and crises arise over time.

Sustainability and Resiliency





Sustainable development can only happen

When all the three needs are

1[redacted] Southeastern Peer Exchange for Resilient & Sustainable Bridges (SPxRSB-2023)

ACI's Perspective on Sustainability of Concrete

Antonio Nanni – ACI President & University of Miami

American Concrete Institute
Always advancing

Global Movement

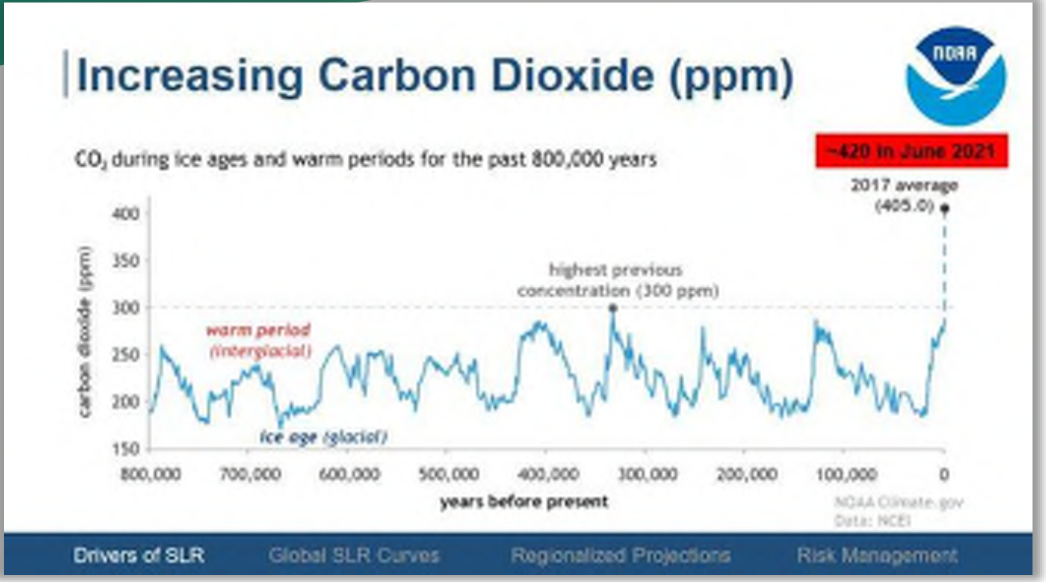
- Paris Agreement – targets limiting global warming to 1.5 degrees Celsius
- U.S. goal is to reduce emissions 50% below 2005 levels by 2030
  - 100% carbon pollution-free electricity by 2035
  - Achieving net–zero emissions by 2050

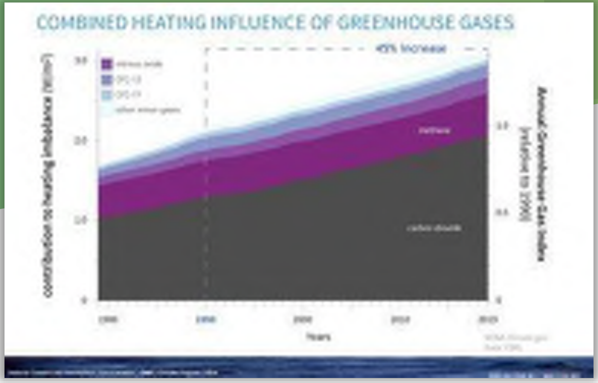
Why Focus on Carbon?

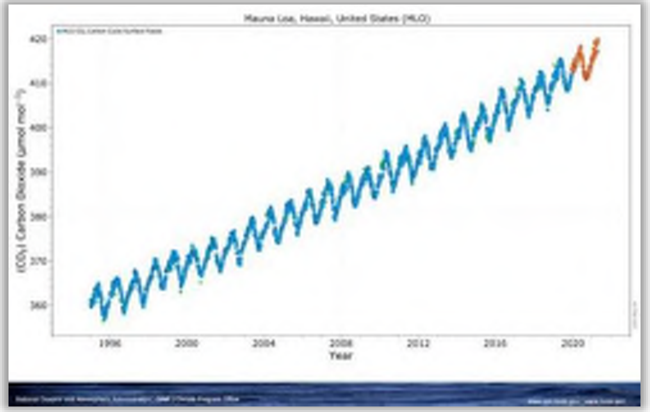
- We know there is a lot more to sustainability than Global Warming
  - Environmental, Social and Economic factors all play into sustainability
- We also know that concrete really shines in many areas related to sustainability
  - Resilience, thermal mass, durability, etc.
- Global warming is affecting everyone on the planet
- But we also know that the industry is in an excellent position to improve upon the one area that tends to receive the most negative attention – CO_2 emissions
- We can measure the amount of CO_2 associated with concrete
- Can't improve something without being able to measure it first

Visual Aids on CO_2

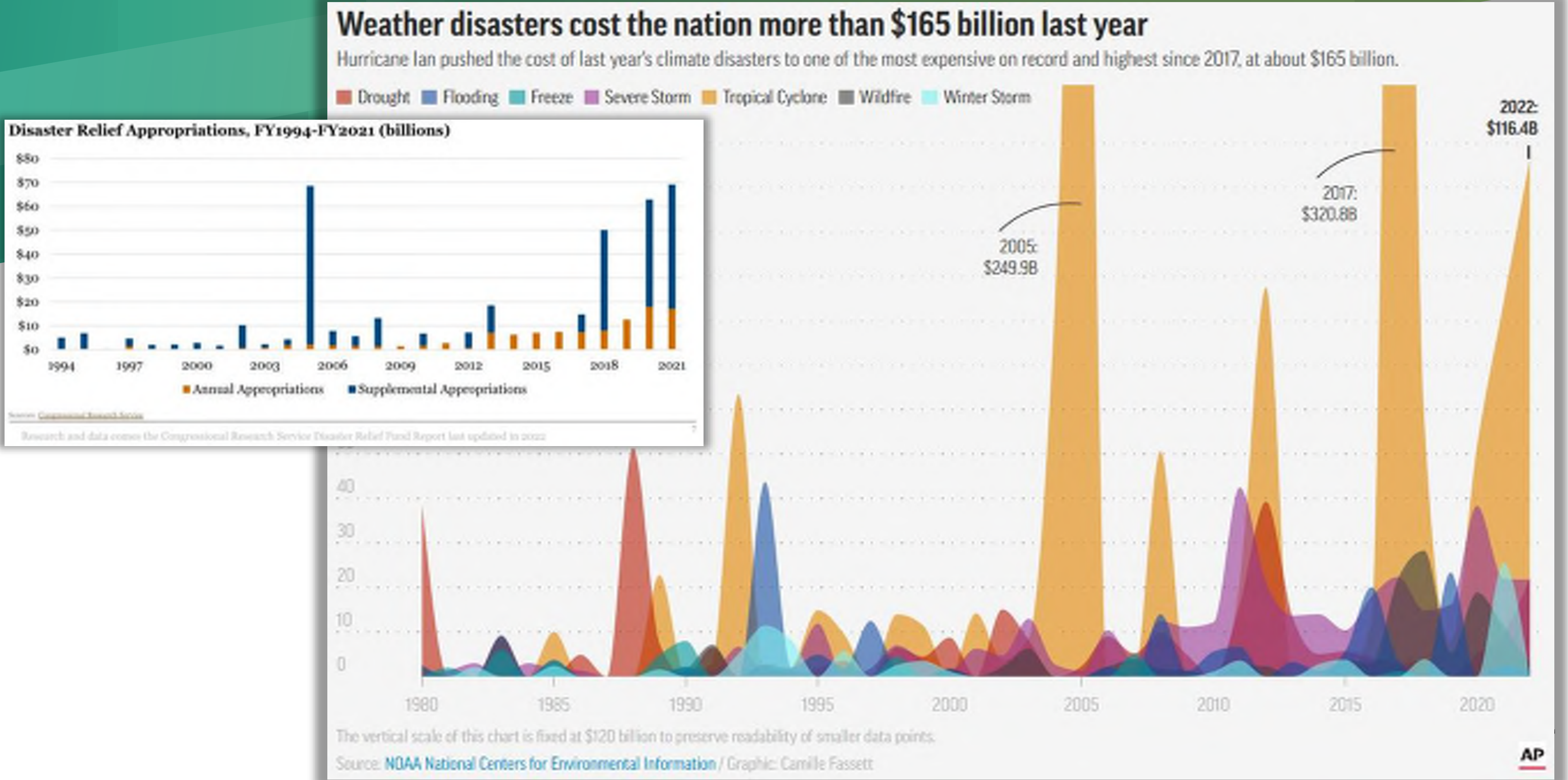
- From NOAA sources







Accelerating Effects from Increased CO_2 on Disasters



What do we mean by Carbon Neutrality?

- The term Carbon represents CO_2 released into the atmosphere
- Carbon Neutral: balancing carbon emissions with the absorption of carbon from the atmosphere through carbon sequestration, offsets, or sinks
  - Soil, forests, oceans
  - Concrete
- Carbon offsetting from emissions made in one sector and reducing them elsewhere
  - Renewable energy
  - Energy efficiency
  - Lower carbon technologies
- Carbon reduction is necessary to reach neutrality

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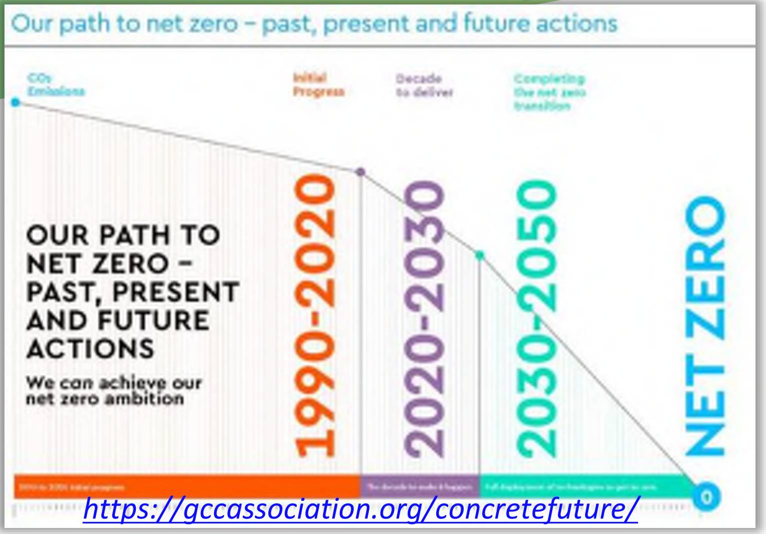
Cement and Concrete Industry Roadmaps

Various construction sectors, organizations, and global regions are creating roadmaps.



https://gccassociation.org/concretefuture/

- Carbon Capture, Utilization and Storage (36%)
- Efficiency in Design and Construction (22%)
  - Design optimization, site efficiency, re-use, etc.
- Clinker Production Savings (11%)
  - Reducing traditional limestone use, fuel sources, etc.
- Efficiency in Concrete Production (11%)
  - Optimized mix designs, quality control, industrialized manufacturing
- Savings in cement and binders (using SCM's) (9%)
- Recarbonation (6%)
- Decarbonizing Electricity (5%)

*Global Cement and Concrete Association

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What's a professional to do?

- Overwhelming amount of information
- Concrete is a multi-faceted industry
- Various professional knowledge levels from both the supply and demand side of the industry
- Need for accelerated adoption of new materials and technologies

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ACI's Influence for Cultural Change in the Industry

ACI's leadership for over 100 years

- Non-trade association
- Education, training and certification
- Code and specification development
- Many start in the industry with ACI
- Strong student and international membership
- Aware of the urgency

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neu

An ACI Center of Excellence for Carbon Neutral Concrete

Vision

The Center envisions a concrete industry where all stakeholders have access to technologies and the knowledge needed to effectively and safely produce and place carbon-neutral concrete and concrete products in the built environment

Mission

To drive education, awareness, and adoption of the use of carbon-neutral concrete materials and technologies

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ACI Center of Excellence for Carbon-Neutral Concrete

Core Functions:

- Material and Technology Validation/Verification Program
- Technology Transfer and Acceleration/Implementation
- Advocacy and Technical Support
- ACI Committee Assistance
- Training and Professional Development
- International and Student Outreach

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Members of NEU

Sustaining Members

Meta

Breakthrough Energy

Supporting Members

BAKER
CONCRETE CONSTRUCTION

Affiliate Members

aoe
Advancing Organizational Excellence

Atlantis FIBER

ASH GROVE
A CRH COMPANY

OZINGA

Heidelberg Materials

aci Foundation
Knowledge to Practice

CarbonBuilt™

ceEntek

STONE COAT

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Allied Organizations

- NEU will work with industry collaborators through an allied organization level of participation.
- Mission aligned industry associations, govt. agencies, universities, etc.

Allied Organizations

- International Code Council Evaluation Services (ICC-ES)
- Inter-American Cement Federation (FICEM)
- Concrete Innovation Hub – UC – Santiago, Chile (CIHUC)
- ASTM, International
- NRMCA
- CP Tech Center at ISU

Pending Allied Organizations

- PCA
- ACPA

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Thank you!

www.neuconcrete.org

info@neuconcrete.org

NEU: An ACI Center of Excellence for Carbon Neutral Concrete

@NEUCarbonNeutralConcrete

@NEUconcrete

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Strategies on Resilience for Bridges & Structures

Prepared and presented by:

Steven Nolan, P.E.

FDOT State Structures Design Office

Senior Structures Design Engineer

Ponte Pietra Bridge (Born 100 BC)

Condition in 2016 (Verona, Italy)

Resilience Definitions

FDOT

- *"the ability of the transportation system to adapt to changing conditions and prepare for, withstand, and recover from disruption."* (April 27, 2020)

USACE

- *"the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions."* (Dec 1, 2020)

USDOT/FHWA (Pavements)

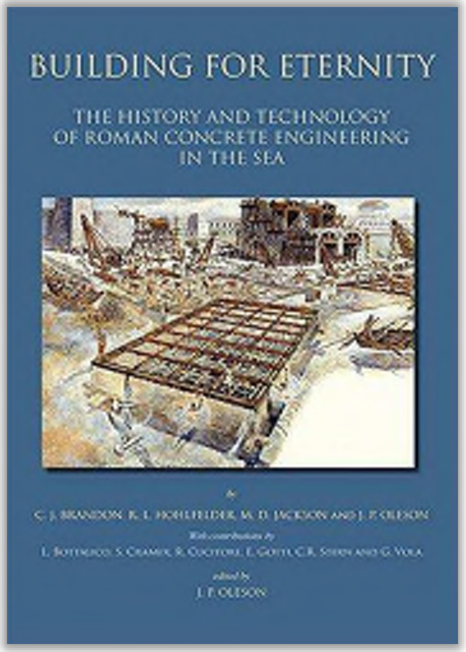
"…the ability to anticipate, prepare for, or adapt to conditions or withstand, respond to, or recover rapidly from disruptions, including the ability to:

- *Resist hazards or withstand impacts from weather events and natural disasters.*
- *Reduce the magnitude or duration of impacts of a disruptive weather event or natural disaster.*
- *Have absorptive capacity, adaptive capacity, and recoverability to decrease project vulnerability to weather events or other natural disasters.*
- *The consideration of incorporating natural infrastructure."*

(May 15, 2023)

Resilience Policy & Planning

Antiquity



FDOT Resiliency Policy (2020)

FDOT

Florida Department of Transportation

POLICY

Effective: April 27, 2020
Office: Policy Planning
Topic No.: 000-525-053

RESILIENCY OF STATE TRANSPORTATION INFRASTRUCTURE

It is the policy of the Florida Department of Transportation to consider resiliency of the State's transportation system to support the safety, mobility, quality of life, and economic prosperity of Florida and preserve the quality of our environment and communities. Resiliency includes the ability of the transportation system to adapt to changing conditions and prepare for, withstand, and recover from disruption.

The Department will continue to identify risks, particularly related to sea level rise, flooding, and storms; assess potential impacts; and employ strategies to avoid, mitigate, or eliminate impacts.

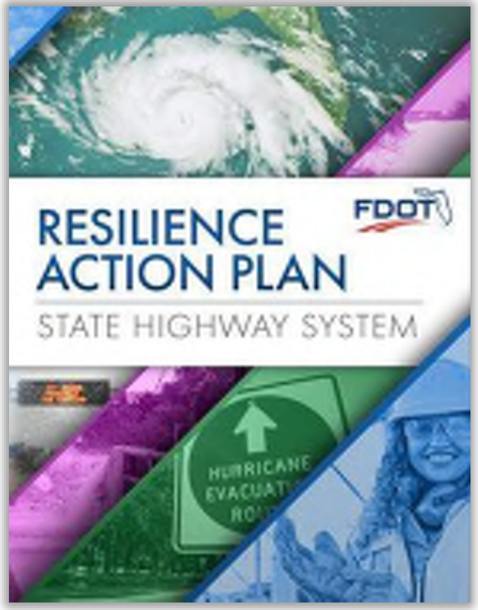
The Department recognizes that shocks and stresses vary throughout the State, and on-going multidisciplinary efforts by other agencies are important considerations. The Department will collaborate with the appropriate agencies and organizations for information sharing and alignment of resiliency strategies.

This policy will be implemented through the Department's long-range and modal plans; work program; asset management plans; research efforts; and internal manuals, tools, guidelines, procedures, and related documents, guiding planning, programming, project development, design, construction, operations, and maintenance.

Kevin J. Thibault, P.E.
Secretary

https://www.fdot.gov/planning/policy/resilience/default.shtm

FDOT Resilience Action Plan (RAP-2023)



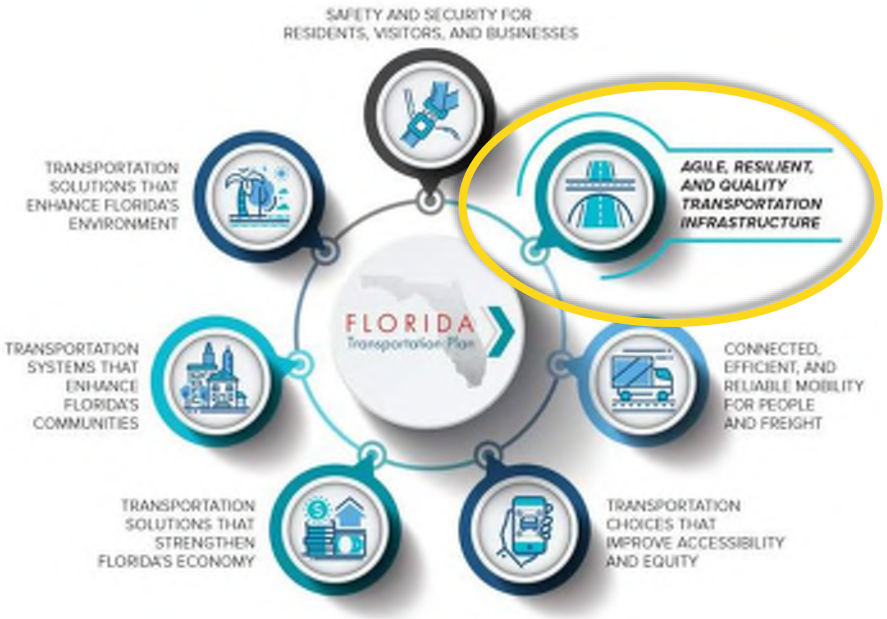
https://www.fdot.gov/planning/policy/resilience/resilience-action-plan

FDOT Resilience Policy & Plan

How does the RAP-2023 fit into the 2045 Florida Transportation Plan?

- The goal of "***Agile, resilient, and quality transportation infrastructure***" recognizes the importance of transportation resilience and speaks to the need to plan, design, and construct infrastructure to withstand and recover from potential risks, such as extreme weather events and climate trends. Resilience is addressed in many FDOT plans. The **Resilience Action Plan** builds on the goals and objectives of FDOT and its partners.

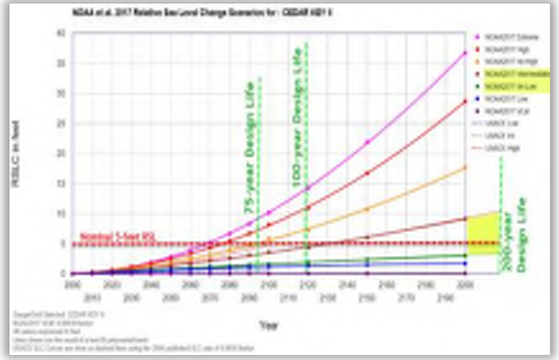
http://floridatransportationplan.com/



→ Focusing on Structures: LRFD Design Practice

LOAD (Stressors & Shocks)

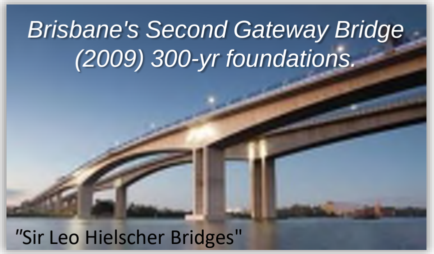
- Structural Loading *(Traffic, Extreme Event – Vessel Collision, Weather)*
- Environmental Loading *(Cl^-, SO_4, pH, ASR, UV, SLR, Freeze-Thaw, Wildfire)*
- Future Use *(Capacity increase, Functional change, Hydraulic change)*
- Justification *(LCC, LCA, Social Benefit & Equity; Cost Benefit comparison)*



RESISTANCE (Resilience)

- Structural Capacity *(Mandatory Codes vs. Guide Specifications; ULS vs. SLS)*
- Material Endurance *(Strength, Fatigue; Creep - constant vs. declining threshold limits?; extrapolation validity)*
- Material Durability *(Aging effects; Accelerated testing vs. Durability models)*

Aspiration for Structures – **R&A Design Goals**



"Sir Leo Hielscher Bridges"
(Photo courtesy Transurban Limited)

RESILIENCE

- **Robustness** *(Bend don't break)*
- **Durability:** Inert or Regenerative materials *(Ultra-durable, Self-healing, or easily replaceable)*
- Rapid **Repair &/or Replacement** *(component upgrade, periodic replacement)*

ADAPTABILITY

- **Repurposing** *(Roadway - commuting/freight, vs. Transit, vs. Shared-use)*
- **Tunable** *(Strengthening, Widening, Raise, Lengthen?)*
- **Future** Proofing *(Hydraulic Capacity, Vertical Clearance, Sea-water encroachment)*

→ Structures <u>LR</u>FD Design Practice

+

Structures <u>R&A</u> Design Goals

=

Load & Resistance Factor Design for Resilience & Adaptability (LRFD-R&A)

Questions & Discussion

SAFETY IS EVERYONE'S RESPONSIBILITY

THE SAFE SYSTEM APPROACH

Zero is our goal. A Safe System is how we will get there.

TARGET ZERO FATALITIES & SERIOUS INJURIES

1st Southeastern Peer Exchange for Resilient & Sustainable Bridges – Part 2

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Session 1 : Introduction & Logistics (August 8th, 2023)

Participants & Sponsors

LADOTD Perspective on Resilient Bridges

2023 SASHTO
8/8/2023

Zhengzheng (Jenny) Fu, P.E.
LADOTD Bridge Design Administrator

LOUISIANA DEPARTMENT OF TRANSPORTATION & DEVELOPMENT

OUTLINE

- LADOTD Strategies
- Wave and Surge Atlas Project
- NCHRP 23-32 Project Overview

LADOTD Strategies

- Evaluate risks from major events (hurricanes, flooding, wind, fire, vehicular/vessel collisions, etc.) and consider resiliency in all project development stages from planning to operation.
- Elevate bridges and movable bridge equipment as high as possible to avoid wave and flooding. Sometimes it's impossible to do so due to R/W and other constrains, then these bridges have to be designed for the conditions.
- Implement sacrificial beams for bridges vulnerable to vehicle collisions.
- Evaluate and implement better materials to minimize maintenance cost and extend service life (surface resistivity requirement in concrete, stainless steel, UHPC, CFCC cable, FRP rebar, etc.)

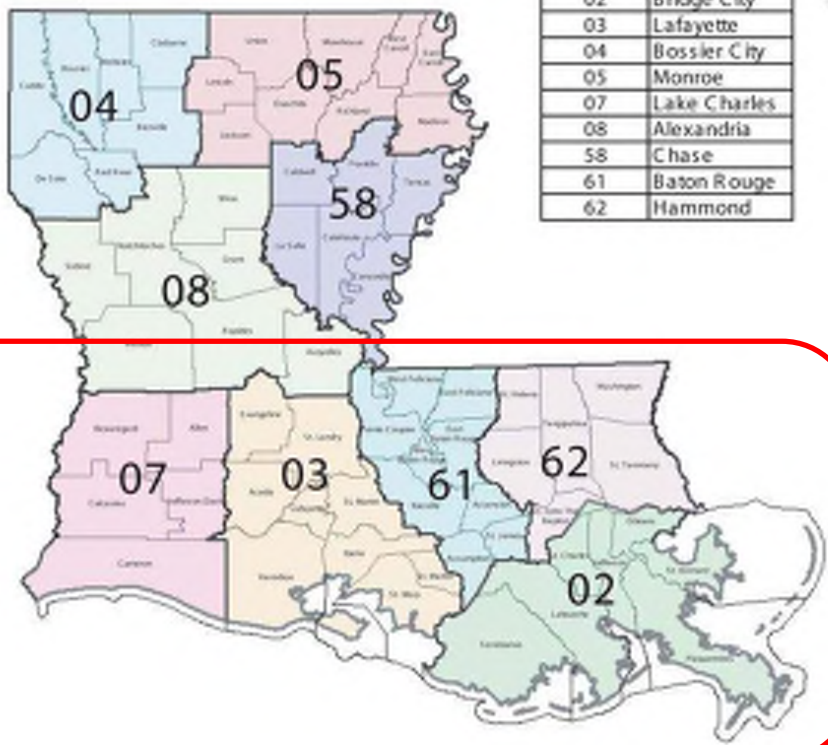
Wave and Surge Atlas Project

(LTRC Projects 10-4ST & 15-1ST, 2011-2015, by OEA/INTERA Inc.)

8000 On-System Bridges
5000 Off-System Bridges

DOTD Districts

Number	District Name
02	Bridge City
03	Lafayette
04	Bossier City
05	Monroe
07	Lake Charles
08	Alexandria
58	Chase
61	Baton Rouge
62	Hammond



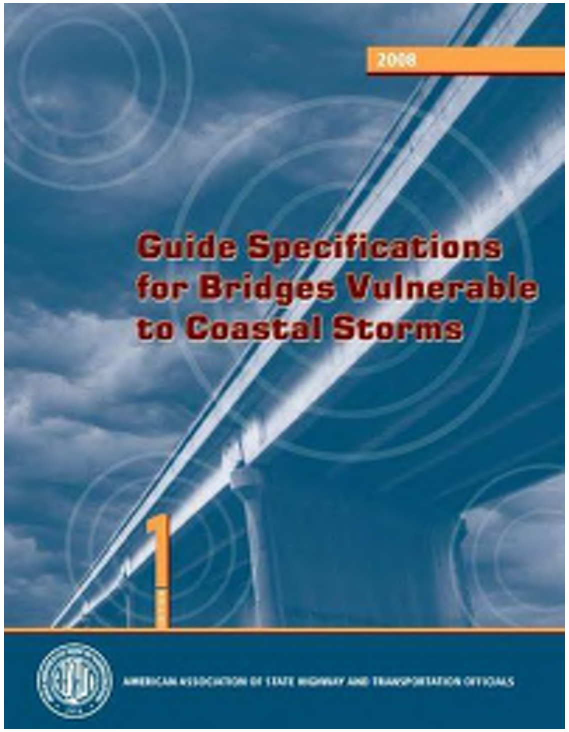
3177 (40%) On-System Bridges in Coastal Parishes

Hurricane Katrina in 2005 destroyed many coastal bridges including the I-10 Twin Span Bridges

How vulnerable are our coastal bridges?

Purposes of the Project

- Prior to 2005 Katrina, no guidance on wave and surge
- I-10 Twin Span Project – Moffatt & Nichol Study
- 2008 AASHTO Guide Specifications – Three Levels of Analysis – Level I, II and III
- Develop site specific wave and surge atlas for coastal Louisiana (Level III analysis) to provide wave parameters needed for wave force calculations per Guide Spec – needed for vulnerability study of existing bridges and new bridge design



LOUISIANA DEPARTMENT OF TRANSPORTATION & DEVELOPMENT

Purposes of the Project

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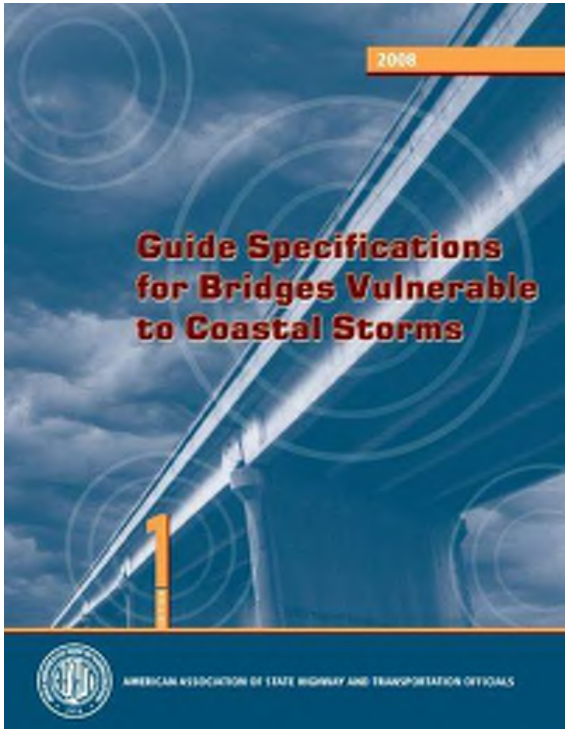
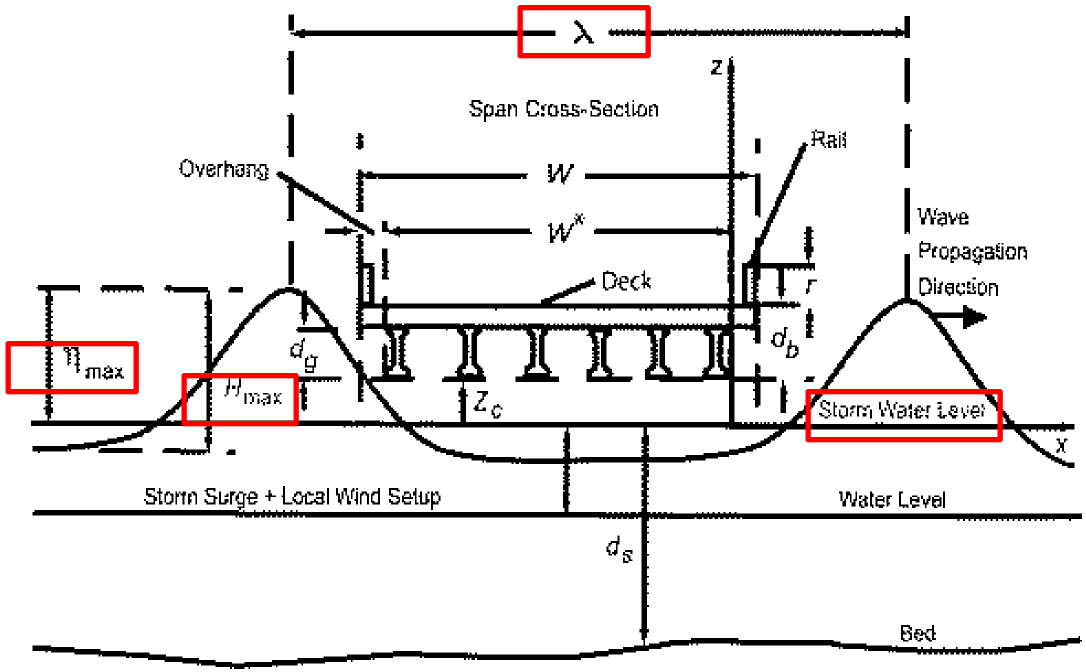


Wave Parameters



Water Level	=	mean sea level if storm surge includes astronomical tide
	=	mean higher high water level if astronomical tide not included in surge
η_{max}	=	wave crest height above storm water level
H_{max}	=	maximum wave height
λ	=	wave length
d_s	=	storm water depth at the bridge
d_b	=	girder height + deck thickness
d_g	=	girder height
Z_c	=	positive or negative distance from storm water level to bottom of girder
r	=	rail height
W	=	deck width

Figure 6.1.2.2.1-1—Nomenclature in Eqs. 1–8

Methodology

METHODOLOGY 7

Wind, Storm Surge, and Wave Models 7

Wind and Atmospheric Pressure Fields 7

Storm Surge and Wave Model Selection 9

Storm Surge and Wave Hindcast Procedure 21

Selection of Hindcast Storms 22

Model Runs/Example Results 25

Extreme Value Analyses 30

Design Conditions for Wave Loading 30

Extreme Value Analysis Results 31

Wave and Surge Atlas 38

Coastal Bridge Vulnerability to Surge/Wave Forces 41

Selection of Bridges for Evaluation 41

Method of Analysis 47

LTRC Project 10-4ST Final Report 528

LOUISIANA DEPARTMENT OF TRANSPORTATION & DEVELOPMENT

Selection of Hindcast Storms

Table 7
Storms identified for hindcasting

Storm	Date
Not Named	19-Aug-1852
Not Named	15-Sep-1855
Not Named	09-Aug-1856
Not Named	08-Aug-1860
Not Named	11-Sep-1860
Not Named	30-Sep-1860
Not Named	06-Sep-1865
Not Named	02-Oct-1867
Not Named	19-Aug-1879
Not Named	29-Aug-1879
Not Named	14-Sep-1882
Not Named	13-Jun-1886
Not Named	08-Oct-1886
Not Named	14-Aug-1888
Not Named	04-Sep-1893
Not Named	27-Sep-1893
Not Named	10-Sep-1897
Not Named	27-Aug-1900
Not Named	19-Sep-1906
Not Named	13-Sep-1909
Not Named	05-Aug-1915
Not Named	21-Sep-1915
Not Named	28-Jun-1916
Not Named	20-Sep-1917
Not Named	01-Aug-1918
Not Named	22-Aug-1926
Not Named	12-Aug-1932
Not Named	02-Aug-1940
Not Named	25-Jul-1943
Not Named	04-Sep-1947
Not Named	27-Sep-1949
AUDREY	25-Jun-1957
ETHEL	14-Sep-1960
HILDA	28-Sep-1964
BETSY	27-Aug-1965
CAMILLE	14-Aug-1969
EDITH	05-Sep-1971
CARMEN	29-Aug-1974
FREDERIC	29-Aug-1979
DANNY	12-Aug-1985
ELENA	28-Aug-1985
JUAN	26-Oct-1985
ANDREW	16-Aug-1992
GEORGES	15-Sep-1998
LILI	21-Sep-2002
KATRINA	23-Aug-2005
RITA	18-Sep-2005
HUMBERTO	12-Sep-2007
GUSTAV	25-Aug-2008
IKE	01-Sep-2008

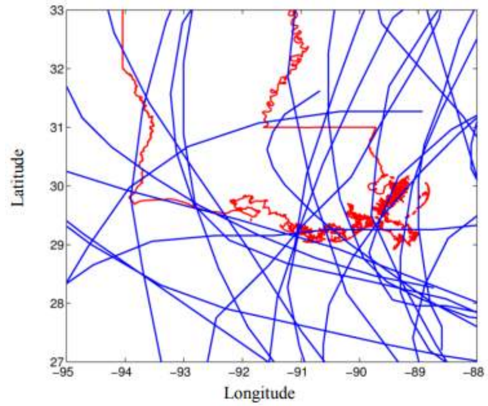


Figure 10
Paths of storms that occurred before 1920

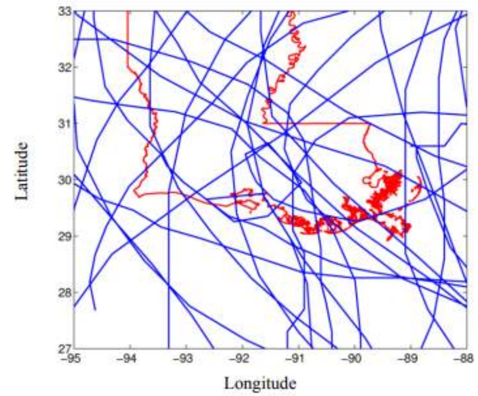


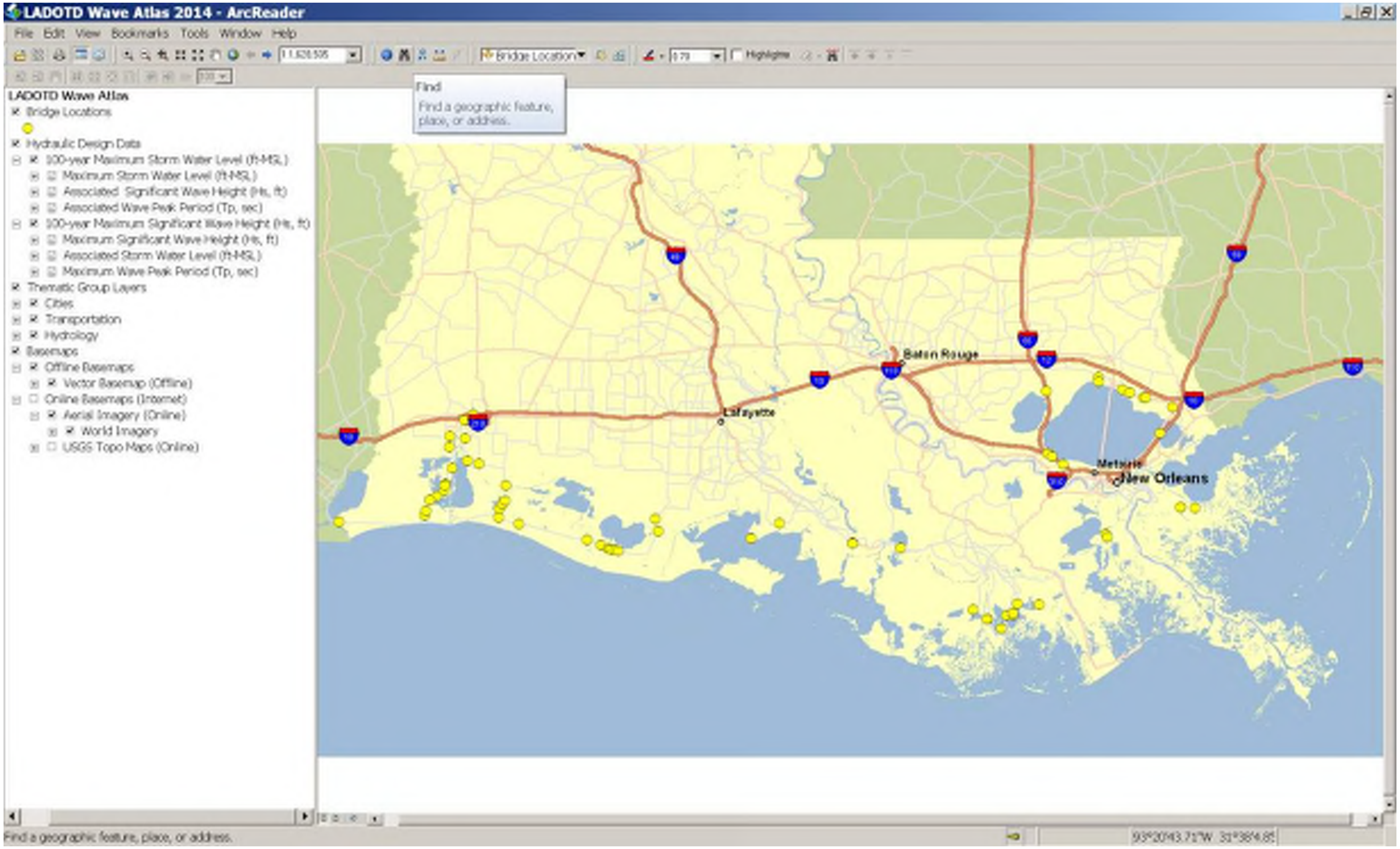
Figure 11
Paths of storms that occurred after 1920

50 major storms over 160 years
+
a selected number of storms were shifted to the left and right of the actual path
=
124 hindcast storms

(enough data set for extreme value analysis)

LOUISIANA DEPARTMENT OF TRANSPORTATION & DEVELOPMENT

Wave and Surge Atlas - GIS Database



Wave and Surge Atlas Project Results

For any bridge location:

- Wave parameters for 5, 10, 25, 50, 100 year return periods
- Wave parameters for the worst actual storm (50)
- Wave parameters for all hindcast storms (124)

AASHTO Wave Load Calculation Program (Visual Basic Program)
Based on AASHTO Guide Specification

NCHRP 23-32 Transportation Asset Risk and Resilience Project Status

Information Provided by

Ahmad Abu-Hawash, PE
NCHRP Senior Program Officer

Phone: 202-334-2257
Cell: 515-231-2329
E-mail: aabu-hawash@nas.edu

- A contractor was selected
- In contracting process
- Expect to start later this year

NCHRP 23-32 [Pending]

Transportation Asset Risk and Resilience

Project Data	
Funds:	$3,500,000
Contract Time:	36 months
Staff Responsibility:	Ahmad Abu Hawash
Comments:	A research agency has been selected for the project. The contracting process is underway.

NCHRP 23-09 “Scoping Study to Develop the Basis for a Highway Standard to Conduct an All-Hazards Risk and Resilience Analysis”

(Project completed in 2022/Final Report 1014 published in 2023)

Objectives: Provide a scoping study for a transportation framework for all-hazards risk and resilience analysis of transportation assets. The scoping study is to accomplish the following :

- Develop a comprehensive and consistent set of **risk- and resilience-related terminology** for transportation agency use; and
- Provide a **research roadmap** for developing a framework for a quantitative all-hazards risk and resilience analysis of transportation assets, with its associated tools, and guidance on its application.

[Developing a Highway Framework to Conduct an All-Hazards Risk and Resilience Analysis]

1 Summary

3 **Chapter 1** Introduction
3 1.1 Background
4 1.2 Research Objectives
4 1.3 Organization of Report

6 **Chapter 2** State-of-Practice Review
6 2.1 Glossary of Terms
6 2.2 Literature Review
7 2.3 Gap Assessment
8 2.4 Stakeholder Engagement

11 **Chapter 3** Risk and Resilience Framework
11 3.1 Organization
12 3.2 Scoping
13 3.3 Assessment
14 3.4 Management

15 **Chapter 4** Roadmap
15 4.1 Roadmap Mission
15 4.2 Roadmap Goals
16 4.3 Roadmap Thematic Lanes
17 4.4 Roadmap Phases and Duration

21 **Chapter 5** Research Problem Statement Development

25 **Chapter 6** Stakeholder Engagement

27 **Chapter 7** Research Outputs, Recommendations, and Next Steps
27 7.1 Research Outputs
27 7.2 Findings and Recommendations
28 7.3 Opportunities for Implementation
29 7.4 Next Steps

30 **Chapter 8** Conclusion

31 References

A-1 **Appendix A** Glossary of Terms

B-1 **Appendix B** Literature Review

C-1 **Appendix C** Gap Assessment

D-1 **Appendix D** Research Problem Statements

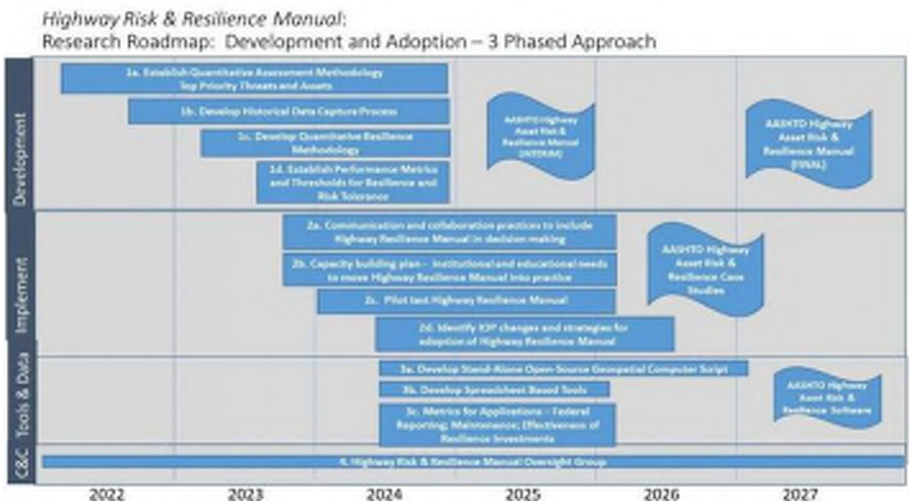
E-1 **Appendix E** Technical Memorandum—Stakeholder Engagement

Glossary of Terms and Page Number

Absorptive Capacity A-4
Acceptable Risk A-4
Adaptation A-4
Adaptive Capacity A-5
Adversary A-5
All-Hazards A-5
All-Hazards Approach A-5
All-Hazards Preparedness A-5
Analysis A-5
Annual Exceedance Probability (AEP) ... A-6
Assessment A-6
Asset A-6
Asset Class A-6
Asset Condition A-6
Asset Management A-6
Business Risk A-8
Capability A-8
Capability Maturity Framework (CMF) A-8
Change Averse A-8
Climate Change A-8
Climate Stressor A-9
Comprehensive Emergency Management .. A-9
Conditional Probability A-9
Conditional Risk A-9
Consequence A-9
Consequence Analysis A-10
Consequence-Mitigation A-10
Consequence-Mitigation Features A-10
Consequence-Mitigation Strategies A-10
Continuity of Operations (COOP) A-11

40 pages of terms

Research Roadmap (3-phased Approach):



Phase I	Development of an AASHTO manual
Phase II	Implementation
Phase III	Develop tools/software to support the use of the manual

NCHRP 23-32: Transportation Asset Risk & Resilience

Objectives: Provide a science-based technical resource to assess risk and resilience in transportation planning, design, construction, operation, and maintenance decisions. At a minimum, the research will develop:

- Quantitative, repeatable methods for conducting **risk assessments on top priority threats/hazards** for transportation assets;
- A **historical data-capture process and system** to support risk and resilience modeling and assessments;
- Quantitative **resilience assessment methods and metrics** for transportation assets; and
- Standardized methods to help state DOTs and other transportation agencies **identify the most appropriate risk mitigation or resilience improvement strategies**.

NCHRP 23-32: Transportation Asset Risk & Resilience

Deliverables will include:

- A draft language for the AASHTO Transportation Asset Risk and Resilience Manual
- A stand-alone conduct of research report
- Recommendations for future research, including research problem statements; and
- Identification of implementation pathways, key implementers, steps for capacity-building as defined in NCHRP Project 23-09, and well-defined scopes of work for further dissemination and pilot implementation of the methods.

NORTH CAROLINA
Department of Transportation

Fiber Reinforced Polymer Technology – NCDOT History and Vision

W. Cabell Garbee, II, PE
NCDOT Manufactured Products Engineer
May 8, 2023

History in North Carolina

- 2005 – Glass Fiber Reinforced Polymer (GFRP) Bridge Decks
- 2014 – NCDOT/NCSU Research Project 2014-09: *CFRP Strands in Prestressed Cored Slab Units*
- 2017 – Transportation Pooled Fund Research Project – 5(363): *Evaluation of 0.7 inch Carbon Fiber Reinforced Polymer Pretensioning Strands in Prestressed Beams*
- *2021 Harkers Island Replacement Bridge [Under Construction]*
    - *3200 ft long, No Structural Steel Reinforcement, Uses GFRP bars and CFRP strands*
- *2023 Brunswick County NC 179B over Calabash River [May letting]*
    - *FRP Reinforced 20" Square Concrete Piles*
    - *FRP Reinforced Substructure Caps or Precast Prestressed Conventional Steel Reinforced Substructure Caps (Contractor Option)*
- *2024 Tyrrell/Dare County (Alligator River), ~3 miles long*
    - *FRP Reinforced Square Concrete Piles or Drilled Shafts (Contractor Option)*
    - *FRP Reinforced Substructure Caps, Columns, & Footings*

Harkers Island Bridge Project Vision

- Cast-in-place Concrete (Superstructure & Substructure)
  - Glass Fiber Reinforced Polymer (GFRP) Bars

- Prestressed Concrete Girders
  - Carbon Fiber Reinforced Polymer (CFRP) Strands
  - GFRP Stirrup Option (utilized)
  - CFRP Stirrup Option

- Prestressed Concrete Piles
  - CFRP Strands
  - CFRP Spiral

- "NO" Steel Reinforcement
  - Steel ONLY in the Railing (MASH compliance)

Harkers Island

Harkers Island, NC

No in-water, seabottom disturbance, work allowed from April 1 through September 30

Prime Contractor:
Balfour Beatty Infrastructure Inc

Prestress Concrete:
Coastal Precast Systems Inc

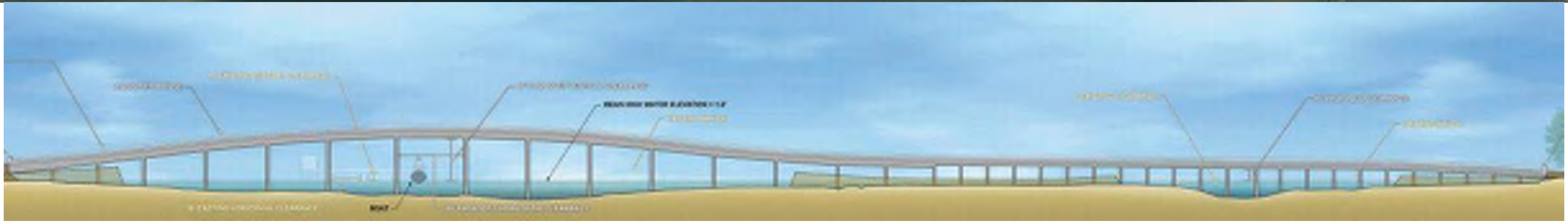
Availability: August 30, 2021
Completion: October 28, 2025

Bridge No. 96

- Built 1970
- Superstructure Replacement 2013
- Functionally Obsolete

Bridge No. 73

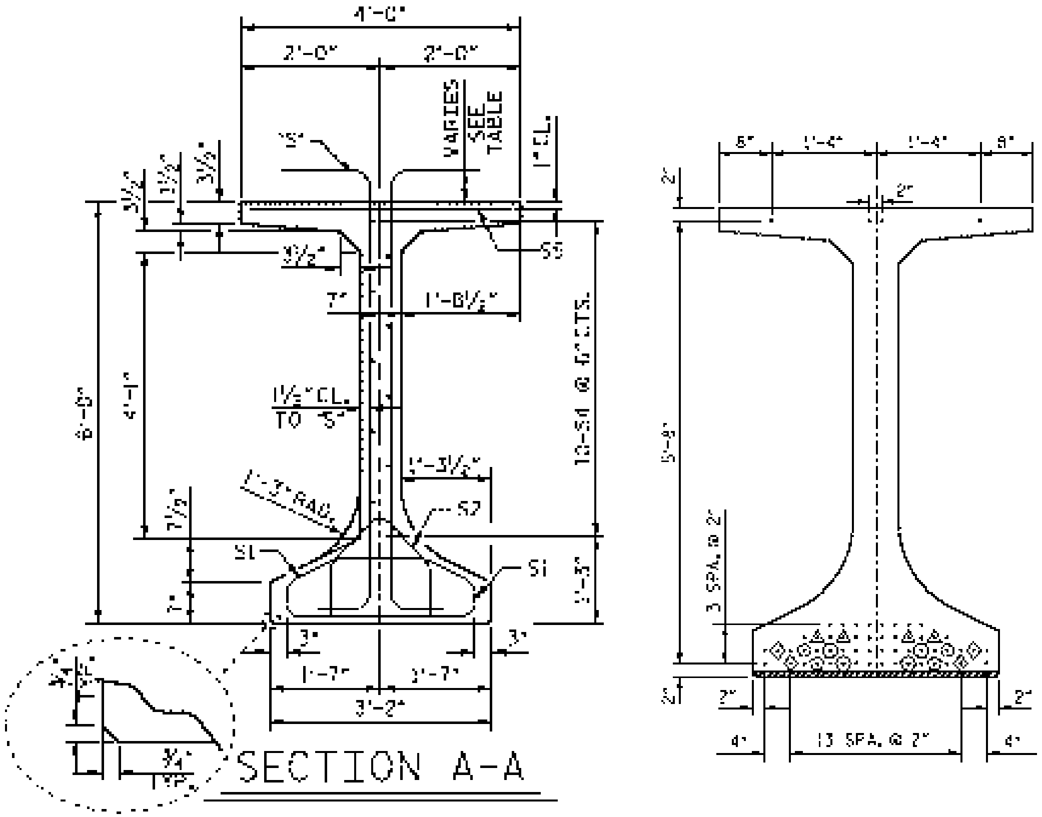
- Built 1969
- Posted SV 24, TTST 37
- Structurally Deficient



Proposed Structure: 3,200’-0”
28 Spans

Harkers Island Bridge Project Quantities

- CFRP Prestressing Strand:
  - Girders: 650,000 Linear Feet
  - Piles: 325,000 Linear Feet
- GFRP Reinforcement:
  - Superstructure: 715,000 Linear Feet
  - Substructure: 200,000 Linear Feet



NCDOT Product and Material Approvals:

1. NCDOT Product Evaluation Program (Approved Product List)
2. *NCDOT Production Facility Approval (HiCAMS Vendor List)*
    - Producer Facility Audit
    - Brand Registration
    - Materials Sampling and Process/Product Inspection

3. Project Acceptance (Job Site)
    - Certification
    - Visual Inspection
    - Materials Sampling and Inspection

Harkers Island Project Material Approvals:

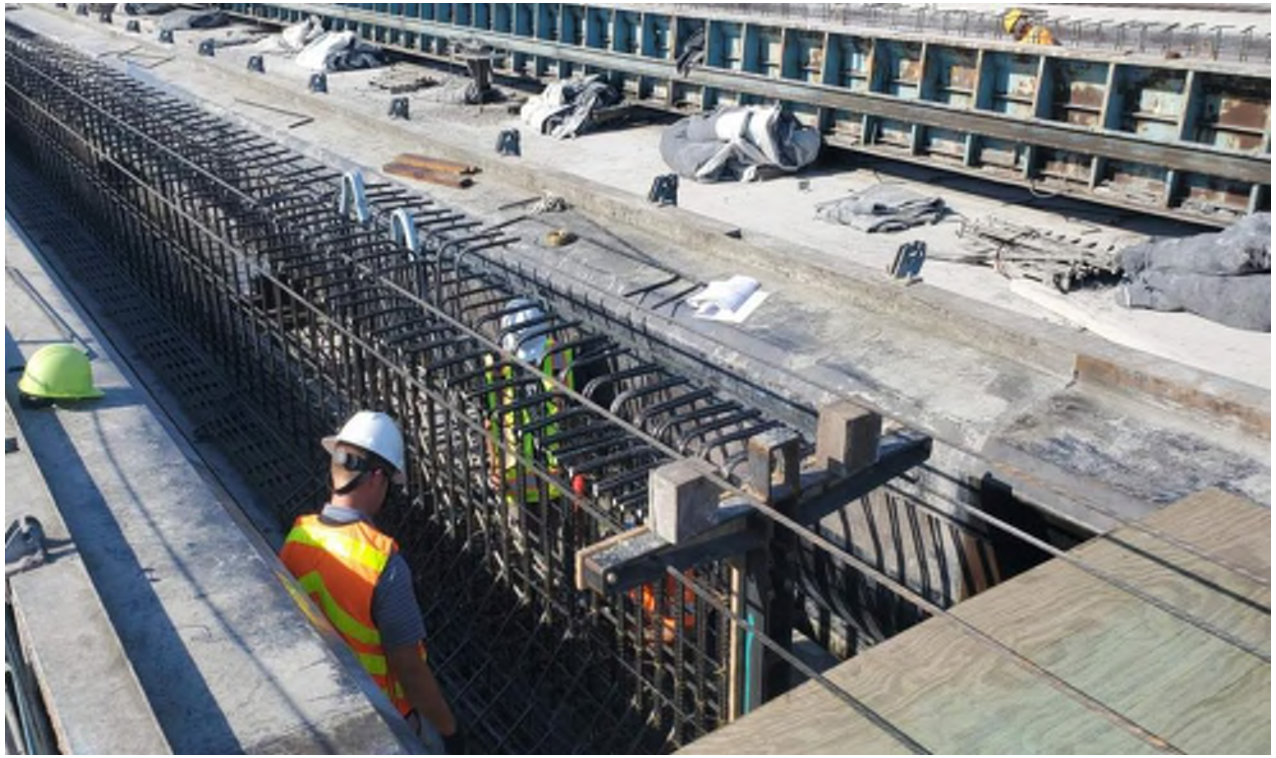
1. NCDOT Product Evaluation (Approved Product List)
2. *NCDOT Vendor Approval (Tokyo Rope, Owens Corning-Mateenbar)*
   Producer Facility Audit (FRP Institute for Civil Infrastructure)

3. Project Acceptance Testing (NCSU)

FRP INSTITUTE for CIVIL INFRASTRUCTURE FRP 2022

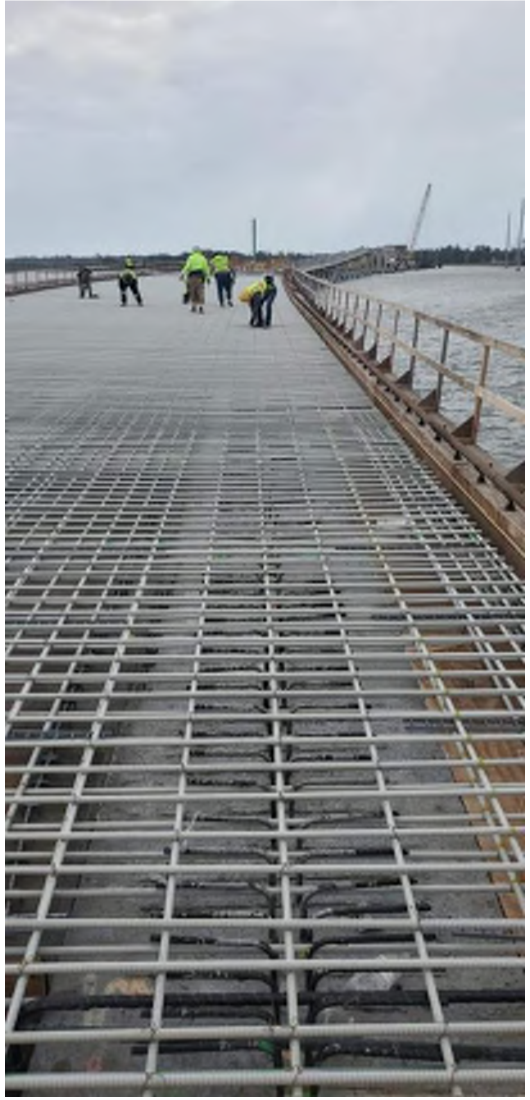
NC STATE UNIVERSITY

Pile production and shipment at Coastal Precast Systems Chesapeake, VA



Production of 54” FIB at Coastal Precast Systems Wilmington, NC

March 31, 2022. Mid-channel. End of phase one piles.



November 9, 2022

Glass Fiber Reinforced Polymer (GFRP) Bars

November 9, 2022
Piles, Caps, Beams…

November 9, 2022
Piles, Caps, Columns, Beams…

April 27, 2023

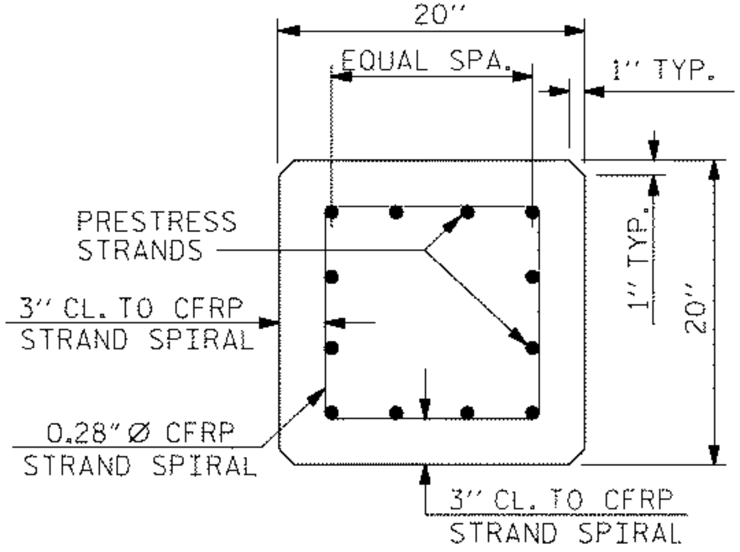
Traffic shift to new structure expected Fall 2023.

Brunswick County Bridge Project

Beach Drive SW (NC 179 Business over Calabash River)
Structure: 576 Feet
Two 12’ lanes with 4’ Shoulder Northbound and 10’ Multi-Use Path Southbound
Replaces bridge built in 1975

Piles: 20” Square
CFRP Spiral
CFRP Strand

Pile Caps:
GFRP Bar



TYPICAL SECTION F(

Alligator River Bridge Project

Replace Lindsay C. Warren Bridge, US64 over Alligator River in Tyrrell and Dare Counties built in 1960 with Swing Span over Intercoastal Waterway.

Letting: 2024

Proposed:

- Fixed span with 65’ vertical navigation clearance
- Two, 12’ lanes with 8’ shoulders
- Length approximately three miles
- One of Nine FHWA MegaGrant Projects, $110 Million Grant

Proposed Design Options:

Piles: 36” Square
- CFRP Spiral
- CFRP Strand

Drilled Shafts: 60” Diameter
- GFRP Bar

Pile Caps, Columns, Footings:
- GFRP Bar

Carteret County Bridge Rehabilitation

BRIDGE #68 OVER BOGUE SOUND ON SR-1182 (ATLANTIC BEACH CAUSEWAY)
BRIDGE #6 OVER BOGUE SOUND ON NC-58.

Comprehensive Structural Rehabilitations with FRP Component

- Pile Encapsulation
  - FRP Outer Jacket
  - Epoxy Grout

Contractor: Freyssinet: Sterling, VA
Let: April, 2017
Material: Foreva TFC350 (carbon fiber fabric)
Foreva EPX (two component epoxy resin)

Revised Project Completion: June 2023

Recap:

Existing/Proposed Projects

- Bridge Deck Reinforcement (2 Bridges)
- Substructure and Superstructure (1 Bridge)
- External Reinforcement (2 Bridges)

Proposed Projects (let 2023 and 2024)

- Substructure Reinforcement (2 Bridges)

Discussion (Future Projects)

- Deck Reinforcement
  - western counties/areas of heavy salt use
  - coastal areas with seawater exposure
- Substructure Reinforcement
  - coastal areas with seawater exposure

Questions?

W. Cabell Garbee, II, PE
NCDOT Manufactured Products Engineer
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cgarbee@ncdot.gov

FDOT Resilience Policy, Action Plan, & Structures Training

- A Focus on Bridges and Coastal Structures

Prepared and presented by:

– <u>Steven Nolan</u> *
– Will Potter


Photo: Courtesy of Fox News 4 (Hurricane Ian, 2022)

* *<u>Presenter</u>*

Abstract

FDOT has a long-standing commitment to improving the resiliency of the state transportation system to support the safety, mobility, quality of life, and economic prosperity of Florida, while preserving the quality of our environment and communities. Years of extreme weather events have led FDOT to improve the system's resiliency including better preparation for severe storms as well as quicker recovery in the event of extreme event. Use of design techniques and planning tools such as the Sea Level Rise Sketch Planning Tool that can provide roadway and bridge impact data for a range of climate and flooding scenarios is helping make our transportation system inherently resilient.

To solidify this commitment, FDOT enacted a Resiliency Policy in 2020 to include the goal of resiliency as an integral component the State's transportation system. Recent legislation at both the federal and state level further this commitment focusing on resiliency and leveraging the federal Infrastructure Investment and Jobs Act (IIJA). For accelerating implementation. The IIJA created the Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation (PROTECT) program and Section 339.157, Florida Statutes requires FDOT to develop a Resilience Action Plan (RAP). Details from the FDOT RAP with a focus on the component related to bridges and structures, are shared to encourage consideration and refinement of similar action by other state DOTs.

FDOT Resilience Policy & Plan

Resiliency Policy (2020)

Florida Department of Transportation

POLICY

Effective: April 27, 2020
Office: Policy Planning
Topic No.: 000-525-053

RESILIENCY OF STATE TRANSPORTATION INFRASTRUCTURE

It is the policy of the Florida Department of Transportation to consider resiliency of the State's transportation system to support the safety, mobility, quality of life, and economic prosperity of Florida and preserve the quality of our environment and communities. Resiliency includes the ability of the transportation system to adapt to changing conditions and prepare for, withstand, and recover from disruption.

The Department will continue to identify risks, particularly related to sea level rise, flooding, and storms; assess potential impacts; and employ strategies to avoid, mitigate, or eliminate impacts.

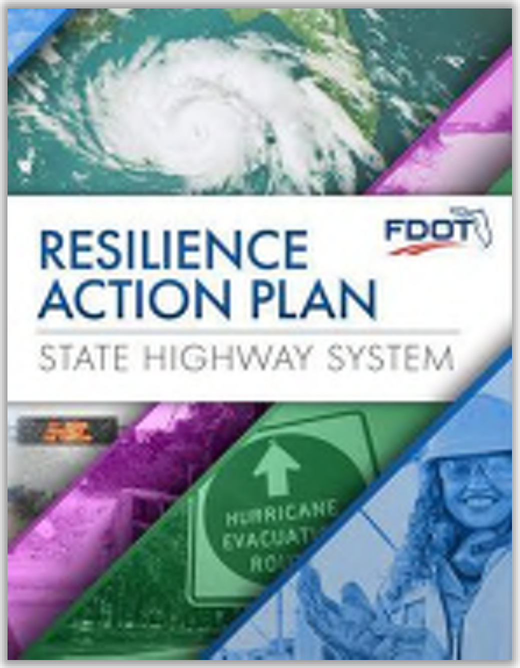
The Department recognizes that shocks and stresses vary throughout the State, and on-going multidisciplinary efforts by other agencies are important considerations. The Department will collaborate with the appropriate agencies and organizations for information sharing and alignment of resiliency strategies.

This policy will be implemented through the Department's long-range and modal plans; work program; asset management plans; research efforts; and internal manuals, tools, guidelines, procedures, and related documents, guiding planning, programming, project development, design, construction, operations, and maintenance.

Kevin J. Thibault, P.E.
Secretary

https://www.fdot.gov/planning/policy/resilience/default.shtm

Resilience Action Plan (RAP-2023)



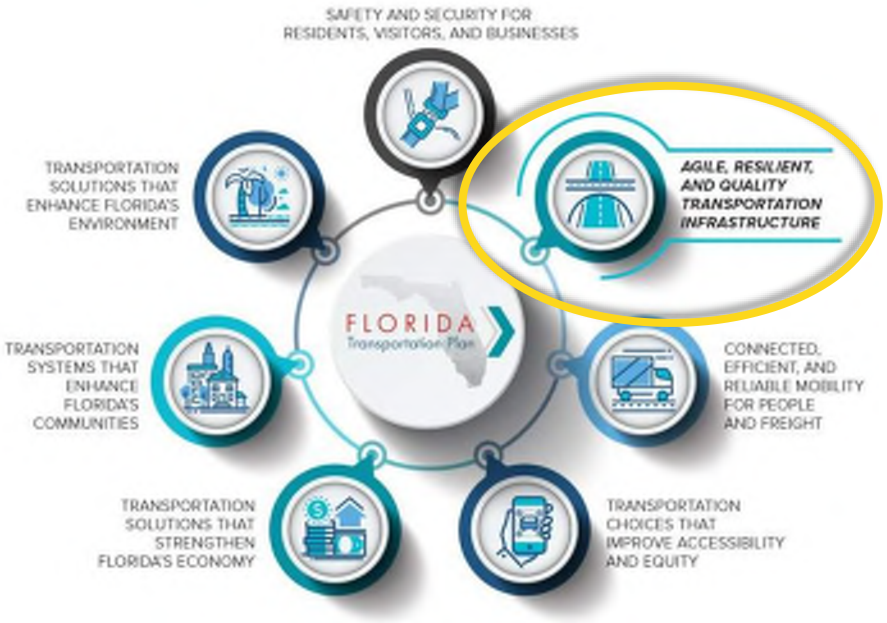
https://www.fdot.gov/planning/policy/resilience/resilience-action-plan

FDOT Resilience Policy & Plan

How does the RAP-2023 fit into the 2045 Florida Transportation Plan?

- The goal of "***Agile, resilient, and quality transportation infrastructure***" recognizes the importance of transportation resilience and speaks to the need to plan, design, and construct infrastructure to withstand and recover from potential risks, such as extreme weather events and climate trends. Resilience is addressed in many FDOT plans. The **Resilience Action Plan** builds on the goals and objectives of FDOT and its partners.

http://floridatransportationplan.com/



Resilience Definitions

FDOT

- *"the ability of the transportation system to adapt to changing conditions and prepare for, withstand, and recover from disruption."* (April 27, 2020)

USACE

- *"the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions."* (Dec 1, 2020)

USDOT/FHWA (Pavements)

"…the ability to anticipate, prepare for, or adapt to conditions or withstand, respond to, or recover rapidly from disruptions, including the ability to:

- *Resist hazards or withstand impacts from weather events and natural disasters.*
- *Reduce the magnitude or duration of impacts of a disruptive weather event or natural disaster.*
- *Have absorptive capacity, adaptive capacity, and recoverability to decrease project vulnerability to weather events or other natural disasters.*
- *The consideration of incorporating natural infrastructure."*

(May 15, 2023)

Sustainability Goals

FDOT

- Although no formal definition has been established, FDOT has used sustainable practices for decades:
  - Recycle Asphalt Pavement
  - Recycle concrete aggregate
  - Reuse of industrial byproducts Flyash & Steel Slag in Concrete
  - Adoption of Silica Fume,Ultrafine Flyash, & Metakaoline for high durability lower Portland Cement content concrete.
  - Recycle Plastics for Guardrail Block & Fender Systems.

Federal Government

- White House Executive Order 14057 (12/13/2021) *Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability*

USDOT/FHWA

- *Sustainable Pavements Program*

SUSTAINABLE PAVEMENTS PROGRAM

- EDC-7 *Environmental Product Declarations for Sustainable Project Delivery*

Sustainability Goals

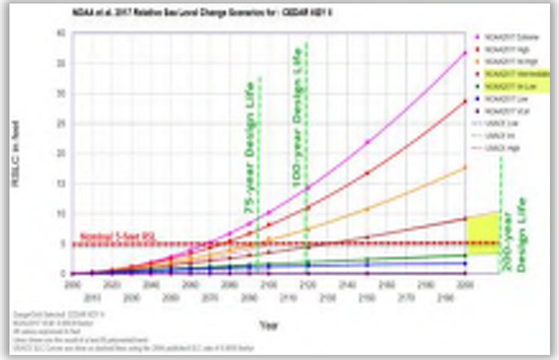
Sustainable Development Goals (SDG)

– United Nations Strategic Plan 2022-2025
  https://strategicplan.undp.org/

→ Focusing on Structures: LRFD Design Practice

LOAD (Stressors & Shocks)

- Structural Loading *(Traffic, Extreme Event – Vessel Collision, Weather)*
- Environmental Loading *(Cl^-, SO_4, pH, ASR, UV, SLR, Freeze-Thaw, Wildfire)*
- Future Use *(Capacity increase, Functional change, Hydraulic change)*
- Justification *(LCC, LCA, Social Benefit & Equity; Cost Benefit comparison)*



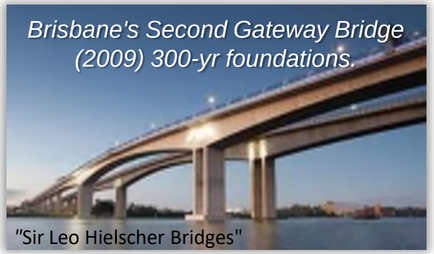
RESISTANCE (Resilience)

- Structural Capacity *(Mandatory Codes vs. Guide Specifications; ULS vs. SLS)*
- Material Endurance *(Strength, Fatigue; Creep - constant vs. declining threshold limits?; extrapolation validity)*
- Material Durability *(Aging effects; Accelerated testing vs. Durability models)*

Aspiration for Structures – **R&A Design Goals**

RESILIENCE

- **Robustness** *(Bend don't break)*
- **Durability:** Inert or Regenerative materials *(Ultra-durable, Self-healing, or easily replaceable)*
- Rapid **Repair &/or Replacement** *(component upgrade, periodic replacement)*



"Sir Leo Hielscher Bridges"
(Photo courtesy Transurban Limited)

ADAPTABILITY

- **Repurposing** *(Roadway - commuting/freight, vs. Transit, vs. Shared-use)*
- **Tunable** *(Strengthening, Widening, Raise, Lengthen?)*
- **Future** Proofing *(Hydraulic Capacity, Vertical Clearance, Sea-water encroachment)*

→ Structures LRFD Design Practice

+

Structures R&A Design Goals

=

Load & Resistance Factor Design for Resilience & Adaptability (LRFD-R&A)

Example of digging deeper → **Durability:**
Corrosion Mitigation & Protection Strategies

Decreasing Level of Mitigation

- Form & Function *(Compression vs. Flexural elements)*
- Inert Members *(Plain Concrete, Synthetic FRC, FRP)*
- FRP Rebar & Strand *(Fibers: Glass, Basalt, Aramid, Carbon; Resins: Thermoset vs. Thermoplastic)*
- SS Rebar & Strand (Duplex--> 316 --> Low-Cr.)

Decreasing Level of Protection

- Barrier Systems *(concrete resistivity, cover, rebar coatings...)*
- Cathodic Protection *(passive-galvanic, induced current-ICCP)*
- RC Re-alkalization
- Encapsulation *(UHPC)*
- Eternally bonded rehab. /strengthening *(FRP/NSM)*

FDOT Resilience Action Plan: **Project List**

MAP 4. HIGH, MEDIUM, & LOW VULNERABILITY GEOGRAPHIC AREAS: AREAS OF 1-3 HAZARD LOCATIONS

PROJECT COST SUMMARY BY TIER

Tier	Exposed SHS Centerline Miles	Exposed Bridge Centerline Miles	Total Number of Projects	Number of Projects in 5-Year Work Program	Total Cost Currently Programmed in 5-Year Work Program (Millions of $)	Average Cost per Project (Millions of $)
High	57	46	43	34	$438.47	$8.22
Medium	709	61	111	37	$230.62	

FDOT Resilience Action Plan:
High Priority Projects (North, Central & SW Florida)

District 1, 2, 3, & 5

ID	DISTRICT	TIER	SIS	DESCRIPTION	TIME FRAME	TOTAL PROJECT C	ADAPTATION STRATEGY
451280-1	1	High	No	SR 758 OVER SARASOTA BAY BRIDGE # 170061	FY 2024 to FY 2028	$ 5,115,956	ROADWAY OR BRIDGE APPROACH STABILIZATION
451357-1	1	High	No	US 41 OVER CALOOSAHATCHEE RIVER BRIDGE # 120002	FY 2024 to FY 2028	$ 1,179,441	ROADWAY OR BRIDGE APPROACH STABILIZATION
444776-1	1	High	Yes	I-75 (SR 93) SB OVER CALOOSAHATCHEE RIVER BRIDGE # 120083	FY 2024 to FY 2028	$ 441,505	ROADWAY OR BRIDGE APPROACH STABILIZATION
430204-2	1	High	No	SR 684 FROM SR 789 (GULF DR) TO 123RD ST W BRIDGE # 130006	FY 2024 to FY 2028	$ 85,387,986	ROADWAY OR BRIDGE APPROACH STABILIZATION
436680-2	1	High	No	SR 789 (RINGLING) FROM BIRD KEY DR TO SARASOTA HARBOR WEST	FY 2024 to FY 2028	$ 77,453,051	ROADWAY OR BRIDGE APPROACH STABILIZATION
445926-2	1	High	No	SR 789 EAST OF SUNSET DR TO BIRD KEY DR	FY 2024 to FY 2028	$ 9,575,684	MATERIALS TO WITHSTAND INUNDATION/OVERTOPPING
NA	1	High	No	SR 739 FROM FIRST ST TO US 41	Unfunded	$ 15,700,000	ROADWAY ELEVATION
NA	1	High	No	SR 789 AT ST ARMANDS CIRCLE	Unfunded	$ 700,000	ROADWAY ELEVATION
445926-2	1	High	No	SR 789 FROM SUNSET DR TO BIRD KEY DR	Unfunded	$ 2,614,310	ROADWAY ELEVATION
NA	1	High	No	SR 789 FROM WESTWAY PLACE TO LONGBOAT CLUB RD	Unfunded	$ 17,400,000	ROADWAY ELEVATION
428359-1	2	High	No	SR 5 (US 1/MAIN ST) AT ST JOHNS RIVER BRIDGE NO720022	FY 2024 to FY 2028	$ 3,521,698	ROADWAY OR BRIDGE APPROACH STABILIZATION
437437-2	2	High	No	SR 115 (LEM TURNER RD) TROUT RIVER BRIDGE #720033	FY 2024 to FY 2028	$ 80,020,855	ROADWAY OR BRIDGE APPROACH STABILIZATION
437428-1	2	High	No	SR 5A (US 1) (KING ST) OVER SAN SEBASTIAN RIVER BRIDGE NO780003	FY 2024 to FY 2028	$ 12,773,344	ROADWAY OR BRIDGE APPROACH STABILIZATION
NA	2	High	No	DRAINAGE BACKFLOW PREVENTERS AT VARIOUS LOCATIONS	Unfunded	$ 3,641,725	BACKFLOW PREVENTERS AND PUMPS
451031-1	3	High	Yes	SR 83 (US 331) OVER CHOCTAWHATCHEE BAY BRIDGE # 600108	FY 2024 to FY 2028	$ 7,712,060	ROADWAY OR BRIDGE APPROACH STABILIZATION
423591-5	3	High	Yes	SR 8 (I-10) OVER BLACKWATER RIVER BRIDGE# 580167	FY 2024 to FY 2028	$ 497,654	ROADWAY OR BRIDGE APPROACH STABILIZATION
440487-1	3	High	Yes	SR 390 OVER MILL BAYOU BRIDGE # 460020	FY 2024 to FY 2028	$ 12,375,465	ROADWAY OR BRIDGE APPROACH STABILIZATION
NA	3	High	Yes	US 98 WALTON COUNTY LINE TO SR 79 S ARNOLD RD	FY 2029 to FY 2045	$ 162,107	MATERIALS TO WITHSTAND INUNDATION/OVERTOPPING
449861-1	5	High	No	SR 430 EASTBOUND 790175 & WESTBOUND 790174 BRIDGES OVER HALIFX RIVER	FY 2024 to FY 2028	$ 1,277,181	ROADWAY OR BRIDGE APPROACH STABILIZATION
450561-1	5	High	No	SR 44 FROM THE BEGINNING OF BRIDGE 790152 TO THE END OF THE BRIDGE	FY 2024 to FY 2028	$ 3,679,349	ROADWAY OR BRIDGE APPROACH STABILIZATION

FDOT Resilience Action Plan:

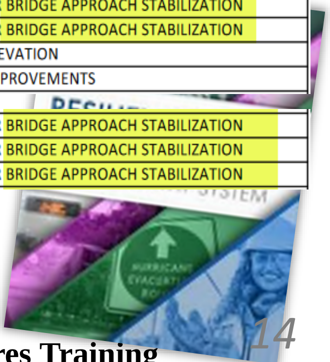
High Priority Projects (South Florida)

District 4, 6, & 7

449691-1	4	High	No	SR 736/DAVIE BLVD BRIDGE OVER SOUTH FORK NEW RIVER	FY 2024 to FY 2028	$	8,541,330	ROADWAY OR BRIDGE APPROACH STABILIZATION
446199-1	4	High	No	SR-A1A/OCEAN DRIVE FROM S. SEACREST PKWY TO S OF MONROE ST.	FY 2024 to FY 2028	$	4,000,000	DRAINAGE IMPROVEMENTS
441714-1	4	High	No	SR A1A FROM GRANT CT TO SOUTH OF LINTON BLVD	FY 2024 to FY 2028	$	10,000,000	DRAINAGE IMPROVEMENTS
447669-1	4	High	No	SR 804/E OCEAN AVE FROM US 1 TO SR A1A	FY 2024 to FY 2028	$	157,000	DRAINAGE IMPROVEMENTS
448577-1	4	High	No	SR A1A FROM BOUGANVILLA TERR TO HARRISON ST	FY 2024 to FY 2028	$	6,237,264	DRAINAGE IMPROVEMENTS
448576-1	4	High	No	SR A1A FROM FRANKLIN ST TO DESOTO ST	FY 2024 to FY 2028	$	5,347,916	DRAINAGE IMPROVEMENTS
441714-1	4	High	No	SR 5/US 1 FROM EDWARDS ROAD TO TENNESSEE AVE	FY 2024 to FY 2028	$	13,722,201	DRAINAGE IMPROVEMENTS
449814-1	4	High	No	SR 704/ROYAL PALM WAY FROM 4 ARTS PLAZA TO S COUNTY RD	FY 2024 to FY 2028	$	3,009,260	MATERIALS TO WITHSTAND INUNDATION/OVERTOPPING
447654-1	4	High	No	SR 820/HOLLYWOOD BLVD FROM SR 5/US 1 TO N OCEAN DR	FY 2024 to FY 2028	$	5,314,436	MATERIALS TO WITHSTAND INUNDATION/OVERTOPPING
448402-1	4	High	No	SR A1A FROM SHERIDAN ST TO E DANIA BEACH BLVD	FY 2024 to FY 2028	$	2,785,409	MATERIALS TO WITHSTAND INUNDATION/OVERTOPPING
446199-1	4	High	No	SR A1A/OCEAN DR FROM S SEACREST PKWY TO S OF MONROE ST	FY 2024 to FY 2028	$	3,970,215	MATERIALS TO WITHSTAND INUNDATION/OVERTOPPING
441733-1	4	High	No	SR A1A FROM DESOTO ST TO BALBOAST	Unfunded	$	500,000	BACKFLOW PREVENTERS AND PUMPS

449664-1	6	High	Yes	SR 112/JULIA TUTTLE CAUSEWAY OVER INTRACOASTAL WATERWAY BRIDGE # 870301	FY 2024 to FY 2028	$	7,556,894	ROADWAY OR BRIDGE APPROACH STABILIZATION
446190-1	6	High	No	SR 9/NW 27TH AVENUE OVER MIAMI RIVER - BRIDGE # 870731 & 870763	FY 2024 to FY 2028	$	3,970,215	ROADWAY OR BRIDGE APPROACH STABILIZATION
446189-1	6	High	No	SR 112-W 41ST ST OVER INDIAN CREEK WATERWAY - BRIDGE # 870055	FY 2024 to FY 2028	$	963,000	ROADWAY OR BRIDGE APPROACH STABILIZATION
443814-1	6	High	No	US 1 FROM HIAWATHA AVE TO KINGWOOD DR	Unfunded	$	5,000,000	MATERIALS TO WITHSTAND INUNDATION/OVERTOPPING
447745-1	6	High	Yes	I-195 EB/NW 36 ST OVER WESTSHORE WATERWAY BRIDGE # 870376	FY 2024 to FY 2028	$	1,298,203	ROADWAY OR BRIDGE APPROACH STABILIZATION
447744-1	6	High	Yes	I-195 WB RAMP TO NE 38 ST OVER WESTSHORE WATERWAY BRIDGE # 870375	FY 2024 to FY 2028	$	157,000	ROADWAY OR BRIDGE APPROACH STABILIZATION
429193-1	6	High	No	SR 907/ALTON RD FROM MICHIGAN AVENUE TO S OF ED SULLIVAN DR/43 ST	FY 2024 to FY 2028	$	52,000,000	ROADWAY ELEVATION
443902-1	6	High	No	SR A1A/COLLINS AVENUE FROM NORTH OF 26 ST TO 44 ST/INDIAN CREEK DR	Unfunded	$	255,000	DRAINAGE IMPROVEMENTS

443837-1	7	High	Yes	US 19/SR 55 OVER PITHLACHASCOTEE RIVER BRIDGE # 140005 SUBSTRUCTURE REPAIR	FY 2024 to FY 2028	$	302,114	ROADWAY OR BRIDGE APPROACH STABILIZATION
447747-1	7	High	No	US 19A/SR 595 OVER LONG BAYOU - SUBSTRUCTURE REPAIR	FY 2024 to FY 2028	$	416,486	ROADWAY OR BRIDGE APPROACH STABILIZATION
449982-1	7	High	No	HILLSBOROUGH COUNTY LONG BRIDGE REPAIRS - VARIOUS LOCATIONS	FY 2024 to FY 2028	$	7,713,336	ROADWAY OR BRIDGE APPROACH STABILIZATION



FDOT Resilience Action Plan:

Medium Tier Projects (North, Central & SW Florida)

District 1, 2, 3, & 5

ID	DISTRICT	TIER	SIS	DESCRIPTION	TIME FRAME	TOTAL PROJECT (	ADAPTATION STRATEGY
451013-1	1	Medium	No	SR 789 FROM LONGBOAT CLUB RD TO MANATEE CO LINE	FY 2024 to FY 2028	$ 7,398,468	MATERIALS TO WITHSTAND INUNDATION/OVERTOPPING
451021-1	1	Medium	No	SR 789 FROM S OF COQUINA PARK ENT TO SR 64	FY 2024 to FY 2028	$ 8,634,624	MATERIALS TO WITHSTAND INUNDATION/OVERTOPPING
449119-1	1	Medium	No	SR 789 FROM SARASOTA COUNTY LINE TO LONGBOAT PASS	FY 2024 to FY 2028	$ 6,194,119	ROADWAY OR BRIDGE APPROACH STABILIZATION
450727-1	1	Medium	No	SR 865 FROM N OF HURRICANE PASS TO S OF SUMMERLIN RD	FY 2024 to FY 2028	$ 1,380,800	ROADWAY OR BRIDGE APPROACH STABILIZATION
441524-1	1	Medium	No	SR 45(US 41) FROM WILLIAM ST TO PEACE RIVER BRIDGE	FY 2024 to FY 2028	$ 6,614,246	ROADWAY OR BRIDGE APPROACH STABILIZATION
441558-2	1	Medium	NO	SR 758 AT CR 789 INTERSECTION ROUNDABOUT	FY 2024 to FY 2028	$ 2,925,252	MATERIALS TO WITHSTAND INUNDATION/OVERTOPPING
444328-1	1	Medium	No	SR 45 (US 41) AT SIX MILE CYPRESS	FY 2024 to FY 2028	$ 1,500,000	MATERIALS TO WITHSTAND INUNDATION/OVERTOPPING
NA	1	Medium	No	SR 29 FROM US 41 TO CR 837	Unfunded	$ 52,700,000	ROADWAY ELEVATION
NA	1	Medium	No	SR 64 (MANATEE AVE) FROM CR 789 TO FLAMINGO DR	Unfunded	$ 37,700,000	ROADWAY ELEVATION
NA	1	Me[illegible]m	No	SR 64 (MANATEE AVE) FROM FLAMINGO DR T[illegible]	Unfu[illegible]ed	$ [illegible],300,000	R[illegible]DWAY ELEVA[illegible]ON
446815-1	1	Medium	No	SR 789 (GULF OF MEXICO DR) FROM CHANNEL PL TO LONGBOAT CLUB RD	FY 2024 to FY 2028	$ 1,441,729	MATERIALS TO WITHSTAND INUNDATION/OVERTOPPING
446393-1	1	Medium	No	SR 776 AT CHARLOTTE SPORTS PARK	FY 2024 to FY 2028	$ 151,000	MATERIALS TO WITHSTAND INUNDATION/OVERTOPPING
451102-1	1	Medium	No	SR 45 (US 41) FROM BRIDGE # 010050 TO CHARLOTTE AVE	FY 2024 to FY 2028	$ 1,041,499	ROADWAY OR BRIDGE APPROACH STABILIZATION
451101-1	1	Medium	No	SR 45 (US 41) FROM S OF AQUI ESTA DR TO S OF CARMALITA ST	FY 2024 to FY 2028	$ 4,359,387	MATERIALS TO WITHSTAND INUNDATION/OVERTOPPING
430897-4	2	Medium	No	SR A1A (AVENIDA MENENDEZ) FROM CHARLOTTE ST TO W END OF BRIDGE OF LIONS	FY 2024 to FY 2028	$ 12,854,682	MATERIALS TO WITHSTAND INUNDATION/OVERTOPPING
NA	2	Medium	No	SR A1A FROM SR 116 (WONDERWOOD) TO COAST GUARD STATION	Unfunded	$ 207,670,786	ROADWAY ELEVATION
NA	2	Medium	No	ST AUGUSTINE SEA WALL: SR 5A (A1A)(KING ST) FROM BRIDGE OF LIONS TO CHARLOTTE ST	Unfunded	$ 19,612,747	COASTAL WAVE ATTENUATION
445761-1	3	Medium	No	SR 30 (US 98) FROM S FRANKLIN ST TO CARRABELLE RIVER BRIDGE	FY 2024 to FY 2028	$ 24,385,415	ROADWAY OR BRIDGE APPROACH STABILIZATION
NA	3	Medium	No	SR 30 AT 9TH ST	Unfunded	Not Available	DRAINAGE IMPROVEMENTS
NA	3	Medium	No	SR 30 AT PUTNAL ST	Unfunded	Not Available	DRAINAGE IMPROVEMENTS
NA	3	Medium	No	SR 30 AT SPRING DR	Unfunded	Not Available	DRAINAGE IMPROVEMENTS
NA	5	Medium	No	SR 524/SR 528 OVER BANANA RIVER	FY 2029 to FY 2045	Not Available	COASTAL WAVE ATTENUATION
NA	5	Medium	No	SR 520 HUBERT HUMPHREY CAUSEWAY FROM RIVEREDGE BLVD TO MYRTICE AVE	Unfunded	Not Available	COASTAL WAVE ATTENUATION
NA	5	Medium	No	US 192/SR 500 MELBOURNE CAUSEWAY FROM RIVERVIEW DR TO N RIVERSIDE DR	Unfunded	Not Available	COASTAL WAVE ATTENUATION

FDOT Resilience Action Plan:

Medium Tier Projects (Tampa Bay/West Coast)

District 7

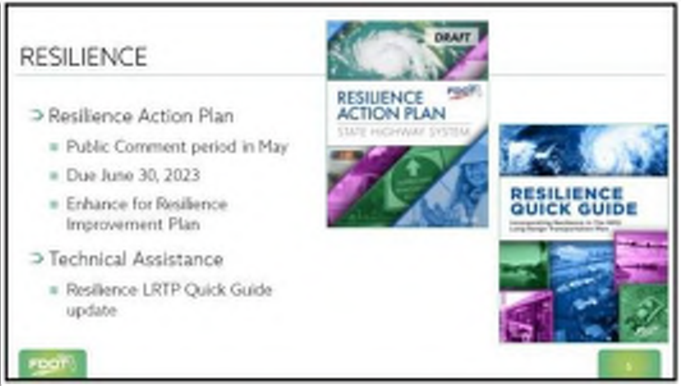
ID	DISTRICT	TIER	SIS	DESCRIPTION	TIME FRAME	TOTAL PROJECT (	ADAPTATION STRATEGY
NA	7	Medium	No	SR 699 (GULF BLVD) FROM NORTH END OF JOHN'S PASS BRIDGE TO 130TH AVE N	Unfunded	Not Available	DRAINAGE IMPROVEMENTS
NA	7	Medium	No	SR 699 AT MADERIA WAY	Unfunded	Not Available	DRAINAGE IMPROVEMENTS
NA	7	Medium	No	SR 699 BETWEEN 177TH AVE W TO N OF CORAL AVE	Unfunded	$ 50,000	DRAINAGE IMPROVEMENTS
NA	7	Medium	No	SR 699, SR 682 AND SR 693 AND OUTFALL AT 2ND AVE EAST AND GULF WINDS DR	Unfunded	Not Available	DRAINAGE IMPROVEMENTS
NA	7	Medium	No	SR 93A	Unfunded	Not Available	DRAINAGE IMPROVEMENTS
NA	7	Medium	No	US 19 AT 46TH AVE	Unfunded	Not Available	DRAINAGE IMPROVEMENTS
NA	7	Medium	No	US 41 AT KITCHEN BRANCH	Unfunded	Not Available	DRAINAGE IMPROVEMENTS
NA	7	Medium	No	ADAMO DR AT N 45TH ST	Unfunded	Not Available	DRAINAGE IMPROVEMENTS
NA	7	Medium	Yes	NB I-275 BETWEEN MM 0 AND MM 1	Unfunded	$ 40,000	DRAINAGE IMPROVEMENTS
NA	7	Medium	Yes	US 19 AT JASMINE BLVD	Unfunded	Not Available	DRAINAGE IMPROVEMENTS
450768-1	7	Medium	No	SR 60/ADAMO DR FROM W OF 45TH ST TO W OF YEOMAN ST	FY 2024 to FY 2028	$ 9,026,122	MATERIALS TO WITHSTAND INUNDATION/OVERTOPPING
440749-1	7	Medium	Yes	US 41/SR 45 AT CSX GRADE SEPARATION FR S OF SR 676 TO N OF SR 676	FY 2024 to FY 2028	$ 142,358	MATERIALS TO WITHSTAND INUNDATION/OVERTOPPING
445674-1	7	Medium	No	US 92/SR 580/W HILLSBOROUGH AVE AT DANIELS RD	FY 2024 to FY 2028	$ 1,517,975	DRAINAGE IMPROVEMENTS
445677-1	7	Medium	No	US 92/SR 580/W HILLSBOROUGH AVE AT GEORGE RD	FY 2024 to FY 2028	$ 1,361,014	DRAINAGE IMPROVEMENTS
448934-1	7	Medium	No	SR 60/ADAMO DR FROM W OF N 34TH ST TO E OF N 34TH ST	FY 2024 to FY 2028	$ 5,218,690	MATERIALS TO WITHSTAND INUNDATION/OVERTOPPING
447236-1	7	Medium	No	SR 686 FROM W OF 28TH ST N TO E OF 28TH ST N	FY 2024 to FY 2028	$ 16,009,793	MATERIALS TO WITHSTAND INUNDATION/OVERTOPPING
449213-1	7	Medium	No	SR 699/BLIND PASS RD FROM N OF 75TH AVE TO N OF W GULF BLVD	FY 2024 to FY 2028	$ 5,678,811	MATERIALS TO WITHSTAND INUNDATION/OVERTOPPING
437515-1	7	Medium	Yes	US 19/US98/SR 55/N SUNCOAST BLVD FR NE 1ST ST TO S OF SNUG HARBOR	FY 2024 to FY 2028	$ 3,063,584	MATERIALS TO WITHSTAND INUNDATION/OVERTOPPING
451073-1	7	Medium	No	ALT US 19/SR 595/BAYSHORE DR FR WILSON ST TO CAUSEWAY BLVD/ CURLEW RD	FY 2024 to FY 2028	$ 2,815,609	DRAINAGE IMPROVEMENTS
255339-2	7	Medium	No	SR 580/SR 600/US 92/HILLSBOROUGH AVE FR BAY PATH LANE TO E OF TUDOR DR	FY 2024 to FY 2028	$ 761,250	DRAINAGE IMPROVEMENTS
NA	7	Medium	No	US 41 SOUTH OF PENDOLA POINT/MADISON TO SOUTH OF CAUSEWAY BLVD	FY 2029 to FY 2045	$ 8,625,000	MATERIALS TO WITHSTAND INUNDATION/OVERTOPPING
NA	7	Medium	No	ALT US 19 AND PINELLAS TRAIL SOUTH OF PALM BLVD PROPERTY OWNER 2048 DOUGLAS AVE	Unfunded	Not Available	DRAINAGE IMPROVEMENTS
NA	7	Medium	No	SR 580 (HILLSBOROUGH AVE) FROM HANLEY RD TO VERTERANS EXPRESSWAY	Unfunded	$ 94,683	DRAINAGE IMPROVEMENTS
NA	7	Medium	No	SR 595 (ALT US 19)(EDGE WATER) FROM PRESIDENT ST TO SOUTH OF FLUME/PED BRIDGE	Unfunded	Not Available	DRAINAGE IMPROVEMENTS
NA	7	Medium	No	SR 595 (ALT US 19)(S PINELLAS AVE) FROM E MORGAN ST TO MLK	Unfunded	Not Available	DRAINAGE IMPROVEMENTS
NA	7	Medium	No	SR 595 (ALT US 19)(TYRONE BLVD) AT TARGET PARKING LOT ENTRANCE	Unfunded	Not Available	DRAINAGE IMPROVEMENTS
NA	7	Medium	No	SR 60 (GULF TO BAY BLVD) AT MCMULLEN BOOTH RD INTERSECTION	Unfunded	Not Available	DRAINAGE IMPROVEMENTS
NA	7	Medium	No	SR 60 (SEVERAL LOCATIONS CCC FROM MID-SPAN TO ROCKY POINT)	Unfunded	$ 70,000	DRAINAGE IMPROVEMENTS
NA	7	Medium	No	SR 699 (GULF BLVD) AND 149TH AVE N	Unfunded	Not Available	DRAINAGE IMPROVEMENTS

FDOT Resilience Action Plan:
Medium Tier Projects (South Florida)

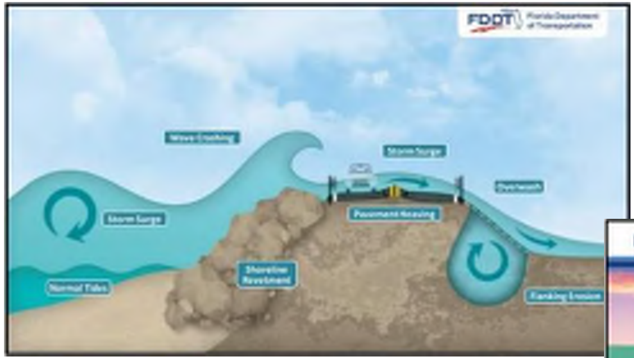
District 4, 6, & 8

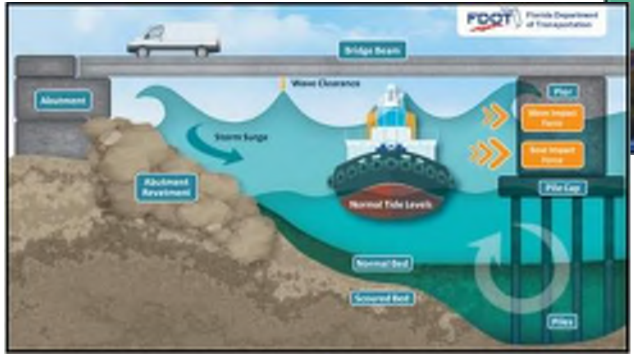
450587-2	4	Medium	No	SR 707 (DIXIE HWY) BRIDGE # 890003	FY 2024 to FY 2028	$ 9,530,010	ROADWAY OR BRIDGE APPROACH STABILIZATION
448574-1	4	Medium	No	SR A1A FROM SHERMAN ST TO SR 822/SHERIDAN ST	FY 2024 to FY 2028	$ 4,614,071	DRAINAGE IMPROVEMENTS
447650-1	4	Medium	No	SR A1A FROM NE SHORE VILLAGE TERR TO SR 732/JENSEN BEACH CAUSEWAY	FY 2024 to FY 2028	$ 3,205,223	ROADWAY OR BRIDGE APPROACH STABILIZATION
229658-4	4	Medium	No	SR-806/ATLANTIC AVE FROM WEST OF SR-7/US-441 TO EAST OF LYONS ROAD	FY 2024 to FY 2028	$ 37,000,000	DRAINAGE IMPROVEMENTS
NA	4	Medium	No	SR 76/KANNER HWY FROM SOUTH OF INDIAN ST TO MONTEREY RD	Unfunded	Not Available	DRAINAGE IMPROVEMENTS
NA	4	Medium	No	SR 842/BROWARD BLVD FROM ANDREWS AVE TO US 1	Unfunded	Not Available	DRAINAGE IMPROVEMENTS
NA	4	Medium	No	SR A1A FROM COLUSA CT TO SR 732/JENSEN BEACH CSWY	Unfunded	Not Available	DRAINAGE IMPROVEMENTS
NA	4	Medium	No	SR A1A FROM GRAND CT TO SOUTH OF LINTON BLVD	Unfunded	Not Available	DRAINAGE IMPROVEMENTS
NA	4	Medium	No	SR A1A FROM NORTH OF E OCEAN AVE TO THE PATRICIAN	Unfunded	Not Available	DRAINAGE IMPROVEMENTS
NA	4	Medium	No	SR A1A/NORTH CAUSEWAY FROM BOATRAMP RD TO MARINA DR	Unfunded	Not Available	DRAINAGE IMPROVEMENTS
NA	4	Medium	No	SR A1A FROM ARIZONA ST TO MICHIGAN ST	Unfunded	$ 3,000,000	BACKFLOW PREVENTERS AND PUMPS
NA	4	Medium	No	SR A1A FROM CUSTER ST TO PERRYSTAND FROM SHERIDAN ST TO FREEDOM ST	Unfunded	$ 100,000	BACKFLOW PREVENTERS AND PUMPS
NA	4	Medium	No	SR A1A FROM MINNESOTA ST TO SHERMAN ST	Unfunded	$ 2,000,000	BACKFLOW PREVENTERS AND PUMPS
NA	4	Medium	No	SR A1A FROM SOUTH OF MAGNOLIA TERR TO EUCALYPTUS TERR	Unfunded	$ 2,400,000	BACKFLOW PREVENTERS AND PUMPS
NA	4	Medium	No	SR A1A SHERMAN ST TO SHERIDAN ST	Unfunded	Not Available	BACKFLOW PREVENTERS AND PUMPS
NA	4	Medium	No	SR A1A SOUTH AND NORTH OF HALLANDALE BEACH BLVD	Unfunded	$ 3,600,000	BACKFLOW PREVENTERS AND PUMPS
NA	[illegible]	Medium	[illegible]	[illegible] UR C[illegible] & FOUNTAIN ST	[illegible]	Not Avail[illegible]	[illegible]
NA	6	Medium	No	SW 7TH ST FROM 3RD AVE TO 2ND AVE	Unfunded	Not Available	DRAINAGE IMPROVEMENTS
NA	6	Medium	No	SR 907/ALTON RD FROM NORTH OF 57TH ST TO ALLISON RD	Unfunded	$ 45,000,000	ROADWAY ELEVATION
NA	6	Medium	No	SR 907/ALTON RD FROM S OF 43RD ST TO N OF WEST 48TH ST	Unfunded	$ 46,000,000	ROADWAY ELEVATION
NA	6	Medium	No	US 1 (OVERSEAS HWY) AT FIESTA KEY WEST	Unfunded	Not Available	COASTAL WAVE ATTENUATION
NA	6	Medium	No	US 1 (OVERSEAS HWY) AT INDIAN KEY FILL	Unfunded	Not Available	COASTAL WAVE ATTENUATION
NA	6	Medium	No	US 1 (OVERSEAS HWY) AT SUMMERLAND KEY	Unfunded	Not Available	COASTAL WAVE ATTENUATION
446224-3	8	Medium	Yes	SR 91 DRAINAGE	Unfunded	$ 1,000,000	DRAINAGE IMPROVEMENTS

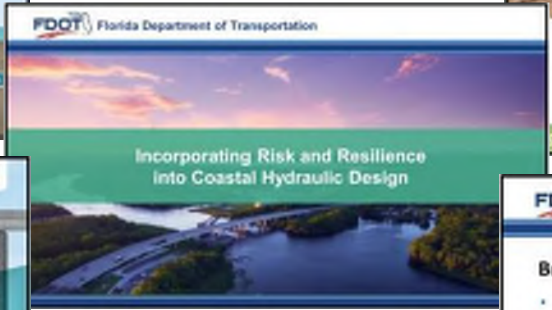
FDOT Statewide Resilience Training: for Planners & Designers



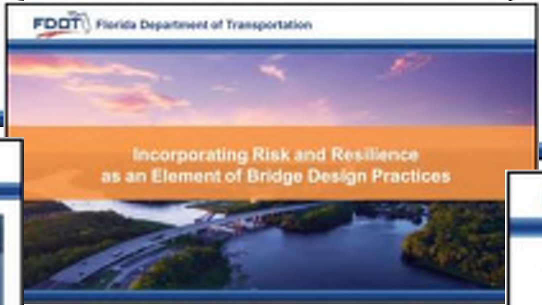
FDOT Statewide Resilience Training: Structures Examples

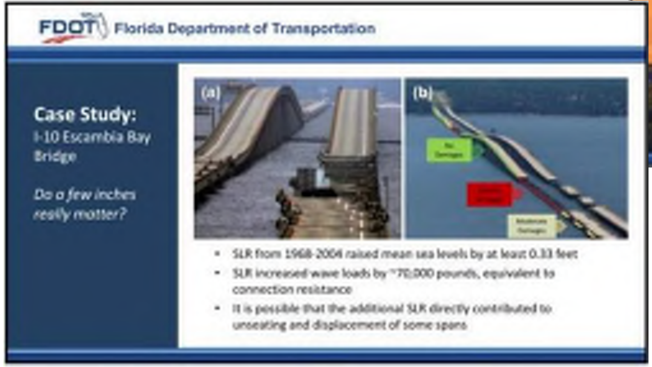


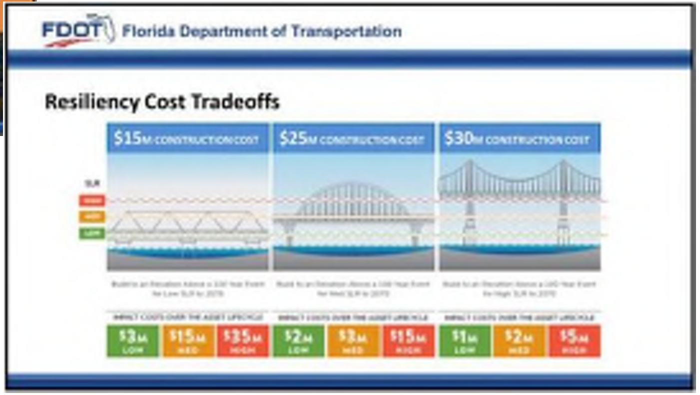




FDOT Statewide Resilience Training: Structures Examples







Questions ?


THE FIGHT TO END
DISTRACTED
DRIVING
STARTS WITH YOU
LET'S GET
EVERYONE HOME.
TARGET
ZERO
FATALITIES & SERIOUS INJURIES

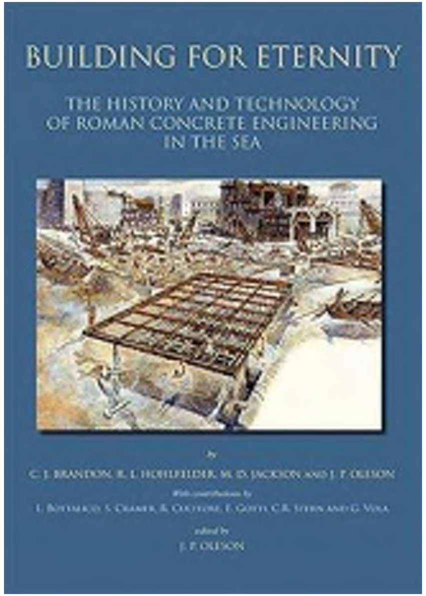

1st Southeastern Peer eXchange for
Resilient & Sustainable Bridges
Mobile, AL August 8th 2023

Extra Slides

(for discussion session)

Resilient Design and Adaptability

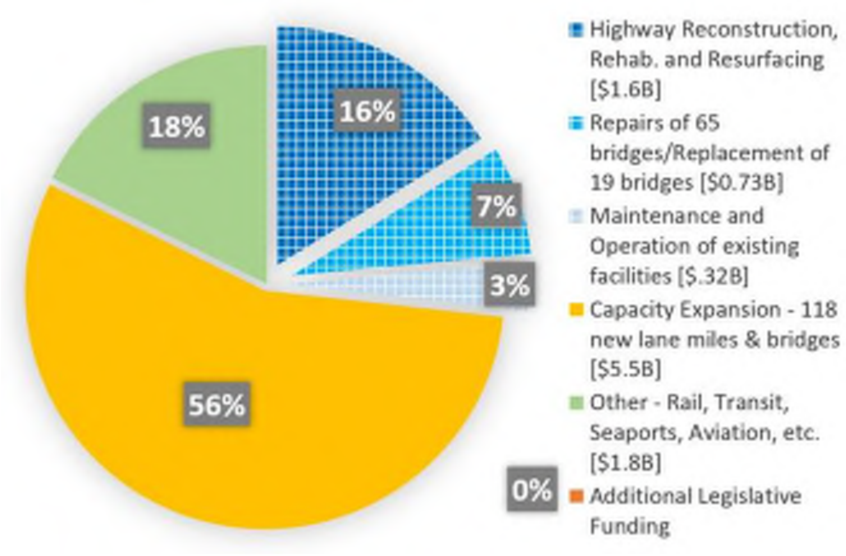
Ponte Pietra Bridge. Born 100 BC



Condition in 2016 (Verona, Italy)

Durable Design Needs & Strategies

Cost of Ownership



Florida DOT FY 23/24 Budget without "Moving Florida Forward": 26% for MRR and deficient bridge replacement (hatched areas).

Increasing Maintenance & Rehab. Liability

US Public Spending on Transportation and Water Infrastructure 1959 to 2017 (State and Local funds)

ASCE Grand Challenge

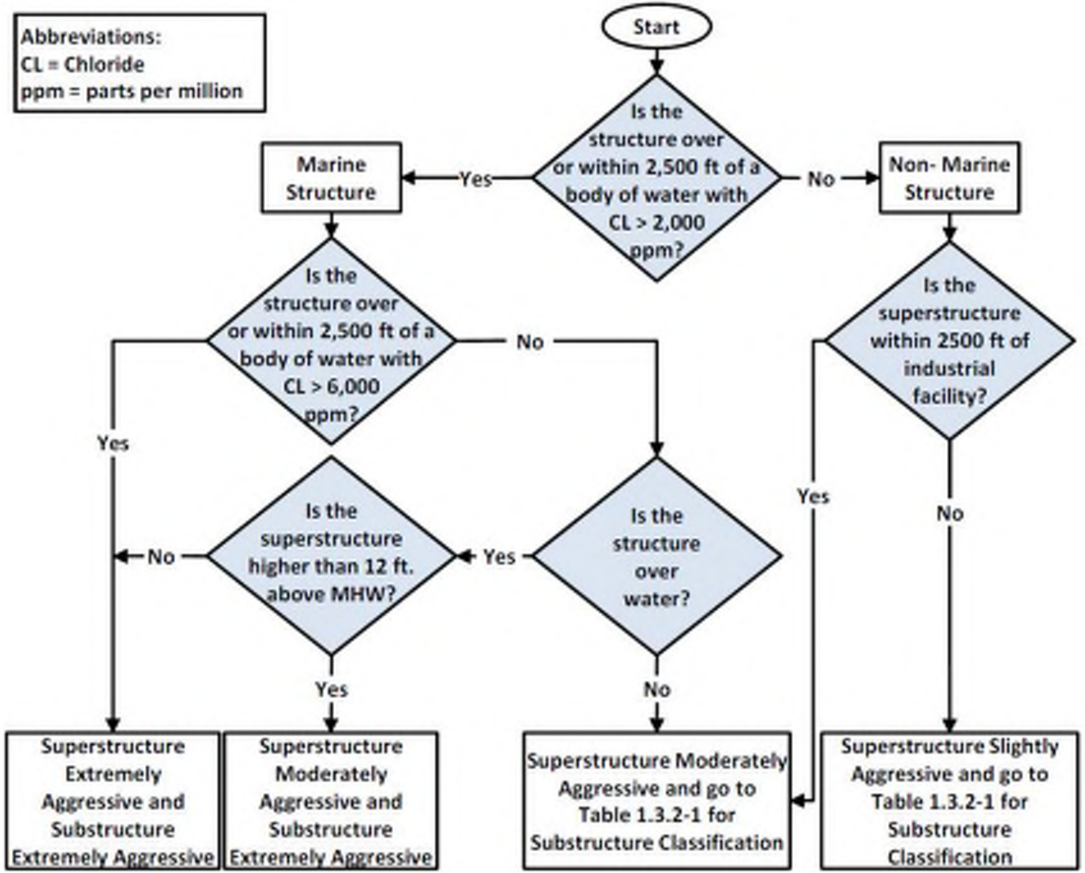
"Reduce the life cycle cost of infrastructure by 50 percent by 2025 and foster the optimization of infrastructure investments for society"

Increasing Maintenance & Rehab. Liability

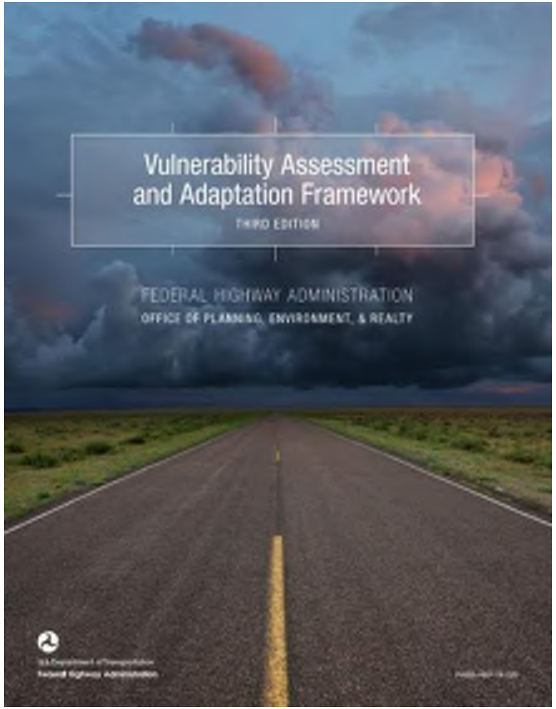
Together we can close the infrastructure gap!

Flow Chart for SDG Environmental Classification of Structures

Similar charts could be developed for Resilience to assist designers unfamilar with the intended concepts



Predicting Future Use & Impacts



Bridge Builders Look for Better Ways at International Conference

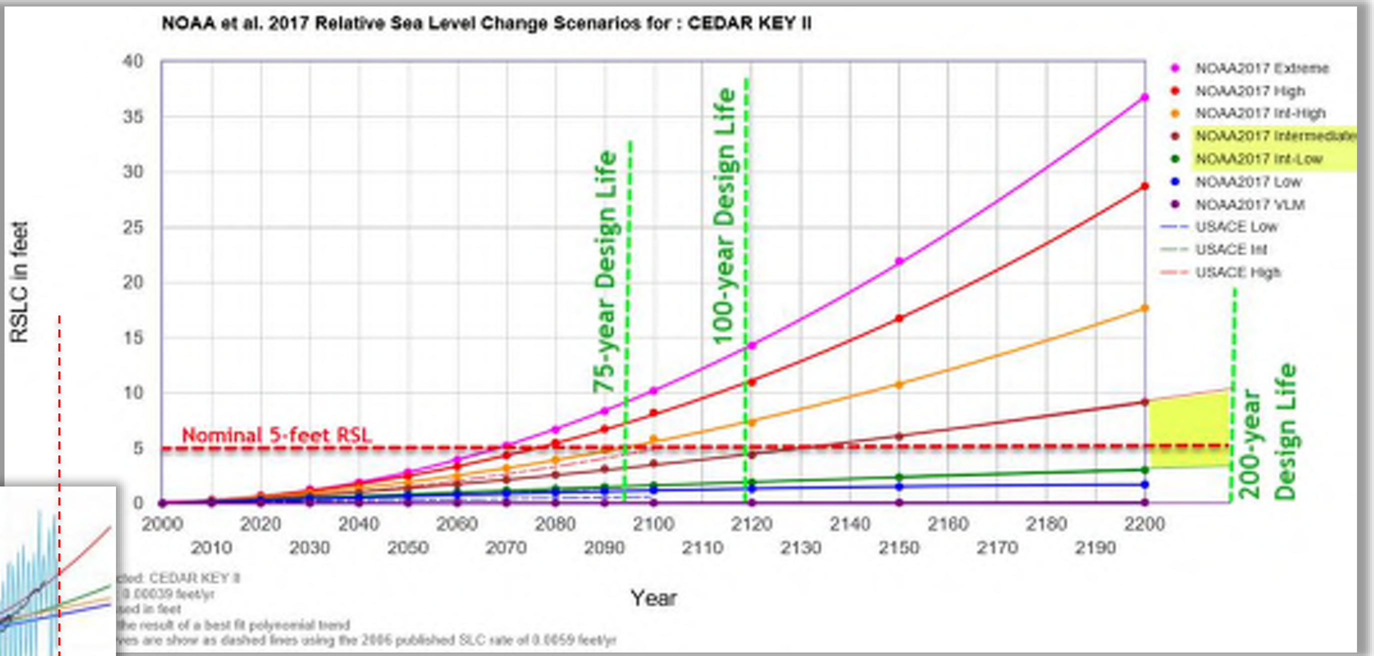
July 8, 2019

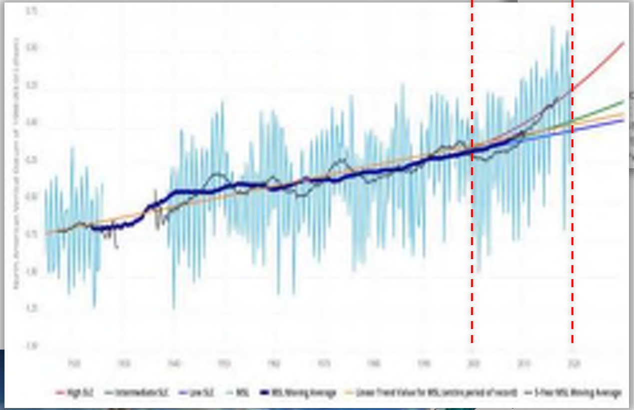
ENR
Engineering News-Record

Shay Burrows, team leader for structures safety and management for the FHWA… cautioned that automated vehicle technology will pose potential new challenges to infrastructure. For example, a fleet of automated trucks traveling close together can cause extra loading on a bridge. "We're not having these conversations," he said, referring to the transportation industry. "We need to be."

Relative Sea Level Change (SLC)

USACE data for Cedar Key, FL. (Gauge: 8727520)
http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html

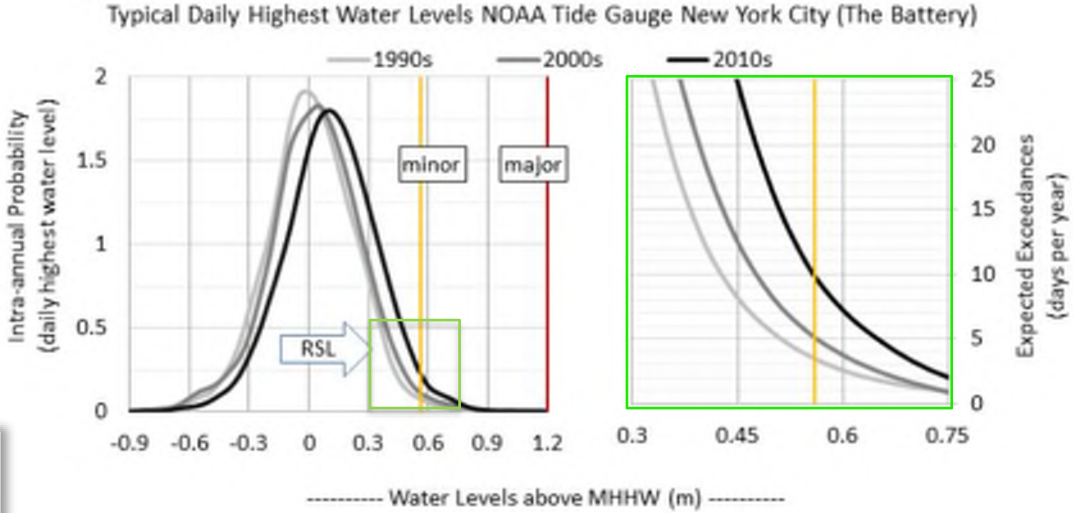




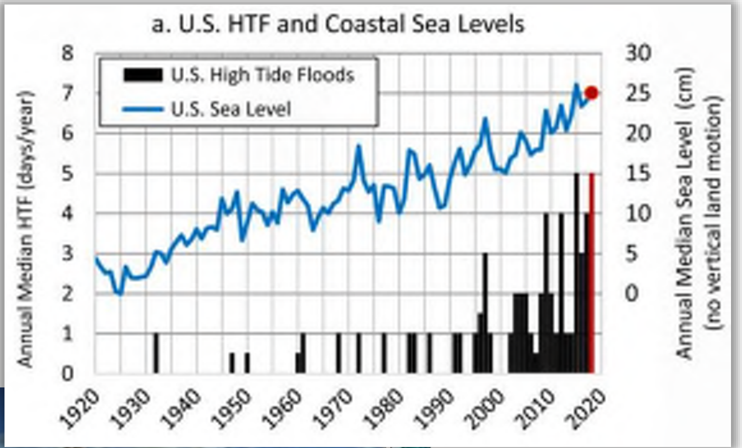
SLC Scenarios for Cedar Key, FL (Gauge 8727520)
https://climate.sec.usace.army.mil/slr_app/

Relative Sea Level (RSL)

NOAA Technical Report NOS CO-OPS 090 (June, 2019)
[*https://tidesandcurrents.noaa.gov/publications/Techrpt_090_2018_State_of_US_HighTideFlooding_with_a_2019_Outlook_Final.pdf*](https://tidesandcurrents.noaa.gov/publications/Techrpt_090_2018_State_of_US_HighTideFlooding_with_a_2019_Outlook_Final.pdf)



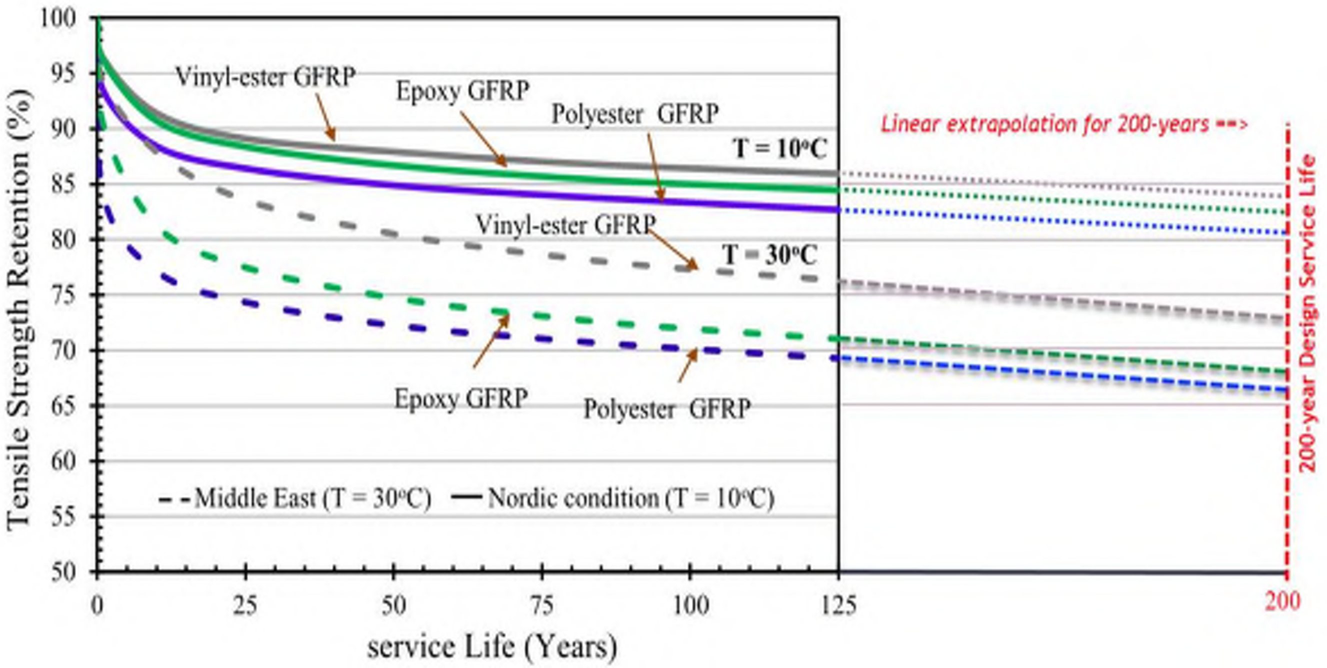
Above: Decadal empirical probability distributions for daily highest water levels in New York City (NOAA tide gauge The Battery) during the 1990s, 2000s, and 2010s changing due to relative sea level RSL



Design Criteria

- FRP Reinforcing and Prestressing….

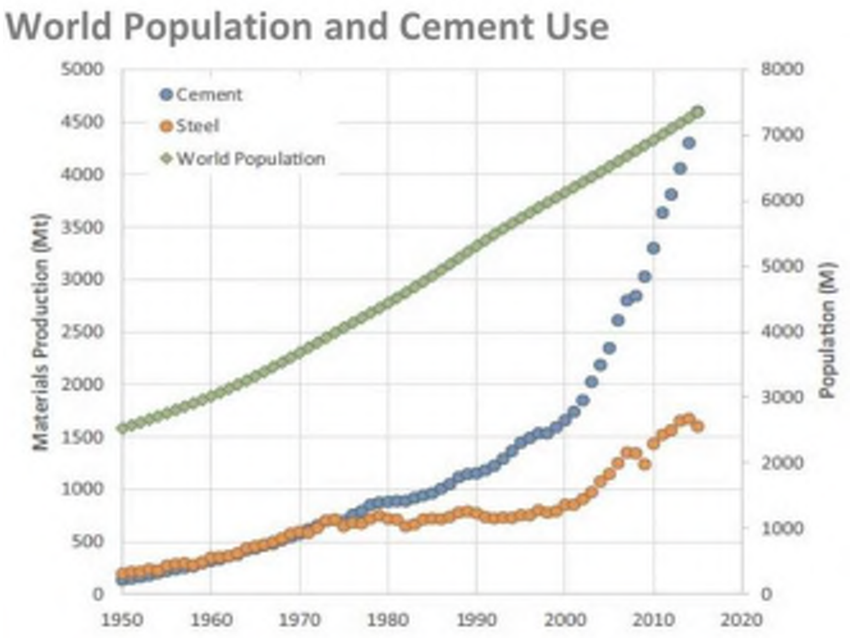
- Stainless-steel Reinforcing and Prestressing….



Tensile strength retention of GFRP Rebar

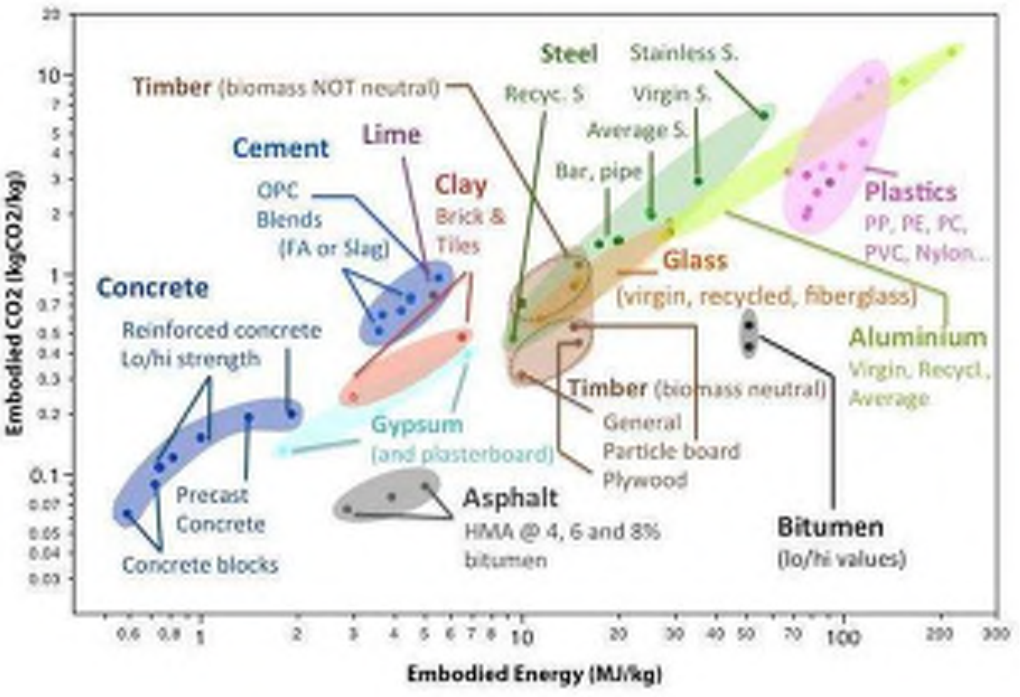
Shows performance for different resin compositions at mean annual temperatures of 10°C and 30°C

Sustainability



- *World population and cement use [Scrivener & Gartner, 2018]*

Sustainability



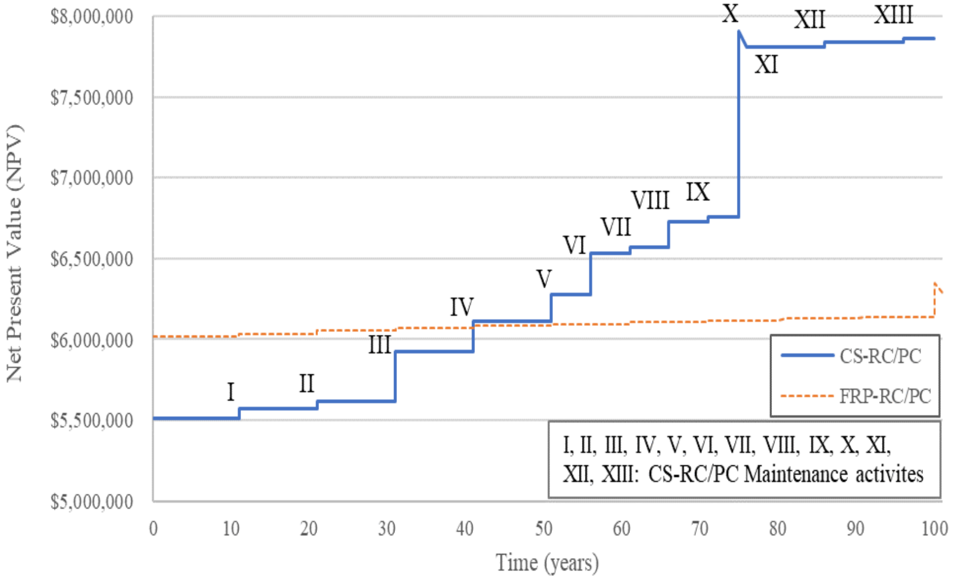
Cement and Carbon Emissions

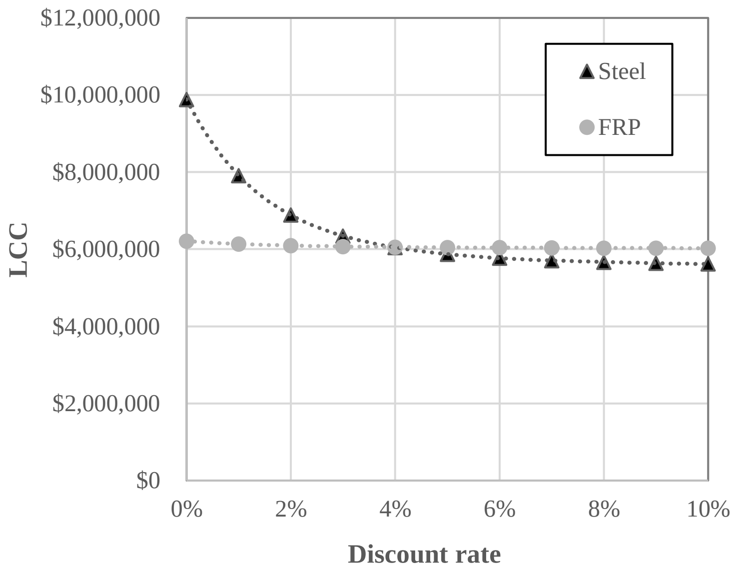
Laurent Barcelo[1,2], John Kline[1], Gunther Walenta[2] & Ellis Gartner[2]

[1] Lafarge Canada Inc., 334 Avro, Pointe-Claire, H9R 5W5, QC, Canada

[2] Lafarge Research Center, 95 Rue du Montmurier, 38290 St Quentin Fallavier, France

Life Cycle Cost (Cadenazzi et al., 2019)





"Life-Cycle Cost and Life-Cycle Assessment Analysis at the Design Stage of a Fiber-Reinforced Polymer Reinforced Concrete Bridge in Florida", https://doi:10.1520/ACEM20180113

- (HRB study) Baseline scenario with discount rate = 1%

Life Cycle Cost (Younis et al., 2018)

Table 4
Summary of LCCA results.

Design alternative	Present costs ($/m^2)					LCC ($/m^2)
	Material	Construction	Repair	Reconstruction	End-of-life	
RC1	90	135	183.9	230.7	50.8	690.4
RC2	389	135	24.6	-	37.3	585.9
RC3	174	108	-	-	54.3	336.3

RC1 = Traditional concrete mix with carbon-(black) steel rebar;
RC2 = Traditional concrete mix with SS rebar;
RC3 = Concrete with seawater & RCA with GFRP rebar.

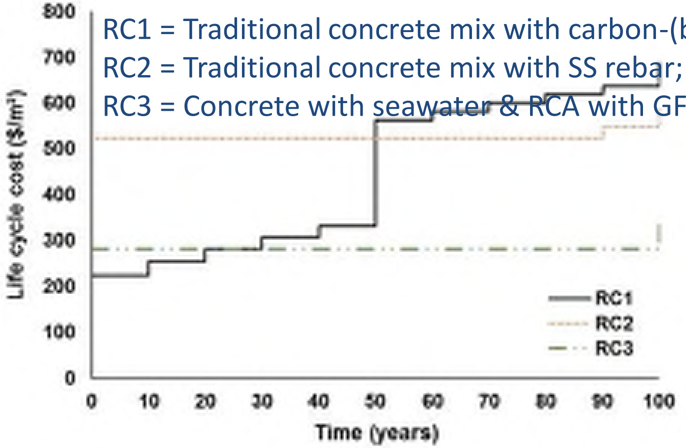


Fig. 5. Life cycle cost results (considering the baseline scenario where $r = 0.7\%$ and $C = 150\%$ of M).

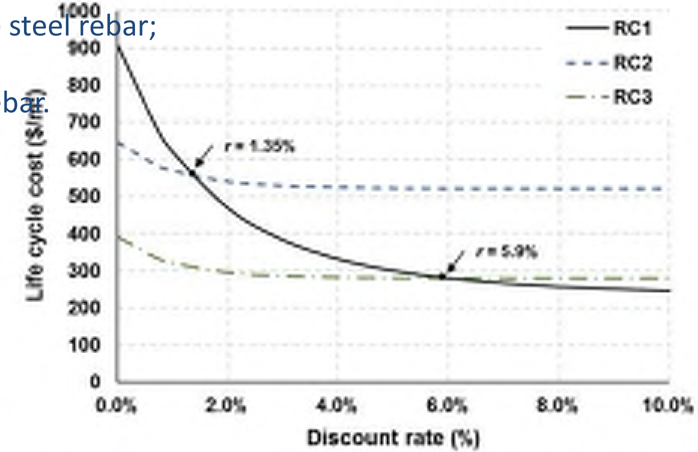


Fig. 6. Sensitivity of LCC results to the discount rate (while C is fixed at $1.5M$).

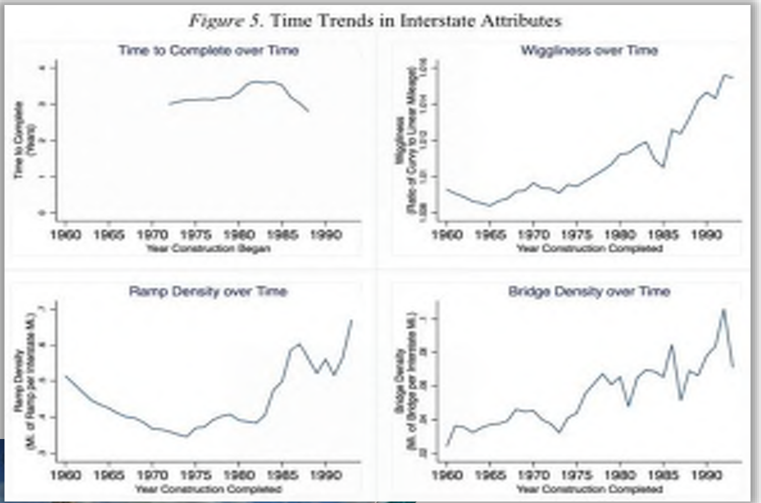
"Life cycle cost analysis of structural concrete using seawater, recycled concrete aggregate, and GFRP reinforcement", https://doi.org/10.1016/j.conbuildmat.2018.04.183

- Baseline scenario with discount rate = 0.7%

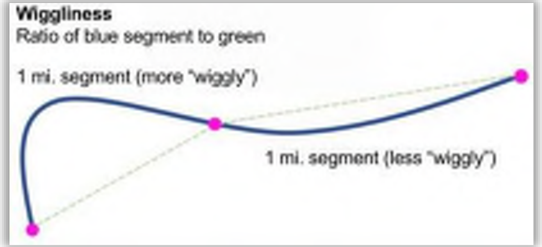
Life Cycle Cost

- Pg.16 …using high-strength steel reinforcement—initially introduced in other forms of construction in the 1960s—was estimated to reduce the cost of reinforcing a bridge during construction by the 1980s by 30 percent (National Academy of Sciences 1984, p. 26)
- Pg.26 …highway segments become substantially wigglier after the early 1970s.

The cost of building one mile of interstate highway in the 1980s was three times what it cost in the 1960s, adjusted for inflation, Leah Brooks of The George Washington University and Zachary Liscow of Yale University find in a paper prepared for the 2019 Municipal Finance Conference (July 15-16, 2019) at Brookings.

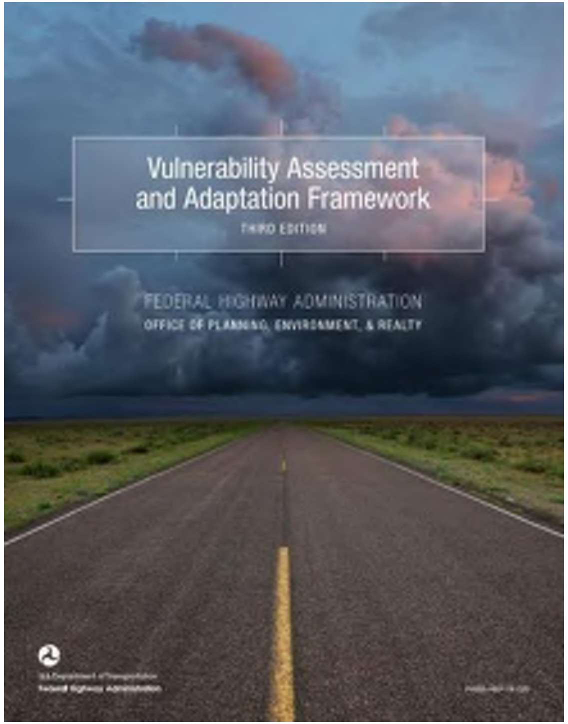


"projects associated with wigglier highways may have encountered resistance that both led to less direct routes and also more expensive construction." They find that a 0.01 mile per year increase in the wiggliness of a highway is associated with a $9.71 million increase in costs.



https://www.brookings.edu/blog/up-front/2019/07/15/what-is-driving-up-the-cost-of-highway-construction/

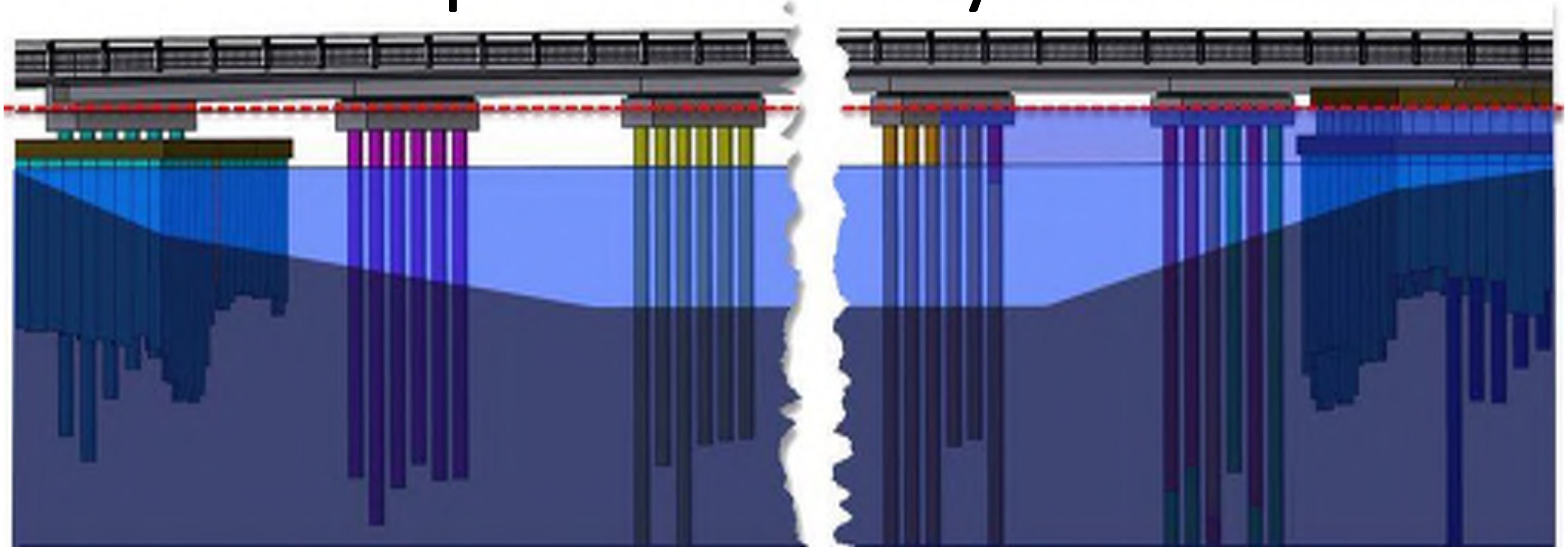
Adaption Pathways



Pg.60 – Incorporating Vulnerability Assessments into Project Level Design and Engineering

Flexible adaptation pathways. Practitioners can choose flexible strategies with timeframes that allow for changing course as new information emerges. The decision tree or pathway is mapped out over a timeline. Transfers from one adaptation strategy to another can be made at various points in time. As climate changes, some adaptation strategies have a limited window of effectiveness at which time they run into terminals or tipping points and new pathways must be followed. Each of the pathways can be rated qualitatively for cost effectiveness and possible unwanted side effects.

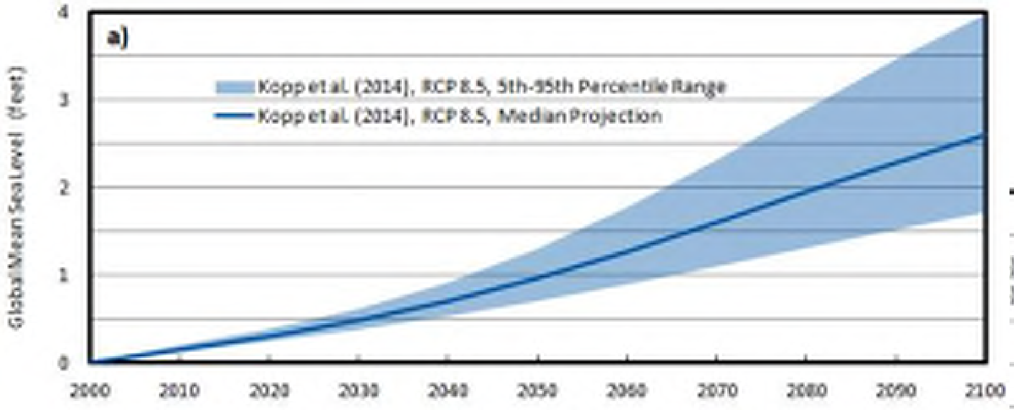
Adaption Pathways

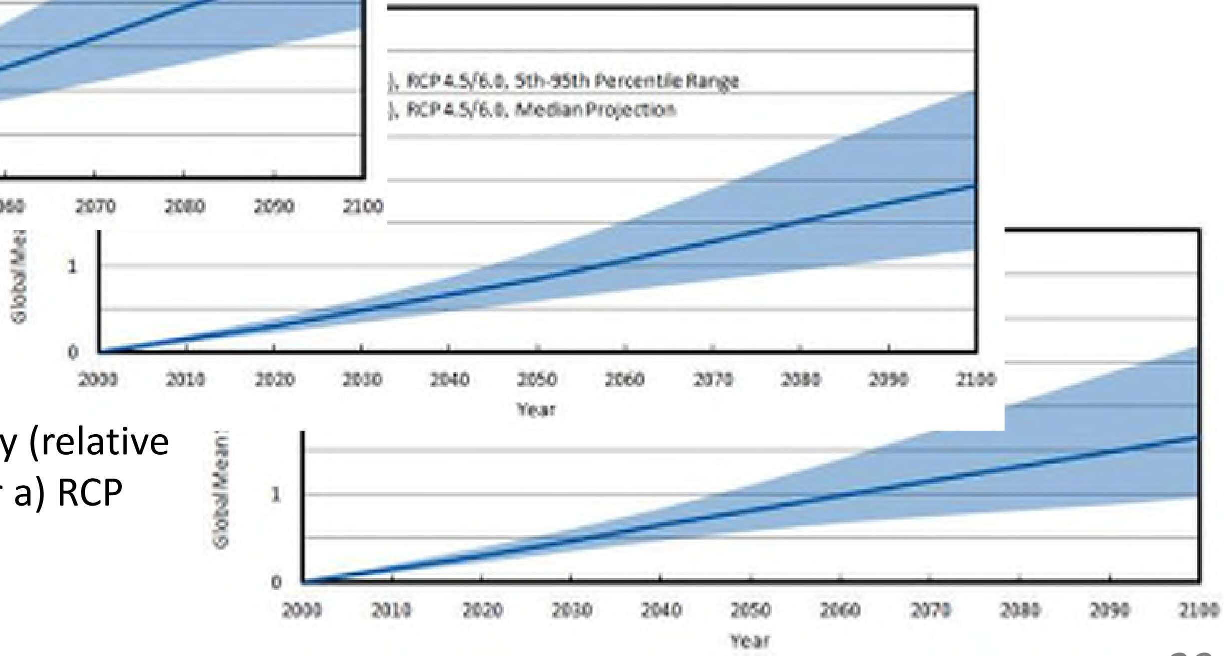


Halls River Bridge showing the impact of a 6-foot RSL

Shows current MHW (blue) and 6-ft. projected RSL (dashed redline),
with possible Adaption Strategy using 5-ft. raised bulkhead (right-side).

Adaption Pathways





Projections of GMSLR in this century (relative to 2000) from Kopp et al. (2014) for a) RCP 8.5, b) RCP 4.5, and c) RCP 2.6

Adaption Pathways

Calif. uses untested powers for 'managed retreat’

https://www.eenews.net/stories/1060427341

1. “Nature's going to have its way in the end, and if we don't plan for it, it's just going to be disastrous, and it's going to cost us more in the long run.“

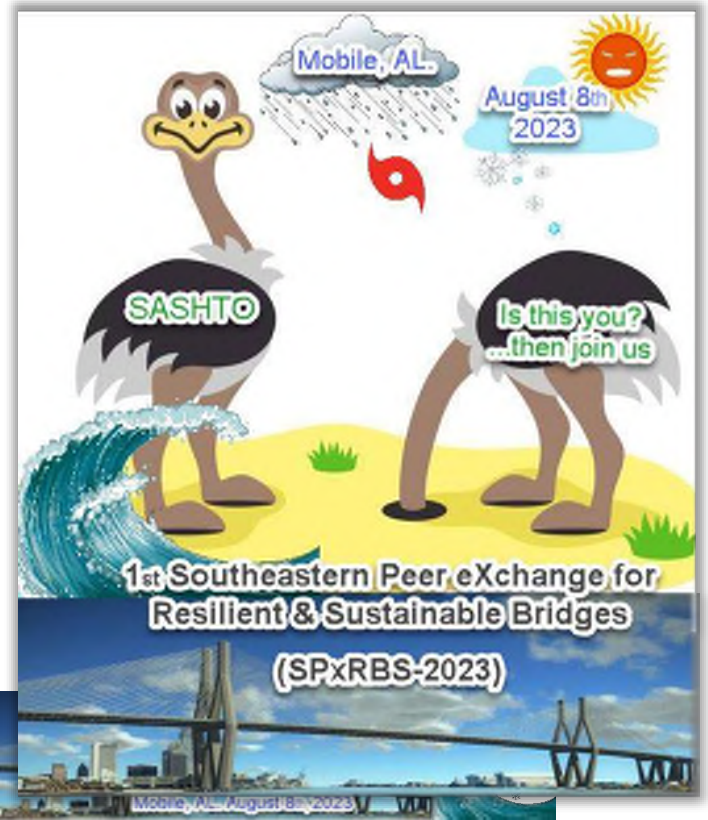
2. ‘Putting off the inevitable’ - "Uncertainty and fear leads to anger. We seem to be the focus of the anger," said Ainsworth of the Coastal Commission. "We're not the enemy. It's sea-level rise and climate change, and that's the message I want to send out. We're trying to help local communities."

3. More storms, more walls

The number of sea walls along California beaches, particularly in Southern California, rose sharply over the last few decades. In 1971, walls existed on roughly 7% of beaches in Ventura, Los Angeles, Orange and San Diego counties. That grew to 33% in 1998, and 38% last year [2018], said Kiki Patsch, assistant professor of environmental science and resource management at California State University, Channel Islands.

That tracks with a shift toward more destructive storms in the Pacific Ocean after 1977. That likely triggered more requests for shoreline protection, she said.

1st Southeastern Peer Exchange for Resilient & Sustainable Bridges – Part 3



Session 1 (12pm – 1:30pm):

- **Part 1**: Round table discussion of goals and commitments (24-minutes)
- **Part 2a: Technical presentations of State of the Art in member states (30 minutes)**
- **Part 2b**: Technical presentations of State of the Art in member states (30 minutes)

**** Breakout (120 minutes) ****

**** Coffee, Tea, Lemonade & Beignets 3:00-3:30pm ****

Session 2 (3:30pm-6:00pm)

- **Part 3: Technical presentations of Manufacturer & Materials Acceptance (60-min)**
- **Part 4**: Technical presentation and discussion on Research Needs (30-min)
- **Part 5**: Technical presentation Open Topics (30-min)
- **Part 6**: Final Q&A, Wrap Up assignment of Follow-up Tasks and Champions. (20 minutes)

Session 1 : Introduction & Logistics (August 8th, 2023)

Participants & Sponsors

Decarbonization with Fiber-Reinforced Polymer Composites

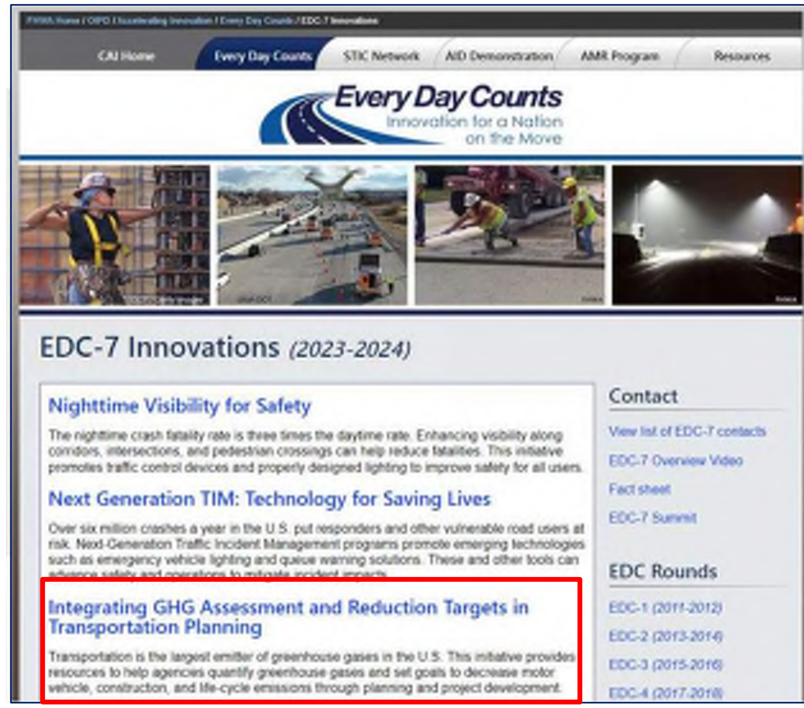
Southeastern Peer eXchange for
Resilient & Sustainable Bridges

Joe Fox
FX Consulting, LLC

August 8, 2023

Decarbonization is a “Hot Topic”

- The federal government wants to lower emissions of greenhouse gases (GHGs)
  - Decarbonization roadmap
- The Inflation Reduction Act provides grants for the use of low carbon materials in construction
  - $2.15B for buildings
  - $2.0B for infrastructure
- One of the DOT’s Every Day Counts (EDC) initiatives is focused on **reducing greenhouse gas emissions** from infrastructure projects



Outline

- Introduction & Terminology
- Sources of Data for Embodied Carbon Calculations
- Lower “Cradle-to-Gate” CO_2 Emissions with FRP Composites
- Lower “Cradle-to-Grave” CO_2 Emissions with FRP Composites
    - Life Cycle Assessment (LCA) for the Halls River Bridge
- Take-home message

Take-Home Message

The use of FRP Composites
can lower Embodied Carbon and CO_2 emissions
in Construction & Infrastructure applications

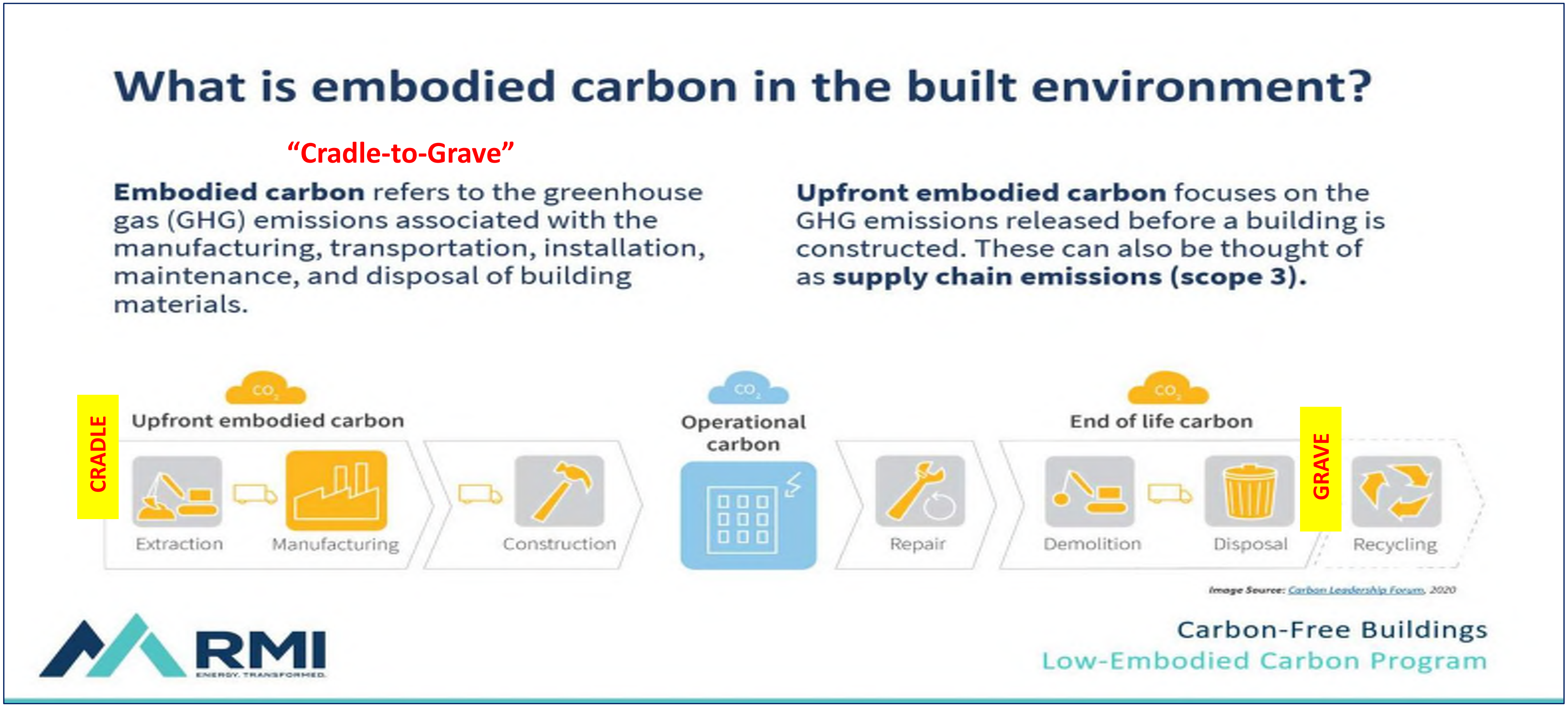
Understanding the Terminology of Decarbonization

- I want to **decarbonize**
- I want to **lower my Carbon Footprint**
- I want to **lower Greenhouse Gas (GHG) emissions**
- I want to **lower Embodied Carbon**

All of these statements are saying essentially the same thing

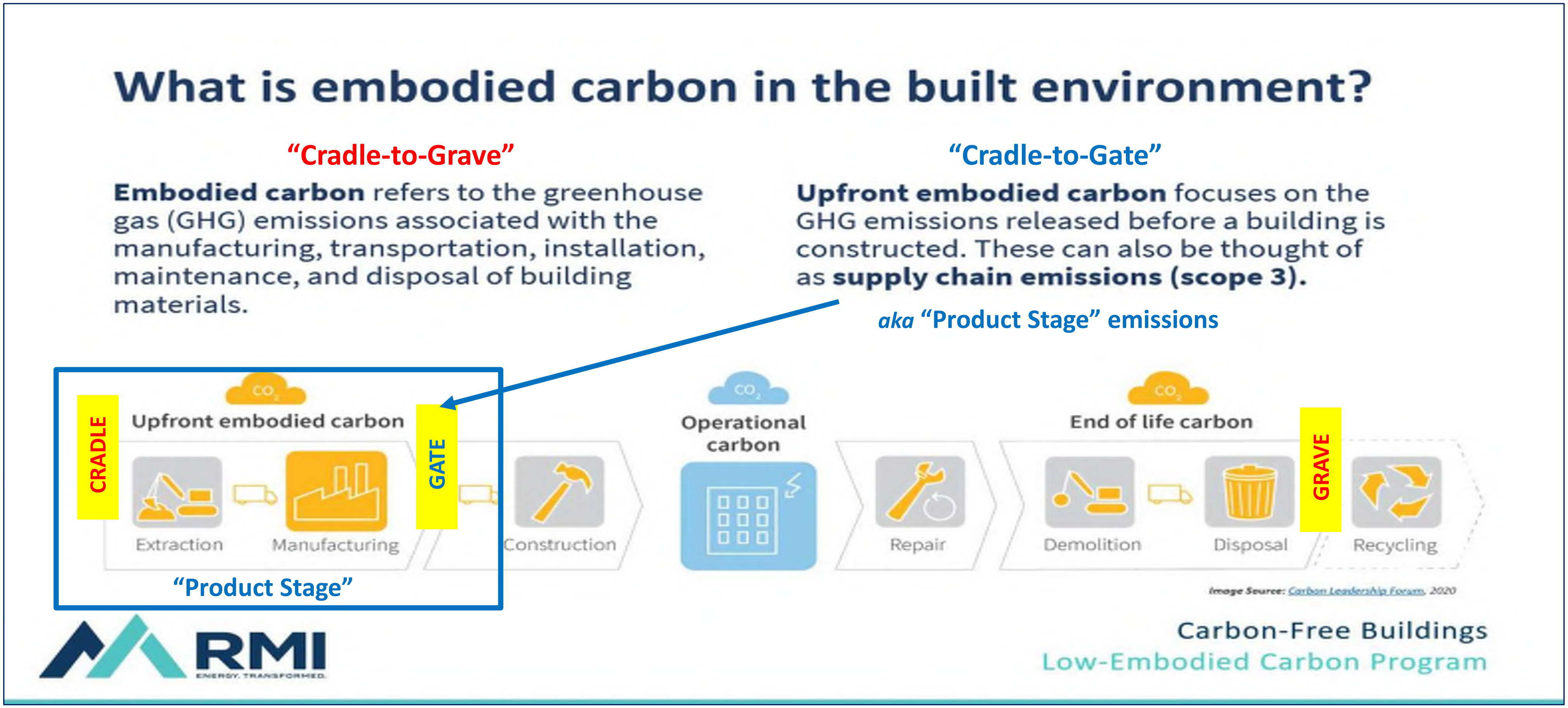
They all want to lower CO_2 emissions !!

Understanding Embodied Carbon



Courtesy of Connor Usry, RMI & ABCC

Understanding Embodied Carbon



Courtesy of Connor Usry, RMI & ABCC

More Terminology

- **Greenhouse gases** (GHGs) include carbon dioxide, methane and nitric oxide
  - Each gas has a different **Global Warming Potential (GWP)**
    - $CO_2 = 1$
    - $CH_4 = 28$
    - $NO_x = 300$
- The GWP is used to calculate **"equivalents of CO_2 emissions"**
- The most common unit is **kg of CO_2 equivalents**

$$\boxed{\mathbf{kgCO_2e}}$$

Outline

- Introduction & Terminology
- **Sources of Data for Embodied Carbon Calculations**
- Lower “Cradle-to-Gate” CO_2 Emissions with FRP Composites
- Lower “Cradle-to-Grave” CO_2 Emissions with FRP Composites
    - Life Cycle Assessment (LCA) for the Halls River Bridge
- Take-home message
- Q & A

Sources of Data for Cradle-to-Gate Emissions Calculations

- **kgCO_2e** were calculated for FRP and steel with data from various databases

2021 Carbon Leadership Forum

Material Baselines

BASELINE REPORT v2 | July 2021

CLF data-base

FINAL REPORT

LIFE CYCLE INVENTORY OF POLYMER COMPOSITES

SUBMITTED TO:

GREEN COMPOSITES COUNCIL
AMERICAN COMPOSITES MANUFACTURERS ASSOCIATION (ACMA)

SUBMITTED BY:

FRANKLIN ASSOCIATES, A DIVISION OF
EASTERN RESEARCH GROUP, INC. (ERG)

JULY, 2012

ACMA's Life Cycle Inventory (LCI)

EPD for FRP rebar

CLF data-base

- Contains Embodied Carbon data for:
  - Concrete
  - Masonry
  - Steel
    - Used for the calculations later
  - Aluminum
  - Wood & Engineered Wood
- Three levels of $kgCO_2e$:
  - Achievable (low)
  - Typical (median)
  - Baseline (high)
- Watch the units!

Steel	$kgCO_2e$ / kg
Concrete	$kgCO_2e$ / m^3

Carbon Leadership Forum

2021 Carbon Leadership Forum

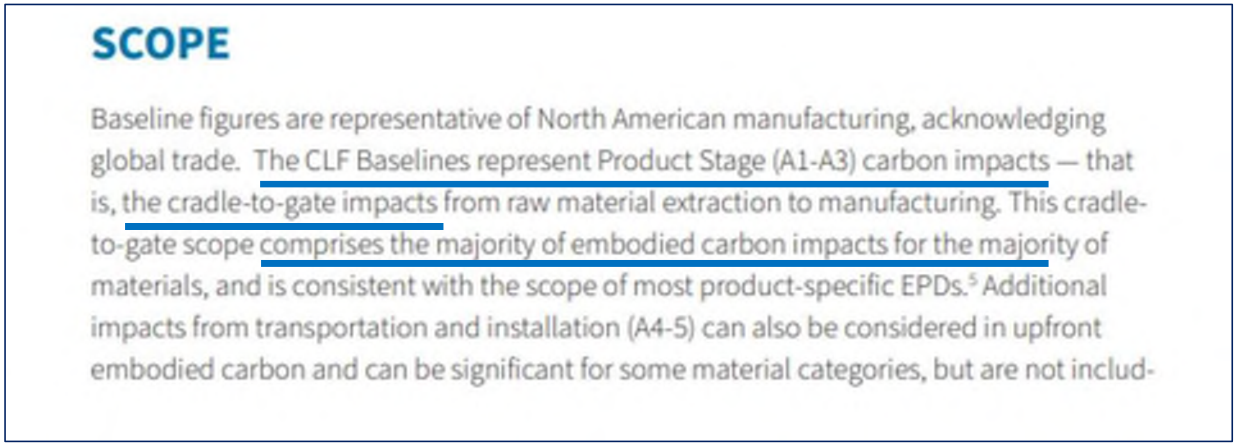
Material Baselines

BASELINE REPORT v2 | July 2021

kg CO_2 equivalents

Category	Subtype	2021 CLF BASELINES v2 kg CO2e per declared unit: Achievable (Low)	Typical (Median)	Baseline (High)	Declared unit	Method	Data Source & Notes
STEEL							
Rebar		0.8	0.98	**1.7**	kg	2	Typical = IW-EPD Fabricated Steel Reinforcement (CSRI, 2017); Low = EC3-calculated 20th percentile Jan 2021; High = EC3-calculated 80th percentile Jan 2021 drawn from IW-EPD and 64 product-specific EPDs.
Steel Wire and Mesh		Match rebar values			kg	4	Due to limited data and product type similarity, rebar values may be used as a reasonable proxy for steel wire and mesh concrete reinforcement until more specific data is available.
Plate Steel		1.0	1.47	**3.0**	kg	3	Typical = IW-EPD Fabricated Steel Plate (AISC, 2016c); Due to low number of EPDs, Low = point between IW-EPD value and estimated global low based on ICE database (Circular Ecology, 2019); High = point between IW-EPD value and estimated global high based on ICE database (Circular Ecology, 2019).
Structural Steel	Hollow Sections	1.5	2.39	**3.0**	kg	3	Typical = IW-EPD Fabricated Hollow Structural Sections (AISC, 2016a); Due to low number of EPDs, Low = point between IW-EPD value and estimated global low based on ICE database (Circular Ecology, 2019); High adjusted to reflect similar ranges as other steel products on this list due to shortage of available data. This aligns with the average value of 2 IW-EPDs (AISC, 2016 and STI, 2016) including EC3-assessed uncertainty factor July 2021.
Structural Steel	Hot-Rolled Sections	0.8	1.16	**1.7**	kg	2	Typical = IW-EPD Fabricated Hot Rolled Structural Sections (AISC, 2016b); Low = EC3-calculated 20th percentile Jan 2021; High = EC3-calculated 80th percentile Jan 2021 drawn from IW-EPD and 34 product-specific EPDs.
Steel decking		1.5	2.37	**3.1**	kg	3	Typical = steel deck IW-EPD (SDI, 2015). Low = IW-EPD minus uncertainty factor to account for variability in e.g., production methods, grid mix, coating types, and changes over time (IW-EPD based on year 2012 primary data). High = IW-EPD plus EC3-assessed uncertainty factor to account for variability. (This also aligns with the midpoint between IW-EPD and highest product EPD value, including uncertainty factor, in EC3 database June 2021.)

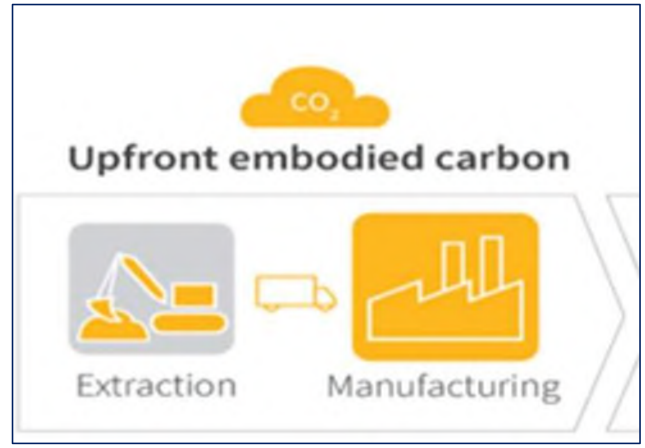
Scope of the CLF Data-Base



SCOPE

Baseline figures are representative of North American manufacturing, acknowledging global trade. The CLF Baselines represent Product Stage (A1-A3) carbon impacts — that is, the cradle-to-gate impacts from raw material extraction to manufacturing. This cradle-to-gate scope comprises the majority of embodied carbon impacts for the majority of materials, and is consistent with the scope of most product-specific EPDs.[5] Additional impacts from transportation and installation (A4-5) can also be considered in upfront embodied carbon and can be significant for some material categories, but are not includ-

"Cradle-to-Gate"

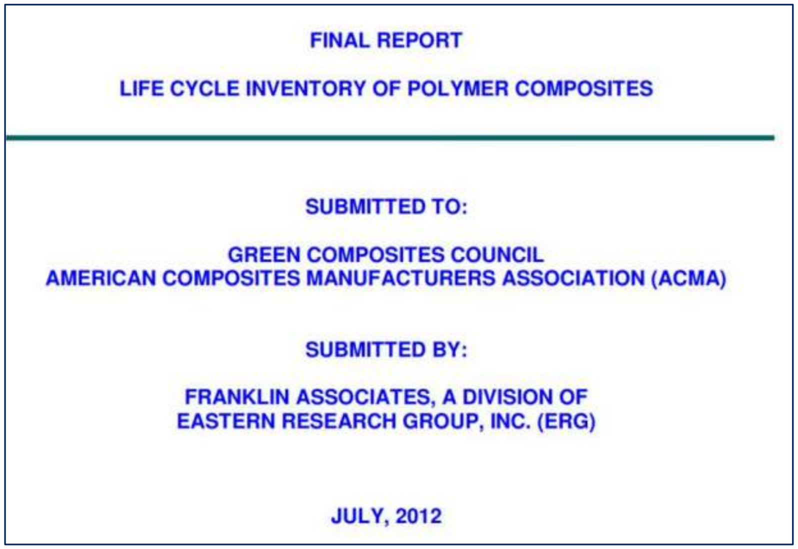


"Product Stage"

- Data for the Product Stage
  - "Cradle-to-Gate"
- …. "comprises the <u>majority</u> of Embodied Carbon impacts for the majority of materials"

Resources for FRP Composites

- ACMA's Life Cycle Inventory (LCI) for FRP composites
  - Cradle-to-Gate
    - Same as the CLF data-base
- Contains Embodied Carbon data for:
  - Unsaturated Polyester Resins (UPRs)
  - E-glass
  - Compression-molded composites
  - Open molding
  - Vacuum infusion
- 2012 version is being updated as part of ACMA's Climate Impacts project



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JULY, 2012

Data from ACMA's LCI

- This data will be used in the "Cradle-to-Gate" calculations later
  - Girders
  - Gratings

Table 43. Cradle-to-Gate GHGs for Production of Vacuum Infused Composites
(Pounds CO2 equivalents per 1,000 pounds of Vacuum Infused Composites)

	UPR Production	E-Glass Production	Other Materials Production	Incoming Transport	Process Energy	TOTAL (1)	PERCENT TOTAL (1)
Fossil CO2	560	543	824	96.6	290	**2,313**	**88%**
Methane	78.8	36.4	155	4.62	22.0	**296**	**11%**
Nitrous Oxide	2.29	2.31	3.35	0.77	1.52	**10.2**	**<1%**
Others	0.69	6.35	2.03	0	0	**9.06**	**<1%**
TOTAL (1)	**642**	**588**	**984**	**102**	**313**	**2,629**	**100%**
PERCENT TOTAL (1)	**24%**	**22%**	**37%**	**3.9%**	**12%**	**100%**	

(1) Totals may not sum due to rounding

Source: Franklin Associates, A Division of ERG

Used for FRP girder calcs

Table 29. Cradle-to-Gate GHGs for Production of Open Molded Composites
(Pounds CO2 equivalents per 1,000 pounds of Open Molded Composites)

	UPR Production	E-Glass Production	Other Materials Production	Incoming Transport	Process Energy	TOTAL (1)	PERCENT TOTAL (1)
Fossil CO2	1,387	443	339	180	822	**3,172**	**91%**
Methane	195	29.7	42.0	8.57	48.2	**323**	**9.2%**
Nitrous Oxide	5.68	1.89	1.73	1.44	5.51	**16.2**	**<1%**
Others	1.70	5.19	-14.9	0	0.0078	**-8.04**	**<1%**
TOTAL (1)	**1,590**	**480**	**368**	**190**	**876**	**3,504**	**100%**
PERCENT TOTAL (1)	**45%**	**14%**	**10%**	**5.4%**	**25%**	**100%**	

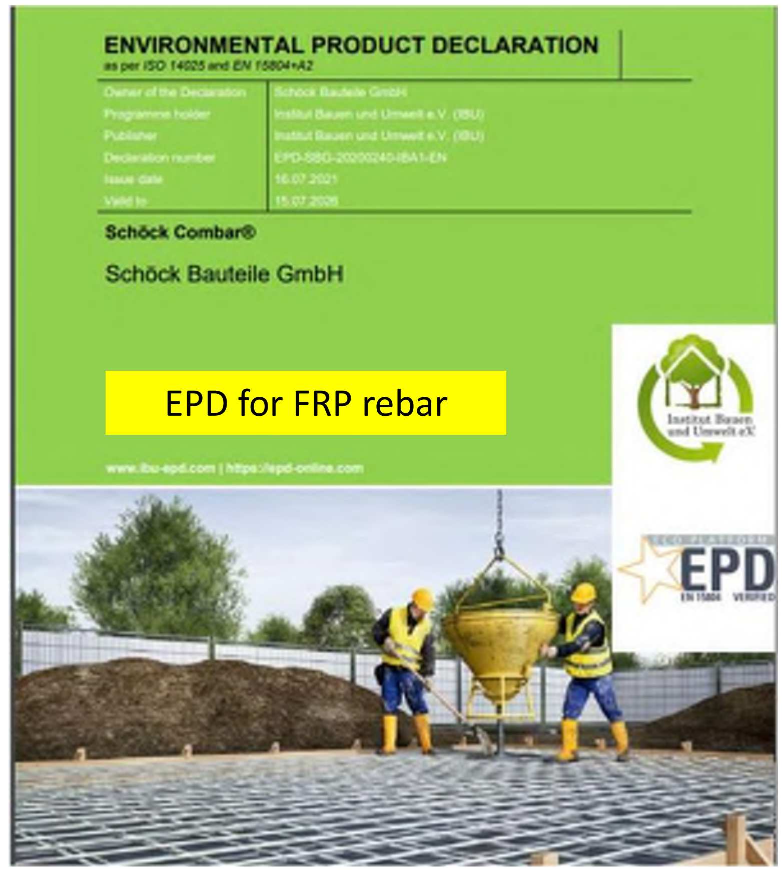
(1) Totals may not sum due to rounding

Source: Franklin Associates, A Division of ERG

Used for FRP grating calcs

Resources for Embodied Carbon Calculations

- **Environmental Product Declarations** (EPDs)
  - Typically data for Cradle-to-Gate
- Buildingtransparency.org is a useful resource
- EPD for FRP rebar from Schock
  - Used for the rebar calculations later



Embodied Carbon Data for FRP Rebar

PRODUCT STAGE			CONSTRUCTION PROCESS STAGE		USE STAGE							END OF LIFE STAGE				BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARIES
Raw material supply	Transport	Manufacturing	Transport from the gate to the site	Assembly	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling-potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
X	X	X	ND	X	ND	ND	MNR	MNR	MNR	ND	ND	ND	X	X	X	X

RESULTS OF THE LCA - ENVIRONMENTAL IMPACT according to EN 15804+A2: 1 kg Combar® mit 25 mm Durchmesser

Core Indicator	Unit	A1-A3	A5	C2	C3	C4	D
Global warming potential - total	[kg CO_2-Eq.]	2.22E+0	2.57E-2	1.89E-3	4.04E-2	1.53E-2	-1.20E-2
Global warming potential - fossil fuels	[kg CO_2-Eq.]	2.20E+0	1.37E-2	1.81E-3	4.03E-2	1.52E-2	-1.20E-2
Global warming potential - biogenic	[kg CO_2-Eq.]	1.74E-2	1.20E-2	8.25E-5	1.34E-4	5.58E-5	-2.81E-5
GWP from land use and land use change	[kg CO_2-Eq.]	1.40E-3	6.12E-7	1.08E-7	5.83E-5	4.37E-5	-8.39E-6
Depletion potential of the stratospheric ozone layer	[kg CFC11-Eq.]	1.68E-14	5.69E-18	3.03E-19	8.86E-16	5.68E-17	-1.25E-16
Acidification potential, accumulated exceedance	[mol H^+-Eq.]	1.33E-2	3.87E-6	1.84E-6	8.89E-5	1.09E-4	-1.68E-5
Eutrophication, fraction of nutrients reaching freshwater end compartment	[kg P-Eq.]	5.94E-6	9.23E-10	4.20E-10	1.08E-7	2.61E-8	-1.55E-8
Eutrophication, fraction of nutrients reaching marine end compartment	[kg N-Eq.]	1.81E-3	1.16E-6	5.73E-7	1.97E-5	2.80E-5	-4.33E-6
Eutrophication, accumulated exceedance	[mol N-Eq.]	1.96E-2	1.78E-5	6.35E-6	2.07E-4	3.08E-4	-4.64E-5
Formation potential of tropospheric ozone photochemical oxidants	[kg NMVOC-Eq.]	5.86E-3	3.23E-6	1.65E-6	5.41E-5	8.48E-5	-1.25E-5
Abiotic depletion potential for non-fossil resources	[kg Sb-Eq.]	4.77E-7	8.59E-11	7.18E-11	1.17E-8	1.37E-9	-1.97E-9
Abiotic depletion potential for fossil resources	[MJ]	3.91E+1	8.36E-3	2.55E-2	7.08E-1	1.99E-1	-2.03E-1
Water (user) deprivation potential, deprivation-weighted water consumption (WDP)	[m^3 world-Eq deprived]	2.15E-1	2.90E-3	5.05E-6	8.77E-3	1.58E-3	-1.24E-3

RESULTS OF THE LCA - INDICATORS TO DESCRIBE RESOURCE USE according to EN 15804+A2: 1 kg Combar® mit 25 mm Durchmesser

This is the same stage in the CLF data-base for steel

Used for the FRP rebar calculations

EPD for FRP rebar

Sources of Data for Cradle-to-Gate Emissions Calculations

- **kgCO_2e** were calculated for FRP and steel with data from various databases

2021 Carbon Leadership Forum

Material Baselines

BASELINE REPORT v2 | July 2021

CLF data-base

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EASTERN RESEARCH GROUP, INC. (ERG)

JULY, 2012

ACMA's Life Cycle Inventory (LCI)

EPD for FRP rebar

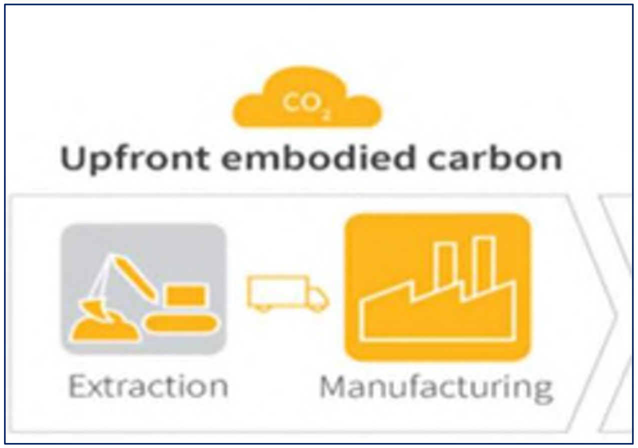
Using data from these 3 sources enables
"apples to apples"
Cradle-to-Gate comparisons

Outline

- Introduction & Terminology
- Sources of Data for Embodied Carbon Calculations
- **Lower "Cradle-to-Gate" CO_2 Emissions with FRP Composites**
- Lower "Cradle-to-Grave" CO_2 Emissions with FRP Composites
  - Life Cycle Assessment (LCA) for the Halls River Bridge
- Take-home message
- Q & A

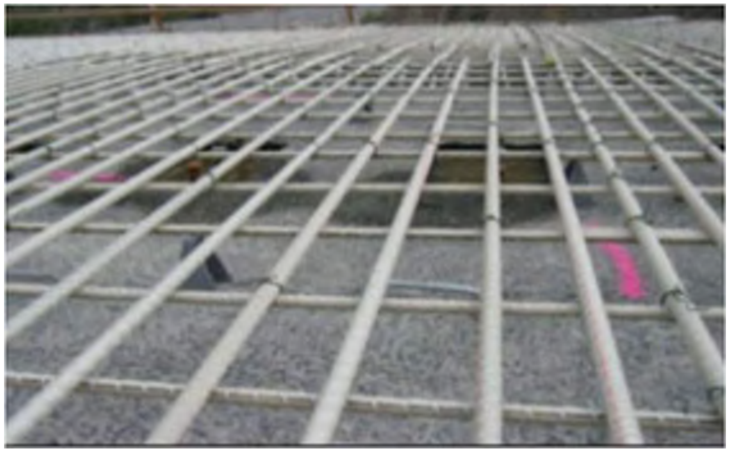
Cradle-to-Gate Comparisons of CO_2 Emissions

- FRP Rebar vs. Steel Rebar
- FRP Girders vs. Steel Girders
- FRP Gratings vs. Steel Gratings



FRP Rebar

- FRP rebar can replace steel rebar as a reinforcement for concrete
  - Used in place of epoxy-coated steel, stainless steel & galvanized steel rebar
  - Used in buildings, bridges, seawalls ….
- FRP rebar is **72% lighter** than steel rebar and much more corrosion-resistant
- You need **20% more** FRP rebar on a lineal foot basis relative to steel for the same stiffness
  - *Steve Nolan, Florida DOT*



Cradle-to-Gate Emissions: FRP Rebar vs Steel Rebar

	Source Data	Level	$kgCO_2e/kg$	Weight (kg)	kg CO_2 equivalents
Steel rebar	CLF data-base	Achievable (low)	0.80	1000	800
		Typical (median)	0.98		980
		Baseline (high)	1.70		1700
FRP rebar	Schock EPD		2.2	336	739

FRP is 72% lighter
but you need 20% more

Cradle-to-Gate Emissions: FRP Rebar vs Steel Rebar

	Source Data	Level	$kgCO_2e/kg$	Weight (kg)	kg CO_2 equivalents	% Reduction with FRP
Steel rebar	CLF data-base	Achievable (low)	0.80	1000	800	8%
		Typical (median)	0.98		980	25%
		Baseline (high)	1.70		1700	57%
FRP rebar	Schock EPD		2.2	336	739	

CO_2 emissions are at least 8% lower with FRP rebar,
25% lower than for typical steel rebar

FRP Girders

- G-Beam FRP girders have been commercialized by Advanced Infrastructure Technologies (AIT) and used in bridges in Maine and other states
  - Technology developed at U Maine
  - Prepared by infusion with vinyl ester resins

- FRP girders are **70% lighter** than steel girders
  - Easier to transport and install
  - More corrosion-resistant than steel

Grist Mill Bridge in Maine

Cradle-to-Gate Emissions: FRP Girders vs Steel Girders

	Source Data	Level	$kgCO_2e/kg$	Weight (kg)	kg CO_2 equivalents
Plate steel	CLF data-base	Achievable (low)	1.00	1000	1000
		Typical (median)	1.47		1470
		Baseline (high)	3.00		3000
FRP girder	ACMA LCI**		2.629	300	789

Vacuum infusion

FRP is 70% lighter

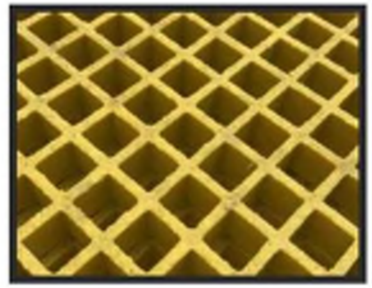
*** Unsaturated Polyester Resin (UPR) used as a surrogate for Vinyl Ester Resin (VER)*

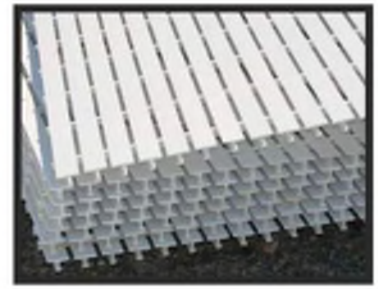
Cradle-to-Gate Emissions: FRP Girders vs Steel Girders

	Source Data	Level	$kgCO_2e/kg$	Weight (kg)	kg CO_2 equivalents	% Reduction with FRP
Plate steel	CLF data-base	Achievable (low)	1.00	1000	1000	21%
		Typical (median)	1.47		1470	46%
		Baseline (high)	3.00		3000	74%
FRP girder	ACMA LCI		2.629	300	789	

CO_2 emissions are at least 21% lower with FRP girders, 46% lower than for a typical steel girder

FRP Gratings, Decking & Railings





- FRP gratings, decking & railings are used in:
  - Oil & gas industry
  - Wastewater treatment
  - **Inland waterways**

Wastewater Treatment

Offshore Drilling

- FRP gratings & decking are **73% lighter** than their steel counterparts
  - More corrosion-resistant than steel

Inland Waterways

Courtesy Eric Johnson, USACE

Cradle-to-Gate Emissions: FRP Gratings vs Steel Gratings

	Source Data	Level	$kgCO_2e/kg$	Weight (kg)	kg CO_2 equivalents
Steel decking	CLF data-base	Achievable (low)	1.50	1000	1500
		Typical (median)	2.37		2370
		Baseline (high)	3.10		3100
FRP grating	ACMA LCI		3.504	270	946
	Open molding			*FRP is 73% lighter*	

Cradle-to-Gate Emissions: FRP Gratings vs Steel Gratings

	Source Data	Level	$kgCO_2e/kg$	Weight (kg)	kg CO_2 equivalents	% Reduction with FRP
Steel decking	CLF data-base	Achievable (low)	1.50	1000	1500	37%
		Typical (median)	2.37		2370	60%
		Baseline (high)	3.10		3100	70%
FRP grating	ACMA LCI		3.504	270	946	

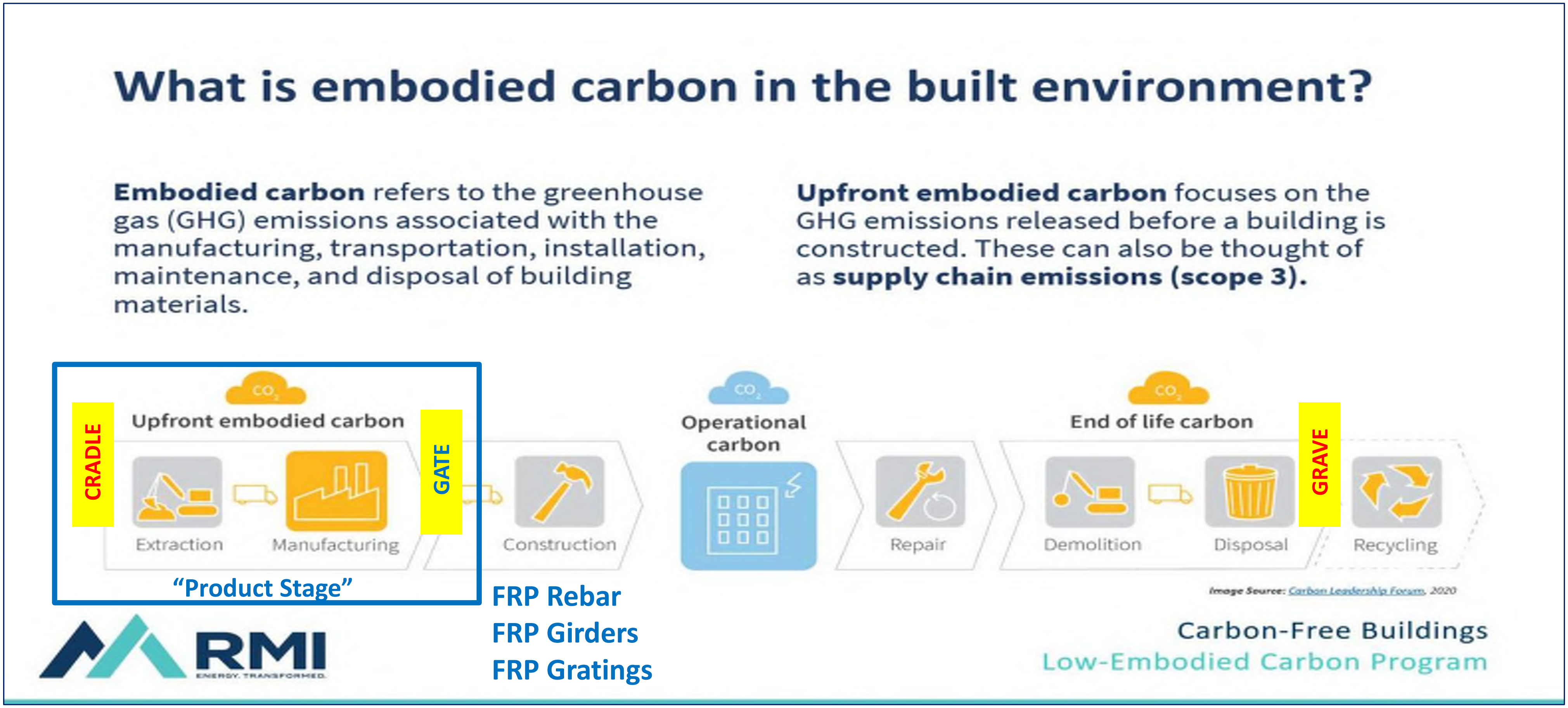
CO_2 emissions are at least 37% lower with FRP gratings, 60% lower than for a typical steel grating

Summary

	% Reduction Possible with FRP vs Steel		
	Achievable (Low)	Typical (Median)	Baseline (High)
Rebar	8	**25**	57
Girders	21	**46**	74
Gratings	37	**60**	70

FRP has a very good “Cradle-to-Gate” Decarbonization story to tell vs. steel

What You've Seen So Far = "Cradle-to-Gate"

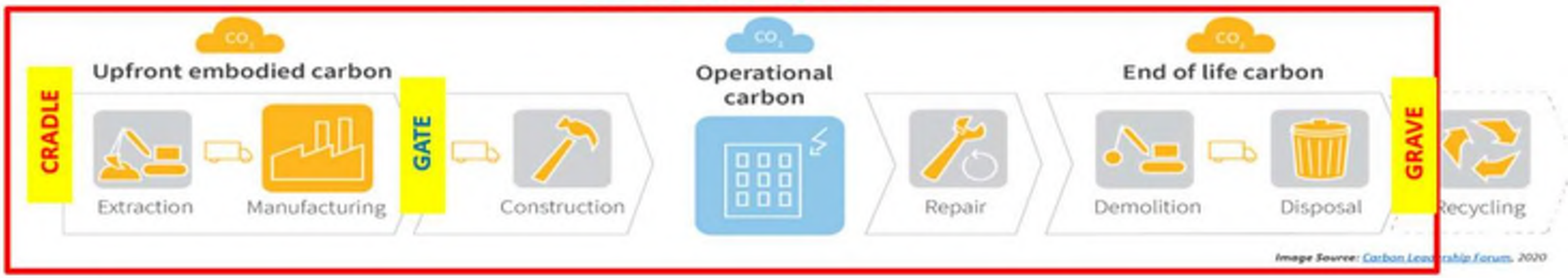


Courtesy of Connor Usry, RMI & ABCC

Outline

- Introduction & Terminology
- Sources of Data for Embodied Carbon Calculations
- Lower "Cradle-to-Gate" CO_2 Emissions with FRP Composites
- **Lower "Cradle-to-Grave" CO_2 Emissions with FRP Composites**
  - **Life Cycle Assessment (LCA) for the Halls River Bridge**

Halls River Bridge LCA



Life Cycle Assessment (LCA) for the Halls River Bridge

Advances in Civil Engineering Materials

Thomas Cadenazzi,[1] Giovanni Dotelli,[2] Marco Rossini,[3] Steven Nolan,[4] and Antonio Nanni[3]

DOI: 10.1520/ACEM20180113

Life-Cycle Cost and Life-Cycle Assessment Analysis at the Design Stage of a Fiber-Reinforced Polymer-Reinforced Concrete Bridge in Florida

LCCA: NPV of Life Cycle Cost is **20% lower with FRP** because of reduced maintenance & replacement costs

LCA: Cradle-to-Grave emissions are **26% lower with FRP** than with steel

Halls River Bridge in Homosassa, FL north of Tampa

- Continuous deck with 5 spans
  - 186’ long, 58’ wide
- Completed in November 2019

Results of the Halls River Bridge LCA: Summary

Advances in Civil Engineering Materials

Thomas Cadenazzi,[1] Giovanni Dotelli,[2] Marco Rossini,[3] Steven Nolan,[4] and Antonio Nanni[3]

DOI: 10.1520/ACEM20180113

Life-Cycle Cost and Life-Cycle Assessment Analysis at the Design Stage of a Fiber-Reinforced Polymer-Reinforced Concrete Bridge in Florida

FRP

TABLE 13
FRP-RC/PC environmental impacts

Item	Product Stage [A1–A3]	Transport to Job Site [A4]	Construction [A5]	Use	EOL	Total
Ozone depletion, kg CFC-11 eq	0.486	0.0197	0.0182	0.000359	0.0102	0.534
Global warming, kg CO_2 eq	883,000	81,200	83,900	8,690	34,300	1,090,000
Photochemical oxidant creation, kg O_3 eq	51,000	9,430	6,400	422	4,390	71,700
Acidification, kg SO_2 eq	4,460	421	291	32	185	5,390
Eutrophication, kg N eq	1,460	92	150	13	42	1,760

Steel

TABLE 14
CS-RC/PC environmental impacts

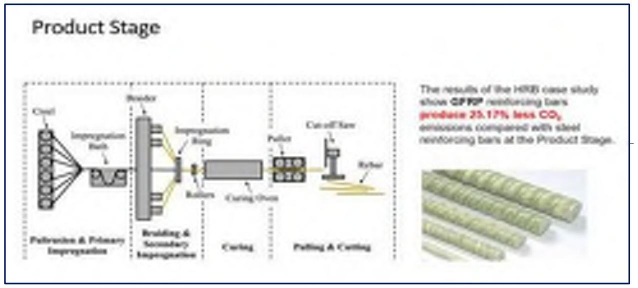
Item	Product Stage [A1–A3]	Transport to Job Site [A4]	Construction [A5]	Use	EOL	Total
Ozone depletion, kg CFC-11 eq	0.0619	0.0265	0.0242	0.00175	0.011	0.125
Global warming, kg CO_2 eq	1,180,000	109,000	112,000	35,200	36,700	1,480,000
Photochemical oxidant creation, kg O_3 eq	57,000	11,800	8,530	1,530	4,740	83,500
Acidification, kg SO_2 eq	4,480	495	388	121	199	5,680
Eutrophication, kg N eq	3,070	120	200	77	45	3,510

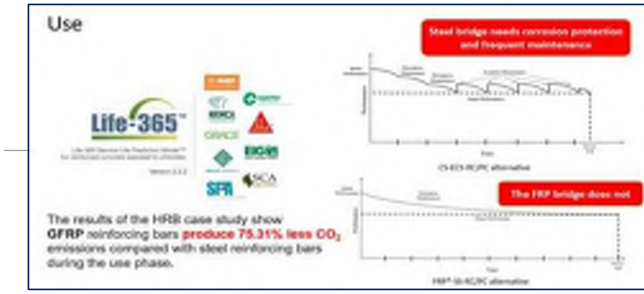
$kgCO_2e$ are 26% lower with FRP than with steel

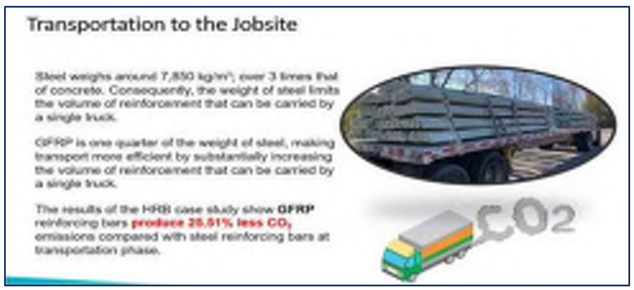
…… and emissions are lower at every stage

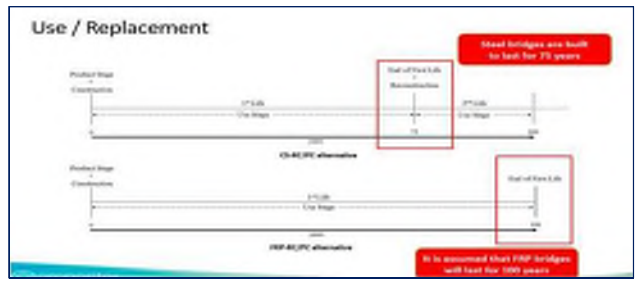
Lower Cradle-to-Grave Emissions with FRP Composites

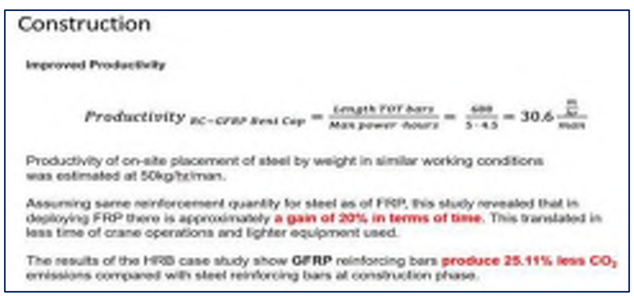
Thomas Cadenazzi, Halls River Bridge LCA

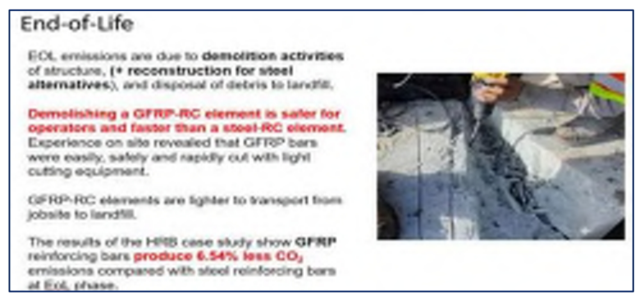












$kgCO_2e$ are 26% lower with FRP than with steel

…… and emissions are lower at every stage

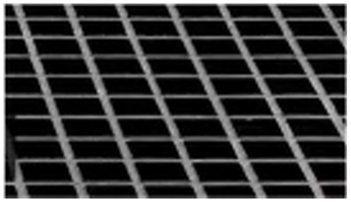
Take-Home Message

The use of FRP Composites can lower Embodied Carbon and CO_2 emissions in Construction & Infrastructure applications

Cradle-to-Gate

Rebar

Girders



Gratings, decking, railings & ladders

8-74% lower

Cradle-to-Grave

26% lower

Contact information:
Joe Fox
FX Consulting, LLC
foxconsulting147@gmail.com
614-648-1791

1st Southeastern Peer Exchange for Resilient & Sustainable Bridges

SPxRSB-2023

Allium Stainless-Clad Reinforcement for Resilient & Sustainable Transportation Infrastructure

Sam McAlpine, PhD
Chief Technology Officer
Allium Engineering, Inc

August 8, 2023
Mobile, AL

The Allium Team

Steven Jepeal,
Chief Executive Officer
MIT Ph.D. materials testing

Sam McAlpine,
Chief Tech Officer
MIT Ph.D. metal design

Advisors

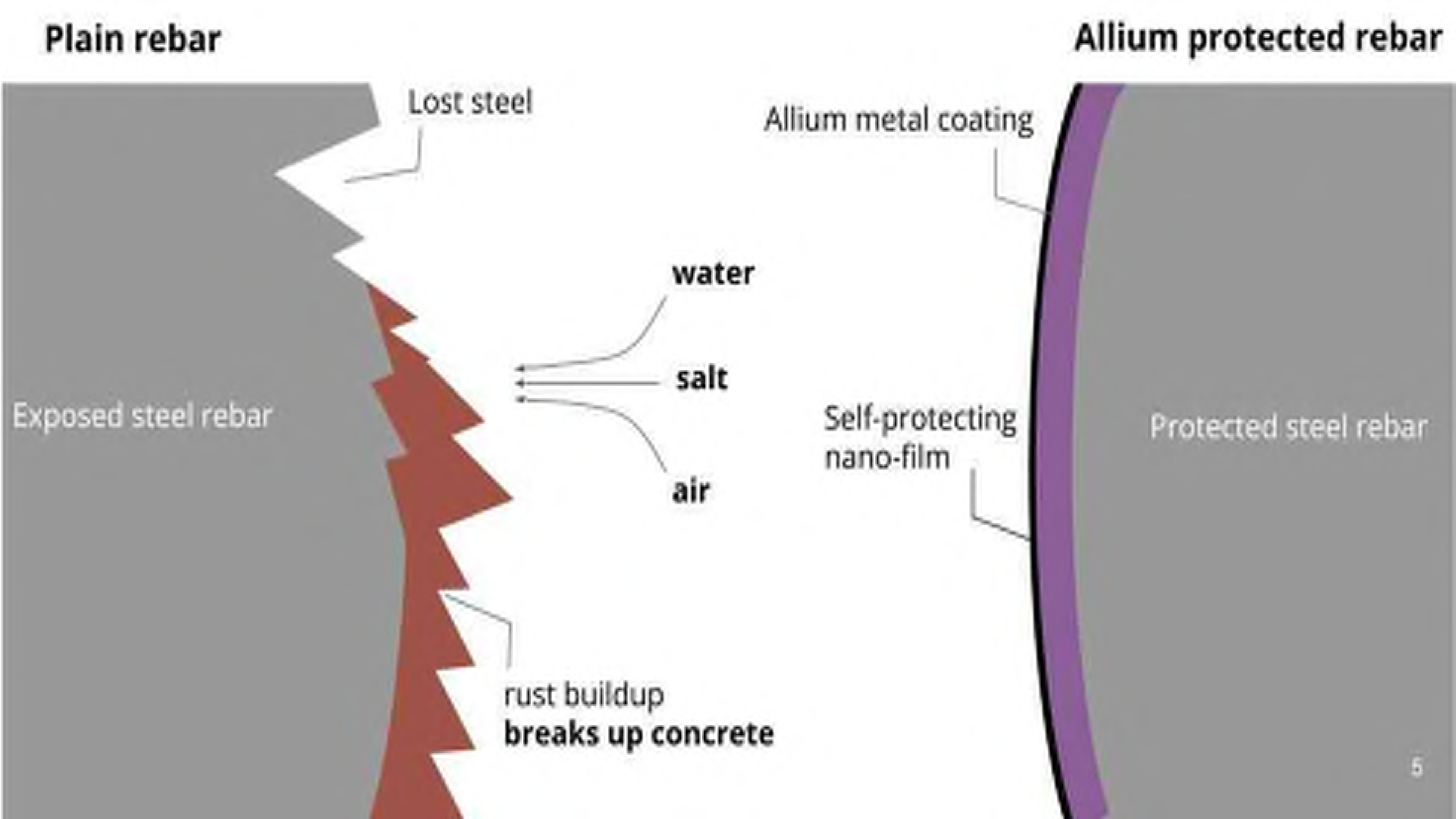
MIT
Nutter uncommon law
Milestone
CARPENTER TECHNOLOGY
SUFFOLK TECHNOLOGIES

"… before the deadly collapse of the Champlain Towers ... evidence of 'major structural damage' to the concrete."

- New York times, 2021

Photo credit: NYT

Corrosion of steel within concrete is a widespread problem in transportation infrastructure



Plain rebar
Allium protected rebar
Lost steel
Allium metal coating
water
salt
air
Exposed steel rebar
Self-protecting
nano-film
Protected steel rebar
rust buildup
breaks up concrete
5

How it's made

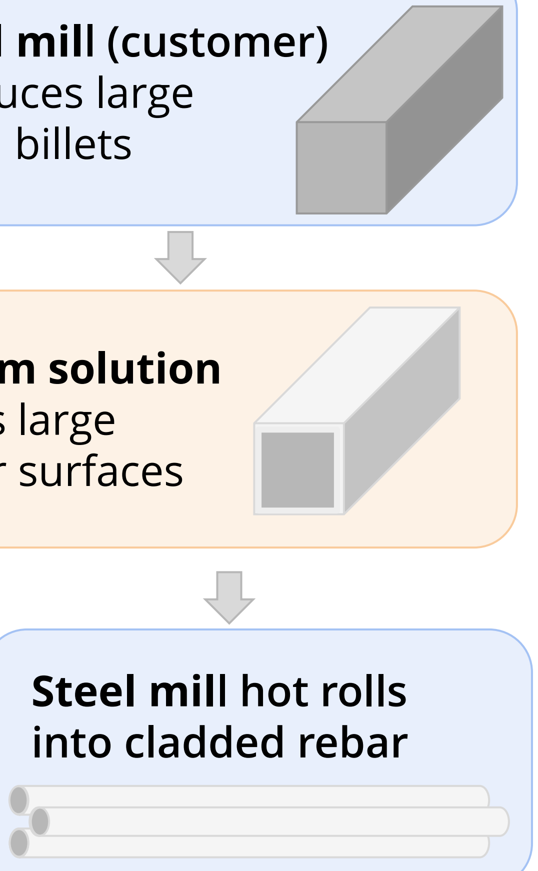
Allium Manufacturing Approach

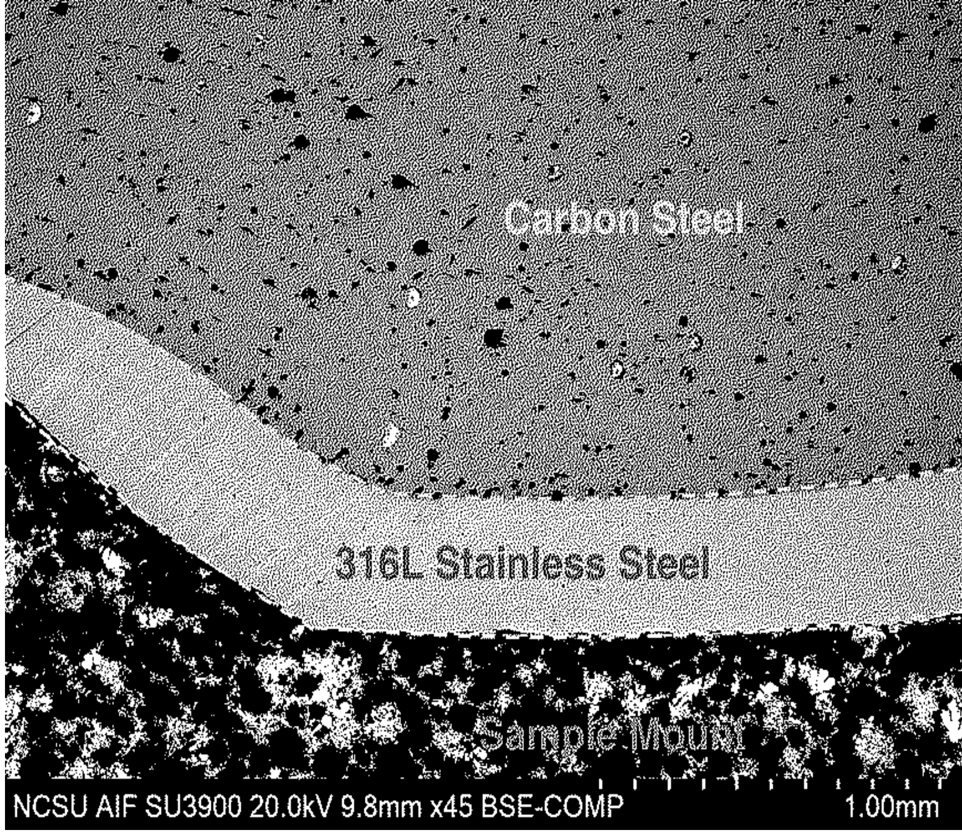
Integrates with steel mill

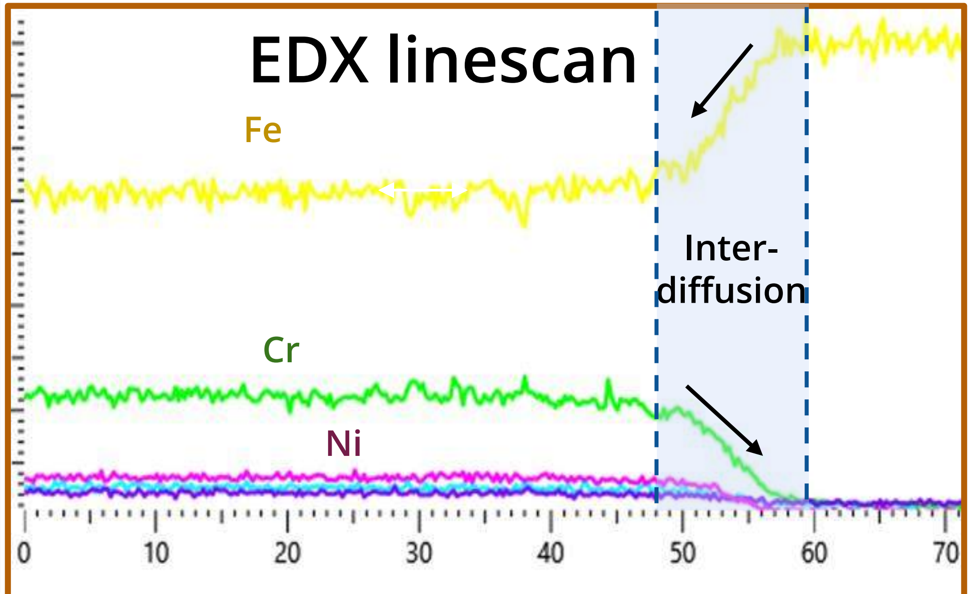
Steel mill (customer)
Produces large steel billets

Allium solution
Clads large outer surfaces

Steel mill hot rolls into cladded rebar

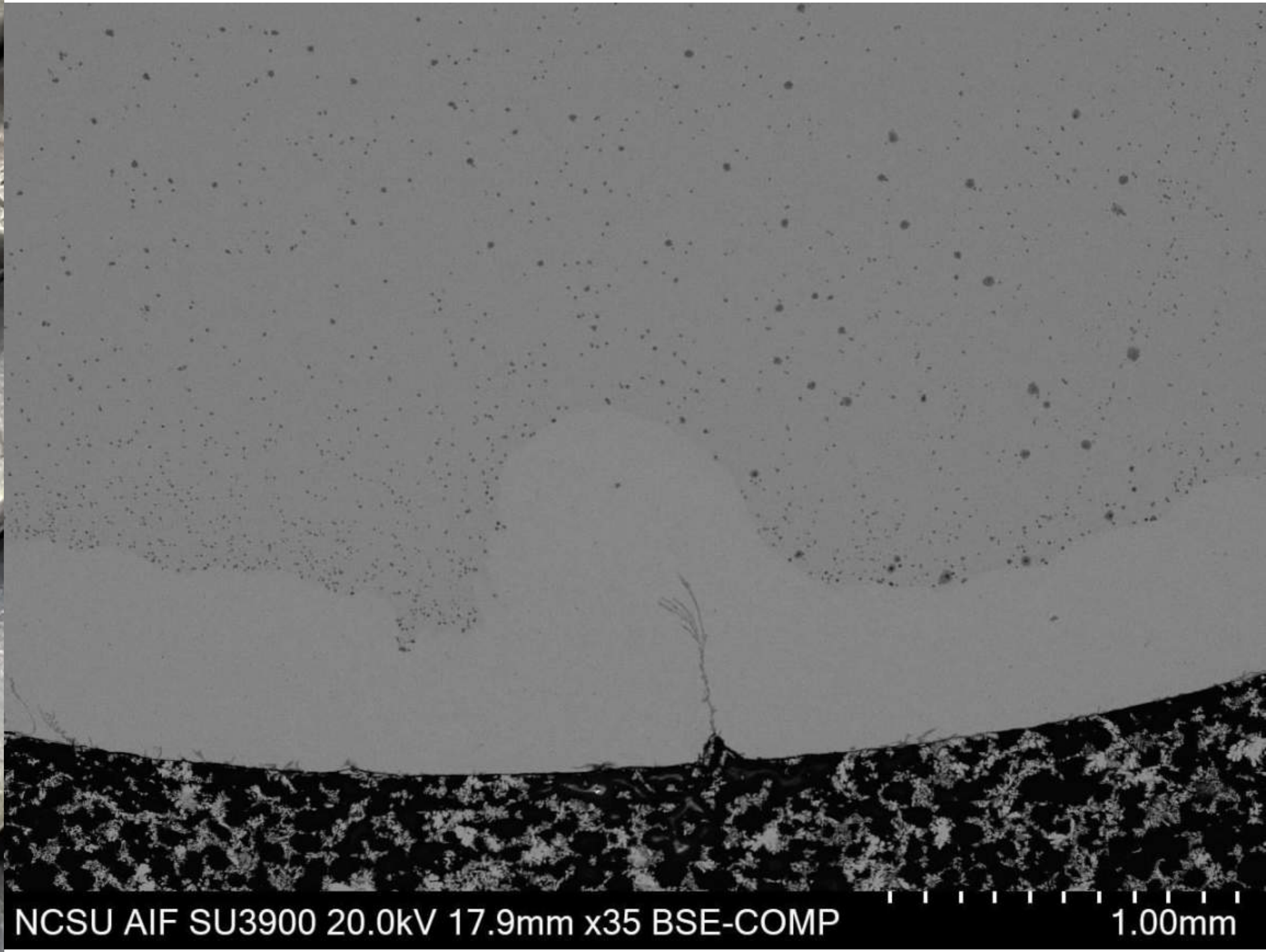







10-feet long stainless steel cladding

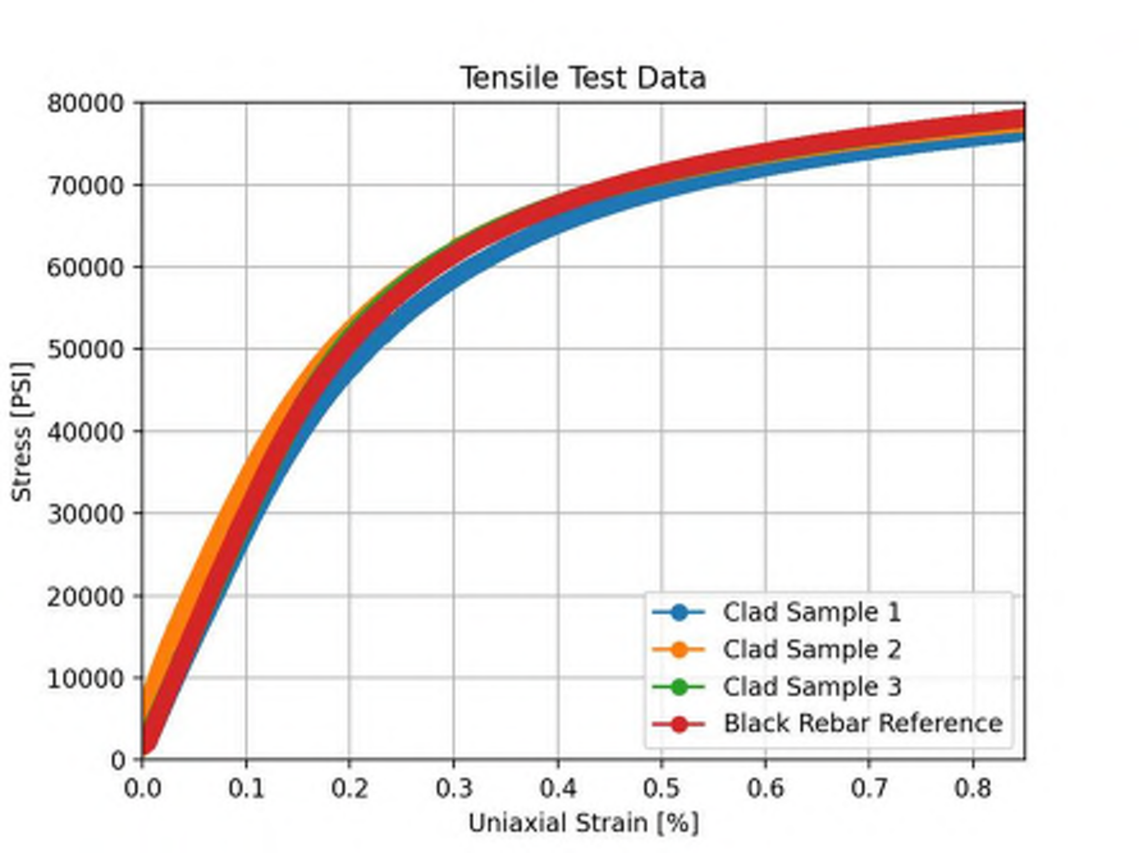
Visible ”seam” can form from excess material.



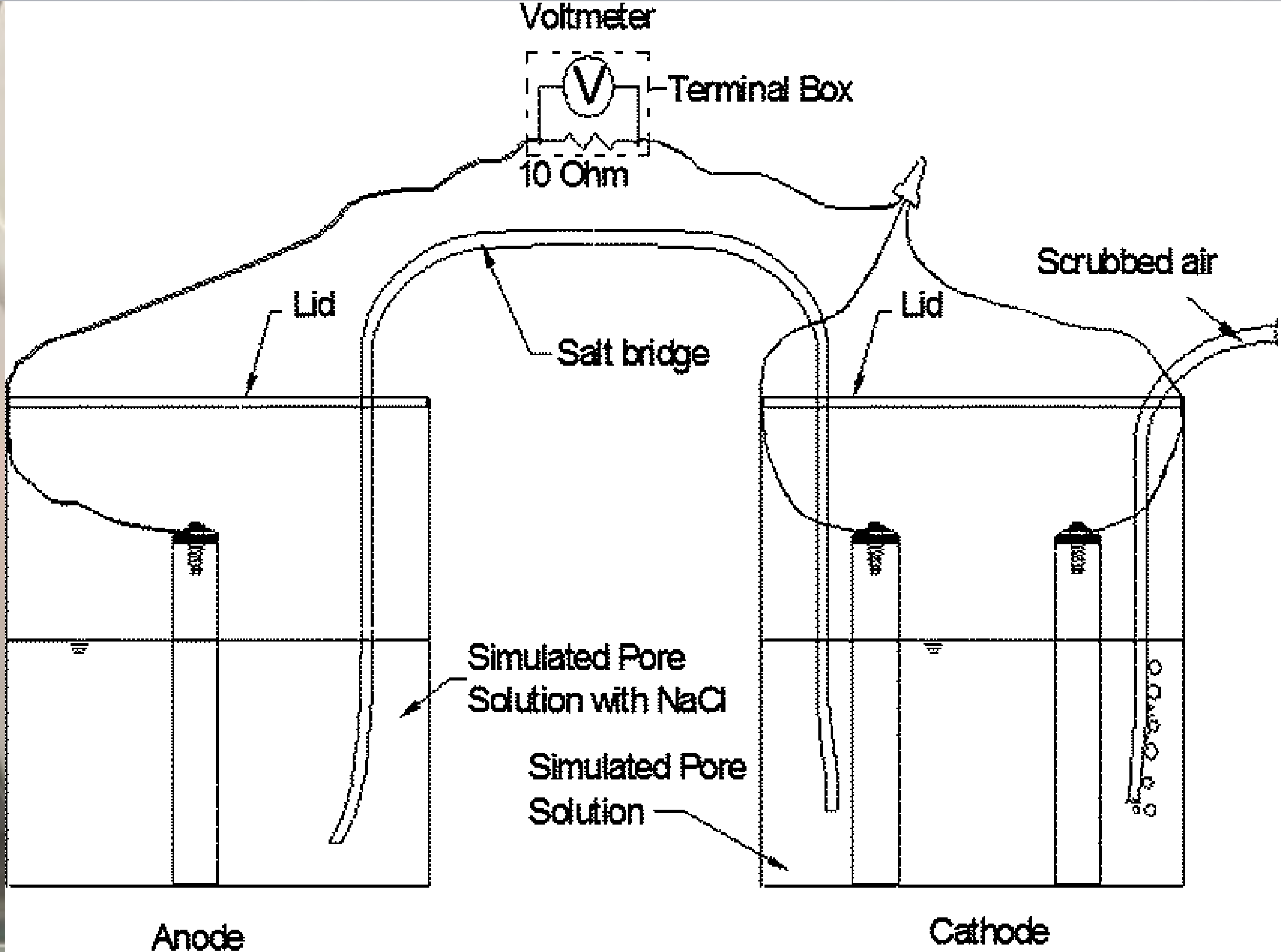
Does not breach through corrosion-resistant layer.

Mechanical Properties are Equivalent to A615

Sample	Ultimate Tensile Strength [PSI]	Yield Strength [PSI]	Total Elongation [%]
SS Clad 1	94,761	68,204	13.71
SS Clad 2	93,843	69,327	12.15
SS Clad 3	96,263	69,659	13.69
A615 Bar	95,457	69,722	13.49



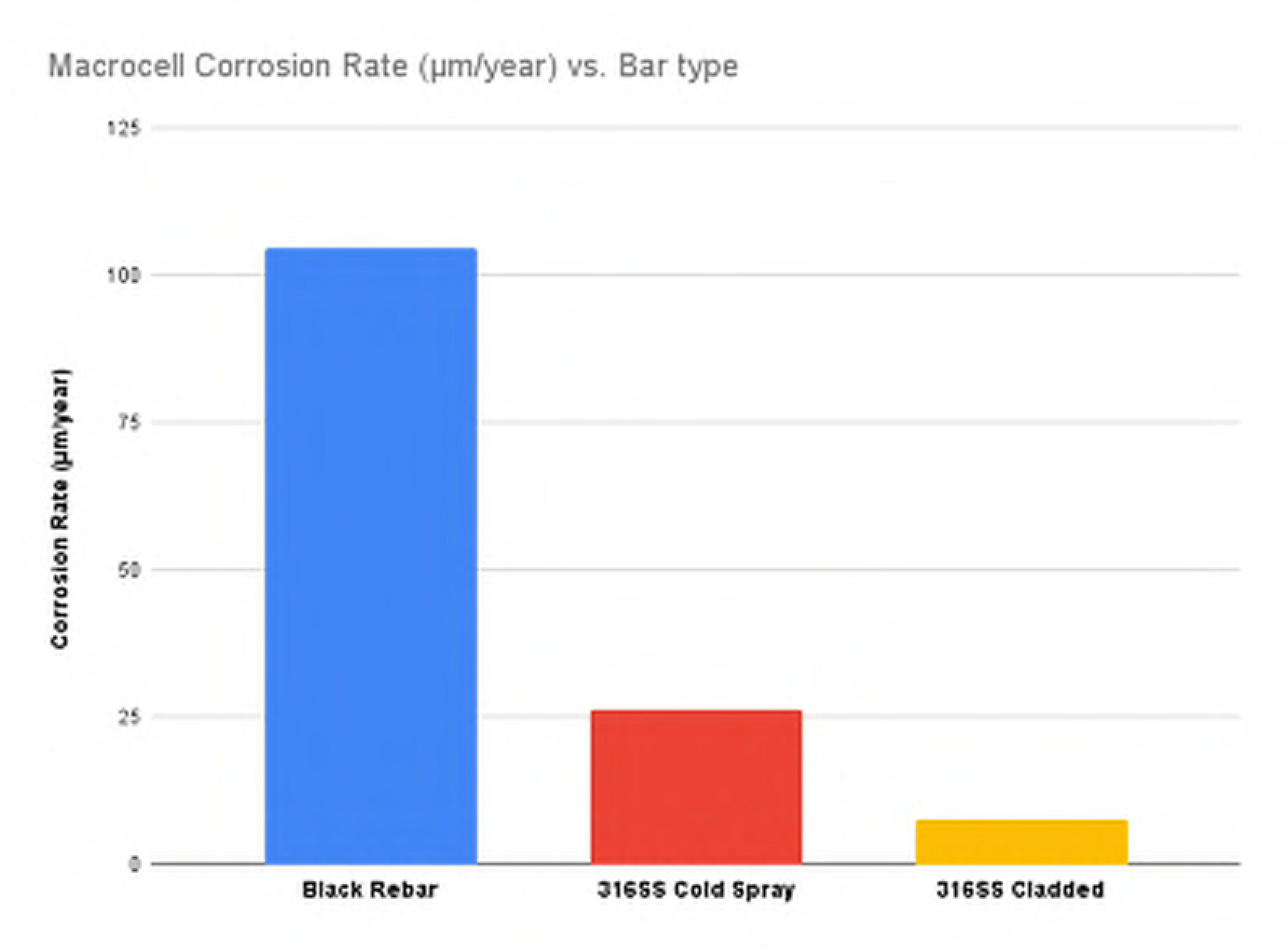
Performance Testing Using Rapid Macrocell Corrosion Test



Rapid Macrocell Corrosion Results

- **Cold Spray 316 coating**
  4X lower corrosion rate

- **Allium Stainless-Clad**
  13X lower corrosion rate



There was 1 UK-based supplier (Stelax/Nuovinox and Cladinox) but not apparent commercial production for 10 years

Pictures from trip to Roanoke, VA steel mill

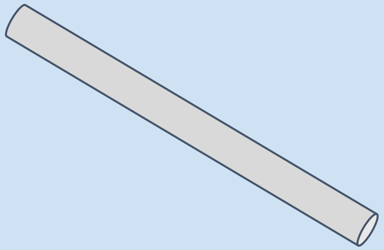
Glue + stainless caps solves the issue of exposed carbon steel at cut ends of the rebar

FRP and Stainless Clad Synergy and Tradeoffs

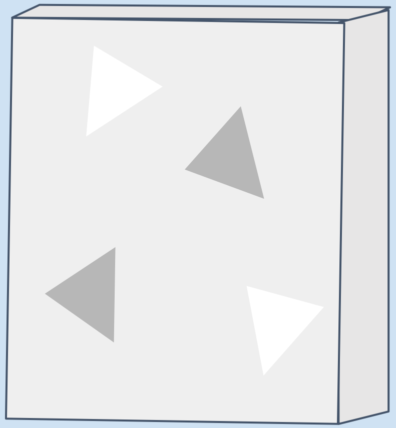
- **Time-Dependent Deformation (Creep)**
- **Elastic Modulus (Stiffness)**
- **Bending/Fabrication**

Durability, Sustainability, and Carbon Avoidance

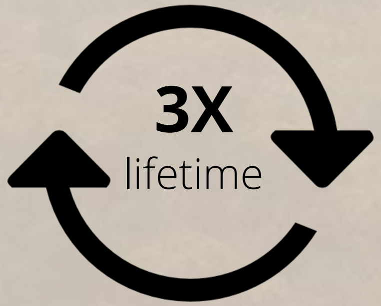
1 ton steel rebar
produces
1.5 tons CO_2



25 tons Concrete
produces
5.8 tons CO_2



+70 years of lifetime
of 1 ton of rebar avoids
20 tons of CO_2



Our Technology Can Enable Low Carbon Footprint Concrete

Portland Limestone Cement

Lower Carbon Footprint of Concrete by 10-15%

Carbon Capture Technology

CARBON CURE™

carbon clean

Use Concrete to Capture and Store CO2 from

Lower pH within concrete (more acidic chemistry) can greatly accelerate corrosion

Our technology eliminates trade off and drives further CO2 reduction

Specification Established for Use in Transportation Infrastructure

Standard Specification for

Stainless Clad Deformed and Plain Round Steel Bars for Concrete Reinforcement

---

AASHTO Designation: M 329M/M 329-11 (2015)[1]

Virginia DOT Policy
Epoxy-coated rebar ban

CRR 1/2/3

Functional Classification	Low Carbon / Higher Chromium	Stainless Clad	Solid Stainless
Freeway			X
Rural Principal Arterial			X
Rural Minor Arterial		X	
Rural Collector Road	X		
Rural Local Road	X		
Urban Principal Arterial			X
Urban Minor Arterial		X	
Urban Collector Street	X		
Urban Local Street	X		

Working with SASHTO members to Pilot & Deploy

- **We want to develop pilot projects and installations with all state DOT members of SASHTO**
- **We can perform additional testing or supply material for internal testing and validation**

- Support for much of the work shown today was provided by an NCHRP IDEA grant

- Thank you to the co-chairs for organizing this peer exchange

- Let’s work together to improve the way we build infrastructure and deliver resilient and sustainable bridges that can last for a century or more

Scan this QR code for my info to get in touch

THANK YOU!

MST-BAR™

GFRP Bars as an Internal Reinforcement to Concrete: Advantages, Misconceptions & Effect on Greenhouse Gas Emissions

Do it Right, Do it Once!

Borna Hajimiragha – CEO
MST Rebar Inc.

MST BAR
MAXIMUM STRENGTH GFRP
Manufactured by MST Rebar Inc.

Outline

1. Cost Of Corrosion In Canada/USA
2. Example Of Corrosion
3. Benefits
4. Projects
5. Misconceptions
6. Effect on Greenhouse Gas Emissions

MAXIMUM STRENGTH GFRP

Association for Materials Protection and Performance (AMPP)
https://amppcanada.ca/2021/11/06/impact-study-canada/

AMPP™ Canada

The cost of corrosion study (IMPACT Study) Reveals

$52 billion USD in Canada

>500 billion USD in USA

Annual cost

$Billions could be saved by using MST-BAR

MST BAR
MAXIMUM STRENGTH GFRP

Why Steel Rebar Corrode

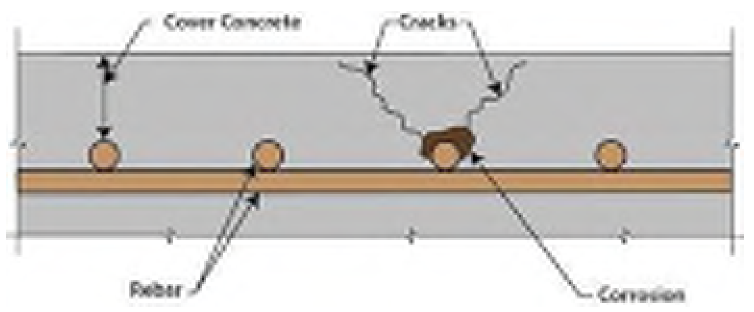
Concrete Lasts

Built **1600 years ago** by Roman Empire (6th Century)

Without Steel Rebar

Built in **2000** in North America

With Steel Rebar



MAXIMUM STRENGTH GFRP

Corrosion damage of pier caps and columns due to leaking joints

MST BAR
MAXIMUM STRENGTH GFRP

Scaling and corrosion damage of barrier wall due to salt splashing

MST BAR
MAXIMUM STRENGTH GFRP

Deterioration of Deck Top Surface due to corrosion and freeze-thaw

MST BAR
MAXIMUM STRENGTH GFRP

Example of Steel Corrosion

Designed for 100 years

Last less than 50 years

Start to corrode after 8 years

Evolution/History of Rebar

Black Bar

1920s

Galvanized & ECR

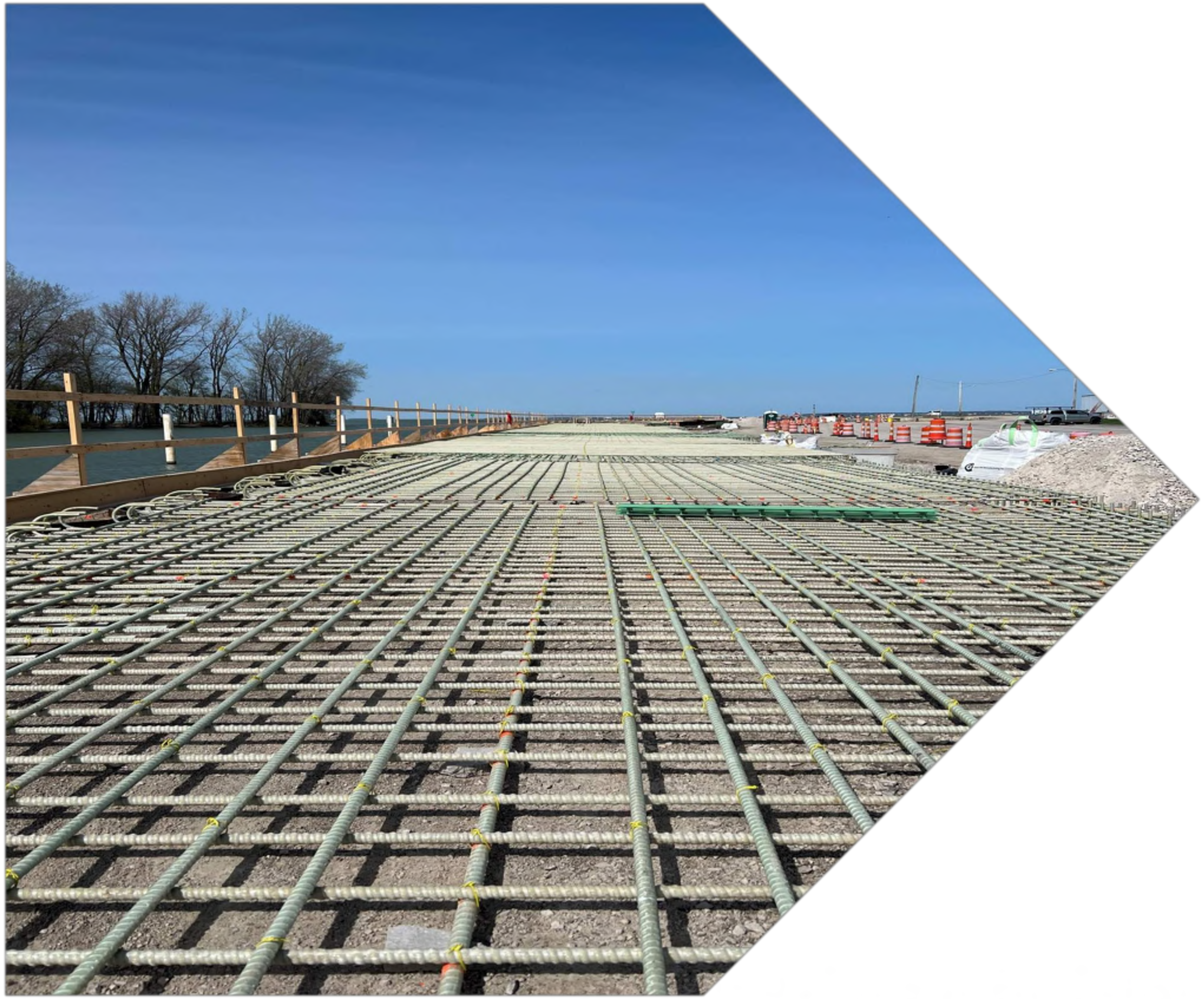
1970s

Fiberglass Rebar

1990s

MST BAR
MAXIMUM STRENGTH GFRP

Solution!
A Material That Never Corrode!



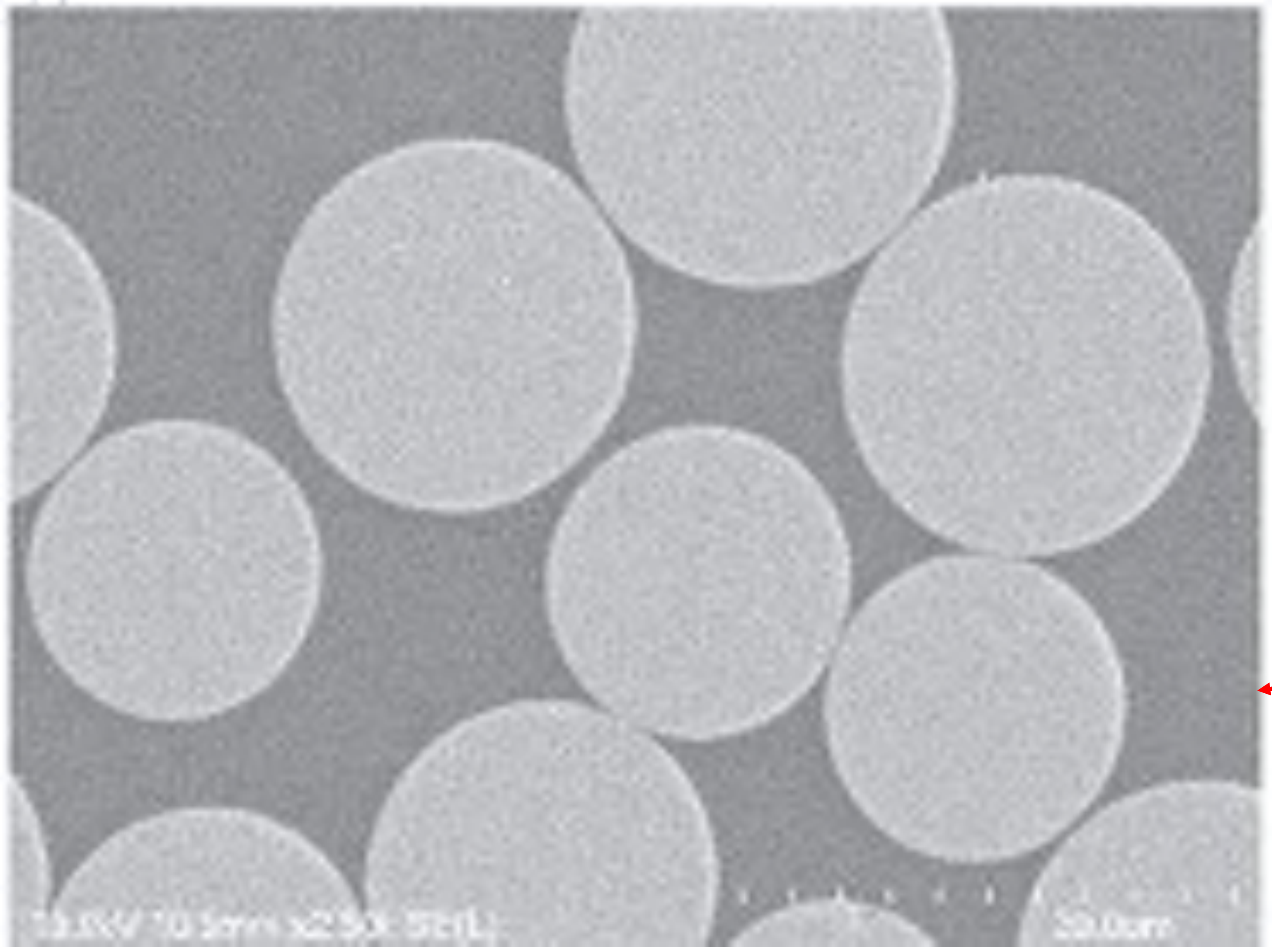
Glass Fiber Reinforced Polymer Rebar

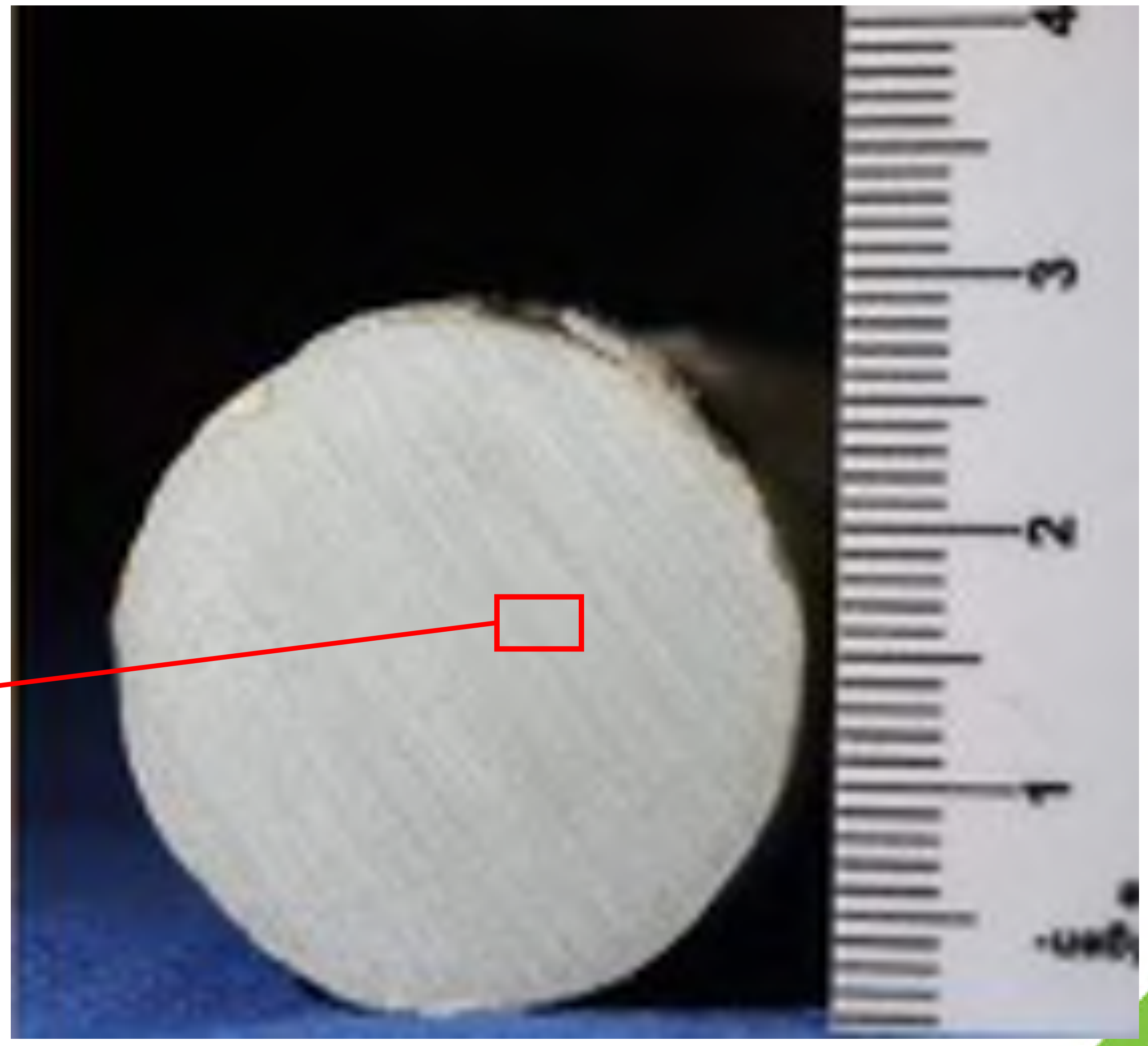
Glass Fiber Reinforced Polymer (GFRP) Bars

Fiber: E-CR glass fiber

Resin: Vinyl ester

Interface

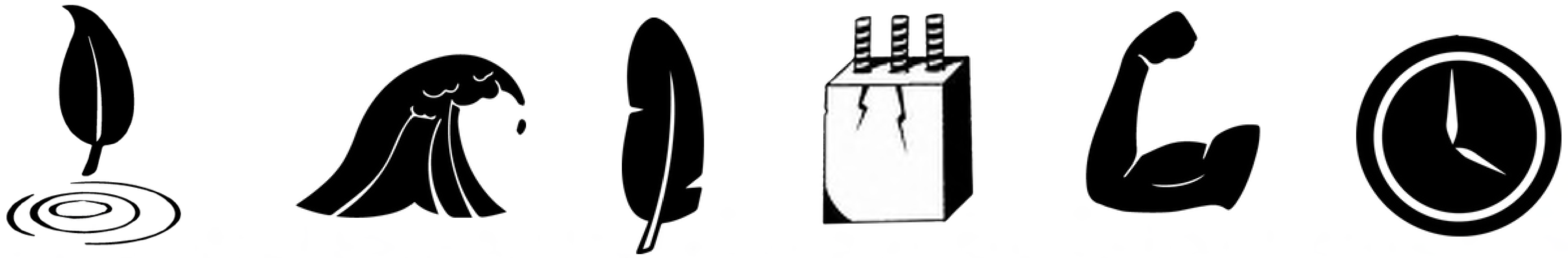




Source: Benmokrane et al. (2019)

Benefits of GFRP

- Corrosion Resistance = Risk Insurance
- **Weight** - 4 X Lighter Than Steel
- Bonding Strength
- Ease Of Cutting - No Sharp Edge
- Fire Rated- Over 3 Hours
- Strength – 3 X Steel
- Fatigue Strength
- Economical Curing – No Need For Fresh Water
- Conductivity – No Grounding Required
- Thermal Non-conductive – Suitable For Use In Hot & Cold Environments
- GREEN – 75% Less Energy to produce compare to Steel



MST BAR
MAXIMUM STRENGTH GFRP

Why GFRP

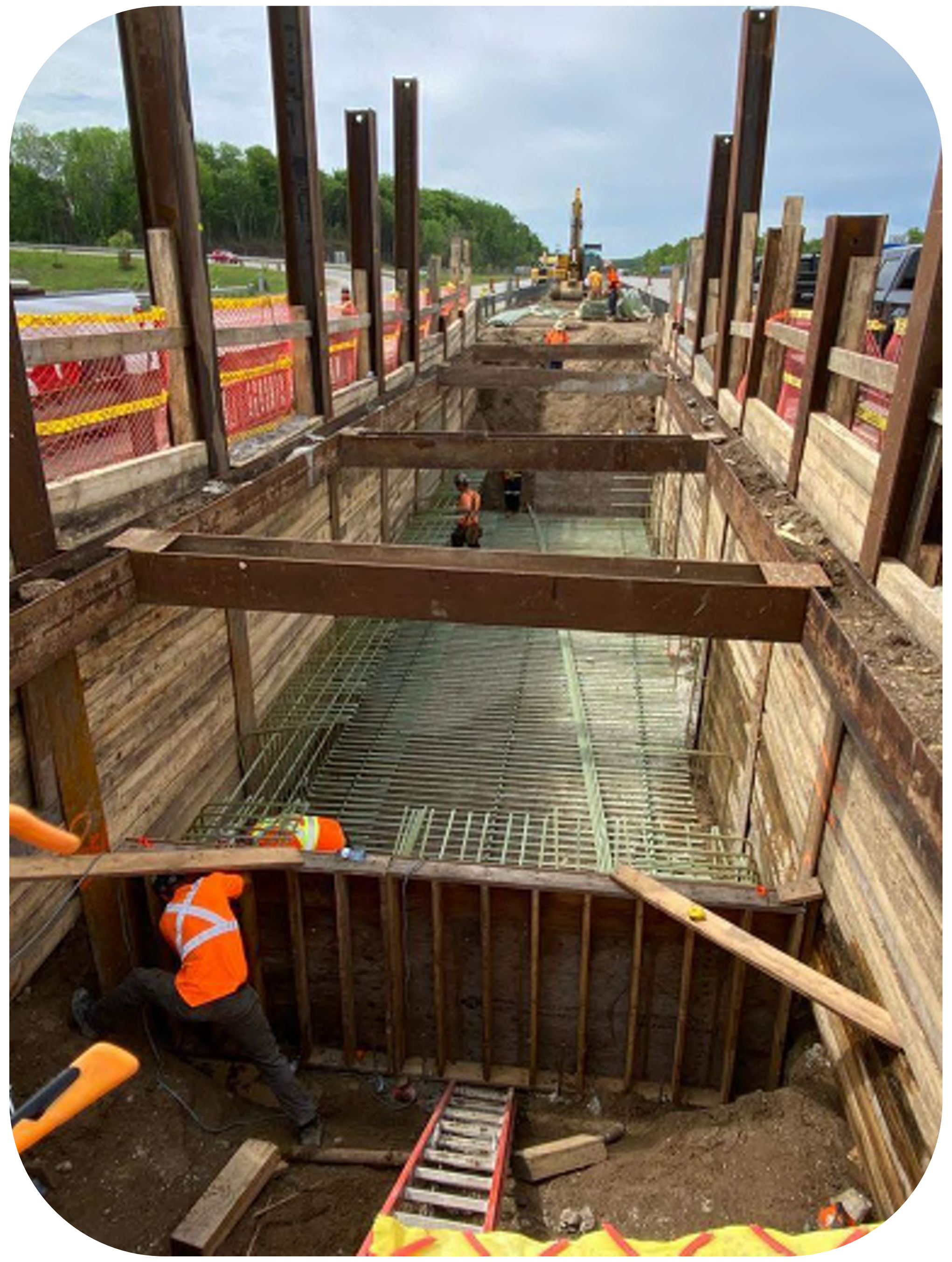
- CODE APPROVED ICC, ASTM, CSA & ACI
- Reduce construction accidents- ‘’OSHA: 61% of Construction accidents are due to steel rebar impalement ‘’
- Reduce back injuries - ¼ of the weight
- Easier to install - Non-Conductive (Thermal & Electrical)

MSTBAR
MAXIMUM STRENGTH GFRP

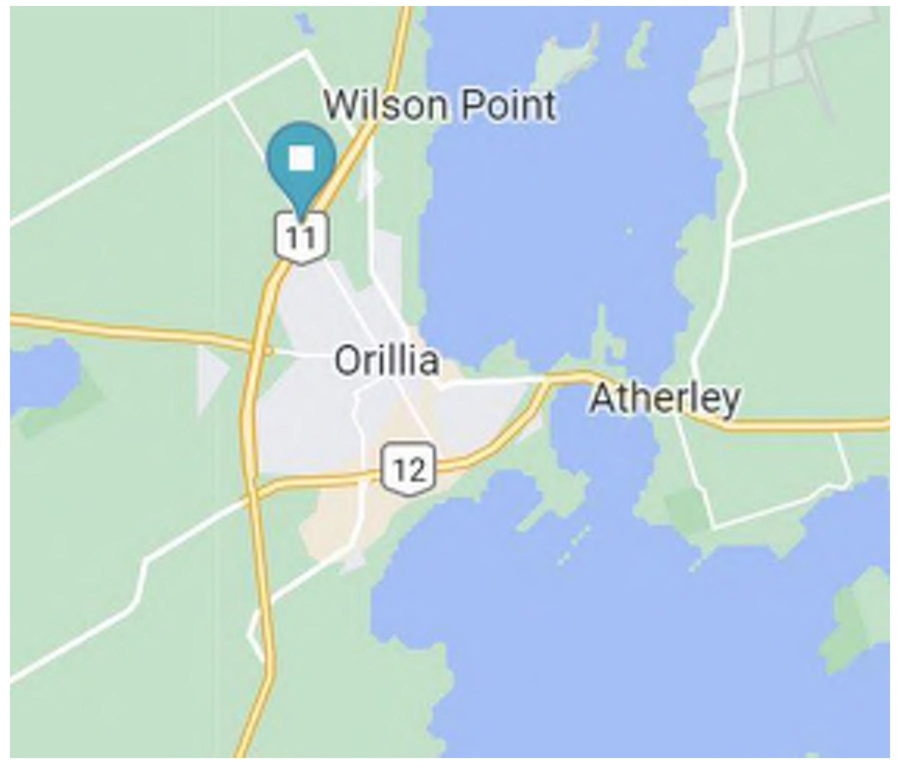
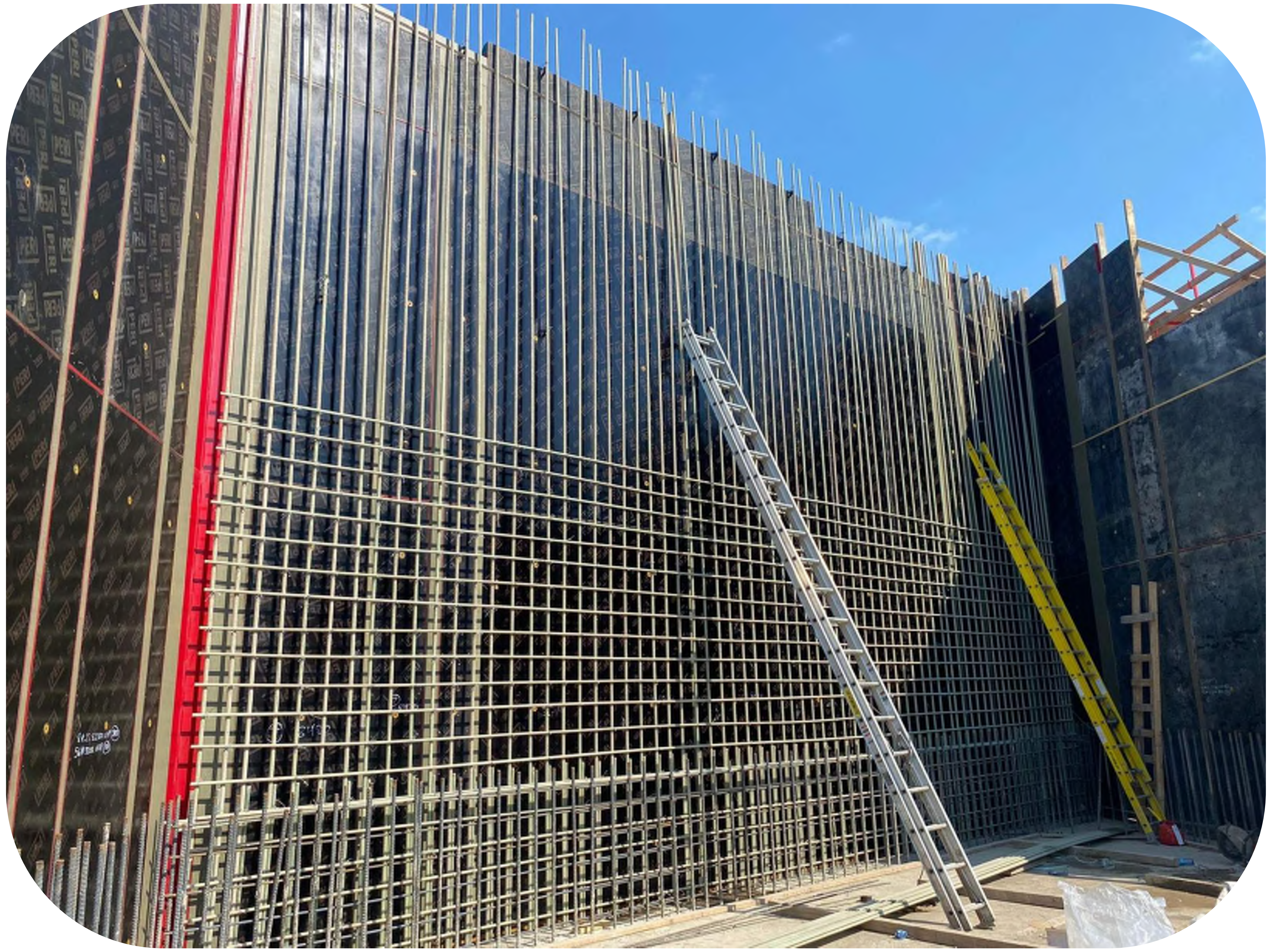
MST-BAR is Heavily Involved in Civil Projects for the Past 10 Years

All MST-BAR bridges

MTO is using MST-BAR on 100s of bridges, but this is the only Steel free one!



- MST-BAR cost similar to black steel rebar
- Life expectancy +100 years
- $18M bridge finishing under budget
- Locally made material
- Delivered faster than Steel
- Lighter Bridge with less Injury


Wilson Point
11
Orillia
Atherley
12



MST Pile Repair Kit

Project Case: South Corridor in Panama City.

MST Rebar Inc. provides the necessary

Assessment, Engineering and Training for proper installation and QC.

Benefits

- No Rust!
- No Divers!
- Lower cost!
- Not prone to freeze and thaw

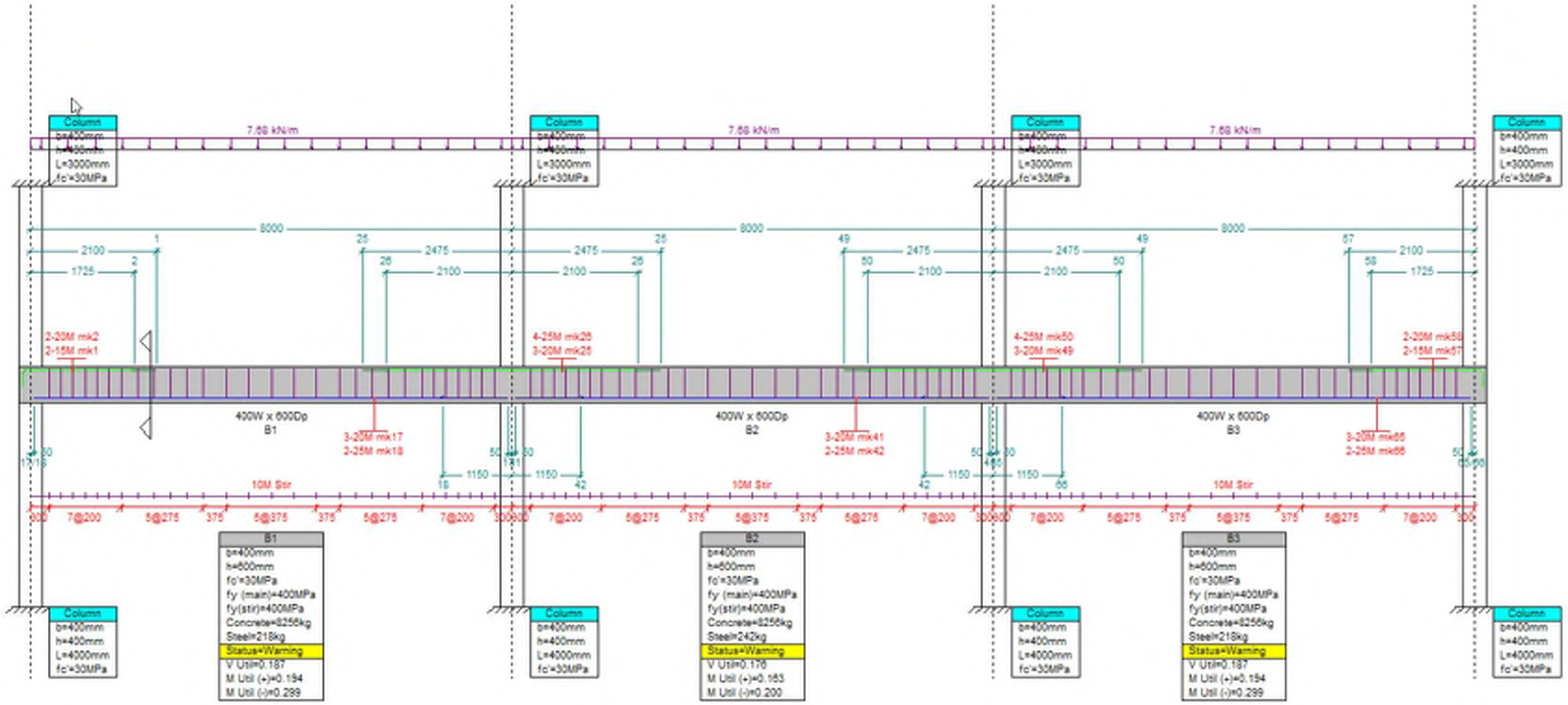
Residentials

Residentials

Residentials

Altair S-CONCRETE, including S-LINE

S-LINE
Continuous beam design



More Than 4000 Customers Worldwide Use S-Frame Software for Their Structural Analysis and Designs

AECOM ATKINS exp. ExxonMobil JACOBS SNC·LAVALIN SOM Thornton Tomasetti WorleyParsons

MST BAR
MAXIMUM STRENGTH GFRP

5 Major Mis-conceptions Regarding GFRP

- Lack of ductility since GFRP is linear elastic until fracture
- Lack of fire resilience since GFRP is like plastic
- Brittle under cold temperature
- Requiring more reinforcement to control Serviceability!
- What is the real-life expectancy of GFRP?

MST BAR
MAXIMUM STRENGTH GFRP

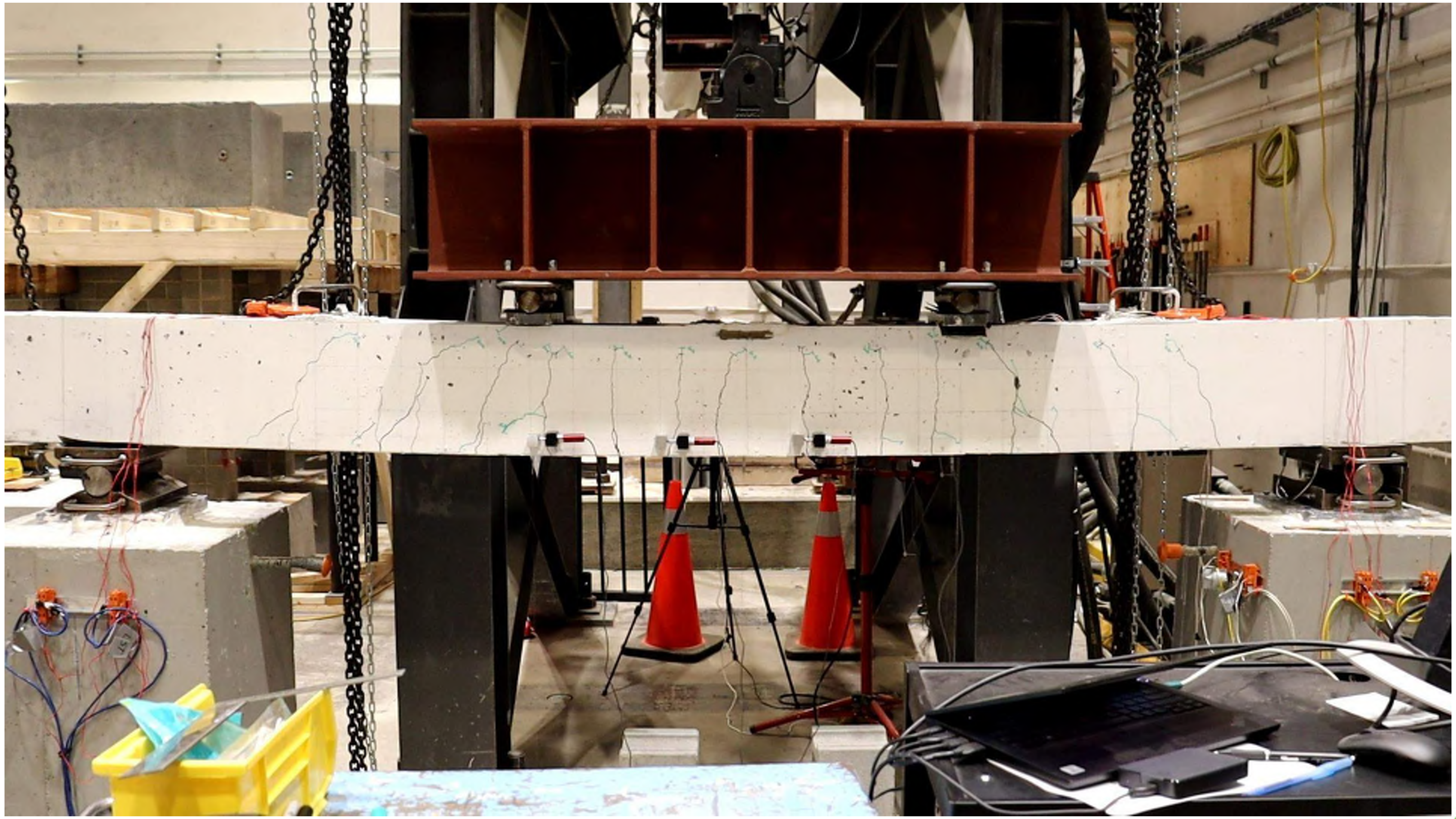
1-What Is Ductility & Why Is It Important?

- The ability of a structural system or element to undergo large deformation and sustain service load without failure
- **Warning**! Sign of Failure

https://theconstructor.org/

MST BAR
MAXIMUM STRENGTH GFRP

MST-BAR in 2,000,000 Cycles at 24,000lbf. Does this beam behave ductile?



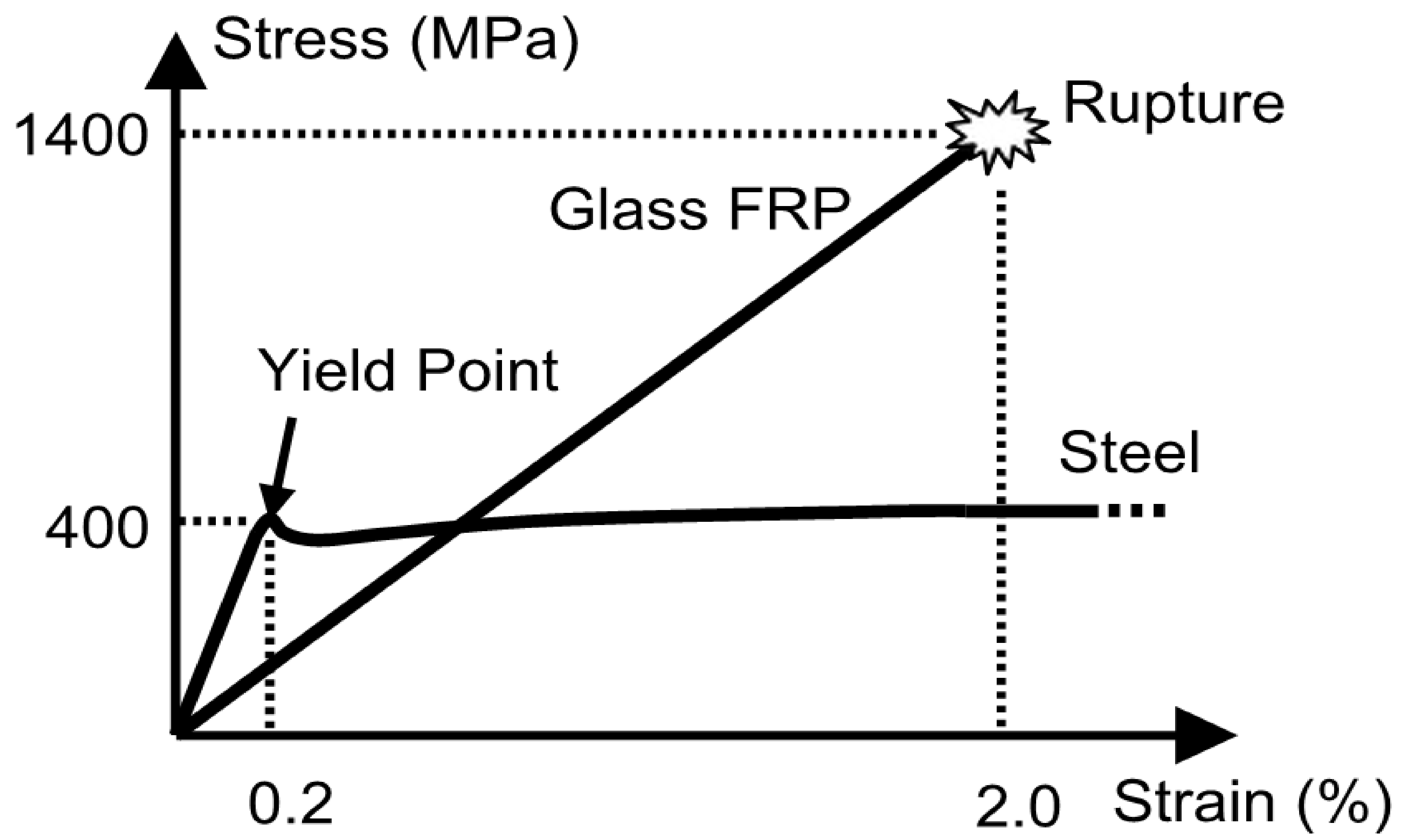
MST BAR
MAXIMUM STRENGTH GFRP

How about this?

MST BAR
MAXIMUM STRENGTH GFRP

Terminology!

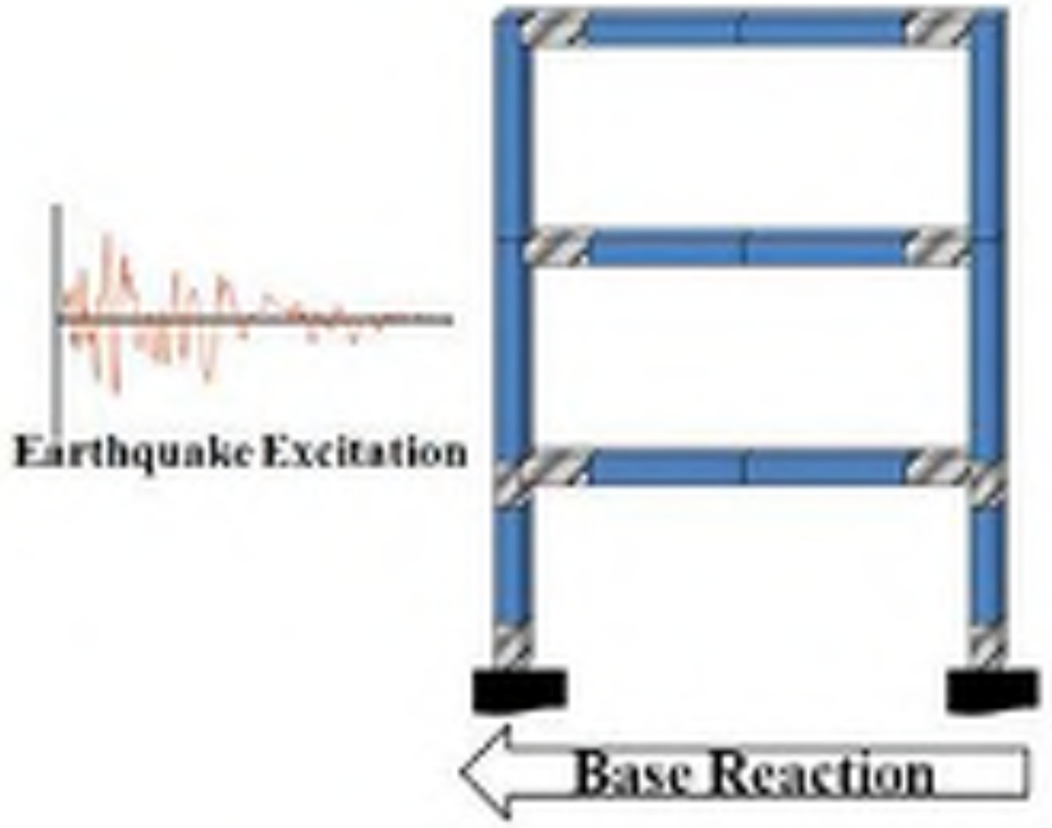
- Definition of Brittle Material?
- Picture of glass and GFRP!

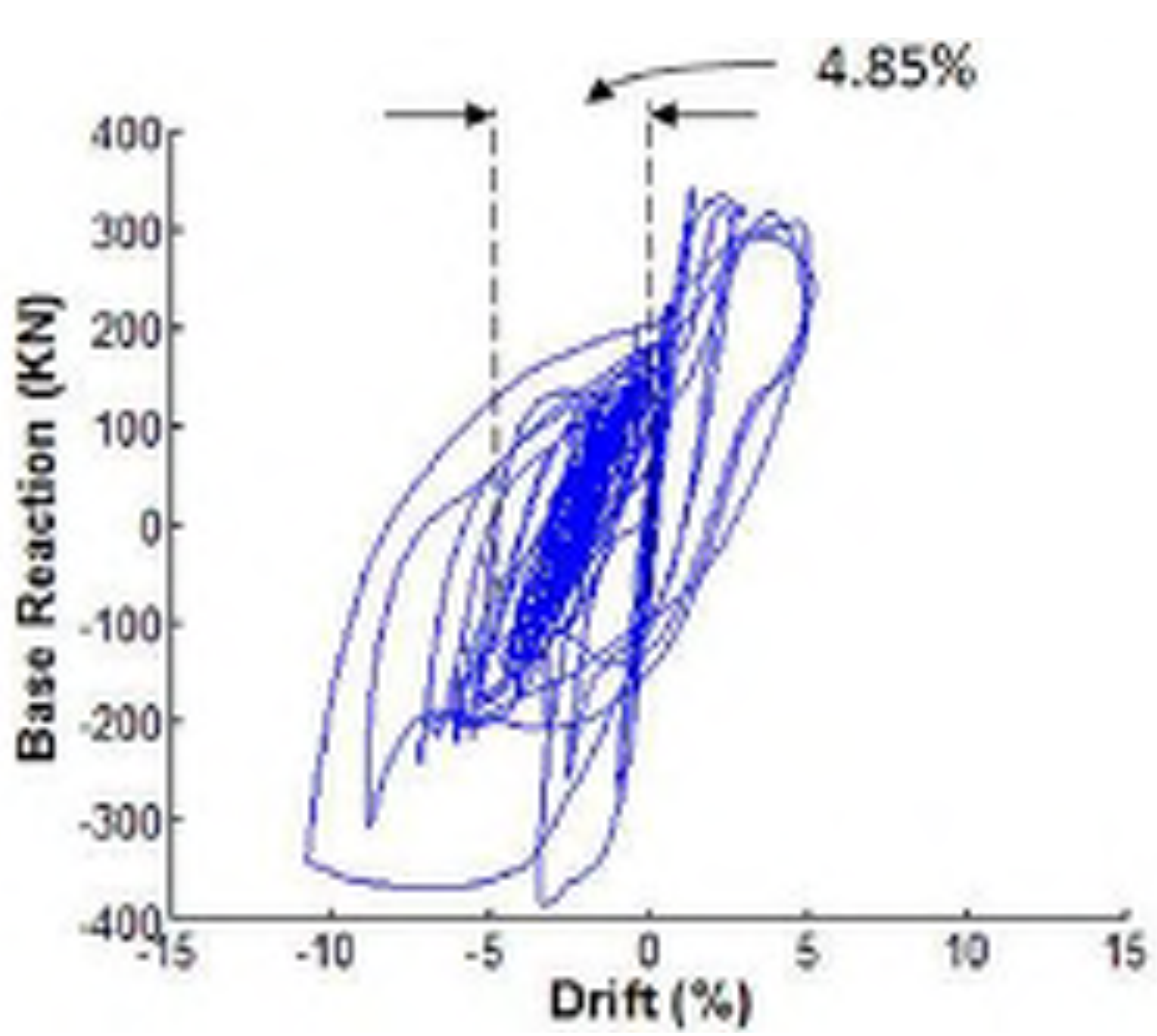


Stress strain curves for GFRP and steel reinforcement (ISIS 2006)

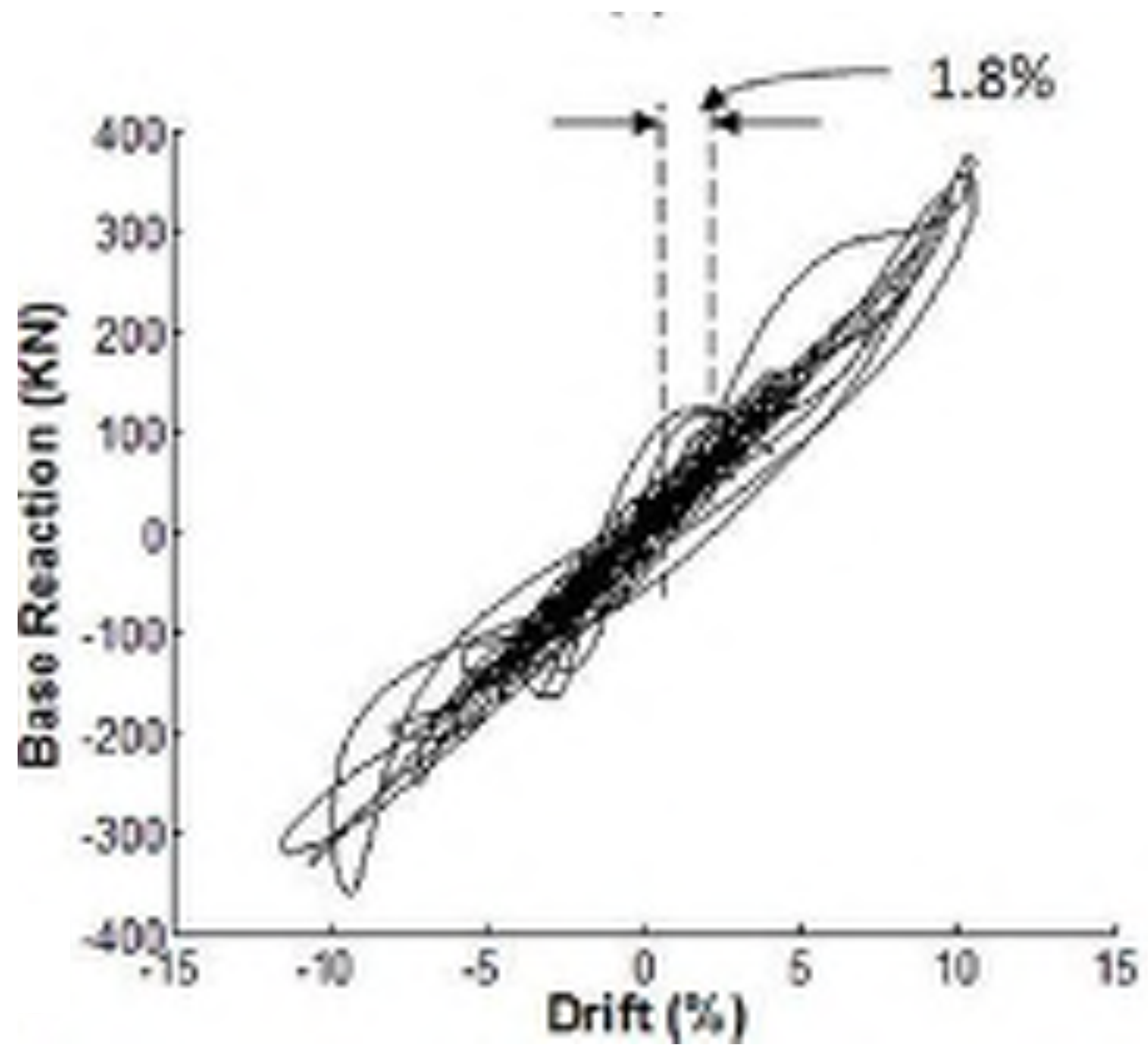
Seismic

Self-centering of GFRP reinforced concrete frames





Steel reinforced concrete



GFRP reinforced concrete

Base shear versus roof drift for a 3-story moment resisting frame subjected to the Kashmir earthquake record

Prof. Andrawes

University of Illinois, Urbana-Champaign, USA

Stress strain curves for GFRP and steel reinforcement
(ISIS 2006)

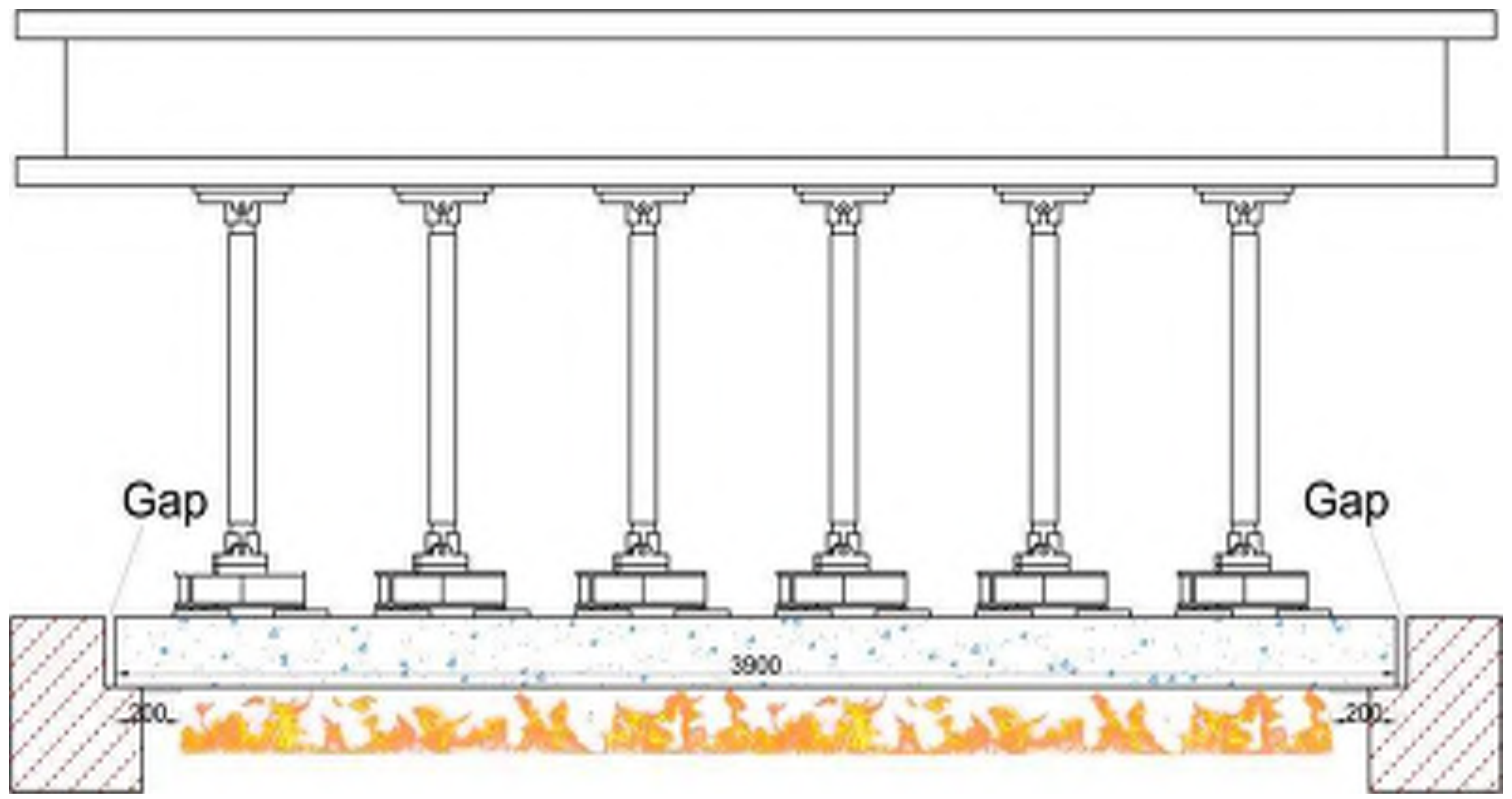
MAXIMUM STRENGTH GFRP

2-Lack of fire resilience since GFRP is like plastic

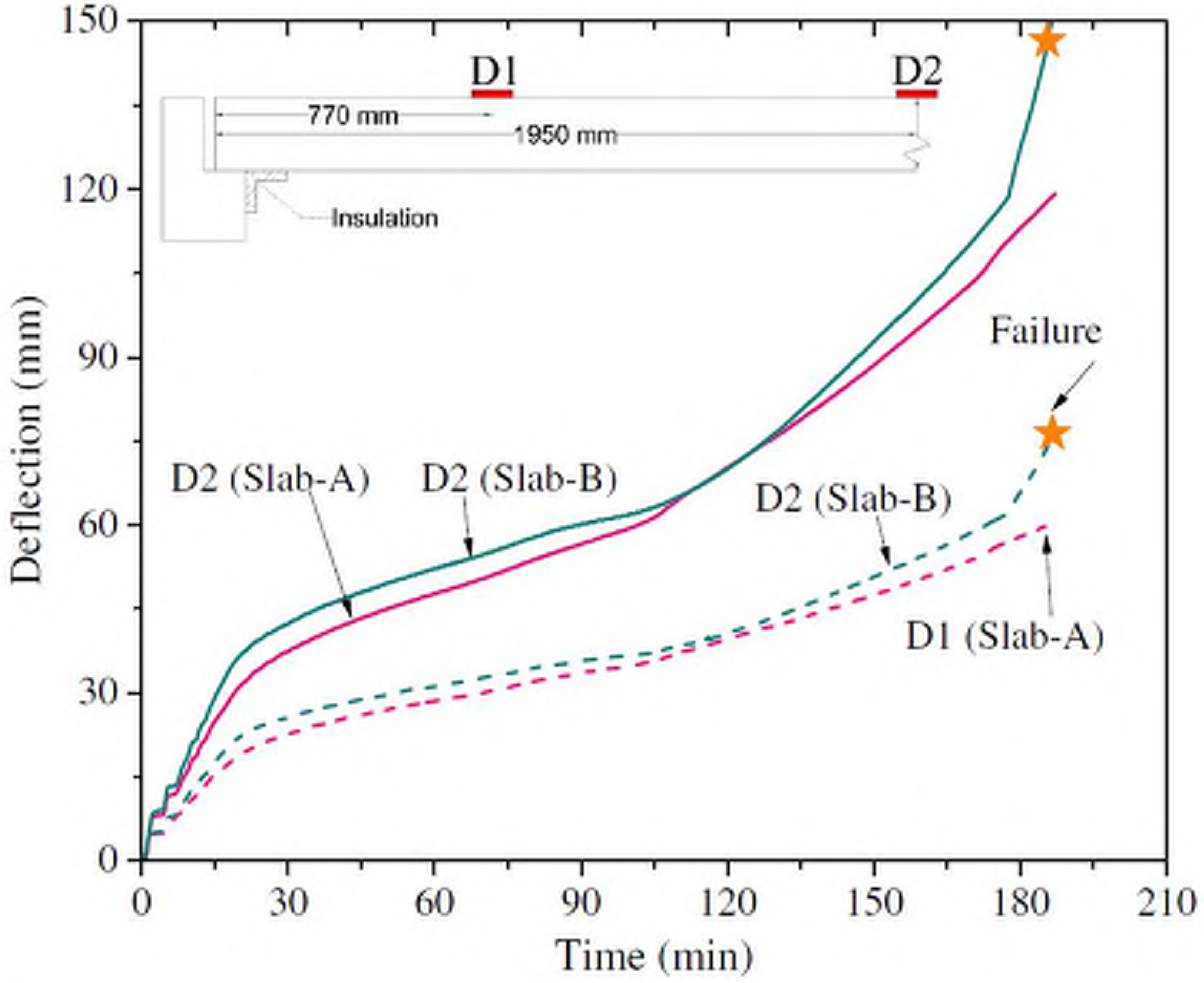
GFRP rebar tested in actual scale slab under fire with 1.5x Service load

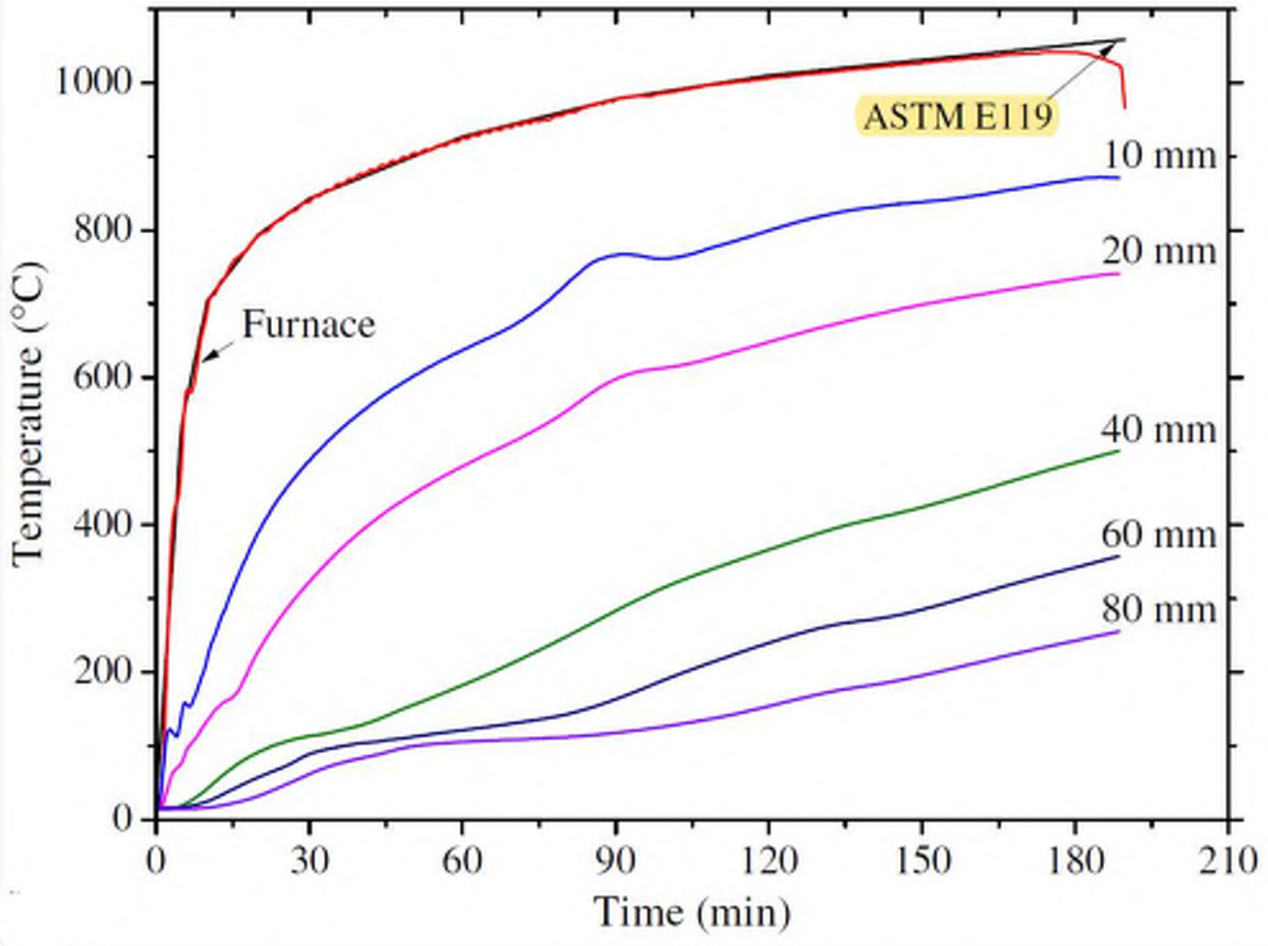
- Minimum cover of 40mm is sufficient to achieve 3hrs fire rating
- Bond degradation is the controlling factor
- At 350 degree C, GFRP can sustain a tensile strength of 40 % Fpu (>60KSI)
- Detailing is the key!

MST BAR
MAXIMUM STRENGTH GFRP



Test Setup at NRC – slab 1200 x 3900 x 200mm thick





MST BAR
MAXIMUM STRENGTH GFRP

Detailing is the key

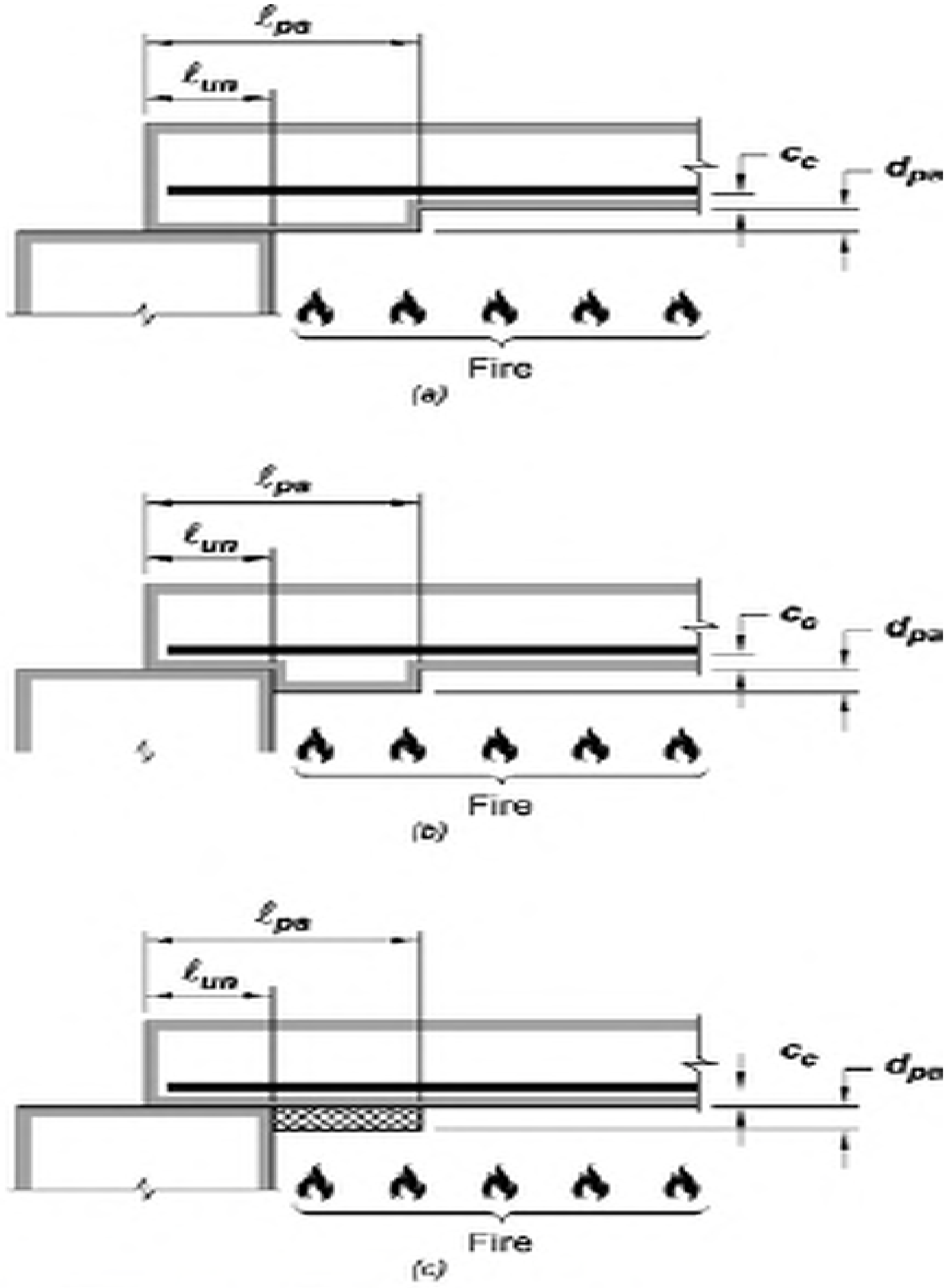


Fig R7.2.4a-c—Protection of GFRP reinforcement near supports.

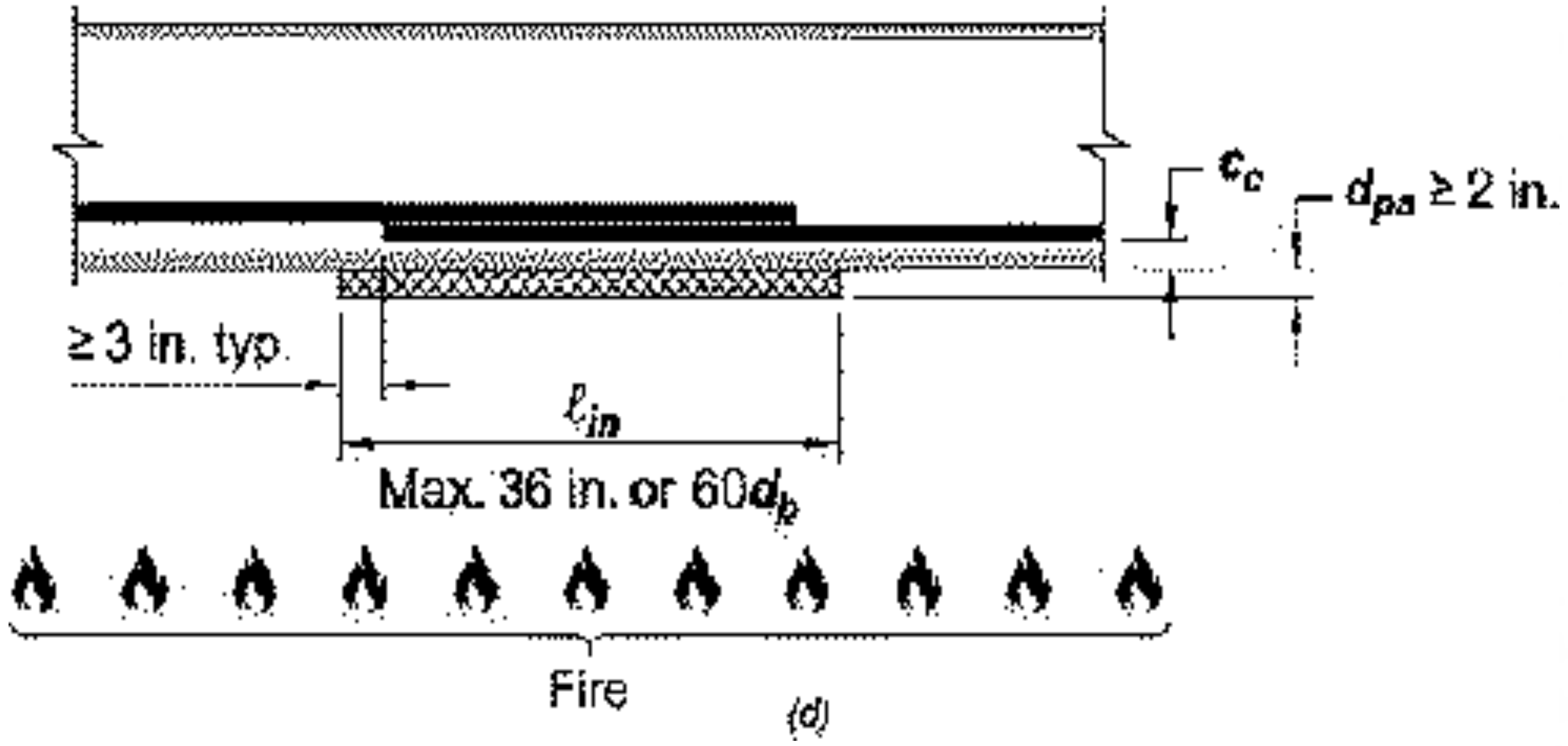


Fig R7.2.4.d—Insulation at spliced GFRP reinforcement.

MST BAR
MAXIMUM STRENGTH GFRP

3. Brittleness under Cold Temperature

- Steel suffers significant reduction in ability to absorb impact energy under cold temperature, leading to charpy V-notch energy requirements for cold temperature applications
- How would GFRP behave?
- MTO conducted Charpy V-notch impact tests on GFRP in 2006 on #5, #6 and #8 GFRP rebars

Fig.1: CVN specimen before test

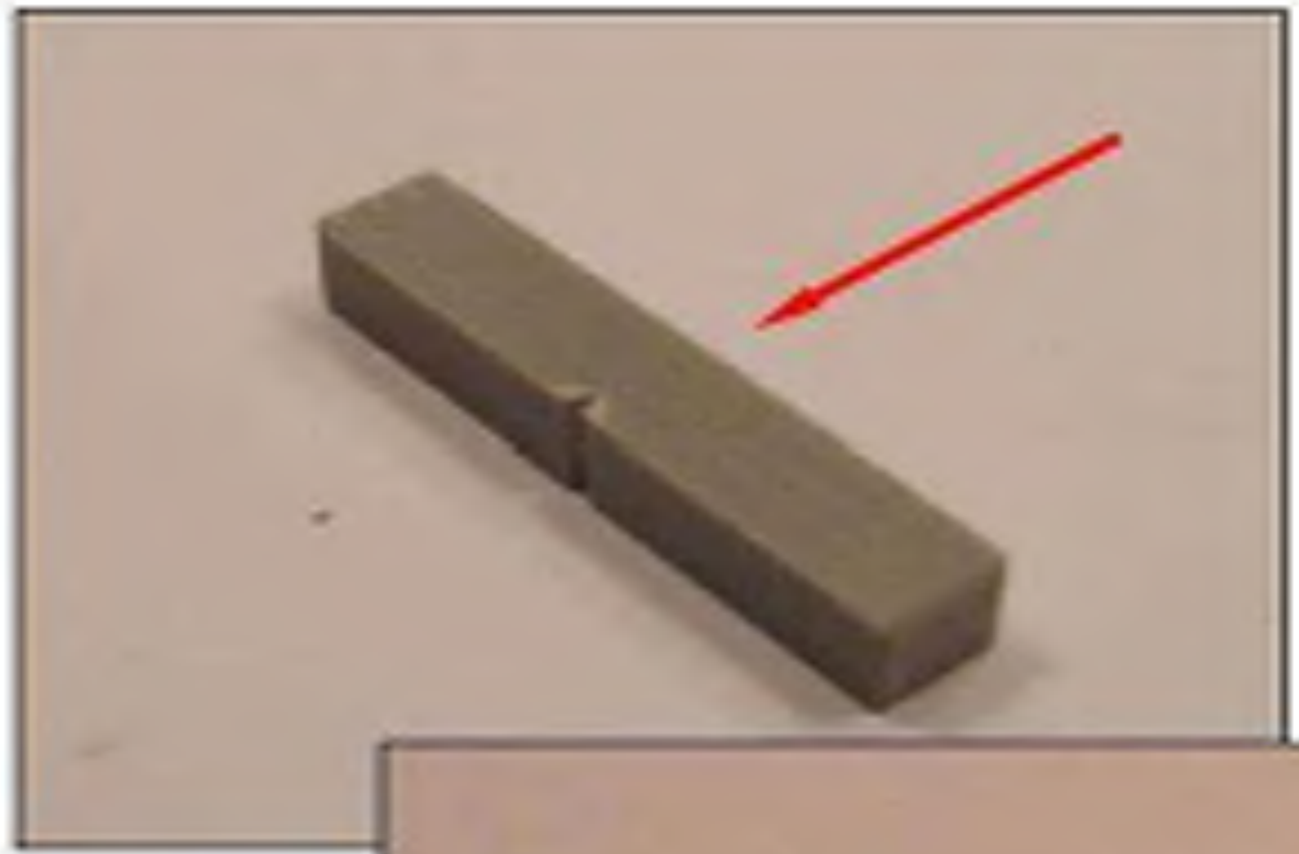


Fig. 2: Fractured CVN specimen after the test

Impact Test Results (ASTM E23) *Table 1*

Test Temperature	Sample ID	Test Results (ft·lbf)		
		Ø0.625 Rod	Ø0.750 Rod	Ø1.000 Rod
26° C	1	30	36	36
	2	33	29	28
	3	28	37	23
	Average	***30***	***34***	***29***
-20°C	1	38	41	36
	2	38	40	39
	3	33	38	36
	Average	***36***	***40***	***37***
-50°C	1	38	45	43
	2	37	41	41
	3	39	41	33
	Average	***38***	***42***	***39***

MST BAR
MAXIMUM STRENGTH GFRP

APPENDIX 8

UNIVERSITÉ DE SHERBROOKE

NSERC Research Chair in Innovative FRP Reinforcement for Concrete Infrastructure

Longitudinal Tensile Properties of MSTBAR GFRP Rebar of Size 15 mm (Lot1, Lot2, & Lot3) at Cold Temperature (-40°C)

Technical Report No 36

Prepared by:

Brahim Benmokrane, P. Eng., Ph.D.

NSERC Research Chair in Innovative FRP Reinforcement for Concrete Infrastructure
Canada Research Chair in Advanced Composite Materials for Civil Structures
Department of Civil Engineering
University of Sherbrooke

MSTBAR
MAXIMUM STRENGTH GFRP

4. Requiring more reinforcement to control Serviceability!

- It is true that GFRP design is usually governed by SLS
- Do we really need 3X of steel area in GFRP because of

  modulus ratio?
- Need to calculate crack width and deflection to compare with steel

$$w_{cr} = 2\frac{f_{FRP}}{E_{FRP}}\frac{h_2}{h_1}k_b\sqrt{d_c^2 + (s/2)^2}$$

Section 16 CHBDC

d_c = distance from the centroid of the tension reinforcement to the extreme tension surface of

h_1 = distance from the centroid of tension reinforcement to the neutral axis, mm

h_2 = distance from the extreme flexural tension surface to the neutral axis, mm

s = spacing of shear or tensile reinforcement, mm

Severability?

- **Deflection**

L/480 Vs L/240!

-Deflections for GFRP according to ACI 440 modified Branson's Equation for I effective

-Reduction in Cover Concrete will increase the effective depth.

- **Crack width**

Corrosion is not an issue even if the crack is larger than 0.5mm

-Maximum increase of around 30% (For high mod rebar) by reducing the spacing

-Considering bars with higher Kb value to control the crack

-Since GFRP does not corrode, the 0.5mm crack width limit is mainly for aesthetics.

5. What is the real-life expectancy of GFRP?

RESEARCH PROGRAM

Accelerated aging and natural aging condition

$$\frac{N}{C} = 0.098\, e^{0.0558T}$$

Temperature (°C)	Solution (pH 12.6-12.8)	Accelerated ages (days)	Natural ages (years)
40	Alkaline	150	13
40	Alkaline	300	27
60	Alkaline	150	100
60	Alkaline	300	199

MSTBAR
MAXIMUM STRENGTH GFRP

Table 3 – Tensile Strength and Modulus Retention of the Conditioned Specimens

Lot No.	Specimens	Average Tensile Strength (MPa)	Tensile Strength Retention R_{et}	Average Elastic Modulus (GPa)	Elastic Modulus Retention R_{et}
1	Reference	1266	88%	60	102%
	Conditioned	1117		61	
2	Reference	1254	90%	60	105%
	Conditioned	1128		63	
3	Reference	1258	90%	61	100%
	Conditioned	1130		61	

Reduction in GH Gas Emissions

Sustainability

- Intensity of the initial inputs

Resilience

- Longevity

A1: Raw Material
A2:Transportation
A3: Production

MST BAR
MAXIMUM STRENGTH GFRP


LUMBER INDUSTRY

Mass Timber: 80 M Street (Washington, DC)

Trees Eat CO_2

Growing a tree takes water, sunlight, and **air (CO_2)**

The Full Story

- Forest management and deforestation need to be considered
- Old growth forests better at carbon capture, AND make better lumber
- Trees store carbon they don't sequester it
- Trees need clean water

WOOD

Time to Wake Up!

MST BAR

MAXIMUM STRENGTH GFRP

“At every point, from pilings to the roof and everything in between, when it came time to make a decision about what level of material or what to use, we didn’t pay attention to code,” said Lebron Lackey, sharing the story of the project with CNN. “We went above and beyond code, and we asked the question: ‘What would survive the big one?’ And we consistently tried to build it for that.”

Walls were made of poured reinforced concrete.

Now that we have such a great material
Why do we let durability gets on the way!

Concrete=Resilient

MST BAR
MAXIMUM STRENGTH GFRP

Sustainability
Reduction in GH Gas Emissions

300% Less in Transportation

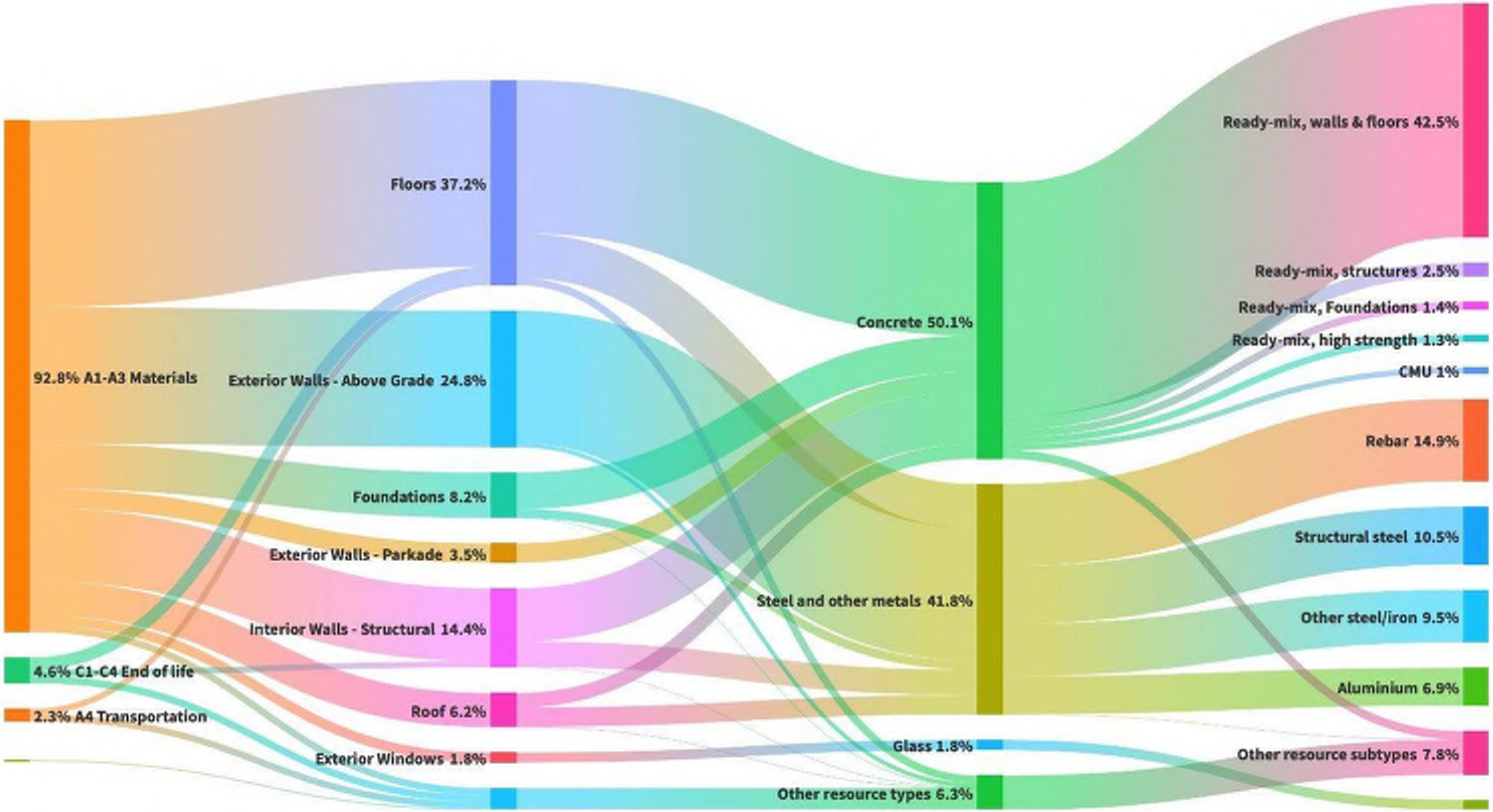
Much less energy to turn the fiber into Rebar

A1: Raw material
A2: Transpiration
A3: Manufacturing

MST BAR
MAXIMUM STRENGTH GFRP

Sustainability: Reduction in GH Gas Emissions

	Rebar	Total Reduction by using Fiberglass	Ref.
Priopta (Anthony Pak) CLF Vancouver	15%	9.5%	https://www.canadianarchitect.com/embodied-carbon-key-considerations-for-key-materials/
Entuitive	8.5%	5.5%	https://www.entuitive.com/ensight-sectors-home/sustainable-design-capturing-embodied-carbon/
LCA Sri Lanka	32% (20% on US)	21% (13%)	https://www.researchgate.net/publication/322538087_Life_cycle_carbon_emission_assessment_of_a_multi-purpose_university_building_A_case_study_of_Sri_Lanka
Clark Nexsen (includes roof)	23%	15%	https://www.clarknexsen.com/blog-tips-tools-for-designing-low-carbon-lab-facilities/
Walter P Moore (Embodied carbon Report)	15% (concrete)+3% (masonry	12.2%	WPM Embodied Carbon Report



Reduction 1% at a time

https://www.canadianarchitect.com/embodied-carbon-key-considerations-for-key-materials/

Resilience
Reduction in GH Gas Emissions

Consumption of gasoline during traffic congestion
MTO Ottawa Queensway Island Park Bridge Replacement Report:

According to Environment Canada, every litre of gasoline used in a vehicle produces 2.4kg of carbon dioxide (CO_2) and every 10 minutes of idling uses 0.10-0.40 litres of fuel [1]. Based on this relationship, every 10 minutes of idling produces 0.24-0.96 kg of carbon dioxide per vehicle.

Additional comment: It would emit a similar amount of CO2 during production of gasoline

Conclusion:

- Bridge rehabilitation work and premature bridge replacement causes increase in green house gas emission
- It is therefore advisable to design for durability with extended service life that does not require major rehabilitation at least for 75 years. Major structures and life-line structures should perhaps be designed for 100 years with corrosion resistant materials.

Resilience
Not So Green!

1. Demolition
2. Transportation
3. Removing Rebar from the Concrete
4. Transporting Rebar to recycle plants
5. Production of billet
6. Production of Rebar

MST BAR
MAXIMUM STRENGTH GFRP

Resilience
Not so Environmentally Friendly

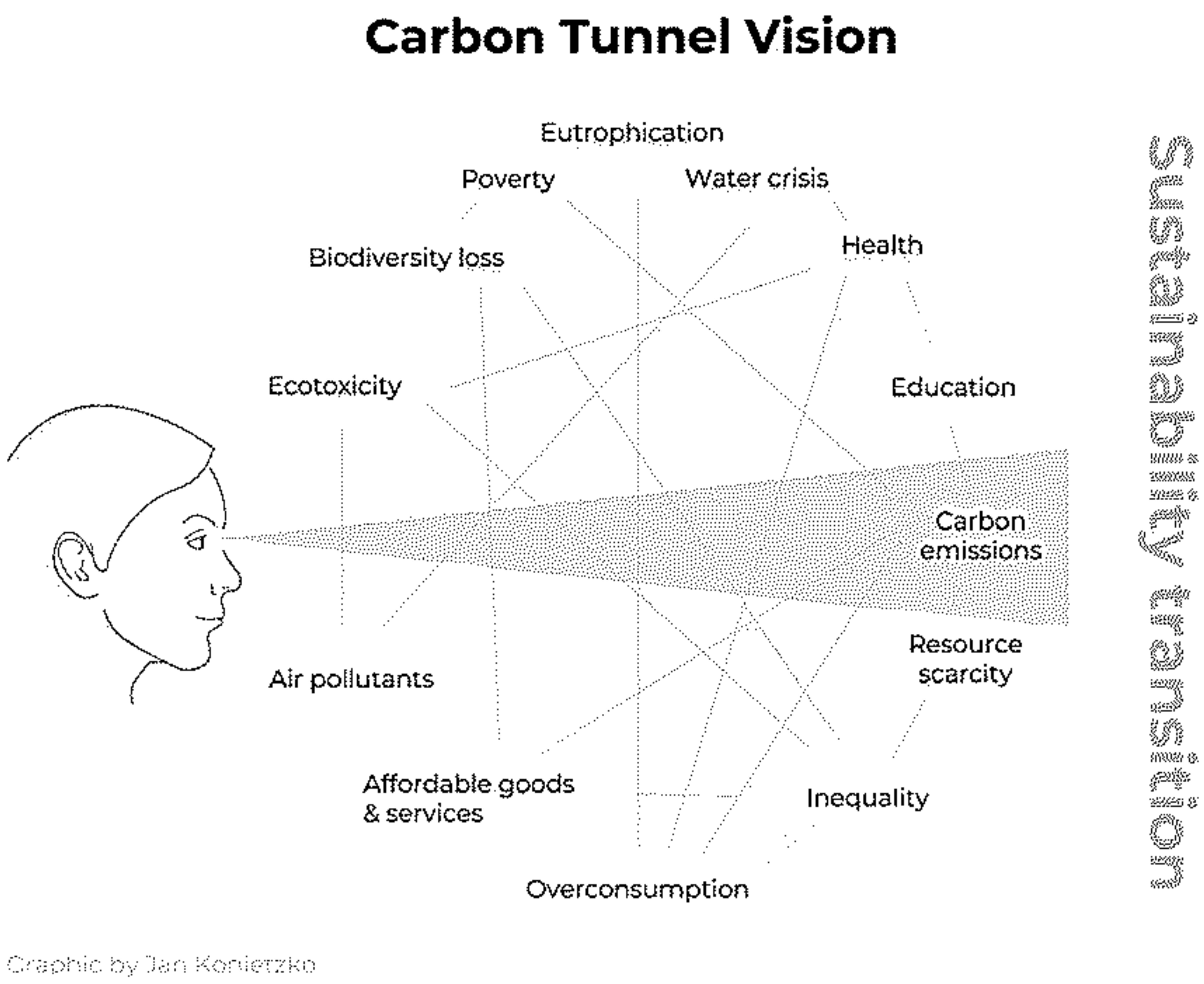
[Dangerous debris, including rusty rebar, worry residents near public beach | CBC News]

MST BAR
MAXIMUM STRENGTH GFRP

Resilience
Reduction in GH Gas Emissions

MST BAR
MAXIMUM STRENGTH GFRP

Lastly- Impacts



YOU ARE WHAT YOU MEASURE

MST BAR
MAXIMUM STRENGTH GFRP

Conclusion

- GFRP can be used in cold, hot and harsh environment
- You DO NOT need significantly more reinforcement to address serviceability by choosing the right product and proper engineering
- GFRP and Concrete can LAST!
- GFRP will reduce the carbon emission at the beginning of the project in compared to traditional reinforcement and will have a significant impact if you consider **Life Cycle**
- GFRP does not degrade or corrode like Steel
- GFRP does not become brittle in cold temperature
- GFRP can be safely use in areas where fire rating is required with proper detailing

MST BAR
MAXIMUM STRENGTH GFRP

Borna Hajimiragha CEO.

MST Rebar Inc.

MST BAR
MAXIMUM STRENGTH GFRP

Resilient and Sustainable Bridges
Ultra-Lightweight Foamed Glass Aggregate

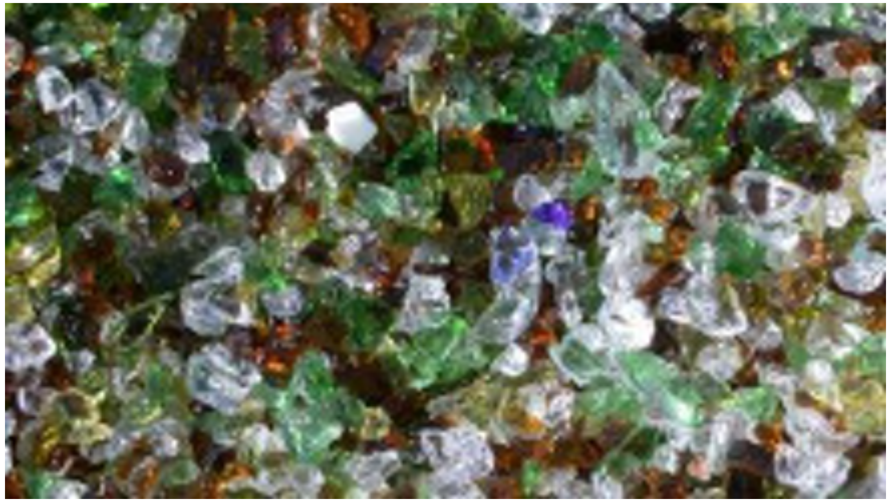
Archie Filshill, Ph.D., ENV SP

SASHTO
August 7th, 2023

AERO AGGREGATES


UL-FGA®
Frost Resistant
Ultra-Lightweight
(15.0 pcf)
Capillary Break
Good Insulator
Free-Draining
High Friction
Angle (54°)
Load-Bearing
Seismic Designs

Manufacturing of FGA




Manufacturing Facility Dunnellon, FL

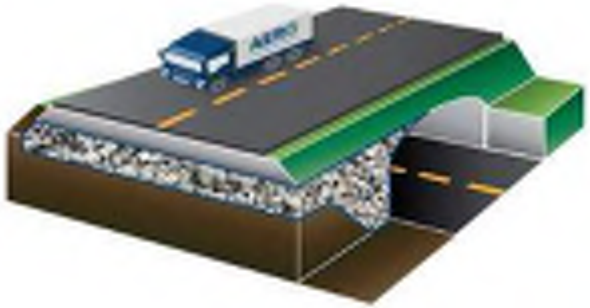
History

- 1977 – EPA Foam Glass Insulation Document
- 1980s – Foamed Glass Aggregate Developed in Germany
- 1990s – Technology taken to Norway
  - Thermal barrier for roadways
  - Led to lightweight applications
- 2000s – Expansion across Europe
- 2017 – Aero begins Manufacturing UL-FGA in USA

INFRASTRUCTURE APPLICATIONS

Embankments

Retaining Walls &
Bridge Abutments

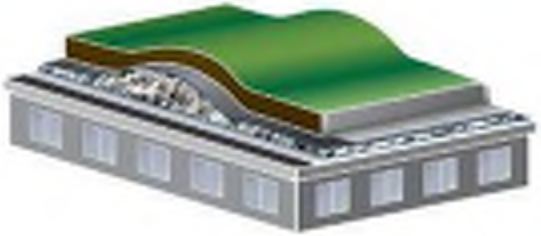


Tunnels & Culverts

Utilities

COMMERCIAL CONSTRUCTION

Foundation Walls
& Slabs



Greenroofs

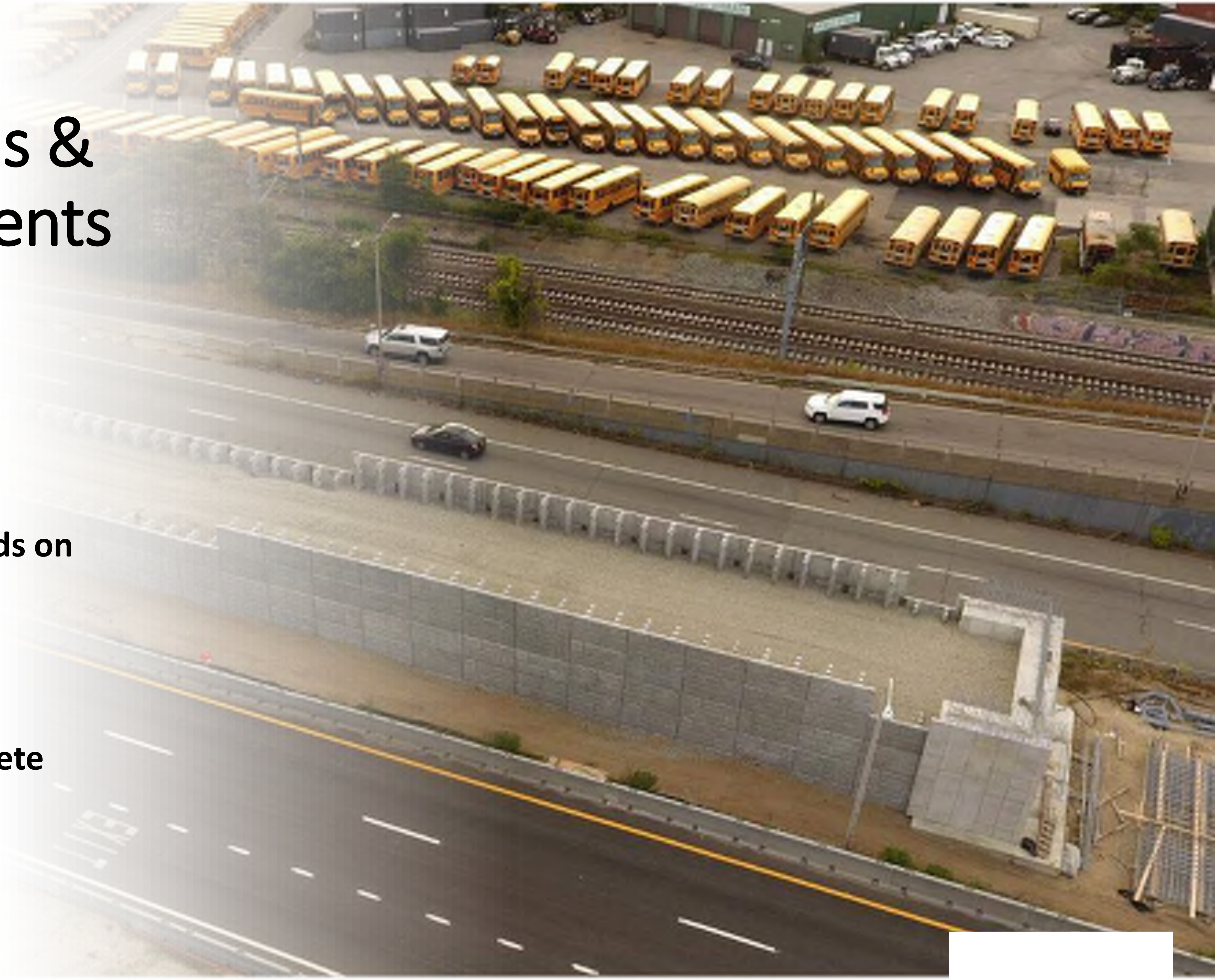
Plaza Decks

Retaining Walls & Bridge Abutments

- **Use in MSE Walls**

- **Reduction of Lateral Loads on Walls and Foundations**

- **Use in Lightweight concrete**



Compressive Strength

European Standard EN 1097-11, “Tests for mechanical and physical properties of aggregates, Part 11: Determination of compressibility and confined compressive strength of lightweight aggregates.” Modified.

Dry Process FGA
Avg. 19,000 psf

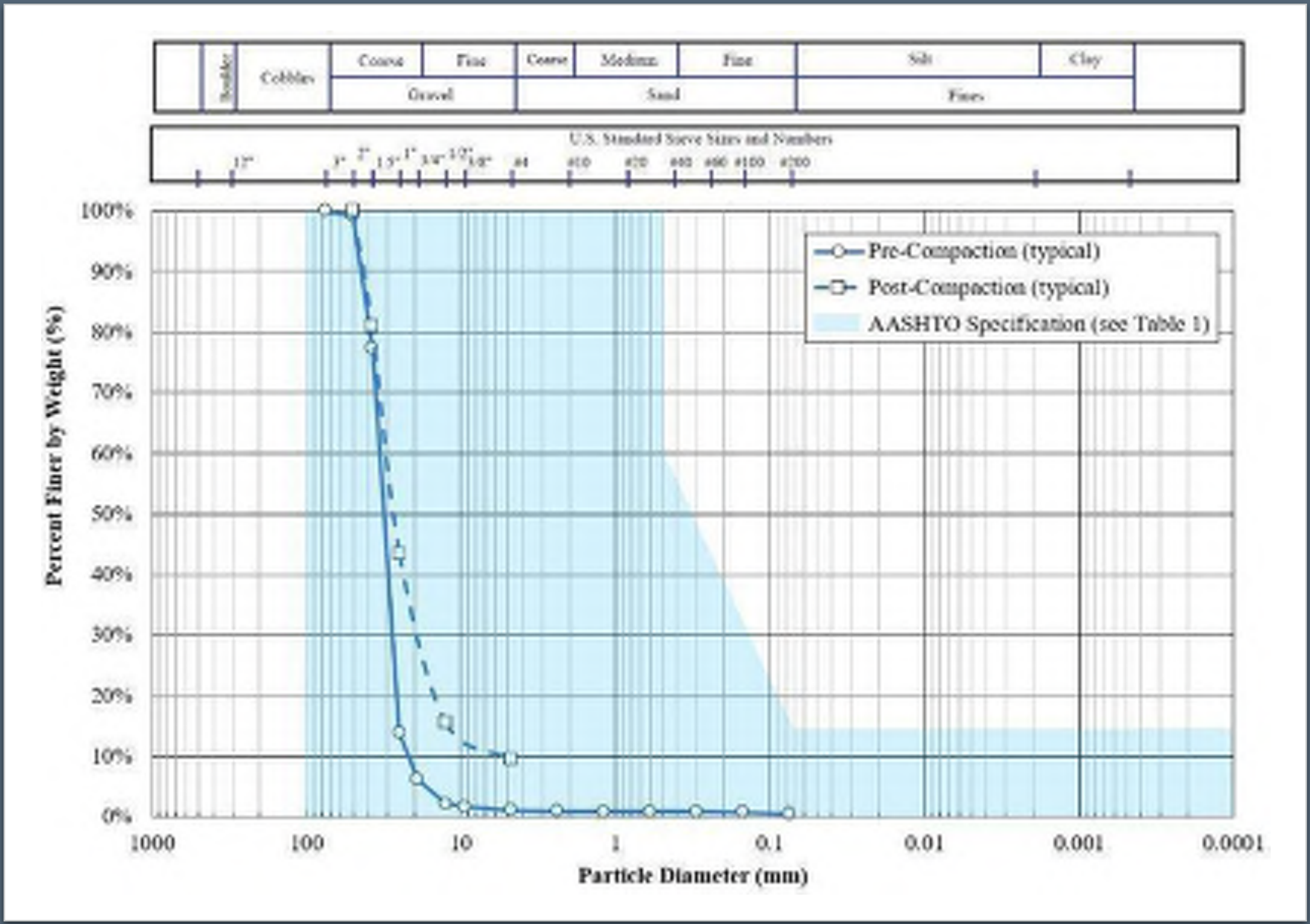
AASHTO Requirements for MSE Wall Backfill

Durability/Compatibility Testing

Electrochemical Results:

Test	Test Value	Required Value (AASHTO)	Aero FGA-G15
Resistivity	Minimum	3,000 ohm-cm	15,606 ohm-cm
pH	Range	5-10	9.2
Soluble Chlorides	Maximum	100ppm	<10ppm
Soluble Sulfates	Maximum	200ppm	11ppm

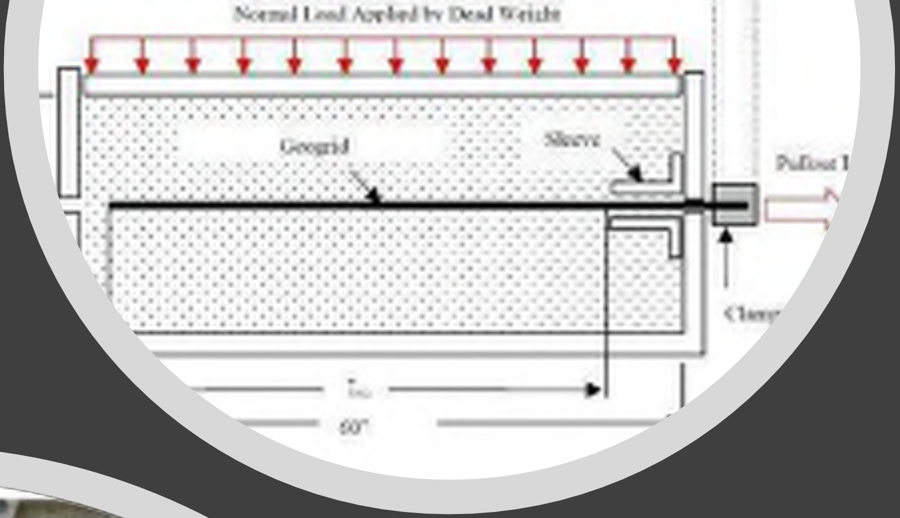
Plasticity Index = 0
Magnesium Sulfate Soundness = 4.1%
Organics = 0%



Gradation

Pre and Post Compaction

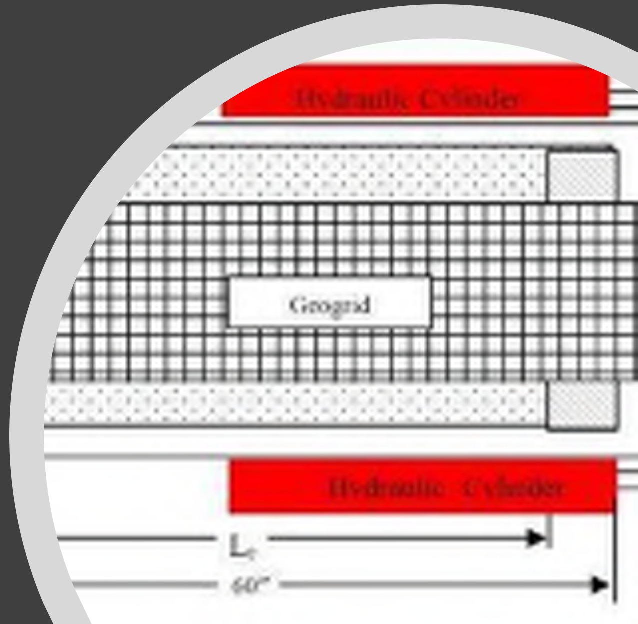
GP per USCS



Steel & Poly Straps

PET & HDPE Geogrids

Pullout Testing of Geogrids and Straps for MSE



Images courtesy of SGI Lab, Atlanta, GA

Logan Airport

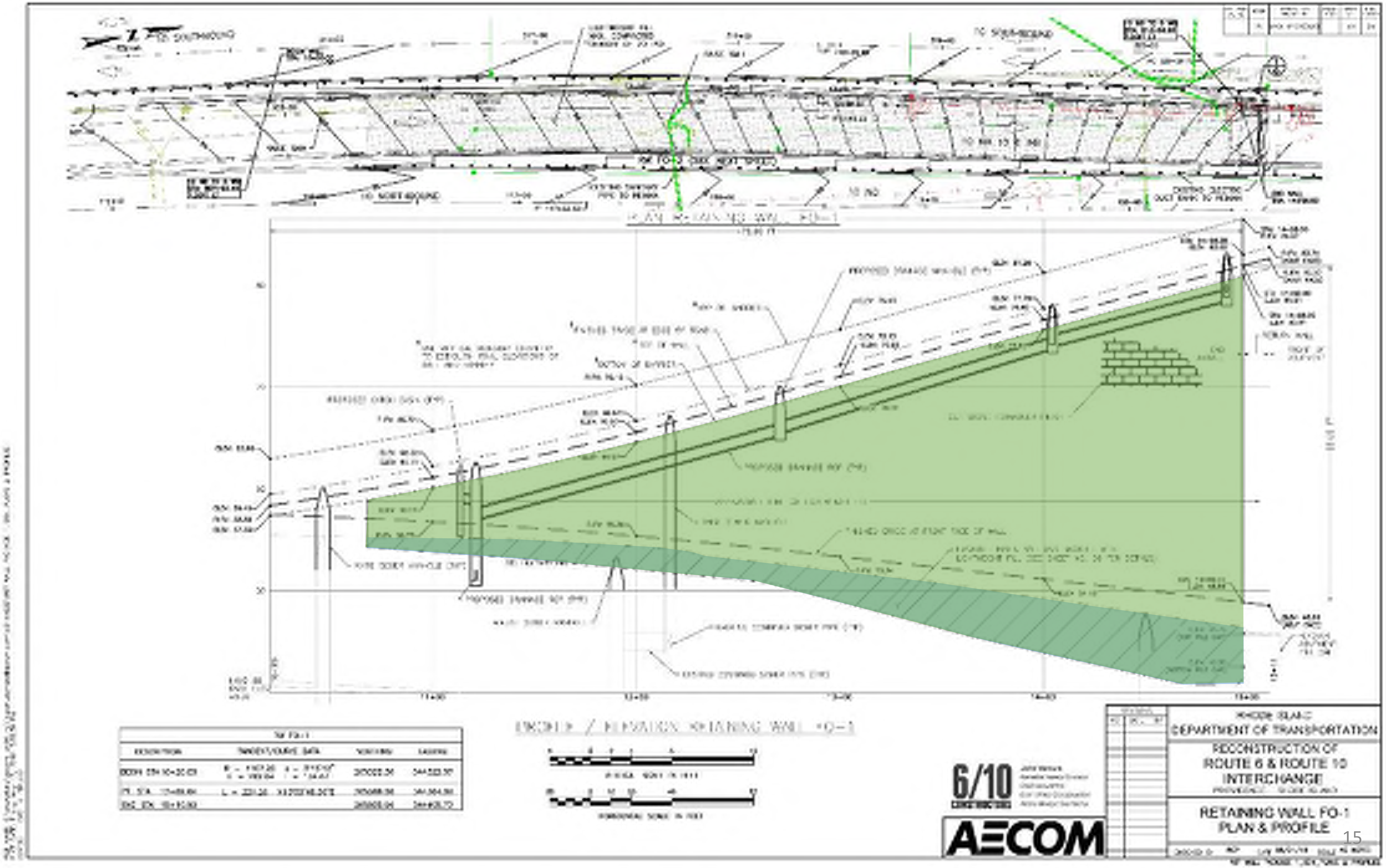
Boston, MA

Logan Airport

Boston, MA

Route 6/10 Interchange Reconstruction

Providence, RI


RHODE ISLAND
DEPARTMENT OF TRANSPORTATION
RECONSTRUCTION OF
ROUTE 6 & ROUTE 10
INTERCHANGE
RETAINING WALL FO-1
PLAN & PROFILE
6/10
AECOM

Route 6/10 Interchange Reconstruction

Providence, RI

I-485 Express Lanes

Charlotte, NC

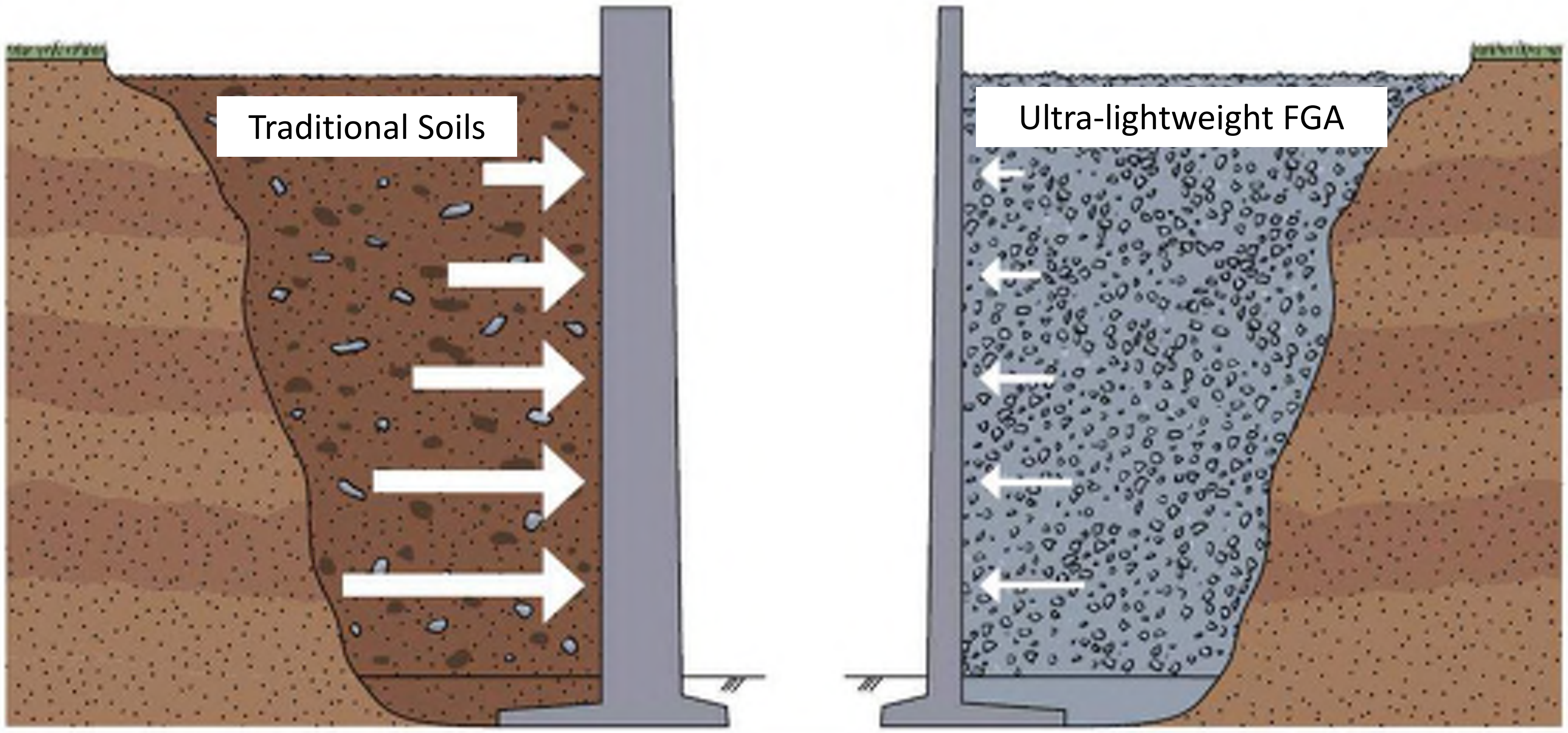
I-485 Express Lanes

Charlotte, NC

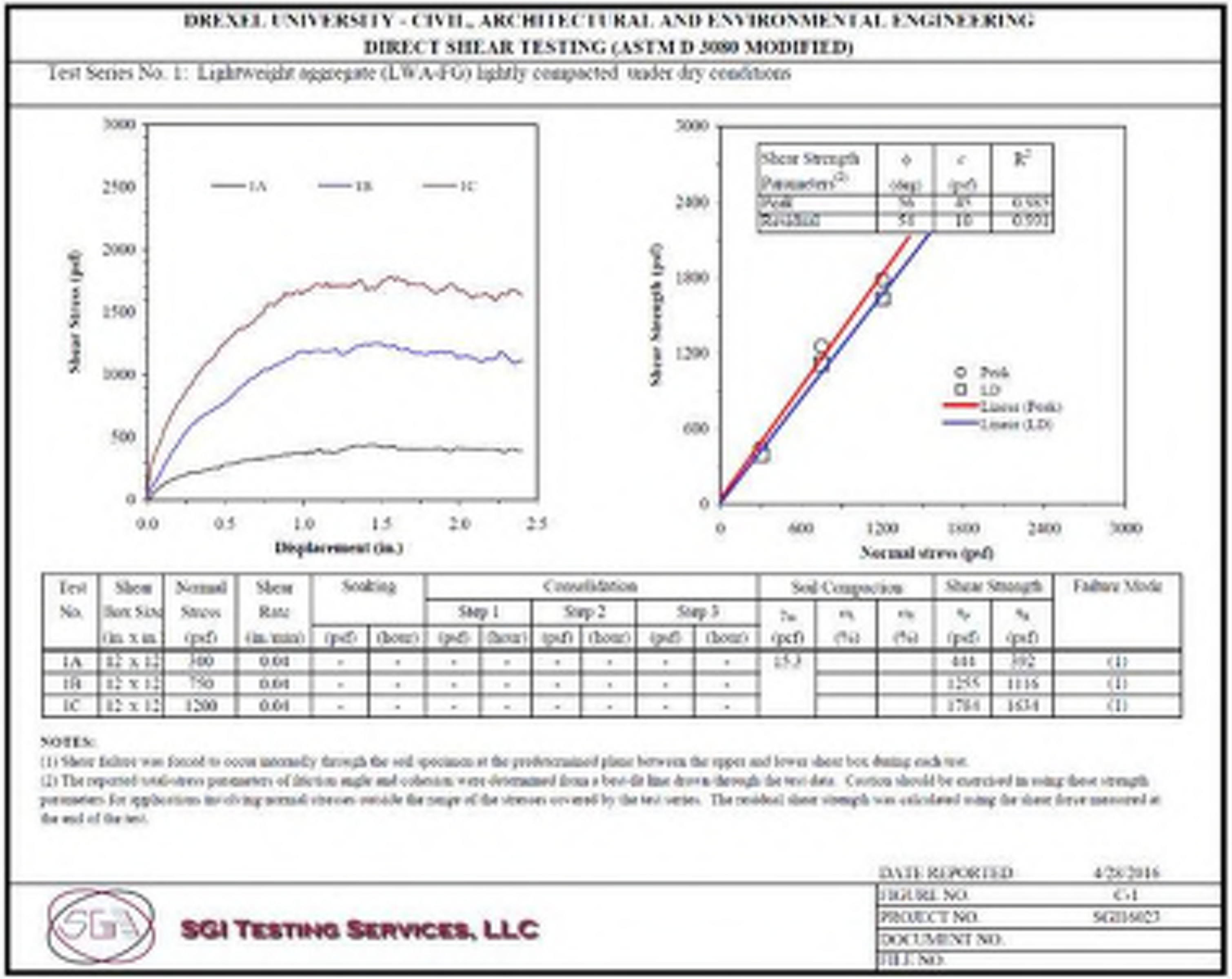
I-485 Express Lanes

Charlotte, NC

Structural Optimization



Friction Angle



DREXEL UNIVERSITY - CIVIL, ARCHITECTURAL AND ENVIRONMENTAL ENGINEERING
DIRECT SHEAR TESTING (ASTM D 3080 MODIFIED)
Test Series No. 1: Lightweight aggregate (LWA-FG) lightly compacted under dry conditions

Test No.	Shear Box Size (in. x in.)	Normal Stress (psf)	Shear Rate (in./min)	Soaking (psf)	Soaking (hour)	Consolidation Step 1 (psf)	Step 1 (hour)	Step 2 (psf)	Step 2 (hour)	Step 3 (psf)	Step 3 (hour)	Soil Compaction γ_d (pcf)	w (%)	w (%)	Shear Strength τ_p (psf)	τ_r (psf)	Failure Mode
1A	12 x 12	300	0.04	-	-	-	-	-	-	-	-	25.3			444	392	(1)
1B	12 x 12	750	0.04	-	-	-	-	-	-	-	-				1255	1116	(1)
1C	12 x 12	1200	0.04	-	-	-	-	-	-	-	-				1784	1634	(1)

NOTES:
(1) Shear failure was forced to occur internally through the soil specimen at the predetermined plane between the upper and lower shear box during each test.
(2) The reported total-stress parameters of friction angle and cohesion were determined from a best-fit line drawn through the test data. Caution should be exercised in using these strength parameters for applications involving normal stresses outside the range of the stresses covered by the test series. The residual shear strength was calculated using the shear force measured at the end of the test.

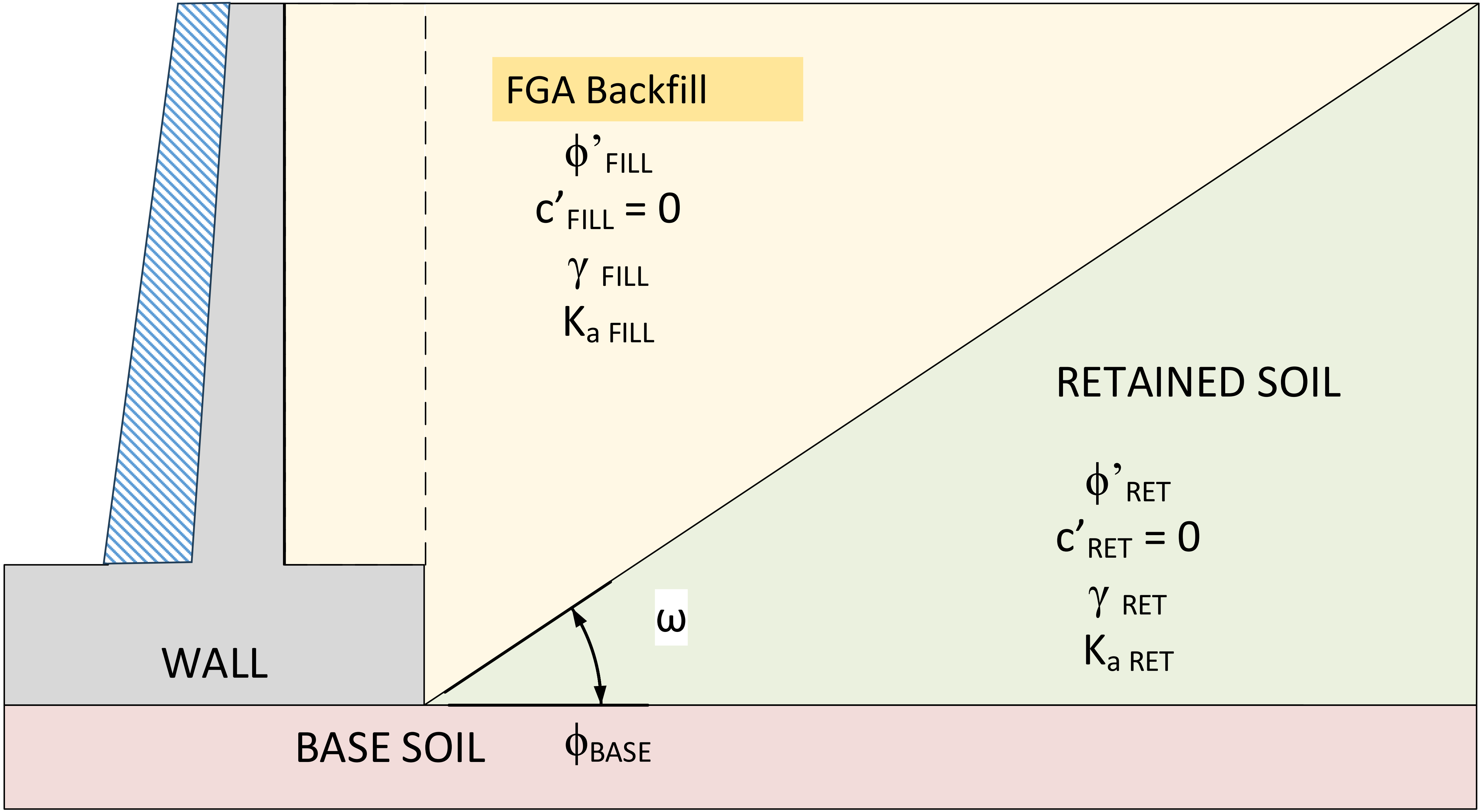
DATE REPORTED 4/26/2016
FIGURE NO. C-1
PROJECT NO. SGI16023
DOCUMENT NO.
FILE NO.

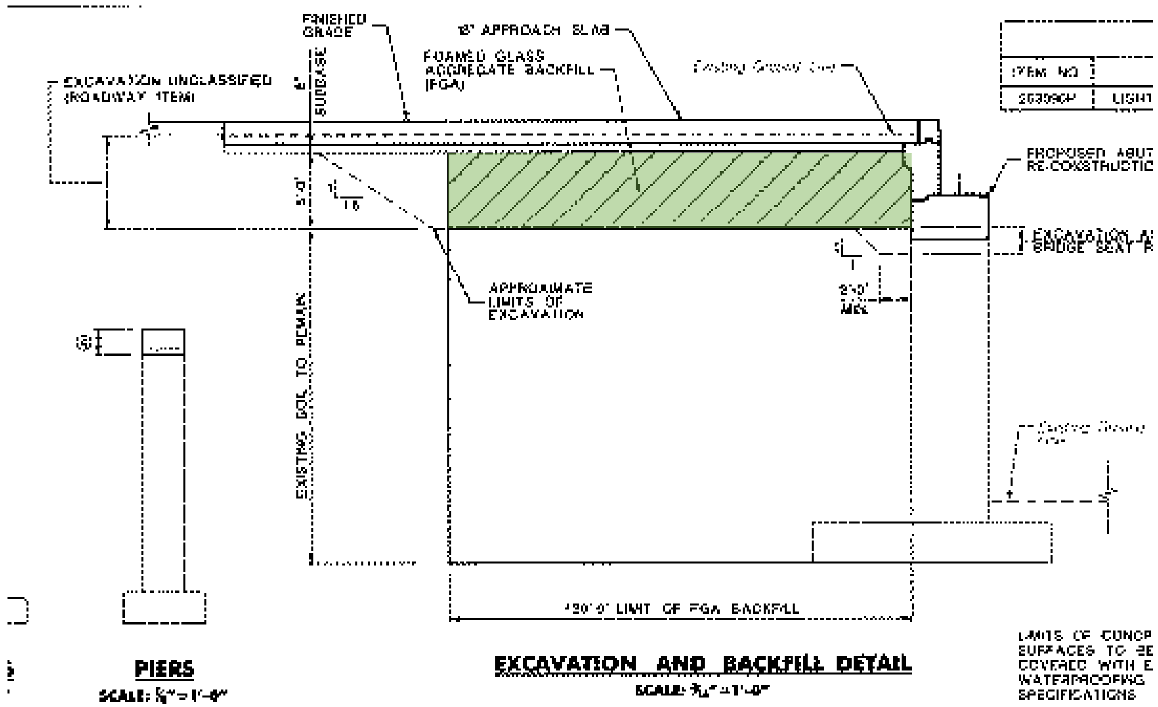
SGI TESTING SERVICES, LLC

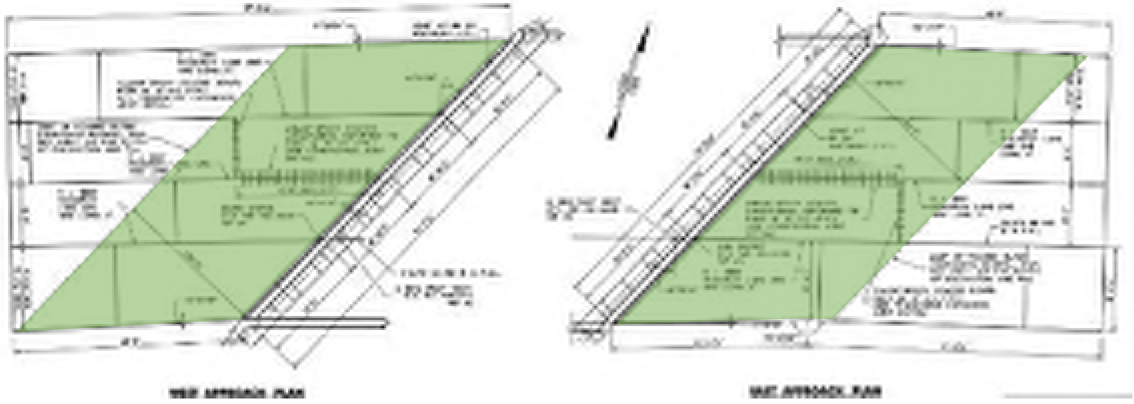
(ASTM D 3080)	*AASHTO (2017) Requirement*	*UL-FGA Apparent Peak Friction Angle*
Up to 57.5 kPa (1,200 psf)	> 34°	54° - 55°
Up to 144 kPa (3,000 psf)	> 34°	41° - 45°

Wall Mockup and PADOT w Face removed

Consider a wall with cohesionless select backfill and retained soil







I-80 Bridges over Rockaway River

NJDOT Denville, NJ


I-80 Bridges over Rockaway River

NJDOT Denville, NJ

Rehabilitation of 178th & 179th Street Ramps GW Bridge

NYC, NY

Rehabilitation of 178th & 179th Street Ramps GW Bridge

NYC, NY

Used or Approved by:

- MD SHA
- VDOT
- PennDOT
- NJDOT
- DDOT
- NYSDOT
  - PANYNJ
- RIDOT
- MassDOT
  - MassPort
- DelDOT
- NHDOT
- MaineDOT
  - MTA
- MDOT
- NCDOT
- SCDOT
- MinnDOT
- LADOTD
- FDOT
- ADOT
- ARDOT

CONCRETE APPLICATIONS

Lightweight Structural Concrete

Up to 65% recycled content

Up to 50% lighter

Insulation value improves 5-8x

CONCRETE APPLICATIONS

Internal Curing Concrete

- "Open Cell" Foamed Glass
- 100% by weight absorption

Summary

Supporting Infrastructure with Ultra-Lightweight Foamed Glass Aggregate

- Predictable Material Behavior
- Lightweight
- High Friction Angle
- Highly Permeable

Sustainable and Resilient

- Post-Consumer Recycled Glass
- Chemically Non-reactive
- Exempt for Waste Regulations

Accelerated Construction

- Not weather sensitive
- Fewer trucks required for delivery
- Less equipment and time for installation


CONSUMER
GLASS WASTE
AERO
AGGREGATES
SUSTAINABILITY
360°

Thank You!
Questions?

Archie Filshill, Ph.D., ENV SP
archie@aeroaggregates.com

Installation – Method Spec

<u>Tracked Excavator or Dozer 625 - 1,025 psf</u>

- 4 passes over the UL-FGA layer
- 24 inch lift thickness

<u>Plate Compactor 110-220 lbs</u>

- 4 passes over the UL-FGA layer
- 12 inch lift thickness

- Nonwoven Geotextile as separator
- Compaction typically 10-20% of a given lift thickness
  - Lidar Compaction Study

Sustainability

Reduces natural resources by a factor 6-7

Reduced truck traffic/emissions

Each facility diverts the equivalent of over 140 million bottles/year

2022 Aero will divert over 0.5 billion bottles from landfill/year


LOCATIONS
Modesto, CA
Eddystone, PA
Dunnellon, FL

Shovel Ready Sustainable Concrete Technologies

1st Southeastern Peer Exchange for Resilient & Sustainable Bridges (SPxRBS-2023)

Presentation Outline

1. Introduction

- Speaker – Larry Rowland 35+ year industry veteran
- Company – Heidelberg Materials & legacy brands
- Sustainability 101 – Concrete is Sustainable

2. PCA's Roadmap to Carbon Neutrality

- Covering the basics
- Cement industry's sustainability approach

3. Heidelberg Materials Response and Outlook

- Shovel ready sustainable concrete technologies
- Promising sustainable solutions

Larry Rowland

Sustainability Market Manager
Heidelberg Materials
North America

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Heidelberg Materials

Heidelberg Materials – Unified to Better Serve

Heidelberg Materials

In 2023 we became Heidelberg Materials, a new brand with a global reach and a focus on sustainability, digitalization and leadership in the building materials industry.

Our evolution to Heidelberg Materials reflects a broad and innovative approach to serving our customers and becoming the industry leader in sustainability and digital solutions. The new name will unify its many legacy brands and nearly 9,000 employees in North America to better serve customers, engage with local communities, and drive the sustainable and circular economies.

Sustainability basics

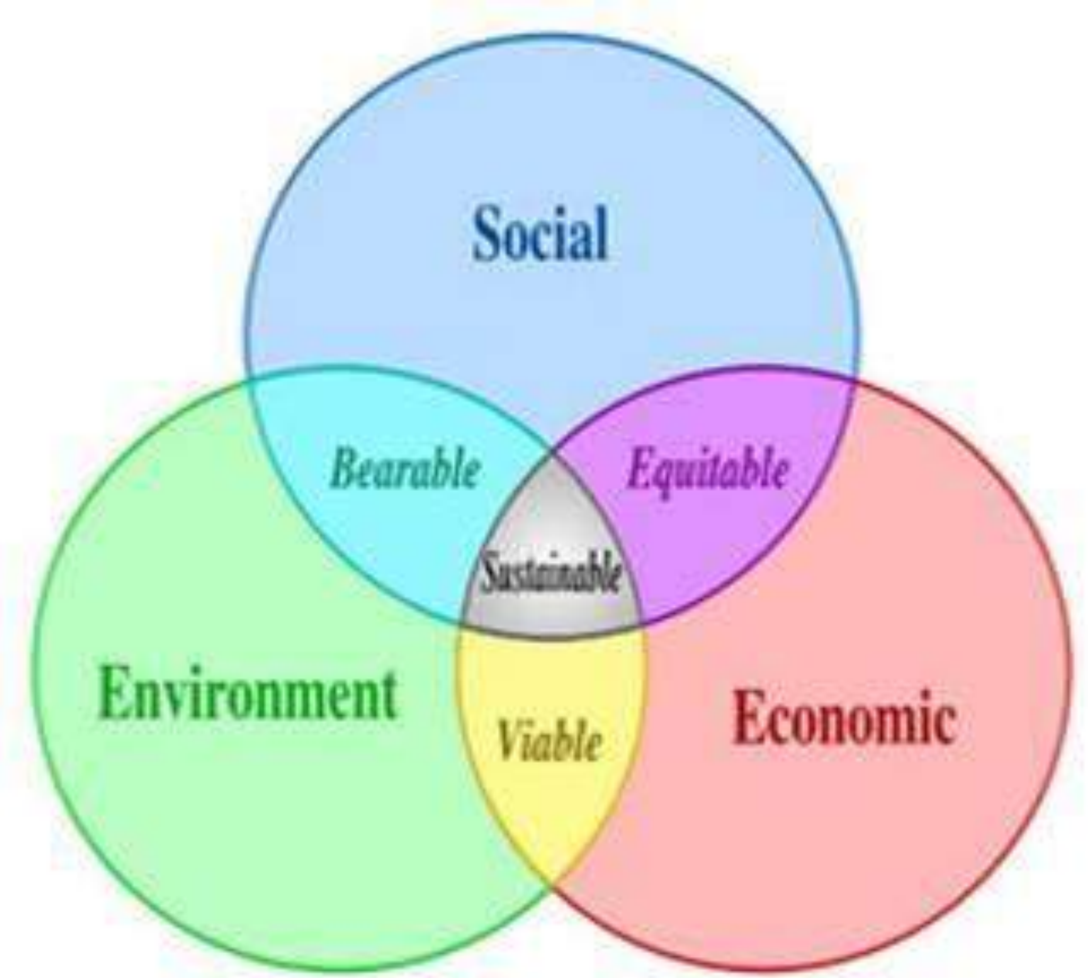
"We do not inherit the earth from our ancestors; we borrow it from our children"

Wendell Berry

The Triple-Bottom-Line

- Social
- Environmental
- Economic

… Sustainability is in the Overlap



What makes a Material more or less sustainable?

Sustainable Constituents

LCA Production Stage A1

CO_2 / Energy Efficient Production

LCA Production Stage A3

Durability and Resilience

LCA Use Stage B1 – B5

Long Service Life, Easily Recycled

LCA Use Stage B1 – B5 &

LCA End of Use Stage

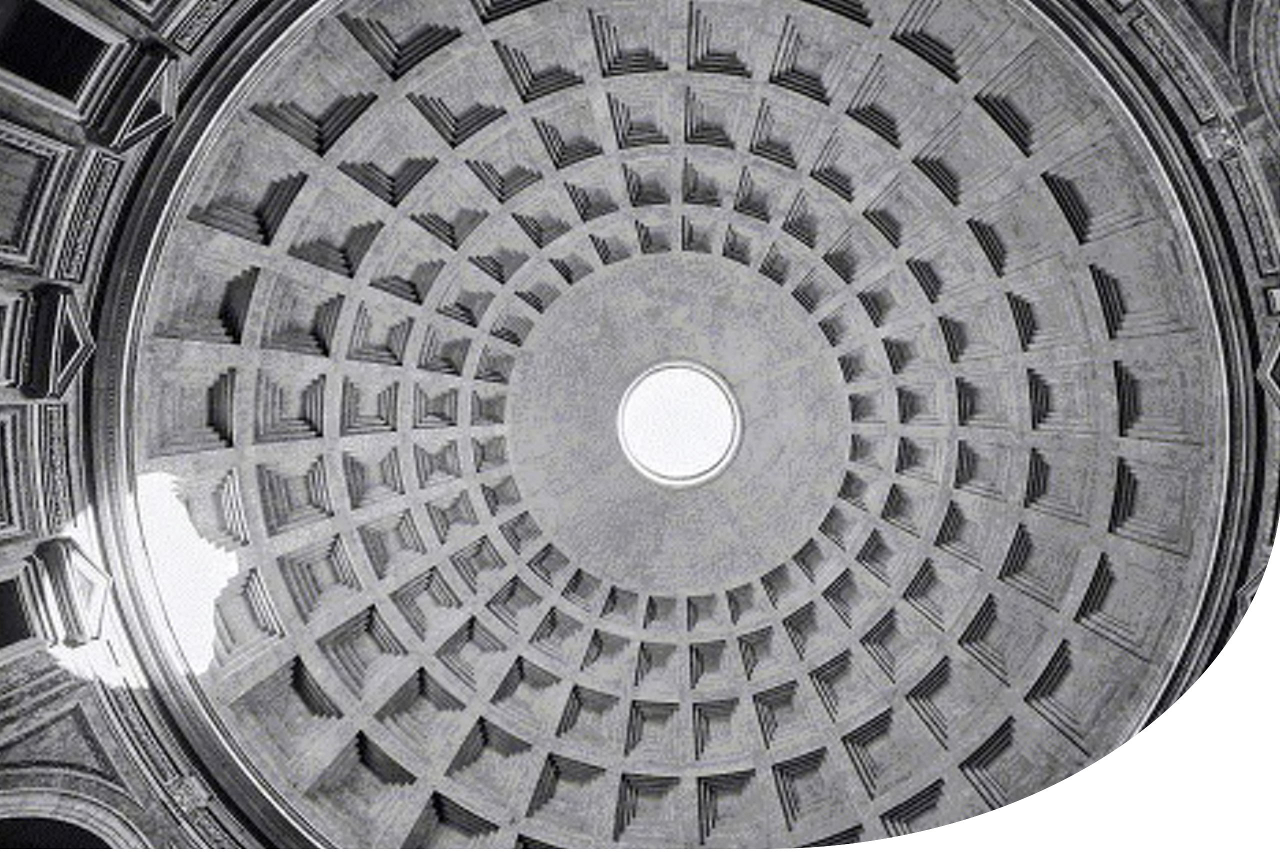


Photo by Mathew Schwartz on Unsplash

The Pantheon in Rome. Built: 120-126 AD

Durable materials are environmentally efficient because they

- Reduce waste
- Conserve resources by
  - Less repair
  - Much later replacement

Do it Once…

Do it Right with Concrete!

Durability and Resilience are key characteristics of sustainable materials

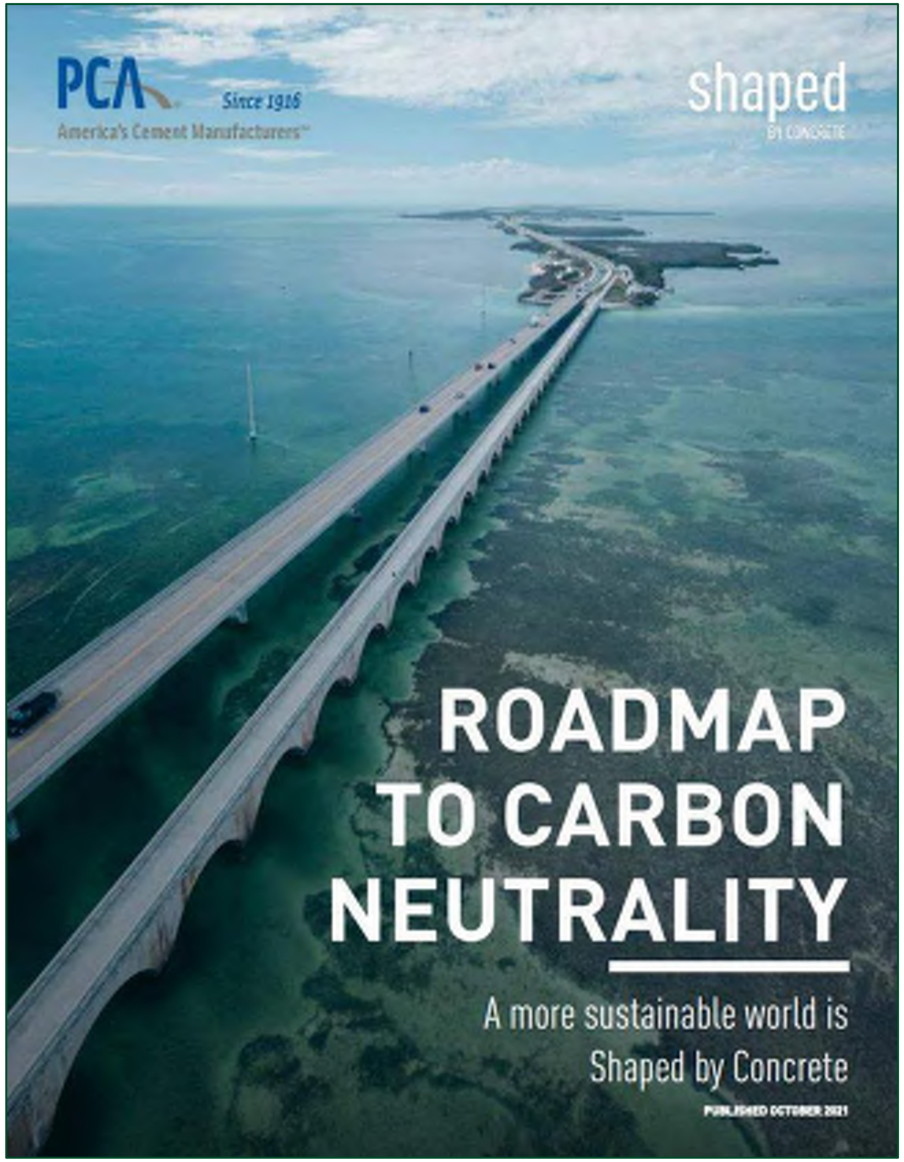
Portland Cement Association's Roadmap to Carbon Neutrality

The industry's approach to meet its commitment to achieve carbon neutrality by 2050

Published October 2021

Takes a LCA approach to decarbonizing concrete

- Looks at the full Value Chain for a concrete project
- Beginning with materials
- Through a project's service life
- Finishing up with circular application and carbonation



The Value Chain

- **Clinker** - The key manufactured portland cement product
  - Process emissions, calcining limestone
  - Fuel and efficiency related emissions
- **Cement** - The basis of resilient structures
  - Low carbon cements / Performance and considerations
- **Concrete** - The basis of structural concrete
  - The earth's sustainable material of choice
- **Construction** – Low carbon procurement approaches
- **Carbonation** – Getting the credit you deserve

SOLUTIONS FOR EACH STEP OF THE JOURNEY

Low-hanging fruit

NEAR-TERM

Replace raw materials with recycled materials

Produce low-carbon cement blends

Optimize designs for the lowest life cycle emissions

MID-TERM

Increase the use of alternative fuels

Use renewable energy

Along the way:

- Ensure necessary changes to codes, standards, and specifications
- Educate stakeholders
- Inspire the next generation of engineers and builders!

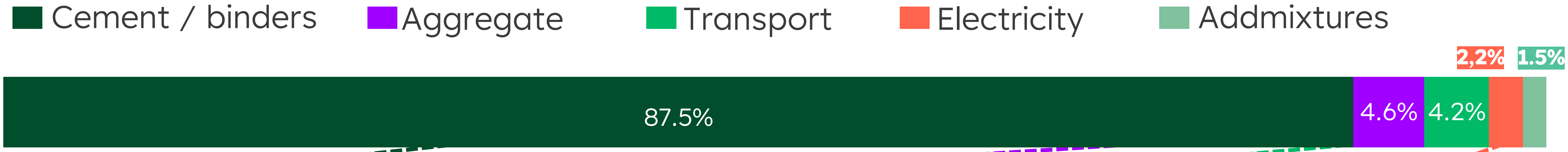
The hard stuff

LONG-TERM

Carbon capture

Introduce new cement blends

CO_2 during ready-mixed concrete production



- Process technology in cement
- Alternative binding agents
- Implementation in concrete by utilising flexible concrete technology mean

Local, low energy and low GWP building materials are a central. An uncounted CO_2 success factor

- Efficient logistics
- Utilising state-of-the-art drive units
- Openness for new technologies

Renewable energy is a usable benefit today

CO_2 in concrete is more than just cement

Cement is a very sustainable binder

US GHG Emissions – EPA Data

Electrical emissions > distributed where used

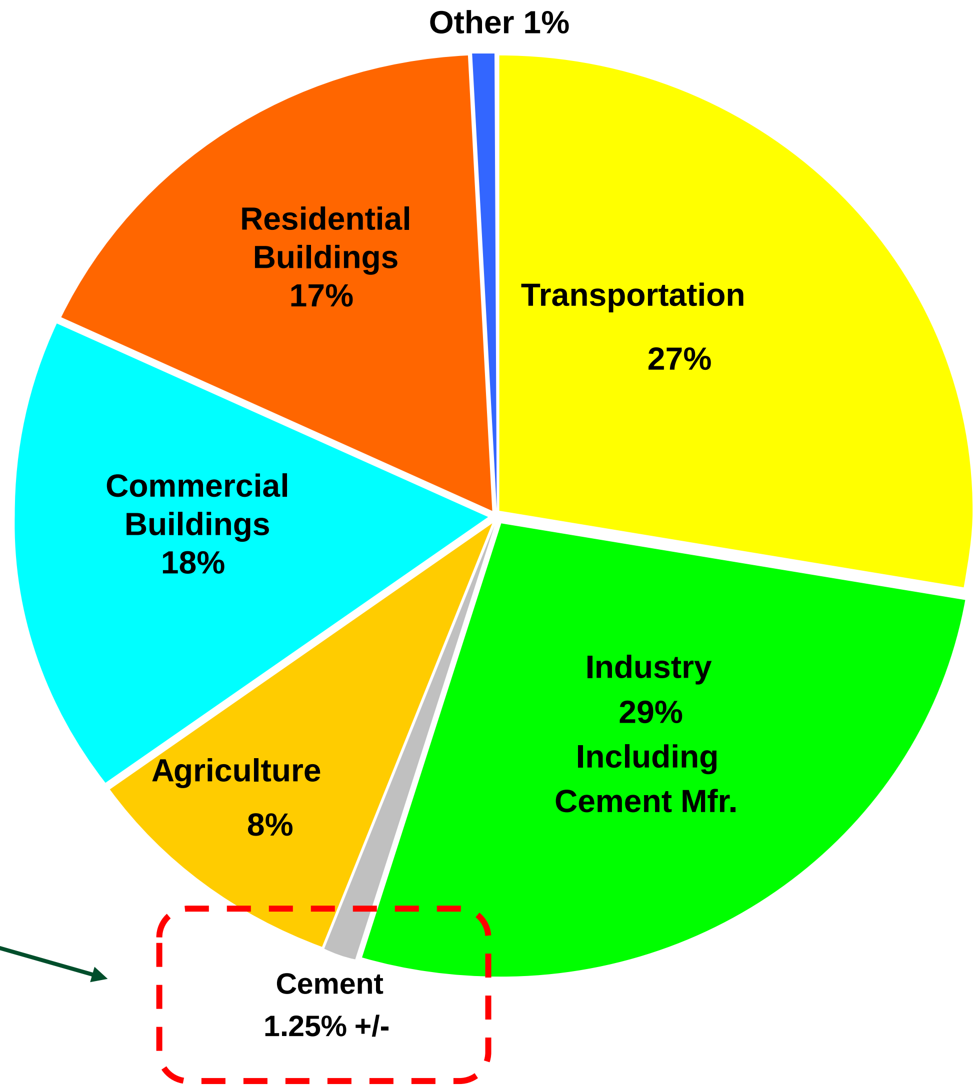
Total Cement GHG Emissions

Process Emissions

+ Direct Fuel & Electrical

1.25% of U.S. GHG Emissions +/-

GHG (Green House Gas) by Sector with Electrical included

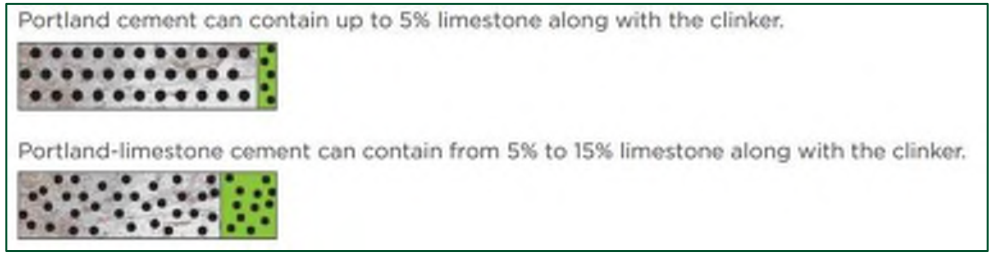


PCA's Roadmap – Reduce Clinker Content via PLC's

Reduce Your Carbon Footprint by ~ 10% with PLC

Details on www.greencement.com

- US cement consumption just under 110-million tons in 2022
  - Currently @ ~45% of total cement shipments
- Portland Limestone Cements = AASHTO M 240 Type IL (Typically)
  - Binary blend with limestone addition 5% – 15%
- AASHTO M 85 Portland Cements, limestone addition max 5%
- Potential CO_2 emissions reduction > 1,000,000 tons/year



Our North America Carbon Roadmap

Leading the way to net zero concrete

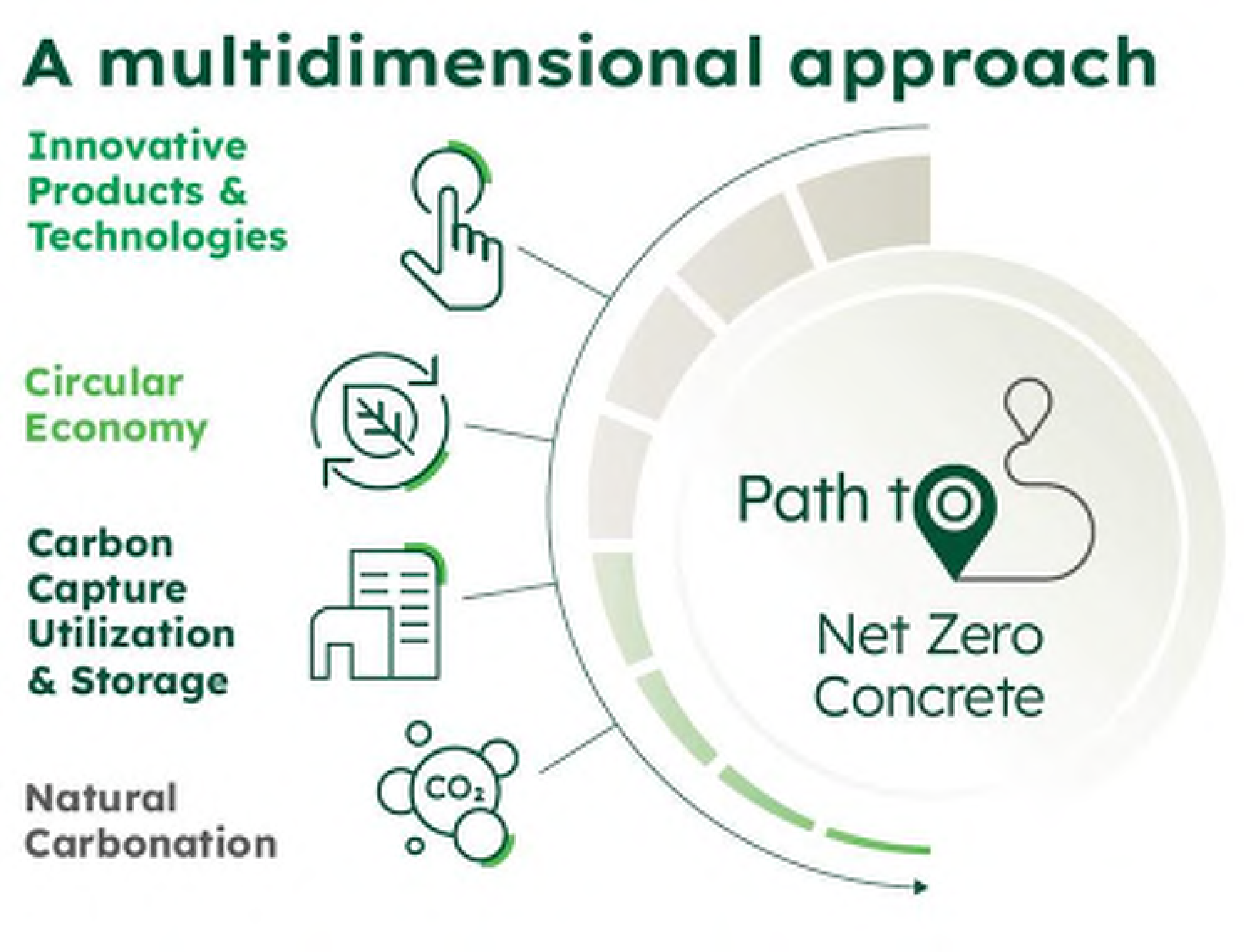
Lower carbon solutions for the built environment

At Heidelberg Materials, we aim to be the industry leader on the path to net zero concrete.

Our CO_2 reduction targets are grounded in science and underpinned by a clear roadmap.

Our North America Carbon Roadmap

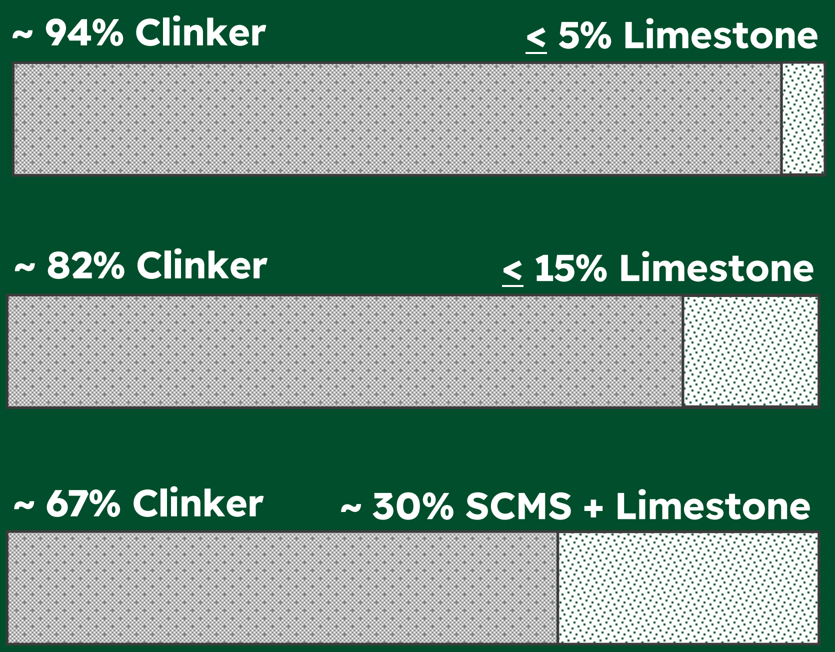
- **Innovative Products**
    - Low Carbon Cements and Concrete Mixes
- **Circular Economy**
    - Use & incorporate reclaimed materials
        - Recycled Concrete Aggregate (RCA)
        - Supplementary Cementitious Materials (SCMs)
- **Carbon Capture Utilization & Storage**
    - Brevik Norway - world's first CCS plant in the cement sector deployed on industrial scale
    - Edmonton, to capture ~ 1-mil. tons CO_{2}/ year
- **Natural Carbonation**
    - Working for transparent uptake accounting



OPC / Portland

ECOCEM™ PLC

ECOCEM™ PLUS



Innovative Products

Low Carbon Cements and Concrete Mixes

Clinker reduction

- Key strategy for reducing embodied CO_2 aka GWP
- Performance Specifications enable use
- Significant reduction potential depending on available materials and type of application

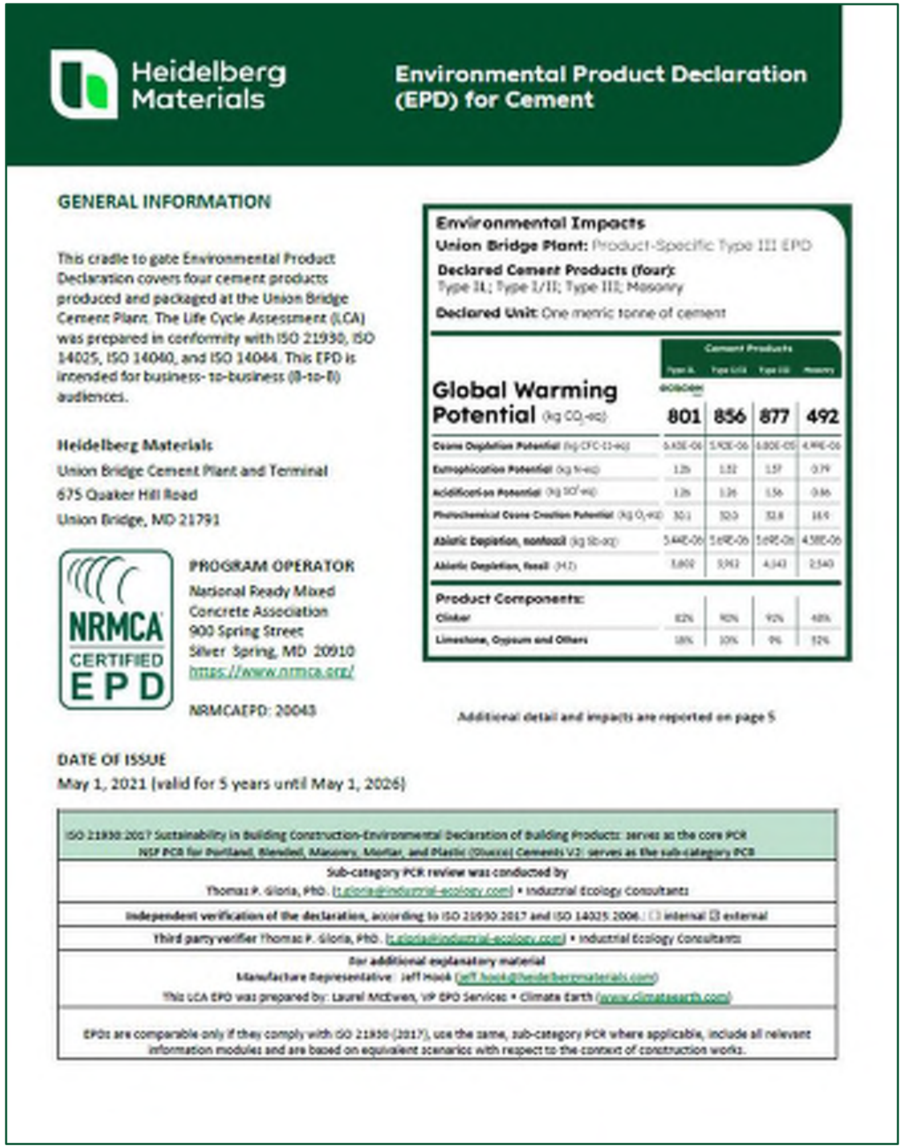
Current technologies at the cement plant

- Interground limestone and SCM incorporation
- Recycled raw materials for clinker production
- Alternative fuels and heat recovery technologies

Heidelberg Materials Shovel Ready Materials

Each Materials backed by EPD's

- Portland Limestone Cements – Reduced Clinker Factor
- Supplementary Cementitious Materials
    - Slag Cements aka Ground Granulated Blast Furnace Slag
    - AASHTO M 295 Coal Ash and Raw or Calcined Natural Pozzolans
        - Fly Ash – Traditional freshly recovered
        - Reclaimed Ash – from stockpiles, ponded and landfilled
        - STAR® Technology is our patented thermal beneficiation process
- Blended Cements – EcoCem® Plus ternary blends per M 240
- Others…



Heidelberg Materials

Environmental Product Declaration (EPD) for Cement

GENERAL INFORMATION

This cradle to gate Environmental Product Declaration covers four cement products produced and packaged at the Union Bridge Cement Plant. The Life Cycle Assessment (LCA) was prepared in conformity with ISO 21930, ISO 14025, ISO 14040, and ISO 14044. This EPD is intended for business- to-business (B-to-B) audiences.

Heidelberg Materials
Union Bridge Cement Plant and Terminal
675 Quaker Hill Road
Union Bridge, MD 21791

NRMCA CERTIFIED EPD

PROGRAM OPERATOR
National Ready Mixed Concrete Association
900 Spring Street
Silver Spring, MD 20910
https://www.nrmca.org/

NRMCAEPD: 20043

Environmental Impacts
Union Bridge Plant: Product-Specific Type III EPD
Declared Cement Products (four): Type IL; Type I/II; Type III; Masonry
Declared Unit: One metric tonne of cement

	Type IL	Type I/II	Type III	Masonry
Global Warming Potential (kg CO_2-eq)	801	856	877	492
Ozone Depletion Potential (kg CFC-11-eq)	[illegible]	[illegible]	[illegible]	[illegible]
Eutrophication Potential (kg N-eq)	1.2[illegible]	1.32	1.37	0.79
Acidification Potential (kg SO_2-eq)	1.2[illegible]	1.2[illegible]	1.36	0.86
Photochemical Ozone Creation Potential (kg O_3-eq)	30.1	32.3	32.8	16.9
Abiotic Depletion, nonfossil (kg Sb-eq)	5.44E-06	5.69E-06	5.69E-06	4.38E-06
Abiotic Depletion, fossil (MJ)	[illegible]	[illegible]	4,143	2,340
Product Components:				
Clinker	82%	90%	91%	48%
Limestone, Gypsum and Others	18%	10%	9%	52%

Additional detail and impacts are reported on page 5

DATE OF ISSUE
May 1, 2021 (valid for 5 years until May 1, 2026)

ISO 21930:2017 Sustainability in Building Construction-Environmental Declaration of Building Products: serves as the core PCR
NSF PCR for Portland, Blended, Masonry, Mortar, and Plastic (Stucco) Cements V2: serves as the sub-category PCR

Sub-category PCR review was conducted by
Thomas P. Gloria, PhD. (t.gloria@industrial-ecology.com) • Industrial Ecology Consultants

Independent verification of the declaration, according to ISO 21930:2017 and ISO 14025:2006.: ☐ internal ☒ external

Third party verifier Thomas P. Gloria, PhD. (t.gloria@industrial-ecology.com) • Industrial Ecology Consultants

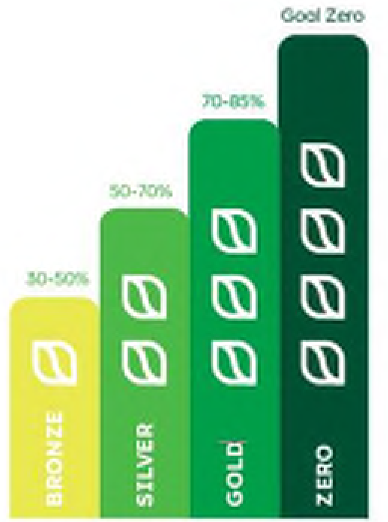
For additional explanatory material
Manufacture Representative: Jeff Hook (jeff.hook@heidelbergmaterials.com)
This LCA EPD was prepared by: Laurel McEwen, VP EPD Services • Climate Earth (www.climateearth.com)

EPDs are comparable only if they comply with ISO 21930 (2017), use the same, sub-category PCR where applicable, include all relevant information modules and are based on equivalent scenarios with respect to the context of construction works.

"Environmental Product Declarations (EPDs) are comparable to a "nutrition label" for products which report a selection of environmental impacts."

Delivering low carbon mixes to the ready mix market

Dial up the Green. Dial down the CO_2



The EvoBuild™ Range: reducing the carbon footprint of concrete

evoBUILD™ LOW CARBON CONCRETE BRONZE

evoBUILD™ LOW CARBON CONCRETE SILVER

evoBUILD™ LOW CARBON CONCRETE GOLD

evoBUILD™ LOW CARBON CONCRETE ZERO

Strong, innovative, sustainable

The world's most versatile construction material is now among it's greenest.

evoBUILD™ LOW CARBON CONCRETE

The evolution of sustainable building materials designed to meet today's sustainability targets

The introduction of EvoBuild™, paired with our comprehensive solutions, keeps you on time, on budget, and on target. Comprising three key elements: knowledgeable experts, science-backed data and sustainable product formulations, EvoBuild™ Solutions is designed to help you meet your sustainability goals without compromising on performance. We work alongside you, offering unparalleled service from concept to completion. And, our partnership doesn't end there—we continue to provide valuable reporting, such as annual CO2 savings, post-project. EvoBuild™ Solutions was developed based on empirical evidence obtained through extensive research and testing. It is backed by trusted sustainable standards and product-specific Environmental Product Declarations (EPDs) that well surpass industry-standard benchmarks for Global Warming Potential. Together, these form a transparent picture of how we can help you navigate and reach your sustainability goals.

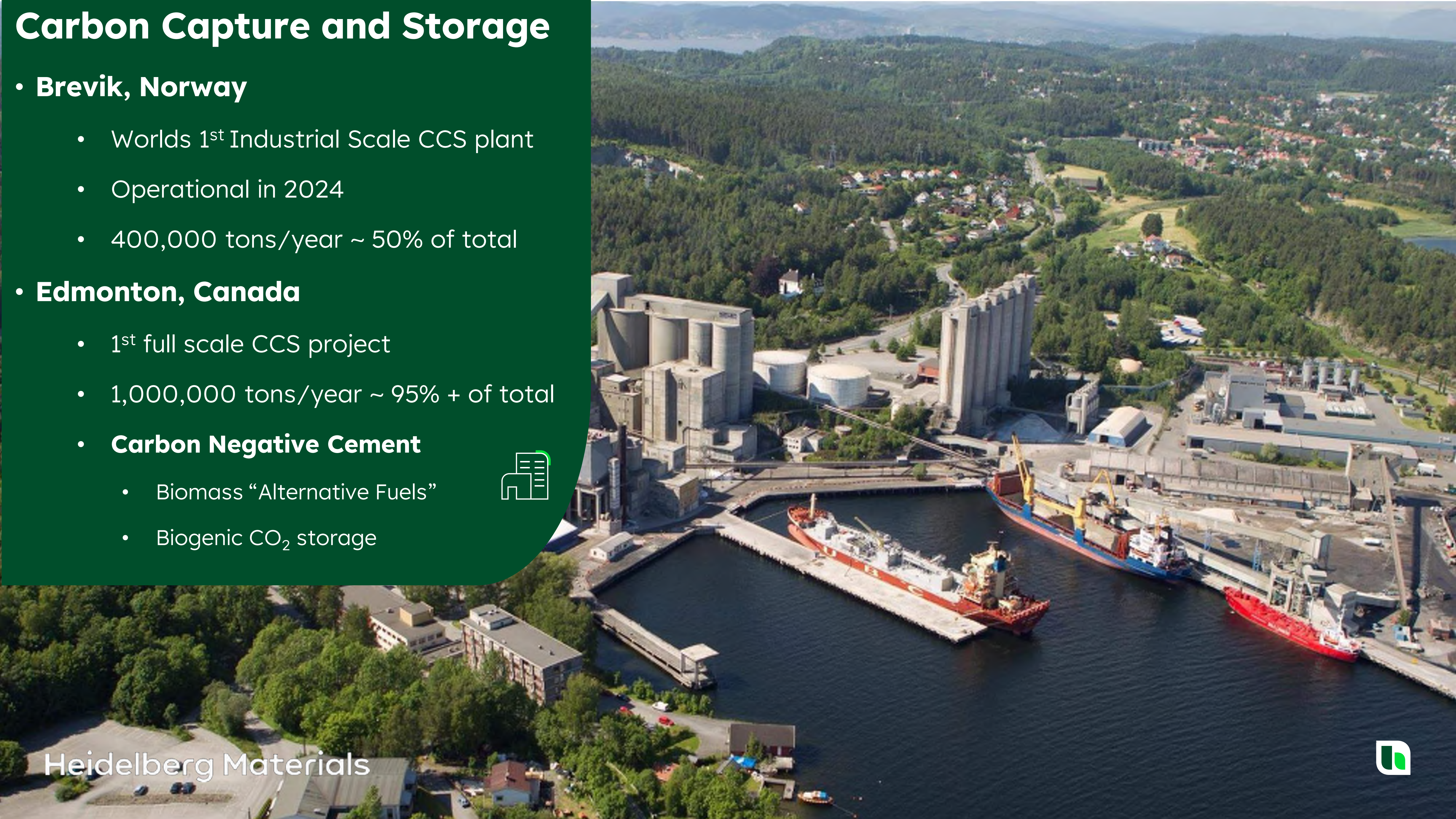
EvoBuild™ Low Carbon Concrete is part of Heidelberg Materials' Evolve™ Family of Products, the evolution of sustainable building materials. Our company, our products, our partnerships are unified behind this single concept—that we must evolve to meet the challenges of tomorrow.

Heidelberg Materials

Bringing Delivery & Material Transparency to Concrete Construction

Carbon Capture and Storage

- **Brevik, Norway**
  - Worlds 1st Industrial Scale CCS plant
  - Operational in 2024
  - 400,000 tons/year ~ 50% of total
- **Edmonton, Canada**
  - 1st full scale CCS project
  - 1,000,000 tons/year ~ 95% + of total
  - **Carbon Negative Cement**
    - Biomass “Alternative Fuels”
    - Biogenic CO_2 storage



Edmonton Carbon Capture and Storage Overview

To produce world's 1st net zero concrete achieved with no carbon offsets

- CCS system to capture ~ 95% CO_2 from…
  - Cement plant and…
  - Onsite Combined Heat and Power Plant (CHP)
- Combined Heat and Power Plant to serve
  - Cement plant operations
  - Local and regional Alberta power consumers
  - Heat recovery for carbon capture technology
- Additional environmental benefits including
  - Improved air emissions
  - Reduced freshwater consumption

Edmonton Carbon Capture and Storage Overview

Storage

- CO_2 to be stored in deep saline reservoirs
  - Permanent storage 1,500-3,000 meters below ground in porous rock filled with brine with multiple overlying layers of impermeable cap-rock
  - Far below potable water and oil and gas reservoirs
  - Current global storage capacity 40 million tons/yr.
- Examples of CO_2 Storage
  - Alberta – Shell's Quest project has permanently stored over 6 million tons of CO2 since 2015
  - Saskatchewan – Aquistore project permanently stored 500,000+ tons of CO_2 annually since 2015
  - Illinois – Decatur project permanently stored over 1 million tons from 2011 to 2014

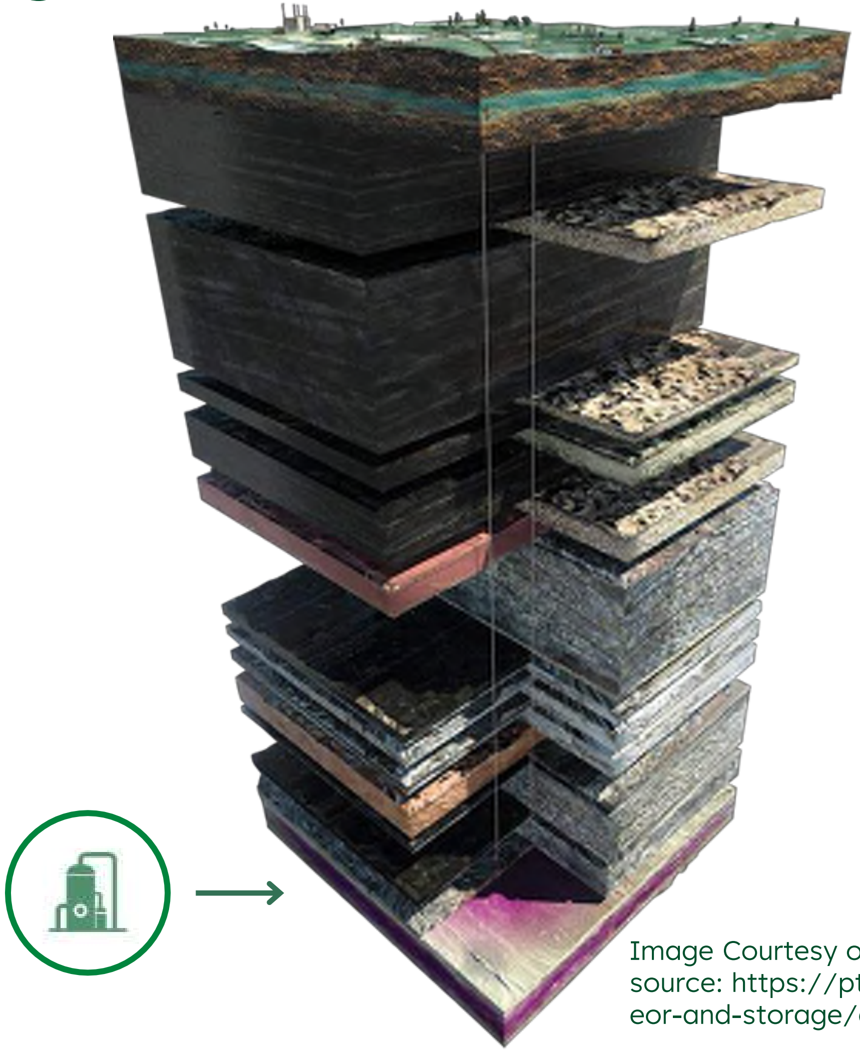
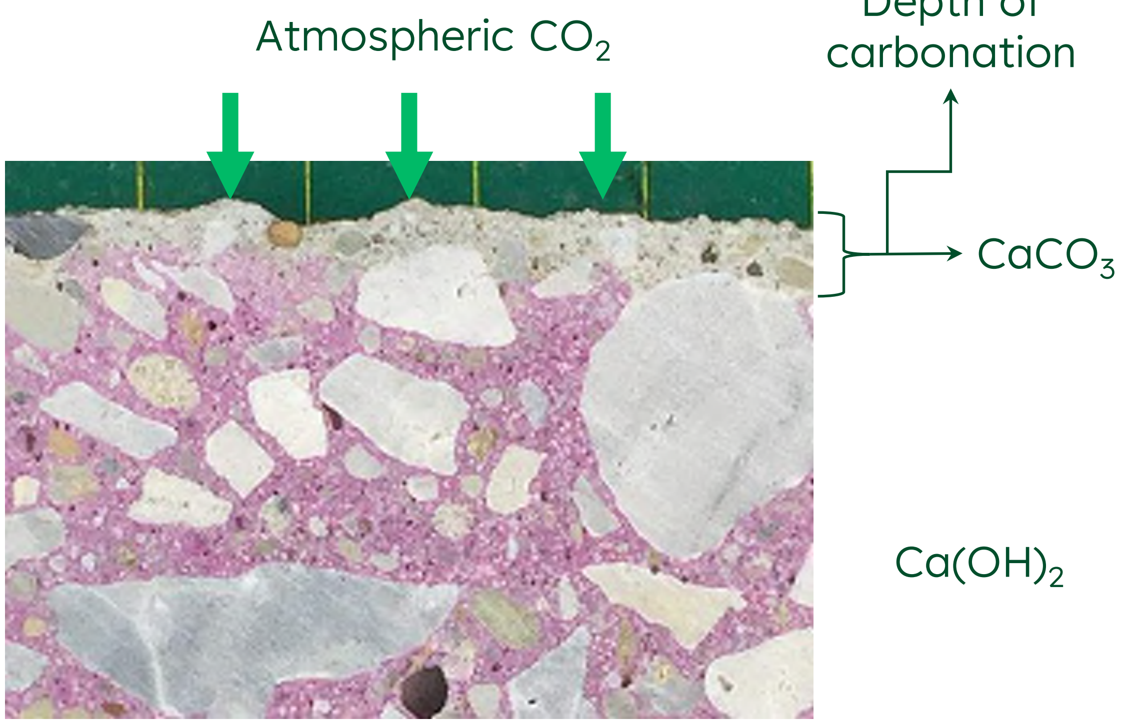


Image Courtesy of Aquistore, online source: https://ptrc.ca/projects/co2-eor-and-storage/aquistore#images-1

Working to Account for Concrete as a Carbon Sink

Carbonation is when concrete takes up CO_2

- During the concrete's service life
- At deconstruction phase of life cycle
- Factors that affect uptake include:
    - Percentage of exposed surface area
    - Surface coatings and treatments
    - Maintenance and surface treatments
    - Concrete mixture and placement
    - Climate, i.e. exposure to moisture
    - End of service life treatment



https://precast.org/2015/07/understanding-carbonation/

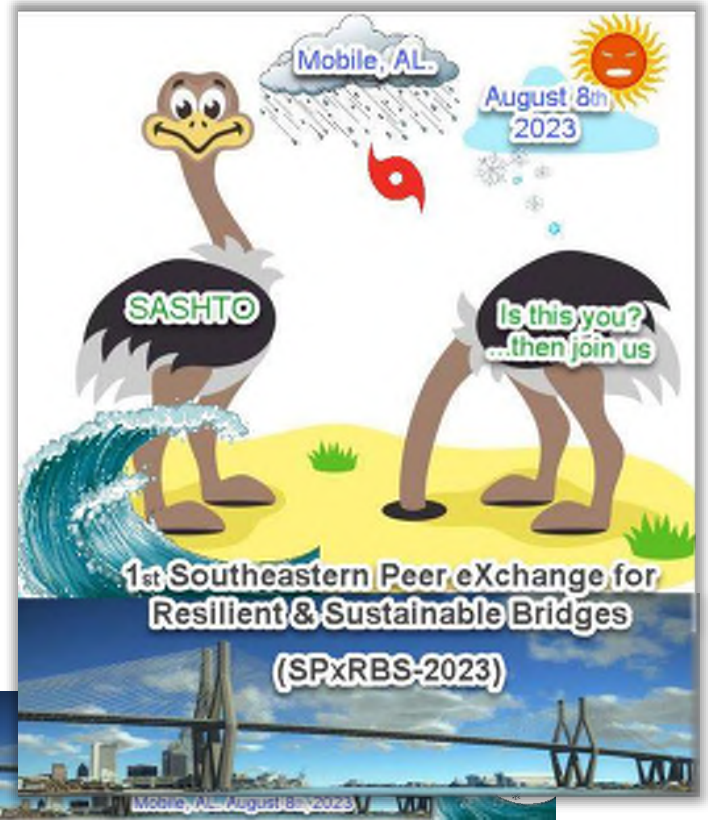
$$CO_2 + H_2O \longrightarrow H_2CO_3$$

$$H_2CO_3 + Ca(OH)_2 \longrightarrow CaCO_3 + H_2O$$

Thank You.

Heidelberg Materials

1st Southeastern Peer Exchange for Resilient & Sustainable Bridges – Part 4



Session 1 (12pm – 1:30pm):

- **Part 1**: Round table discussion of goals and commitments (24-minutes)
- **Part 2a: Technical presentations of State of the Art in member states (30 minutes)**
- **Part 2b**: Technical presentations of State of the Art in member states (30 minutes)

**** Breakout (120 minutes) ****

**** Coffee, Tea, Lemonade & Beignets 3:00-3:30pm ****

Session 2 (3:30pm-6:00pm)

- **Part 3: Technical presentations of Manufacturer & Materials Acceptance (60-min)**
- **Part 4: Technical presentation and discussion on Research Needs**
- **Part 5**: Technical presentation Open Topics (30-min)
- **Part 6**: Final Q&A, Wrap Up assignment of Follow-up Tasks and Champions. (20 minutes)

Session 1 : Introduction & Logistics (August 8th, 2023)

Participants & Sponsors

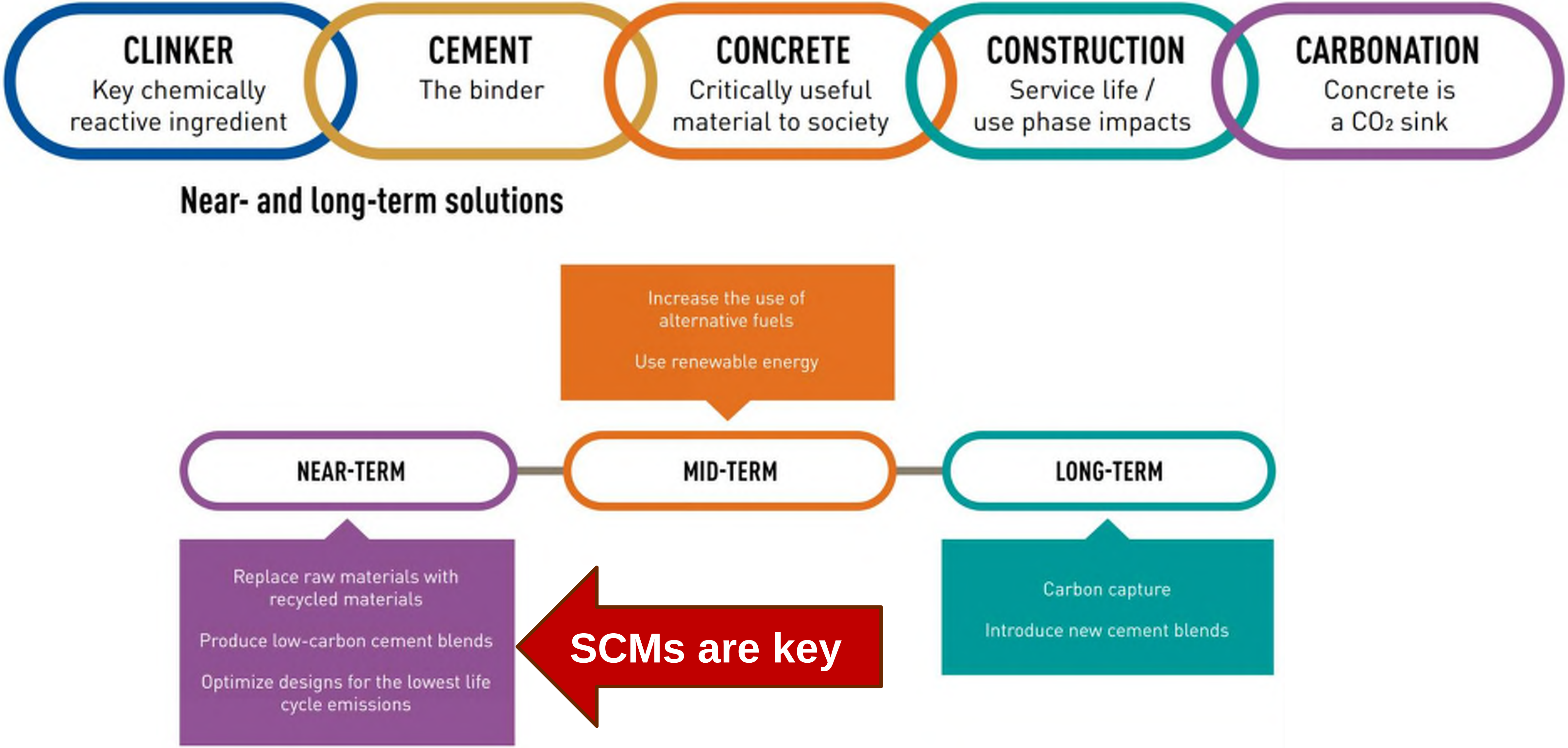
IMPROVING SUSTAINBILITY OF CONCRETE INFRASTRUCTURE THROUGH USE OF SCMS: CURRENT STATE AND RESEARCH NEEDS

Prasad Rangaraju, PhD, PE, FACI
Professor of Civil Engineering
Director of SMaRT Center
School of Civil and Environmental Engineering and Earth Sciences
Clemson University

1st SPxRSB- 2023
August 8th, 2023
Renaissance Mobile Riverview Plaza
Mobile, AL

PCA Roadmap to Carbon Neutrality

SMART CENTER
Sustainable Materials Research and Technology Center
CLEMSON
GLENN DEPARTMENT OF CIVIL ENGINEERING



PCA Roadmap to Carbon Neutrality, October 2021

Supplementary Cementitious Materials (SCMs)

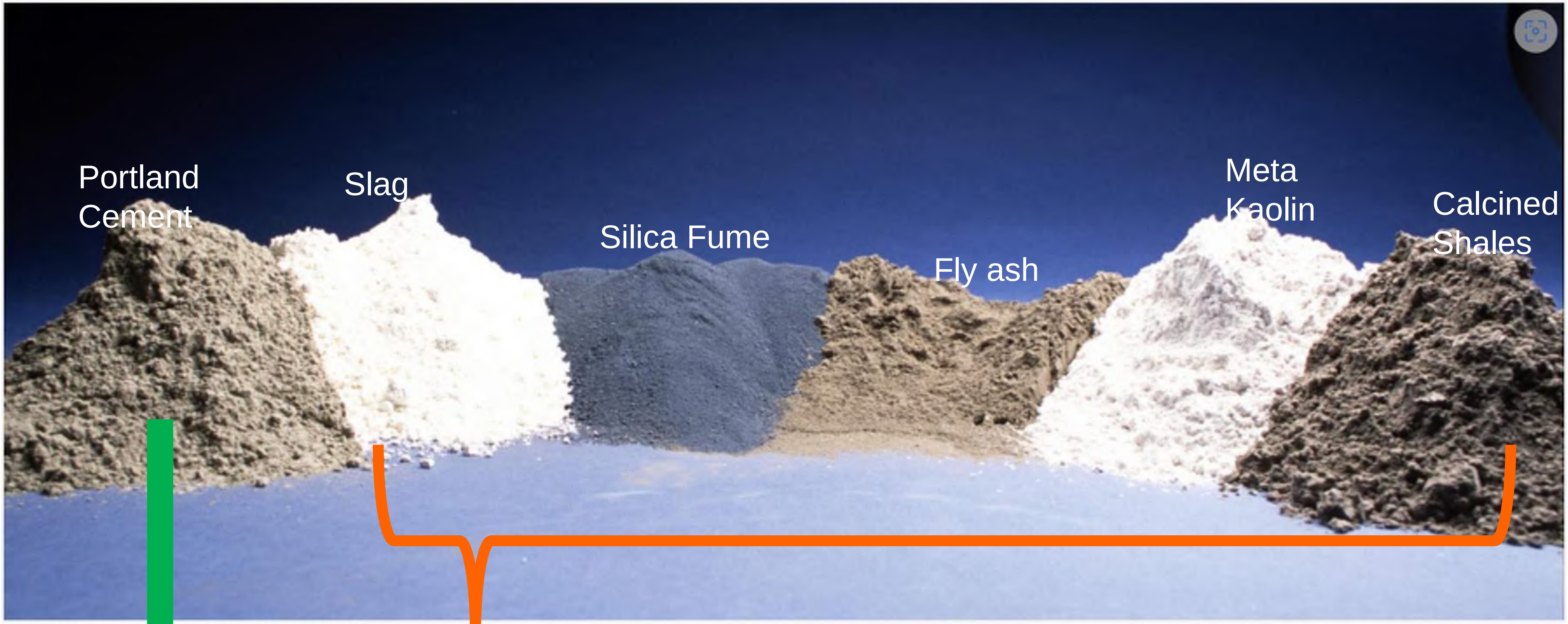
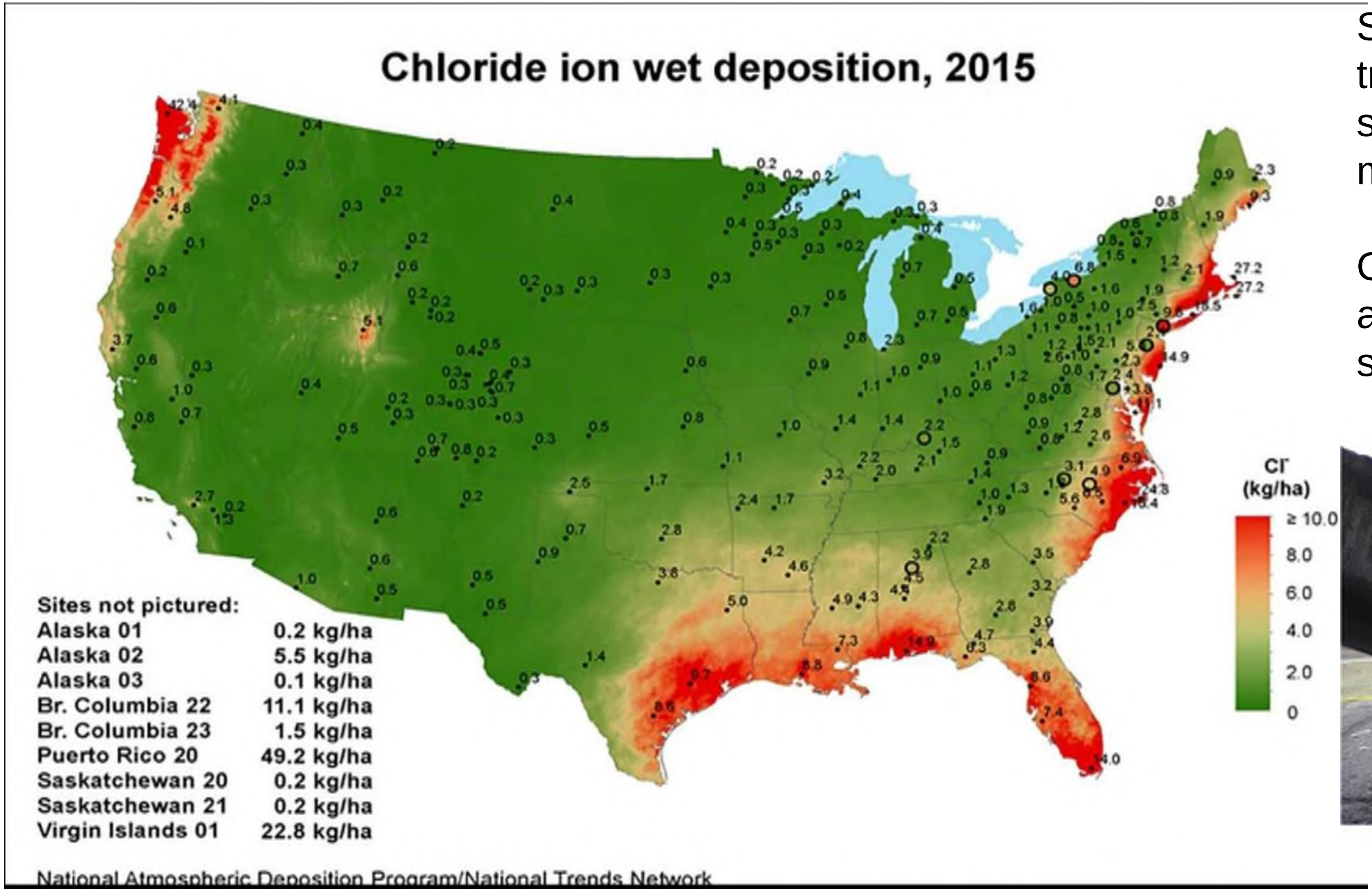


Image: Portland Cement Association (PCA)

Calcium Hydroxide + SCMs + Water → C-A-S-H Gel (Durable and Strong)

Marine Salt Spread Inland and Potential for Corrosion of Steel



Salt chloride deposition map showing United States how far inland salt air affects these coastal areas. Courtesy of the National Atmospheric Deposition Program (NADP).

Salt-laden air from marine regions can travel as much as 50 miles inland, and in some unique cases to as much as 100 miles inland.

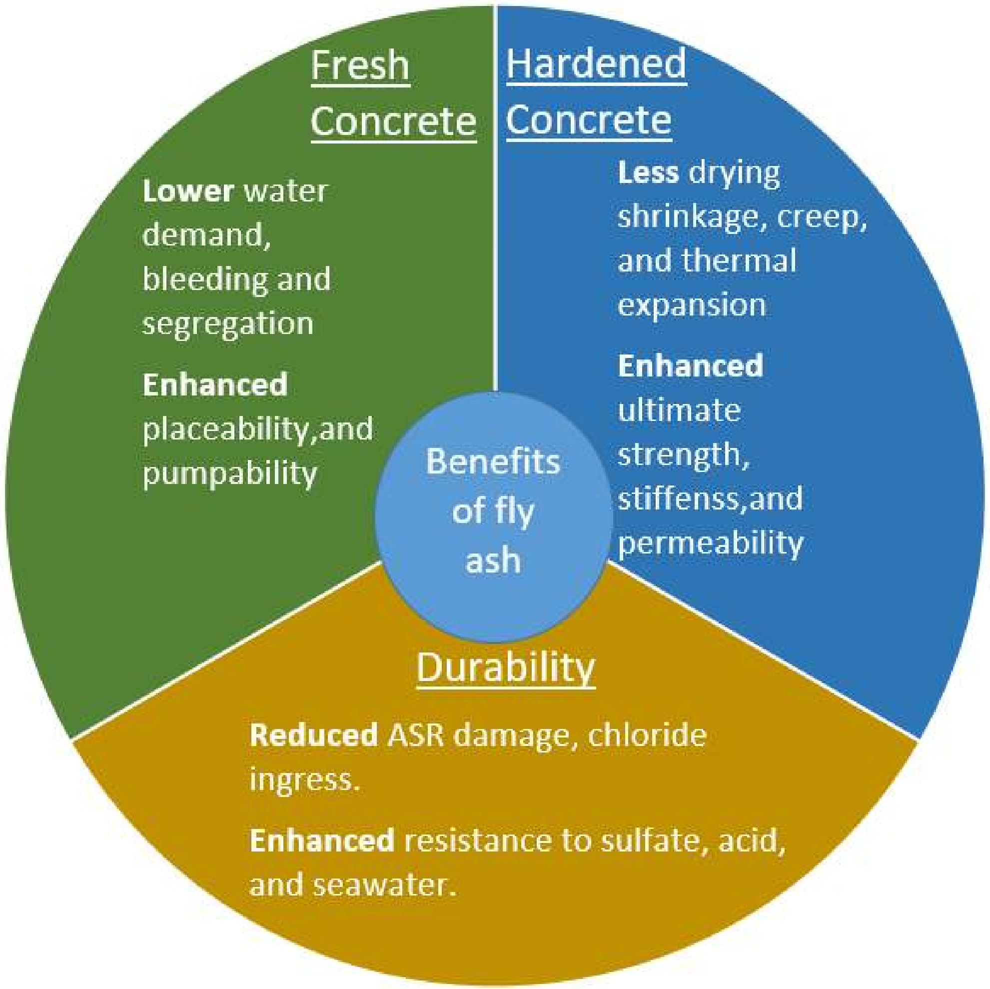
Other sources of salt such as deicers, and brackish waters can cause significant damage as well

© Pennsylvania Department of Transportation.

Fly Ash in Concrete

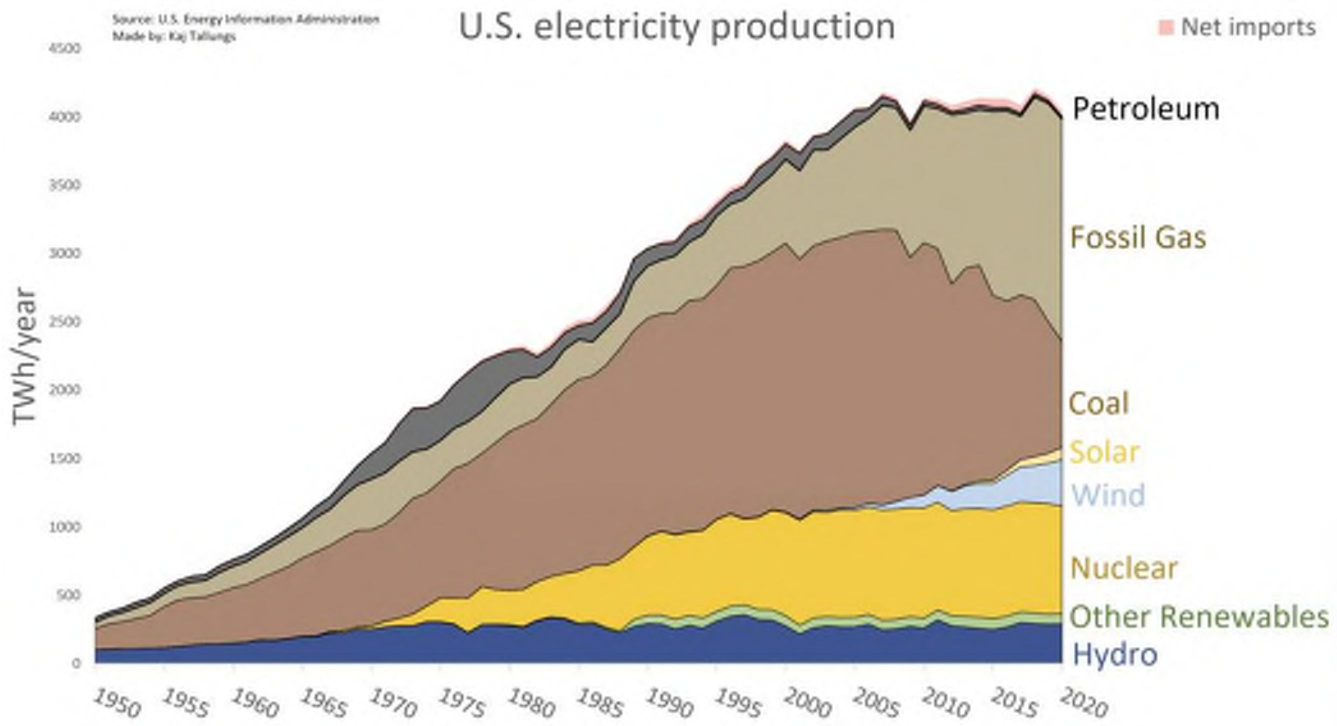
SMART CENTER
CLEMSON

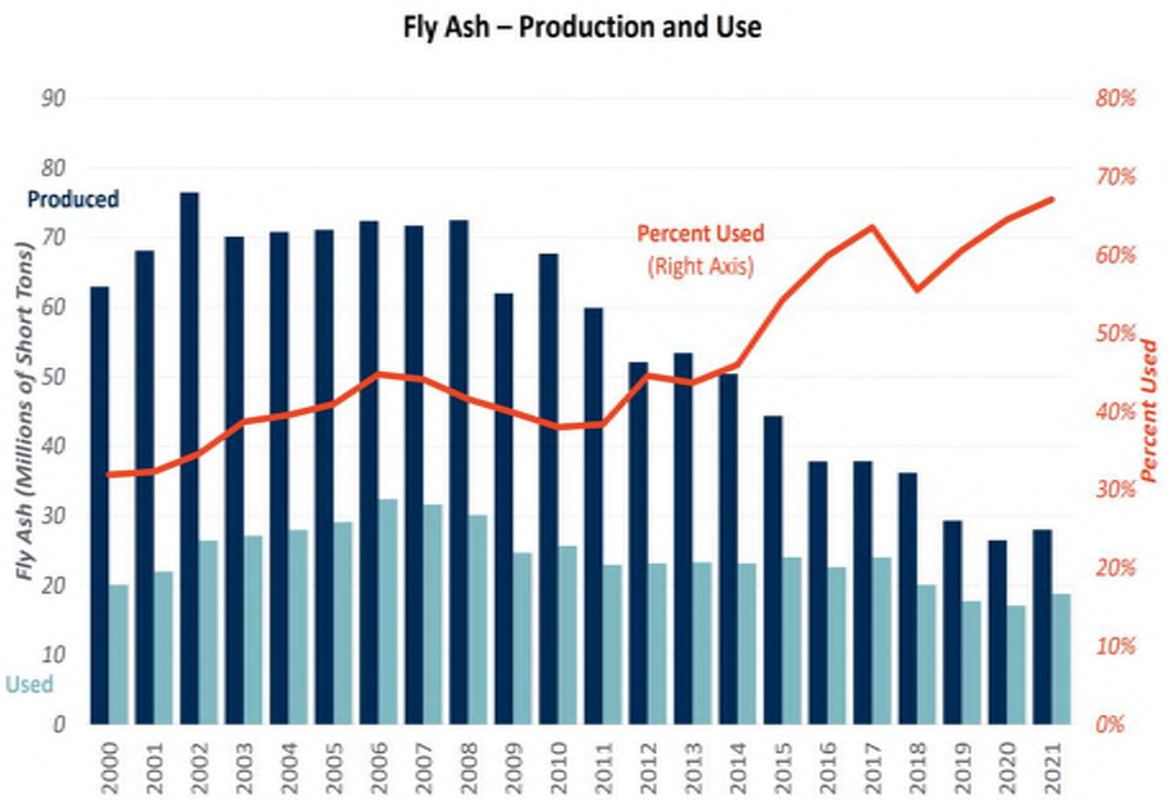
- Benefits of using fly ash as pozzolan in Portland cement concrete:



- Environmental sustainability:
  - Reducing the consumption of cement, and thus the carbon footprint of concrete.
  - Reducing the amount of fly ash that is landfilled as an industrial waste.
  - Conserving natural materials and resources.
  - **Improved durability of concrete**.
- **Same is TRUE for slag and silica fume**

Fly Ash - Production and Use





In 2021, use of coal fly ash in concrete was 11.9 million tons

Source: ACAA

Next Generation of SCMs

- Harvested Fly Ash
- Ground Bottom Ash

Coal Combustion Products

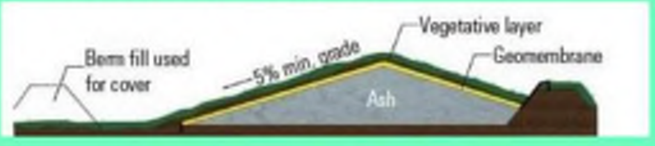
- Calcined Clays and Shales (ex: Metakaolin)
- Ground Glass Pozzolans – Type GS and GE
- Natural Pozzolans – Volcanic Pumice/Tuffs/Tephra/Glass
- Biomass Ash – Rice Husk Ash, Sugarcane Bagasse Ash, Others
- Diatomaceous Earth
- Zeolites
- Others

Basics of Coal Ash Harvesting

Site Conditions

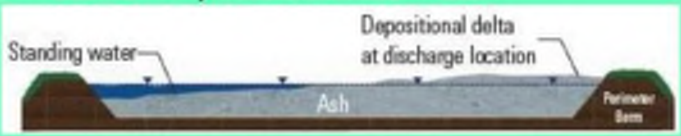
Landfill/Stack

- Typically, 12-20% moisture
- Compacted in lifts
- Ash only or Blend



Pond

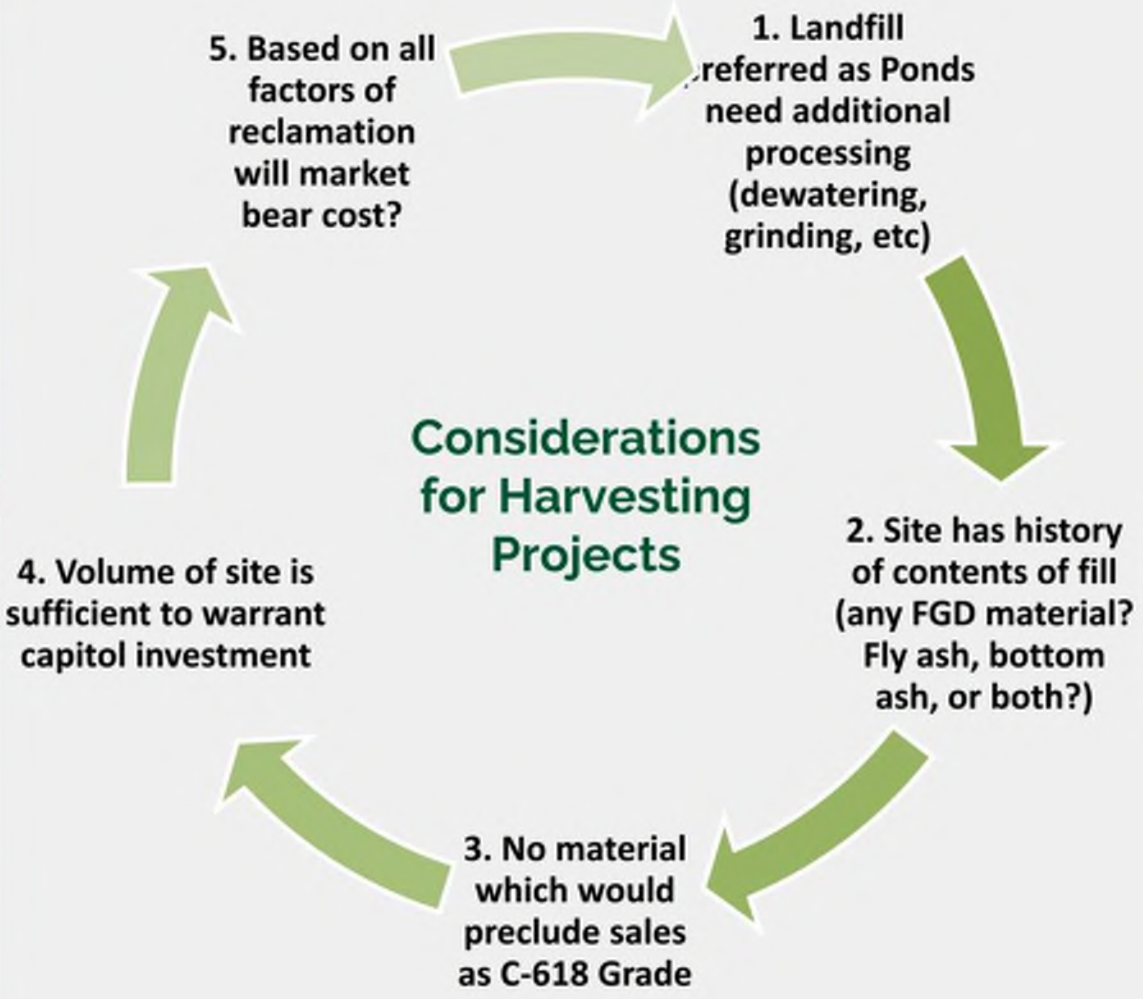
- Wide range of moisture
- Striations/strata of material
- Both Fly & Bottom Ash



Material Challenges

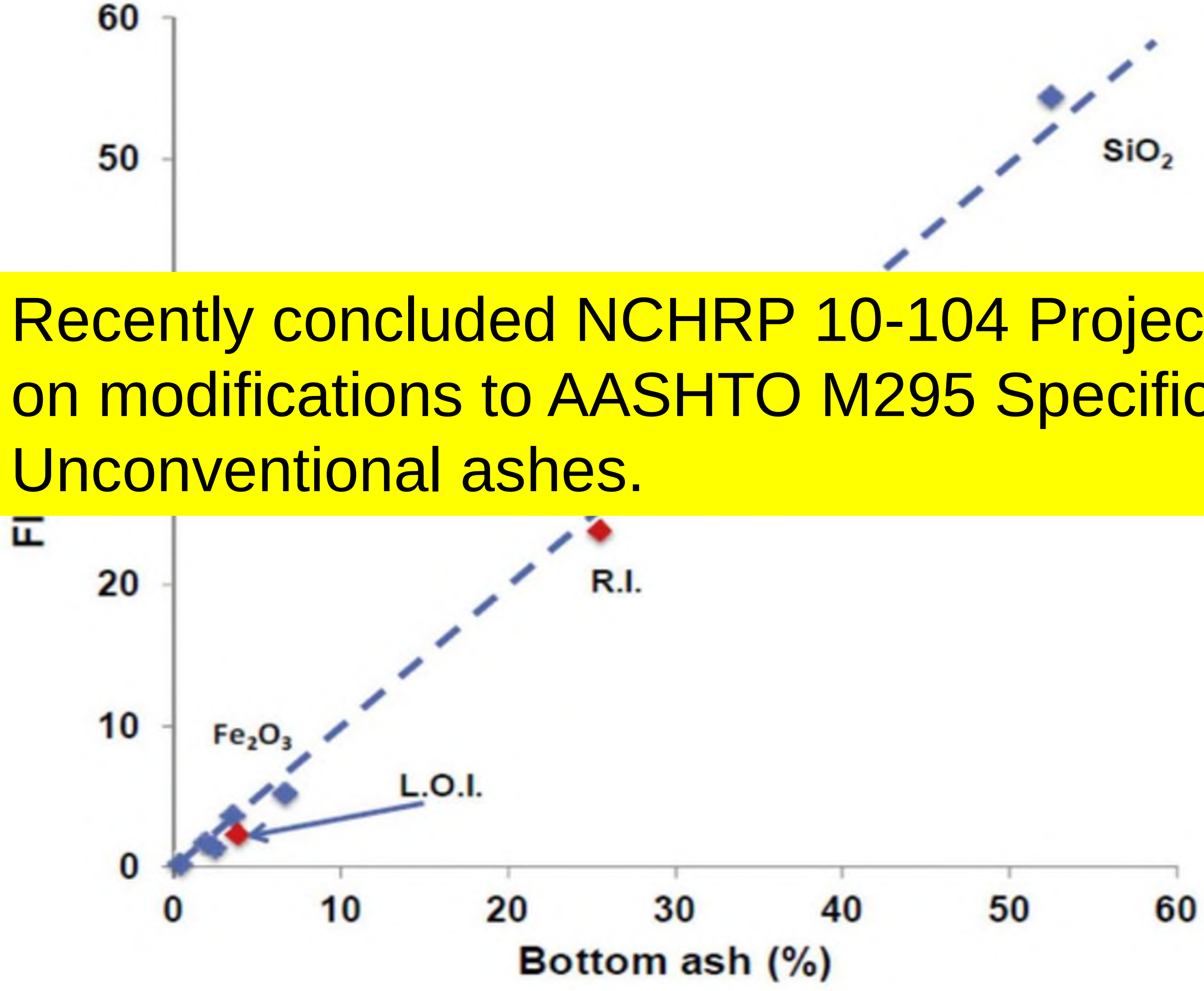
Basic Beneficiation

- Drying
- Screening
- Grinding
- Carbon removal



Source: Eco Material Technologies

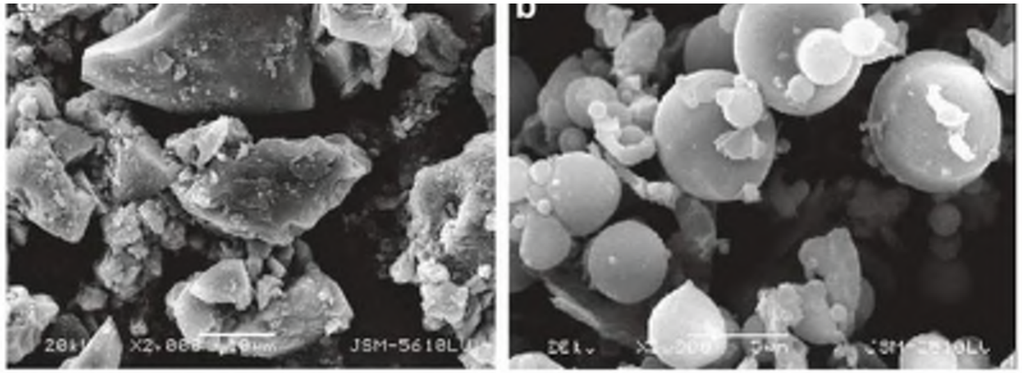
Harvested Ashes



the Washingtonville, Pennsylvania, power plant and
r reference

Fineness	SAI 7 days	SAI 28 days	Water Req.
28.65%	79%	80%	101%

Recently concluded NCHRP 10-104 Project will provide recommendations on modifications to AASHTO M295 Specification on including Marginal and Unconventional ashes.



Width of view approx. 60 µm Width of view approx. 26 µm

Figure 7. SEM images of (a) coal bottom ash and (b) coal fly ash (from Argiz et al. 2017)

Commercial Sources of Harvested Fly Ash

© Boral Resources 2019, used with permission

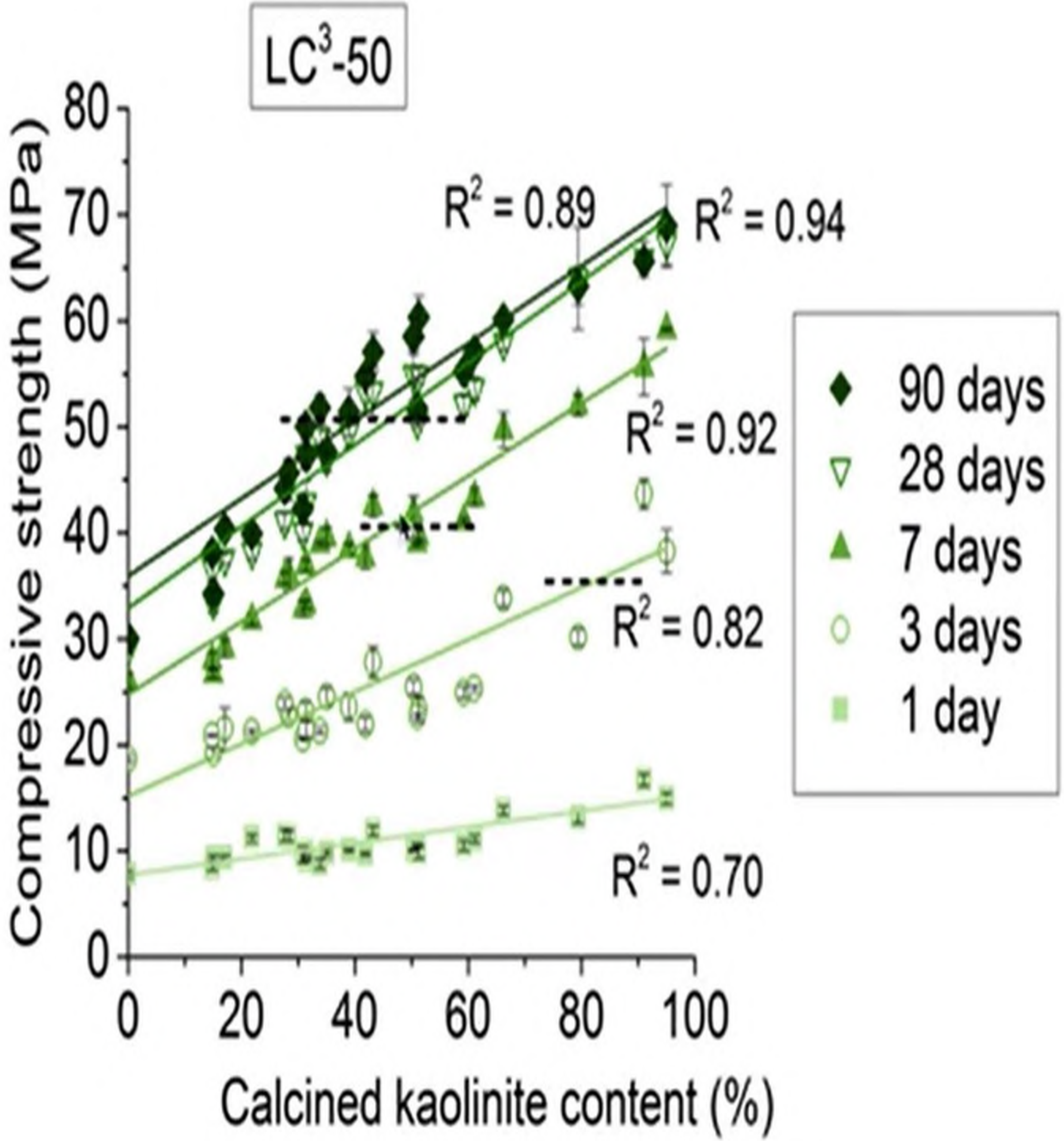
Figure 5. Fly ash harvesting site in Washingtonville, Pennsylvania, with a landfill containing approximately 2 million tons of fly ash (back) and a processing plant (front)

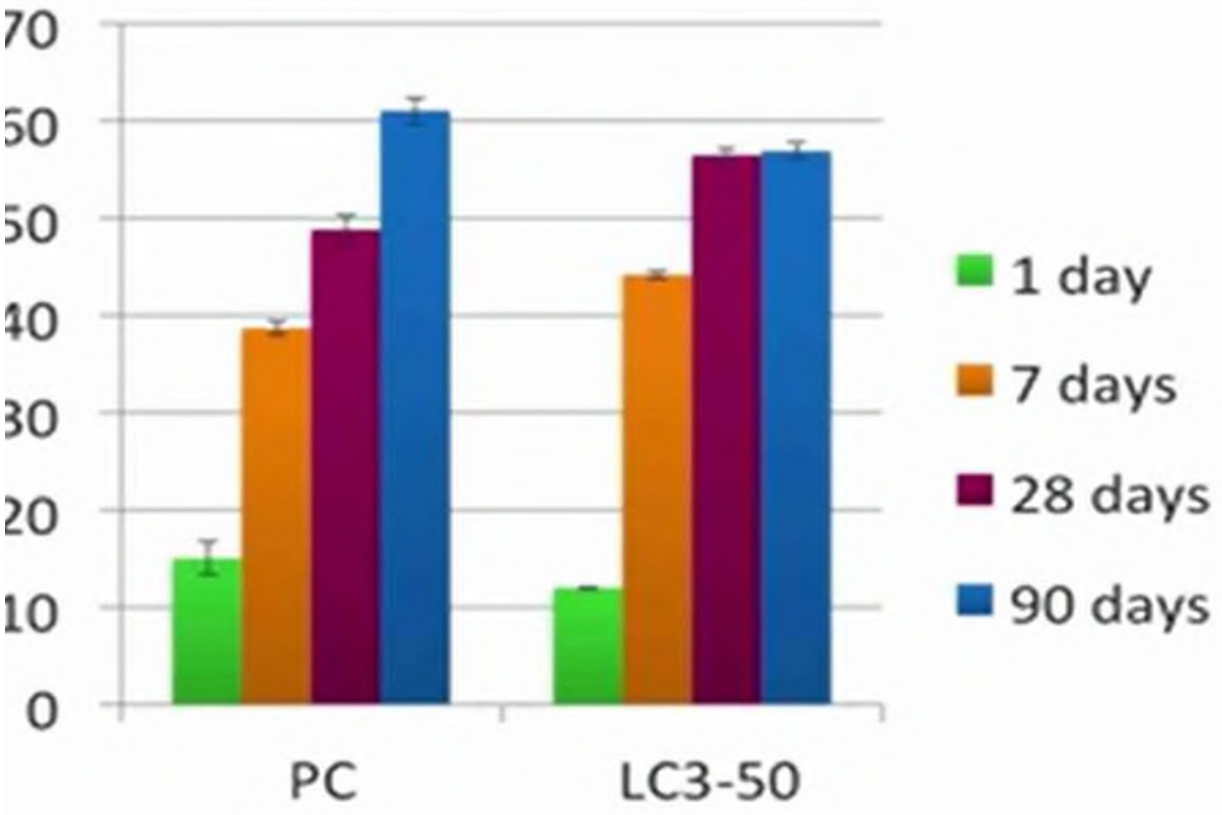
© 2017 The SEFA Group, used with permission

Figure 6. STAR facility at the Winyah Generating Station

Source: Trisch et al., ACPT Solutions Tech Brief, May 2021

les





- 50% less clinker
- 30% less CO_2
- Similar strength
- Better chloride resistance
- ASR resistant

Scrivener, et al., 2018

Marketplace for Calcined Clay Products

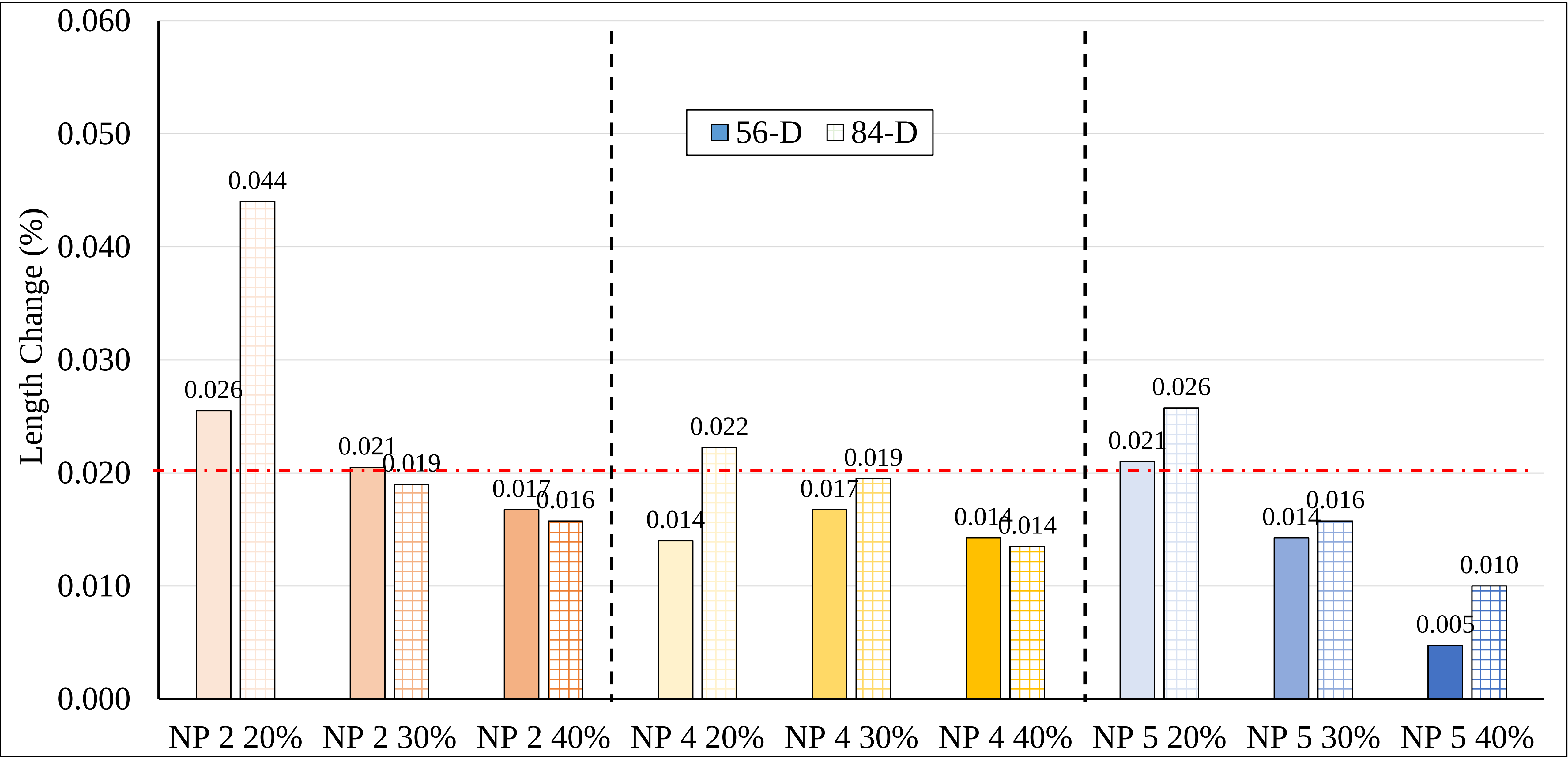
- Burgess – OPTIPOZZ Metakaolin
- BASF MetaMax Metakaolin
- Imerys MetaSTAR Metakaolin
- CARBO Ceramic Metakao
- Sikacrete M-100 Metakaolin
- Advanced Cement Technologies PowerPozz Metakaolin
- GCP HRMK 100 Metakaolin

Natural Pozzolans

- Natural siliceous and alumino-siliceous materials, typically of volcanic origin, that exhibit pozzolanic reactivity.
- Volcanic Glass, Pumice, Tuff, Tephra, etc. (ASTM C618/AASHTO M295, Class N Pozzolans)
- ASTM C595 / AASHTO M240 – Blended Hydraulic Cements (Type IP, IT)
- Natural Pozzolan Association (NPA) ~ 20 Producers (Mostly located in Western States)

Source: Kirkland Mining Company

Effectiveness of Natural Pozzolans in Mitigating ASR (AASHTO T380 Test Results)



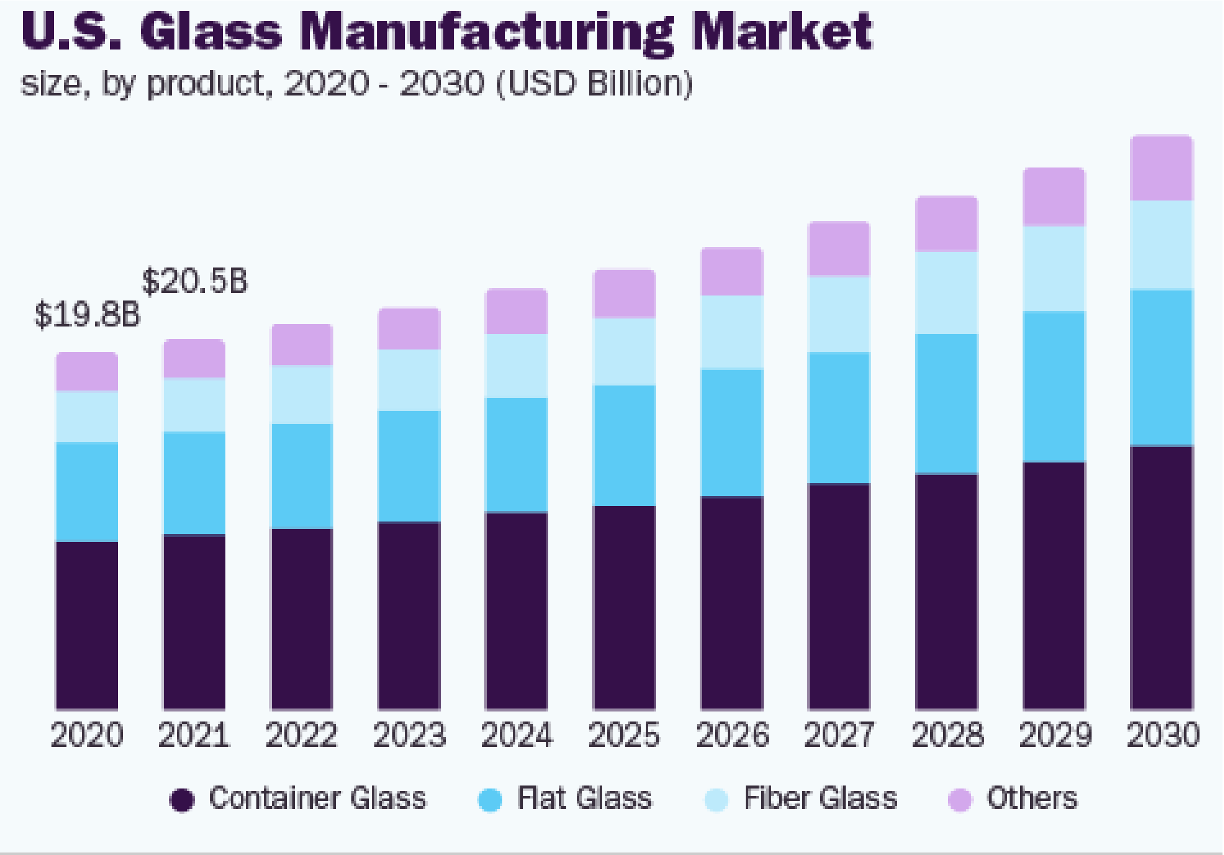
Why Ground-Glass as an SCM in Concrete?

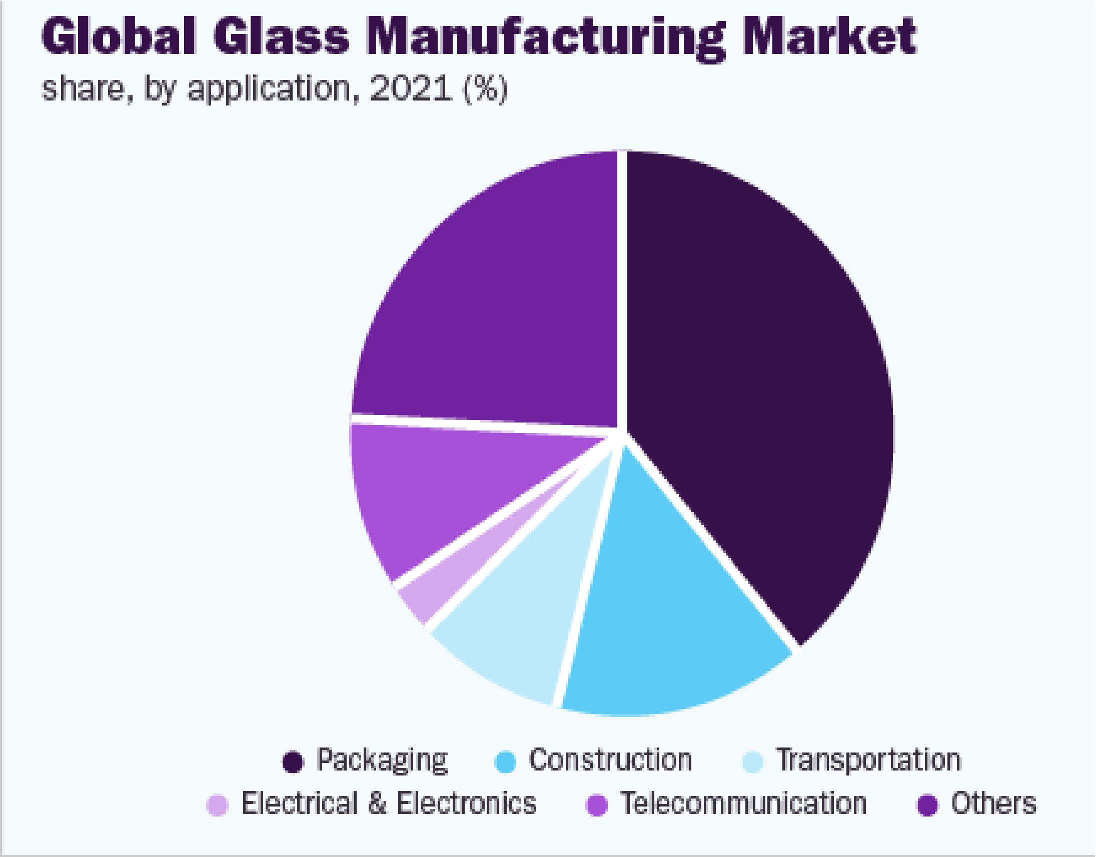
Why now?

Type GS

Type GE

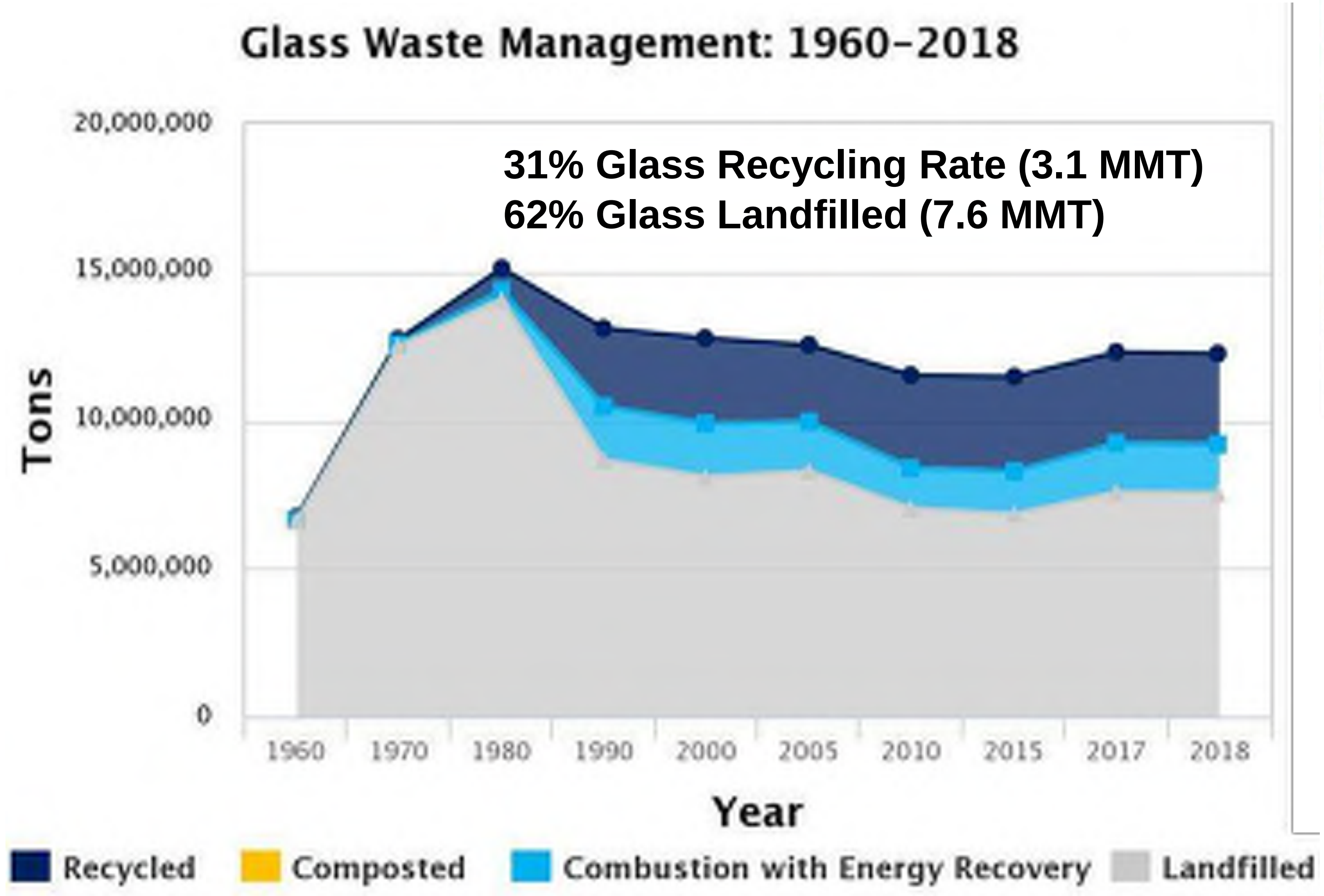
Glass Manufacturing Statistics





Grandviewresearch

Waste Generation and Management Pathways of Glass in the US



https://www.epa.gov/

ASTM C1866 – Standard Specification for Ground-Glass Pozzolan for Use in Concrete

SMART CENTER
Sustainable Materials Research and Technology Center
CLEMSON
GLENN DEPARTMENT OF CIVIL ENGINEERING

This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

ASTM INTERNATIONAL

Designation: C1866/C1866M – 20

Standard Specification for Ground-Glass Pozzolan for Use in Concrete[1]

This standard is issued under the fixed designation C1866/C1866M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers ground-glass pozzolans for use in concrete where pozzolanic action is desired. This specification applies to ground glass from sources that consist of container glass, plate glass, or E-glass.

1.2 The standard references notes and footnotes that provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard. If required results obtained from another standard are not reported in the same system of units as used by this standard, it is permitted to convert those results using the conversion factors found in the SI Quick Reference Guide.[2]

1.4 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.

1.5 This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recom-

C109/C109M Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)

C125 Terminology Relating to Concrete and Concrete Aggregates

C150/C150M Specification for Portland Cement

C204 Test Methods for Fineness of Hydraulic Cement by Air-Permeability Apparatus

C311/C311M Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete

C618 Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete

C1069 Test Method for Specific Surface Area of Alumina or Quartz by Nitrogen Adsorption

C1293 Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction

C1567 Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method)

C1778 Guide for Reducing the Risk of Deleterious Alkali-Aggregate Reaction in Concrete

2.2 *ACI Standards:*[4]

318-2019 Building Code Requirements for Structural Concrete and Commentary

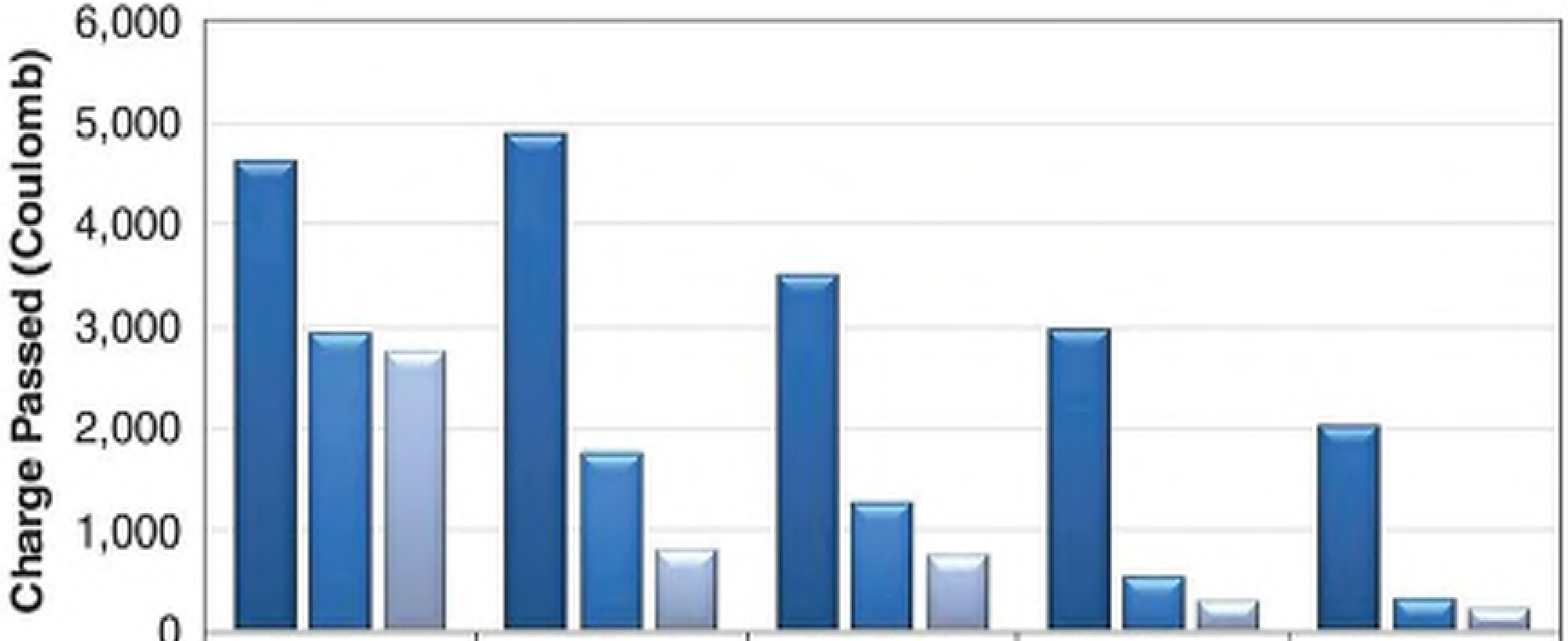
2.3 *CSA Standards:*[5]

A3003 Chemical Test Methods for Cementitious Materials for Use in Concrete and Masonry (Contained in CSA

Type GS

Type GE

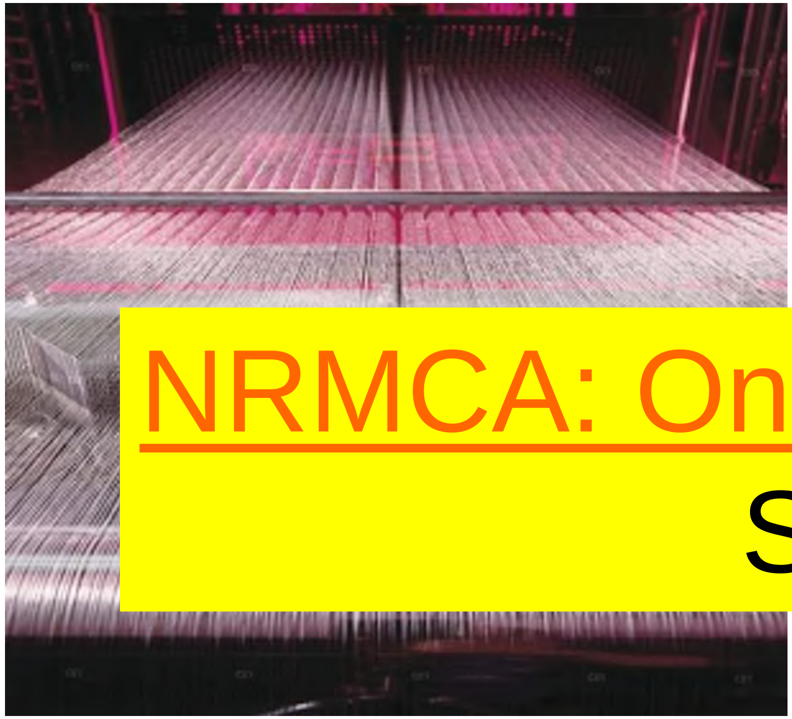
Influence of Type GE on Rapid Chloride Ion Permeability (ASTM C1202)



	CTRL-1	CTRL-2	GGF-10	GGF-20	GGF-30
7 days	4640	4896	3512	2979	2024
28 days	2948	1758	1274	539	316
56 days	2768	796	759	309	223

Rashidian-Dezfouli and Rangaraju, P.R., 2018

Ground-Glass Pozzolans



NRMCA: On-demand | Concrete Innovations

Session: 9, Nov. 2022

Prasad Rangaraju, PhD, PE, FACI

Sustainable Materials Research and Technology (SMaRT) Laboratory

Glenn Department of Civil Engineering

***Clemson University**, Clemson, SC*

NRMCA – Webinar on Concrete Innovations

November 30th, 2022

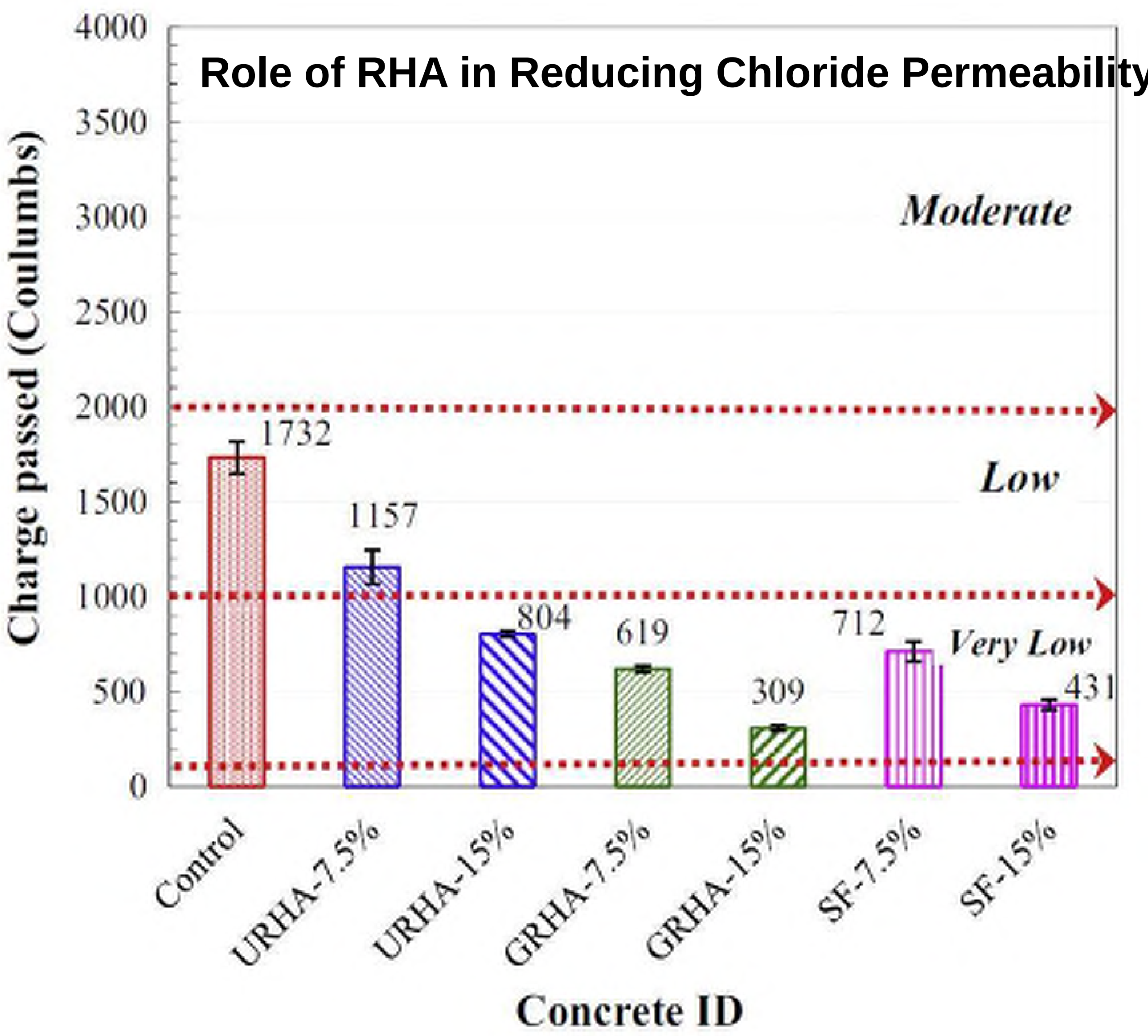
Courtesy: Some images/data from online resources are shown for demonstration purpose only.

Biomass Ashes as Pozzolans

- Agricultural residues are available in large quantities:
  - Residues from processing agricultural products such as rice husk, peanut shell waste, pecan shell waste, sugar cane, cotton seeds, etc.
  - Residues from biomass combustion in power plants, for ex: switch grass
  - Residues from bioethanol production

- **Ash generated from select biomasses can be rich in siliceous content and highly pozzolanic in nature.**

- Typically, such materials are low carbon materials, and can serve as a valuable, regional source of pozzolan.



NRMCA: On-demand | Concrete Innovations

Session: 15, Sep. 13, 2023

Date & Time	Selected Sessions:
	Sep 13, 2023 11:00 AM
Description	Rice Husk Ash Pozzolan - Dr. Prasad Rangaraju, Professor of Civil Engineering, Clemson University

Current State and Future Needs

- A large number of alternate SCMs are available, although many of them are specific to certain geographic regions.
- Several of these materials are recognized and standardized in existing ASTM / AASHTO Standards, although not all are produced at a commercial scale yet, due to lack of demand.
- **However, this is changing… Sustainable Material Choices are Growing**
- ACI, ASTM, AASHTO, FHWA, NCHRP and other agencies have recognized the need for promoting sustainability.

- **State agencies should encourage and promote the use of new SCMs, where feasible, for more sustainable construction.**

Questions?

prasad@clemson.edu

Reducing CO_2 Emissions from Concrete: Emergent Approaches

Prannoy Suraneni, Miami Engineering Career Development Assistant Professor

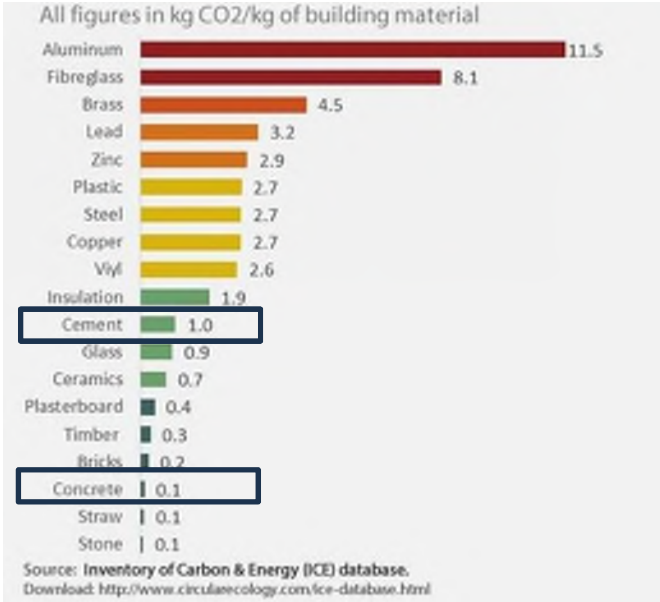
University of Miami

suranenip@miami.edu

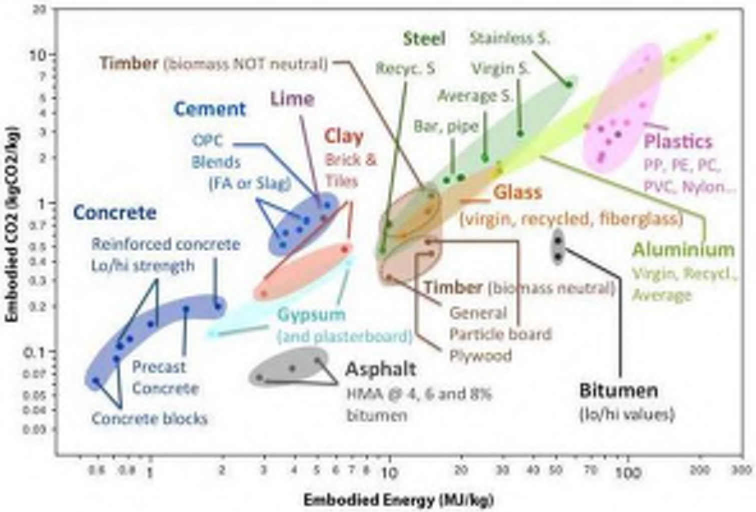
1st Southeastern Peer Exchange for Resilient and Sustainable Concrete Bridges

CO_2 in concrete

- Concrete contributes 6-8% global CO_2 emissions
  - Remember, we make 20 billions tons/year of concrete
- Not possible to replace concrete with any other material
- Cement, which is 10% of concrete by mass, is responsible for 90% of concrete emissions
- We must reduce cement CO_2 emissions



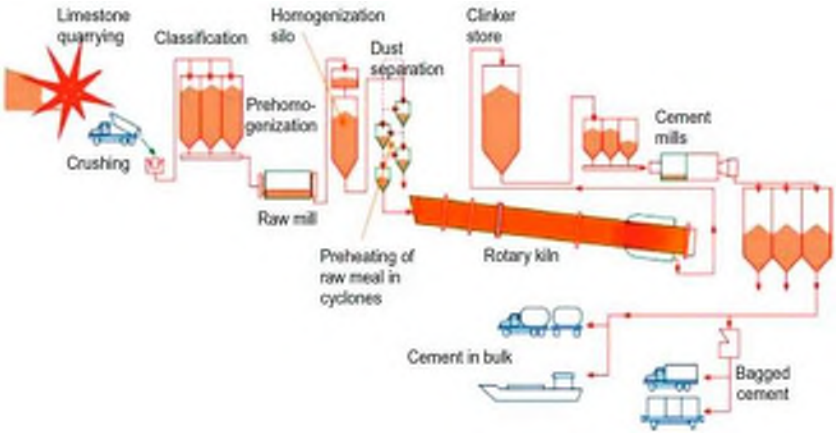
ICE database; Barcelo et al. MS 2014



- Roadmaps to reduce emissions by 40% by 2030 and go carbon neutral by 2050

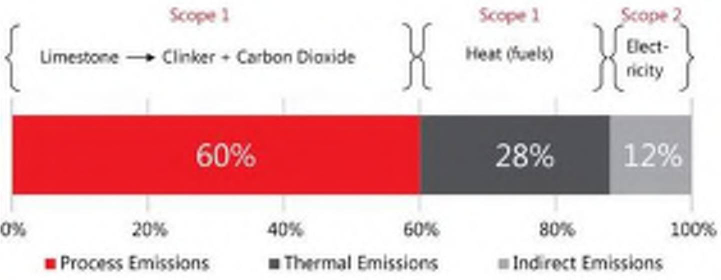
Cement CO_2 emissions

- Limestone, clay, and other materials heated to 1450 °C to produce OPC
- Limestone decomposition reaction causes about 60% emissions $CaCO_3 \rightarrow CaO + CO_2$
- Remaining 40% emissions due to heat and electricity
- Reduce limestone in cement production
  - Portland limestone cement/Type IL cement with 5-15% limestone



Cement Industry Federation; Rahman et al. Energies 2017

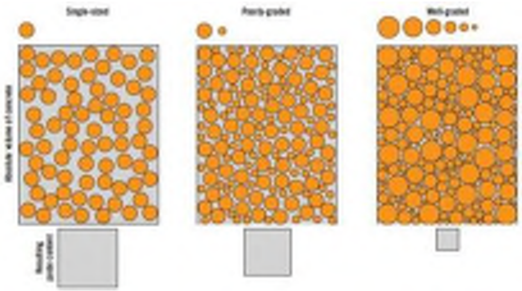
- Most conventional way to reduce concrete emissions is to reduce cement content in concrete
- Many novel methods that have not seen much testing at the concrete scale



ACCESS LAB

Reducing CO_2 in concrete: Standard methods

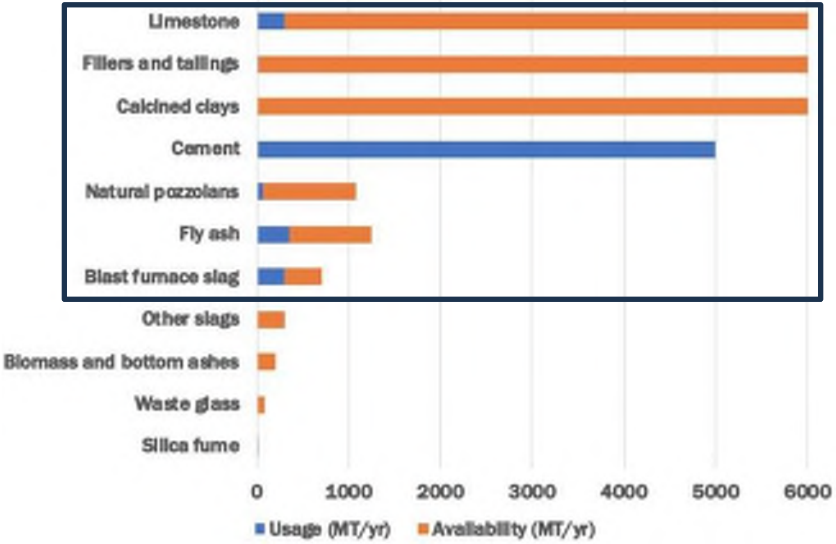
- Use PLC
  - CO_2 reduction by 10% compared to OPC, no/minimal change in performance
- Use high volumes of SCMs
  - Can replace 60% of the cement with SCM; improves durability, but early-age strength reduced
- Strategic use of chemical admixtures
  - Can reduce cement content by 10%; improves durability
- Optimize aggregate gradations
  - Can reduce cement content by 10%; improves durability
- Avoid overdesign, follow guidelines, regular maintenance
- Combining all the above can significantly reduce concrete CO_2 using existing materials & tech
- Effects on concrete durability well understood



CivilWeb

Supplementary cementitious materials

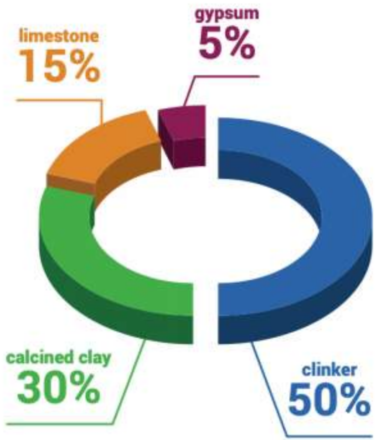
- SCMs critical to reduce CO_2 emissions
- Fly ash, slag, and silica fume most commonly used
  - Amounts much lower than cement
  - Increasing shortfalls being reported locally
- Effects on concrete durability well understood
- Novel SCMs must be identified, characterized, and used for continued CO_2 reductions
  - Calcined clays, natural pozzolans, reclaimed fly ashes
  - Manufactured SCMs: Thermal activation, mechanochemical activation, CO_2 mineralization

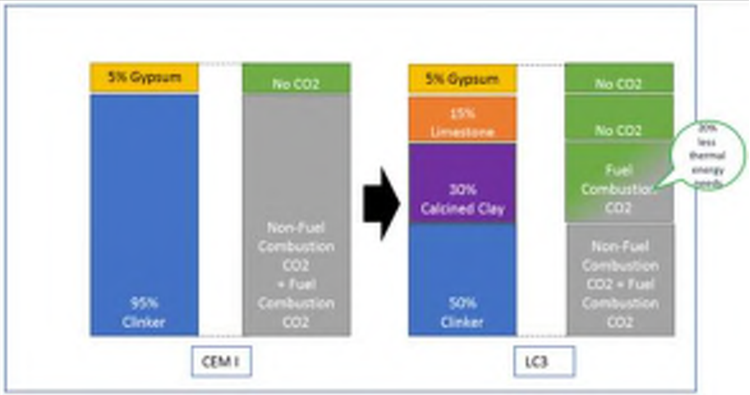


PCA Design and Control of Concrete Mixtures; Snellings RILEM TL 2016; Juenger et al. CCR 2019; Scrivener et al. CCR 2018; Snellings et al. CCR 2023

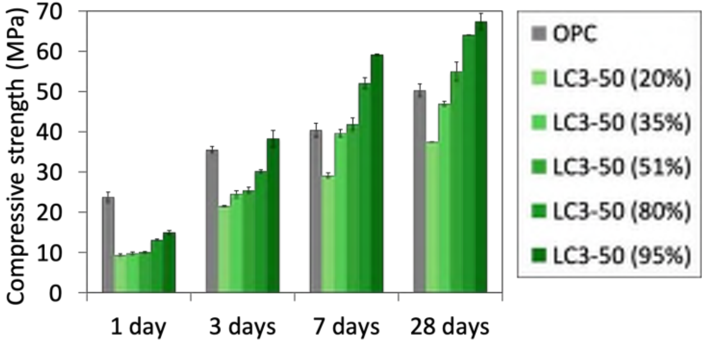
Limestone calcined clay cement (LC^3)

- Replace 50% of cement with a mixture of limestone and calcined clays (massive volumes available)
- Low- and mid-range clays ideal for this purpose; reactivity 200 – 500 J/g SCM
- Similar performance to OPC, except for 1-day strength
- Most of the applications so far in India and Latin America
- ASTM C595, ASTM C1157, ASTM C618 (?), ASTM C1697 (?)
- Well-understood and accepted technology, durable concrete



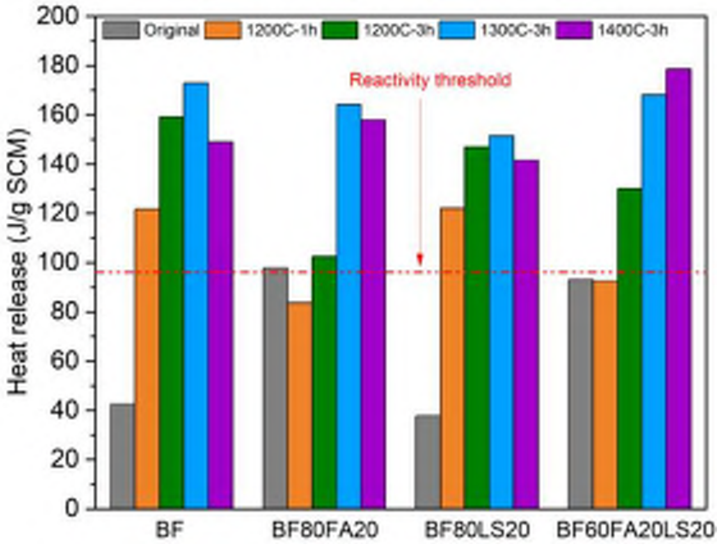


https://lc3.ch/



Thermal activation of fillers

- Fillers can be activated by heating, cooling, and milling
- Clays – 700 °C, fillers – 1200 °C, CAS glasses – 1600 °C
- Important due to filler volumes
- Bulk melting and subsequent amorphization (confirmed by XRD, FTIR)
- Performance similar to fly ash/natural pozzolans
- ASTM C595, ASTM C1157, ASTM C618 (?)
- Optimization/Scaling
  - Blended SCMs for controlled reactivity
  - Fluxers to reduce melting temperature; partial melting
  - Additions/process modifications for workability, strength
- Well-understood, some questions, concrete studies needed



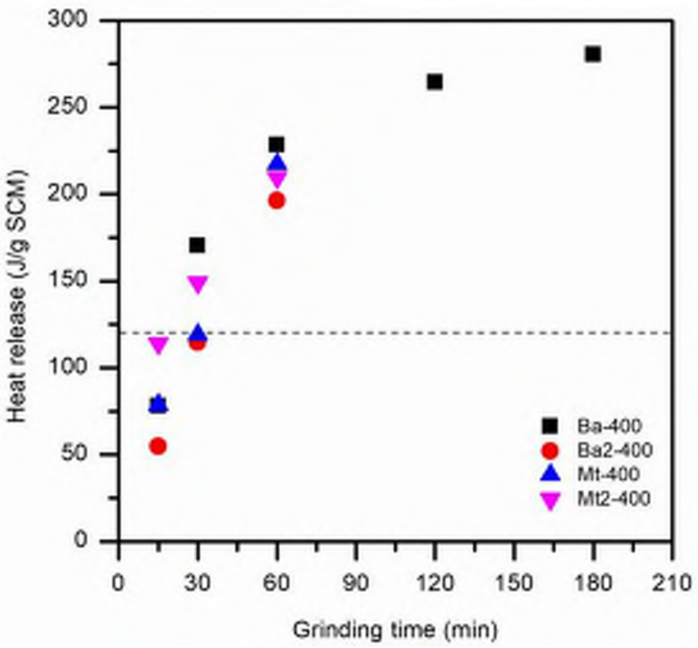
Wang et al. Cement 2023 UR
https://terraco2.com/
https://www.envicoreinc.com/

TERRA CO2

ENVICORE

Mechanochemical activation of fillers

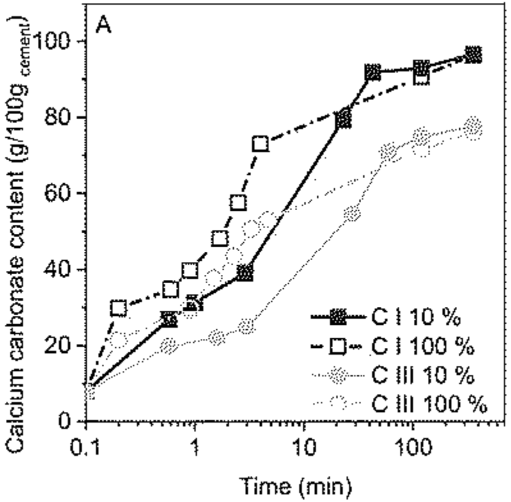
- Fillers can be activated by high-energy grinding (planetary ball mill)
- Activation demonstrated for 10 basalts, clays, tailings
- Performance similar to fly ash/natural pozzolans
- Increased fineness, localized and heterogenous amorphization (XRD and FTIR)
- ASTM C595, ASTM C1157, ASTM C618 (?)
- Optimization/Scaling
  - Blended SCMs
  - Grinding aids
- More research and concrete studies needed; scalability unclear



Amroun et al. CCC 2023 IP

CO_2 mineralization in fillers/SCMs

- High Ca/Mg SCMs such as recycled concrete materials, steel slags, Class C fly ashes can uptake significant CO_2
- Wet, moist, dry carbonation; dry typically combined with milling
- Precursor and processing heavily influence CO_2 uptake and properties
- CO_2 uptake from 5 – 25%
- Reactivity due to aluminosilicate gel, $CaCO_3$, SCM phases, grinding activation
- ASTM C595, ASTM C1157, ASTM C618 (?)
- More research and concrete studies needed; scalability unclear

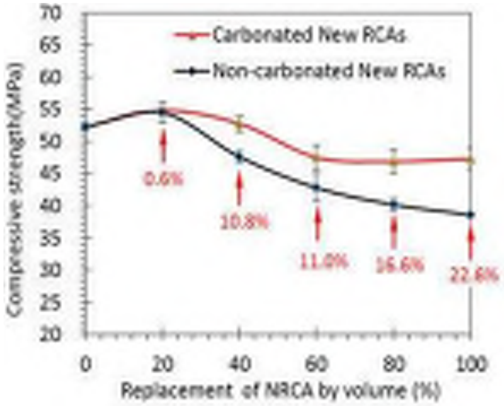


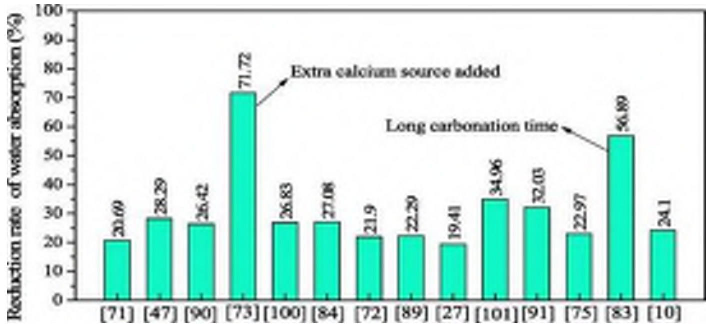
Zajac et al. CCR 2020
Snellings RILEM ROC&TOK https://www.youtube.com/watch?v=yuRSKR1NiyQ&t=1s
https://carbonupcycling.com/

carbon upcycling

Mineral carbonation of recycled aggregates

- Recycled aggregates, could also be lightweight aggregates
- Moist carbonation; few hours-few days duration
- CO_2 uptake from 1 – 5%; some claim much higher numbers
- Well understood technology, RCA and concrete properties significantly improved upon carbonation
- ASTM C33 (?)
- Scalability questions





Snellings RILEM ROC&TOK https://www.youtube.com/watch?v=yuRSKR1NiyQ&t=1s
https://www.blueplanetsystems.com/
Zhang et al. JMCE 2015; Xuan et al. CCC 2016; Pu et al. CBM 2021

CO_2 cured concrete products

- CO_2 injected into fresh (conventional) concrete
  - CO_2 uptake < 1%
  - Cement content reduction 5% with no loss of properties
- CO_2 injected into hardening concrete
  - Moist carbonation of bricks, blocks, pavers, other products
  - Carbonatable clinkers, recycled concrete materials, steel slags
  - CO_2 uptake 5 – 15%; duration ~ 1 day
  - Performance similar to conventional products but depends on precursor and processing
  - Water recovery may be possible
  - Very different concrete, combination with FRP interesting
- Typically these products do not need new specs
- Well-understood, some questions and optimization

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https://www.carboncure.com/
https://carbicrete.com/
https://carbonbuilt.com/
https://www.solidiatech.com/

New cements

- Electrochemical, chemical, heating, various other processes to make cement and byproducts
- Heating step of limestone avoided
- Raw materials typically calcium silicates, magnesium silicates
- Carbon-negative often claimed; CO_2 sequestration also possible
- Details not clearly available but patents are
- Much research needed; scalability unclear, given very different production processes, completely new technology, plus associated CapEx & OpEx, concrete testing absent
- ASTM C1157

https://www.brimstone.com/
https://www.chement.co/
https://sublime-systems.com/

Challenges and Conclusions

- LC³ cement; manufactured SCMs (thermal, mechanochemical, CO_2 mineralized); carbonated RCA and CO_2 cured products; new cements alternative methods to reduce concrete CO_2
- However
  - More research needed, especially for durability and long-term; scalability unclear
  - Newer specs and spec changes needed; start-ups must be active in ASTM
  - Third-party testing and validation critical
  - Analysis of synergies missing, including with FRP
  - Quantification of carbon remains a challenge
  - Resilience with these materials is an open question



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NCHRP
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PCA
Portland Cement Association

NSF

NIST

CARBON LIMIT

FPCA
A CHAPTER OF PRECAST/PRESTRESSED CONCRETE INSTITUTE

Thank U

suranenip@miami.edu

www.youtube.com/channel/UCtAOe9VXSBLrji9ta3Hti0w

WHAT IS MISSING? FRP-RC/PC RESEARCH NEEDS

Francisco De Caso
Principal Scientist, University of Miami
fdecaso@miami.edu

SPxRSB-2023

1st Southeastern Peer Exchange for Resilient & Sustainable Bridges

Mobile, Alabama
Tuesday, August 8th 2023

Accelerating Impact through Partnerships

- National Science Foundation (NSF) Industry University Collaborative Research Center (IUCRC)
- Develop **long-term partnerships** with industry, academia, and government;
- **Promote** research, development and **implementation** programs of mutual interest;
- Enhance the **intellectual capacity of the engineering workforce** through the integration of development, implementation and **education**

Center for Integration of Composites into Infrastructure

NC STATE UNIVERSITY

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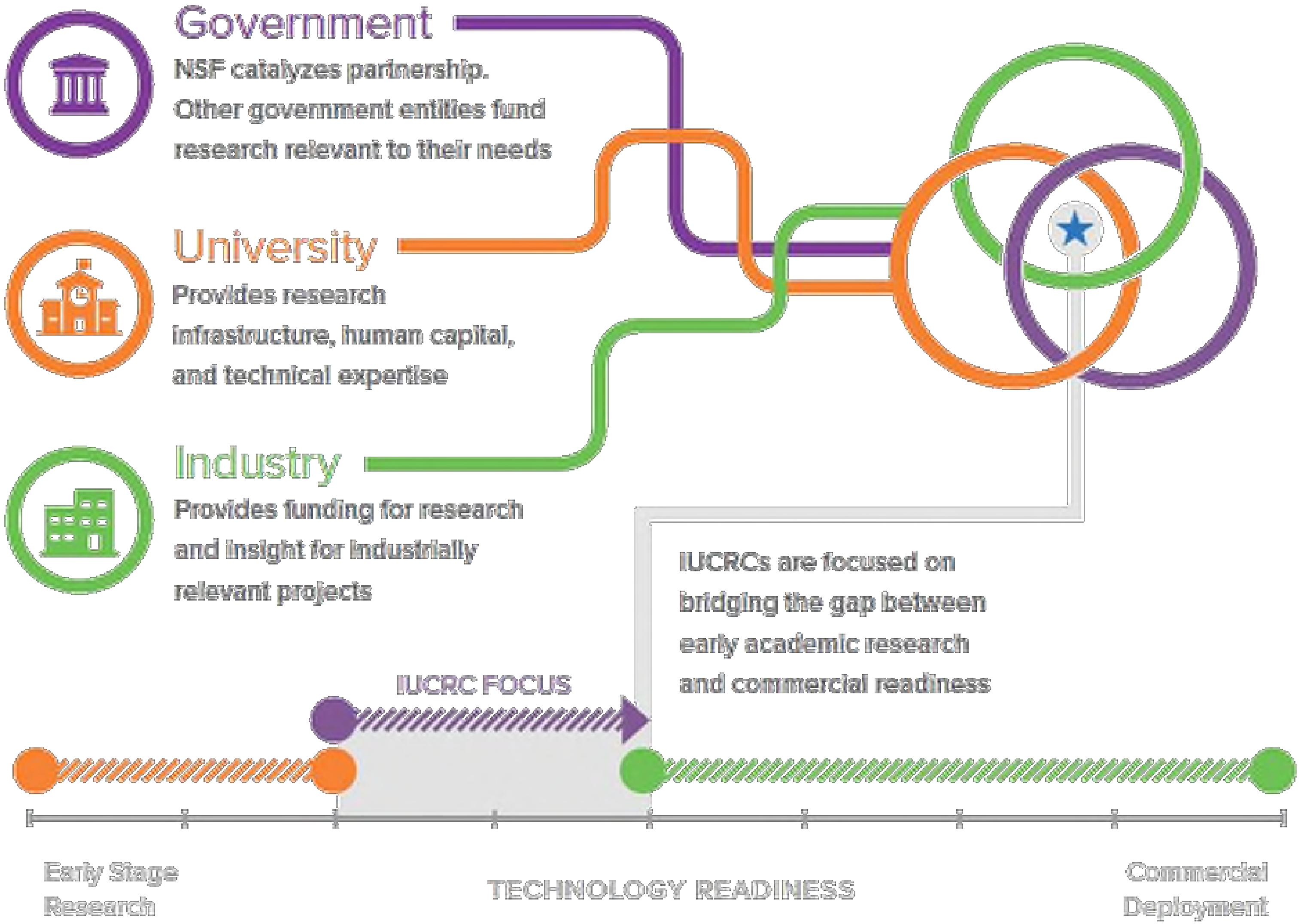
Center for Integration of Composites into Infrastructure (CICI)



Center for Integration of Composites into Infrastructure

- Established in 2008
- Accelerate the adoption of composites and innovative construction materials into infrastructure applications through collaborative research

TEXAS A&M UNIVERSITY

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WHAT IS MISSING? FRP-RC/PC RESEARCH NEEDS

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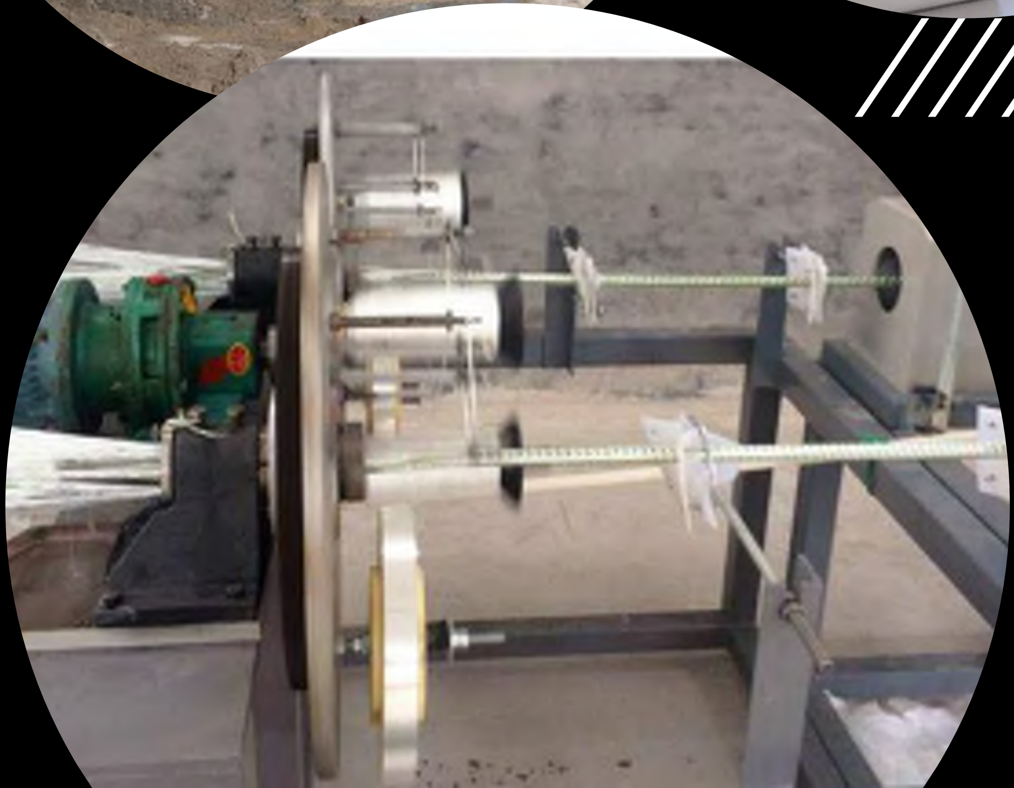
Education

Manufacturing

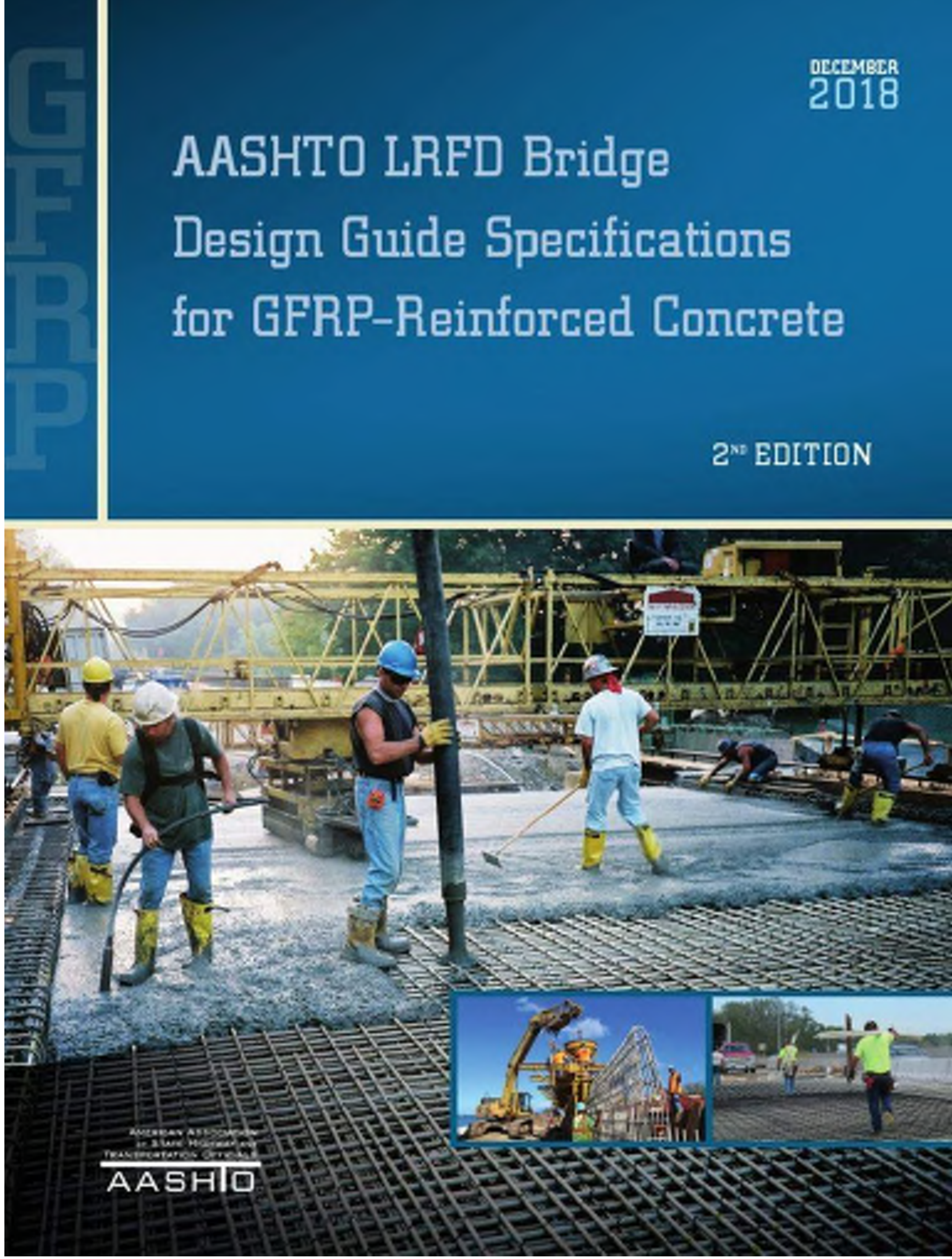
Construction



WHAT IS MISSING? FRP-RC/PC RESEARCH NEEDS

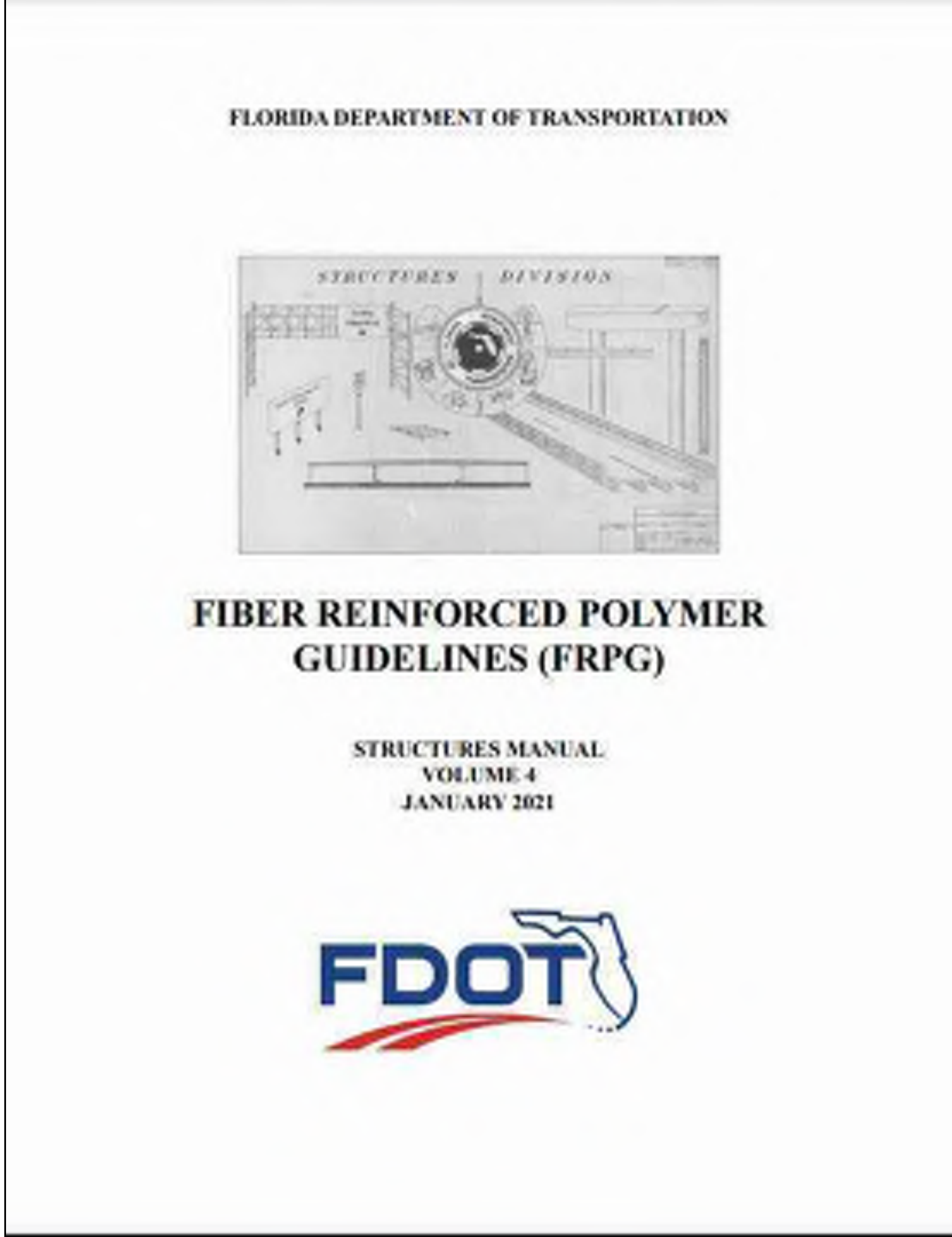
The Wins….

- Design guides!
- FDOT design tools
- Publications
- Building CODE
- Construction Specification
- 100s of constructions….



The Wins….

The **foundation** work has been done!


FLORIDA DEPARTMENT OF TRANSPORTATION

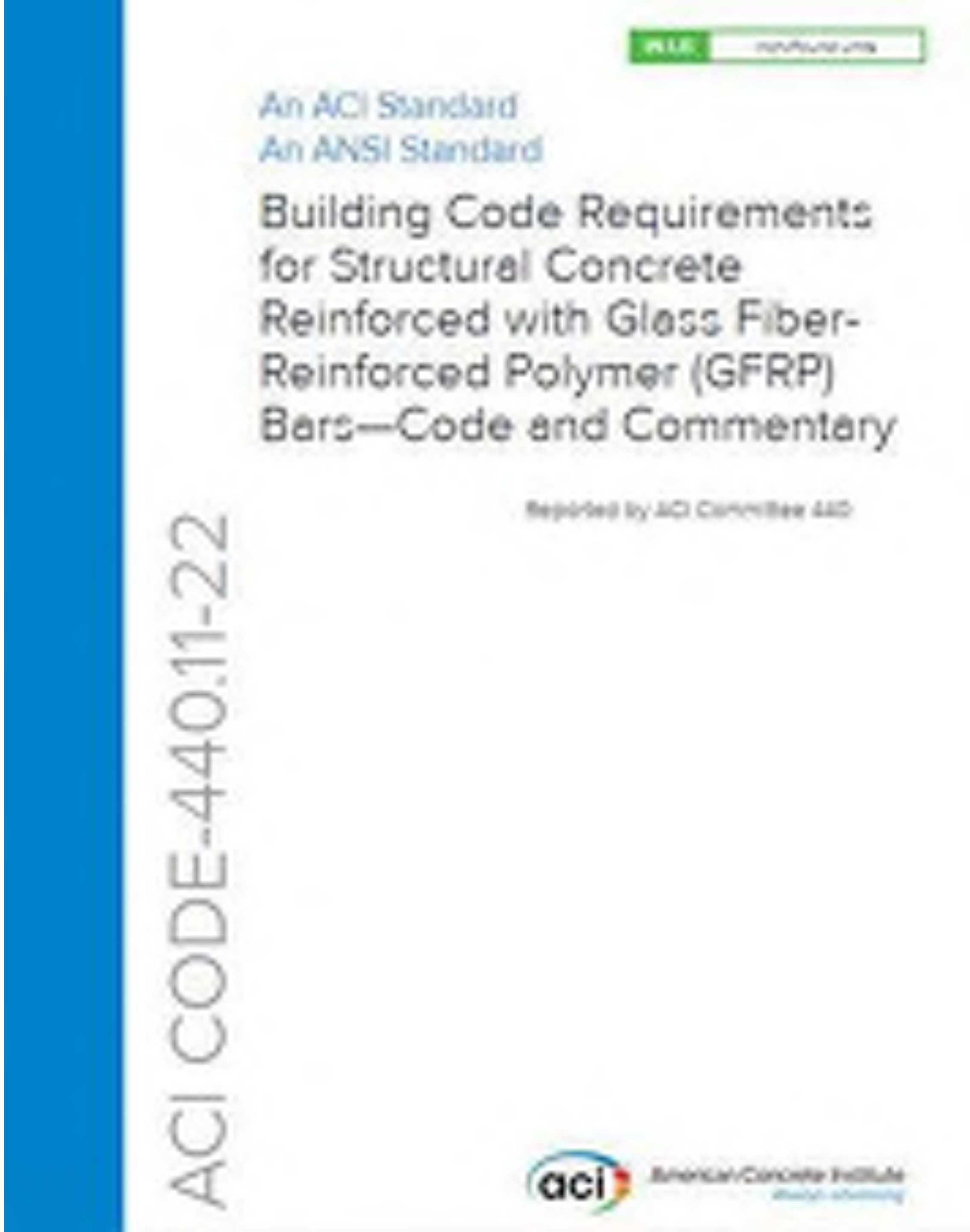
FIBER REINFORCED POLYMER GUIDELINES (FRPG)

STRUCTURES MANUAL
VOLUME 4
JANUARY 2021

FDOT

The Wins….

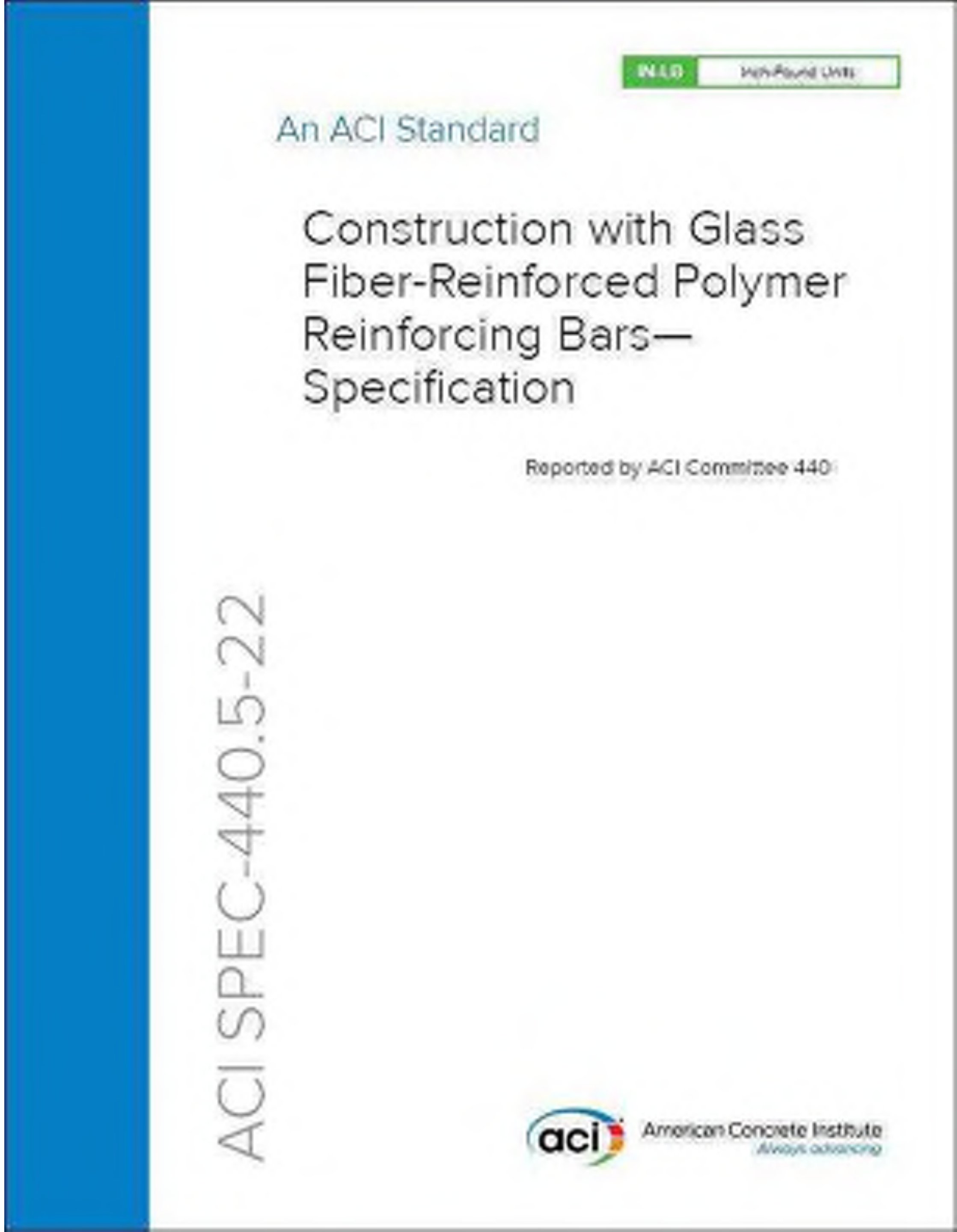
You are **not the first!**



Center for Integration of Composites into Infrastructure

The Wins….

You **won't be the last** either!


An ACI Standard

Construction with Glass Fiber-Reinforced Polymer Reinforcing Bars—Specification

Reported by ACI Committee 440

ACI SPEC-440.5-22

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TRANSPORTATION

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Structures Design

Structures Design / Design Innovation

Fiber Reinforced Polymer Reinforcing

Structures Design - Transportation Innovation

Fiber Reinforced Polymer (FRP)
Reinforcing Bars and Strands

Center for Integration of Composites into Infrastructure

WHAT IS MISSING? FRP-RC/PC RESEARCH NEEDS

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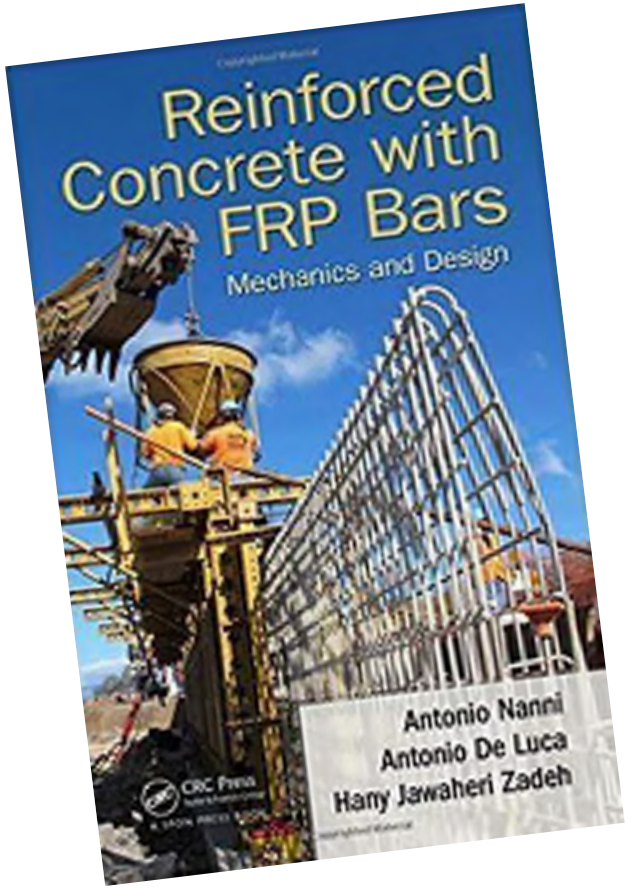
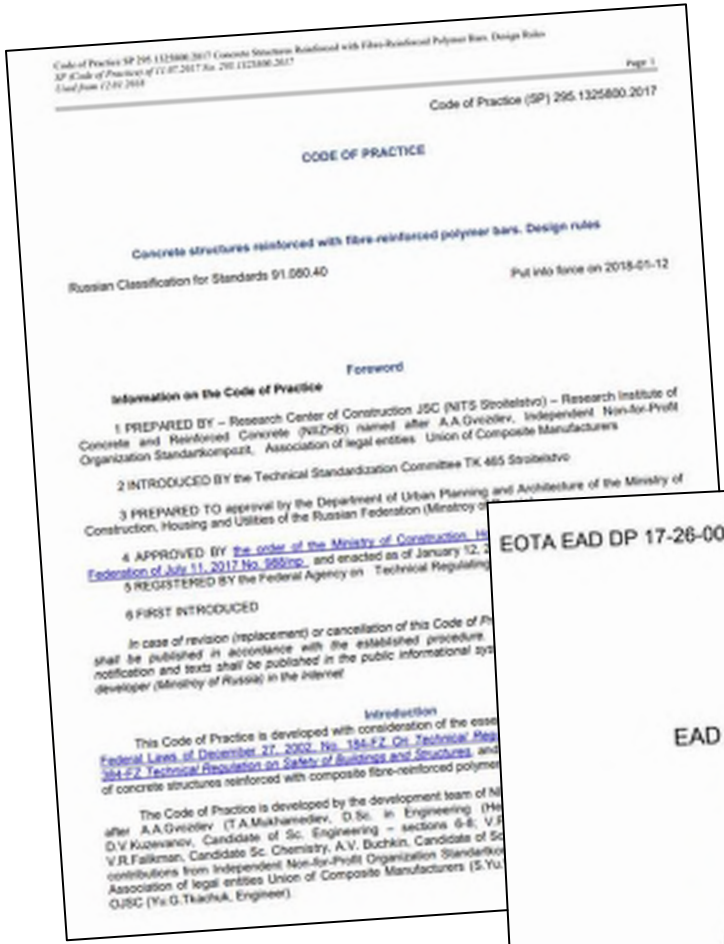
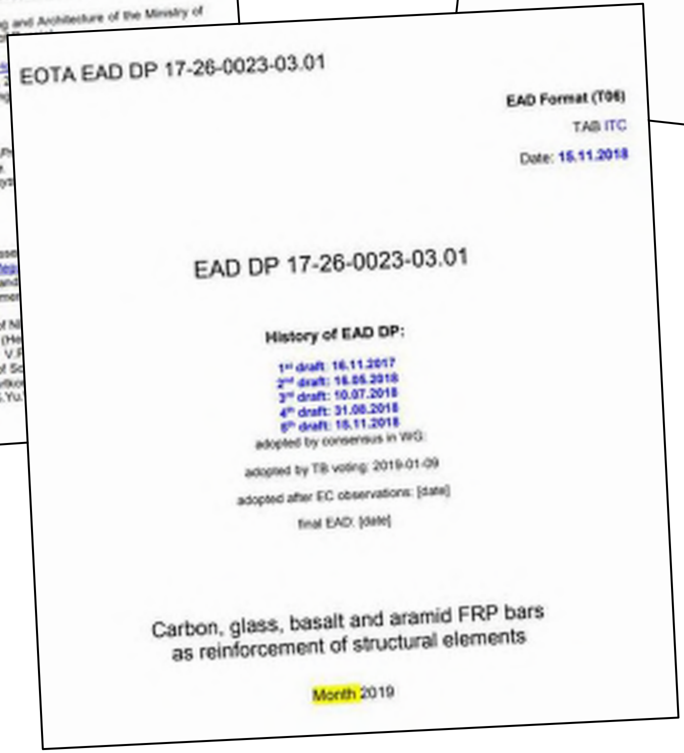
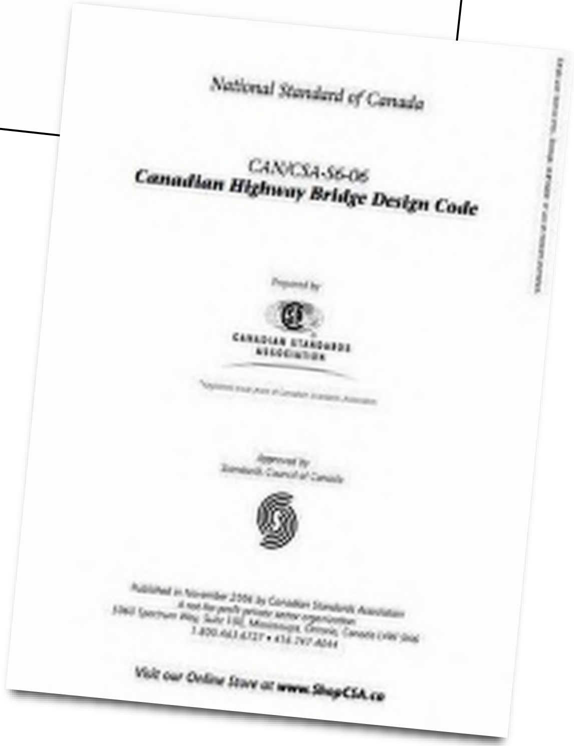
Design Aids & More









Nanni, Antonio, Antonio De Luca, and Hany Jawaheri Zadeh. *Reinforced concrete with FRP bars: Mechanics and design*. CRC Press, 2019.

Codes/Guides also avaiable in: Canada, Germany, England, Eurozone (EAD), Rusia, China

Education

WHAT IS MISSING? FRP-RC/PC RESEARCH NEEDS

What Educational needs are missing?

- ➢ **Relevant design codes**
- ➢ Practical design examples
- ➢ Design tools
- ➢ Engineered solutions
- ➢ Design & Training


Designation: D8505/D8505M − 23

Standard Specification for
Basalt and Glass Fiber Reinforced Polymer (FRP) Bars for Concrete Reinforcement

Center for Integration of Composites into Infrastructure

What Educational needs are missing?

- ➢ Relevant design codes
- ➢ **Practical design examples**
- ➢ Design tools
- ➢ Engineered solutions
- ➢ Design & Training

Additional Input for Water Load (WA)

NOTES:

- *Current version of Load Generator focuses on design and analysis of Bent-Cap, which is typically controlled by Strength I and Service I, III limit states with water load of 100 year Basic Flood. The flood elevation is typically below the bottom of cap. Thus, calculation of WA is omitted in current version.*
- *To consider WA load (e.g. existing bridges with flood elevation above the bottom of cap), directly input the WA load acting on the bent-cap that is under consideration.*

100 year event: parallel to the bent-cap...	0	kip
100 year event: perpendicular to the bent-cap	0	kip
500 year event: parallel to the bent-cap...	0	kip
500 year event: perpendicular to the bent-cap	0	kip

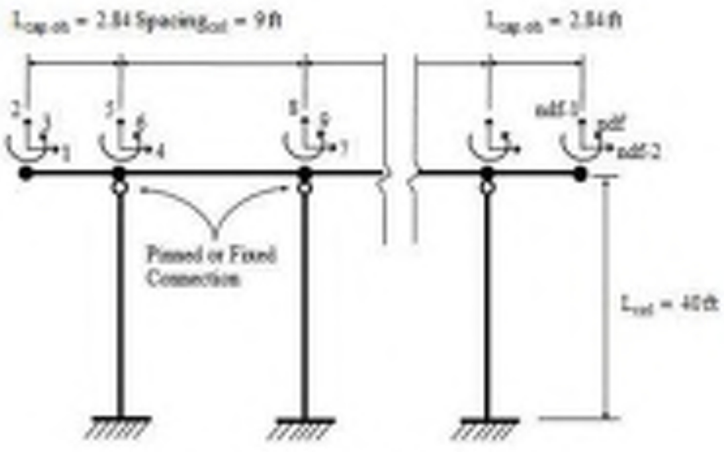
Additional Input for Force Effect due to Uniform Temperature (TU)

NOTES:

- *TU load is typically perpendicular to the plane of bent-cap and thus resisted by cantilever columns. Calculation of TU is omitted in current version.*
- *To consider TU load (e.g. bridges with big skew), directly input the TU load acting on the bent-cap that is under consideration.*

TU load in the longitudinal direction of the bridge	0	kip

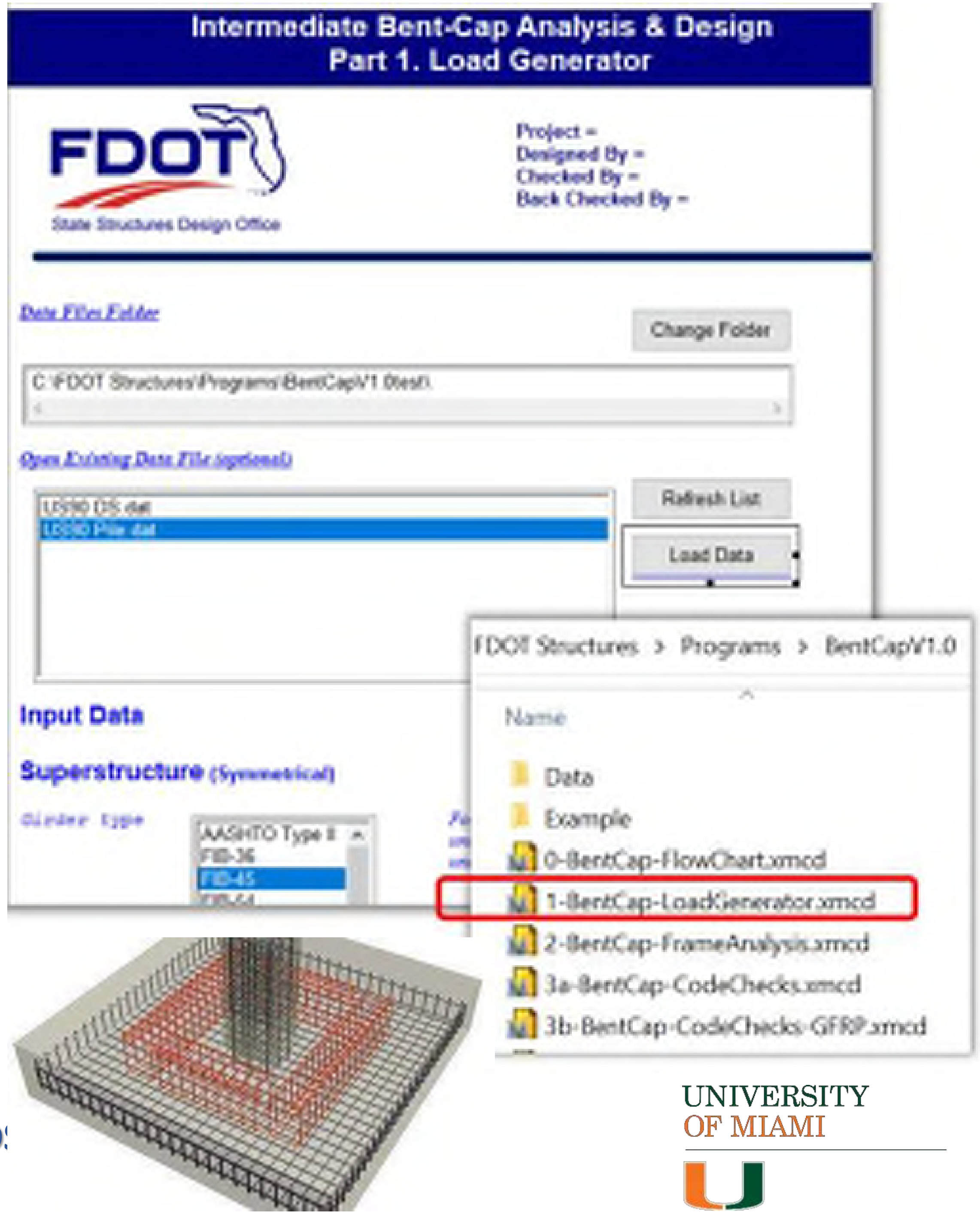
Model



Bent Cap Analysis Model

What Educational needs are missing?

- ➢ Relevant design codes
- ➢ Practical design examples
- ➢ **Design tools**
- ➢ Engineered solutions
- ➢ Design & Training



What Educational needs are missing?

- Relevant design codes
- Practical design examples
- Design tools
- **Engineered solutions**
- Design & Training

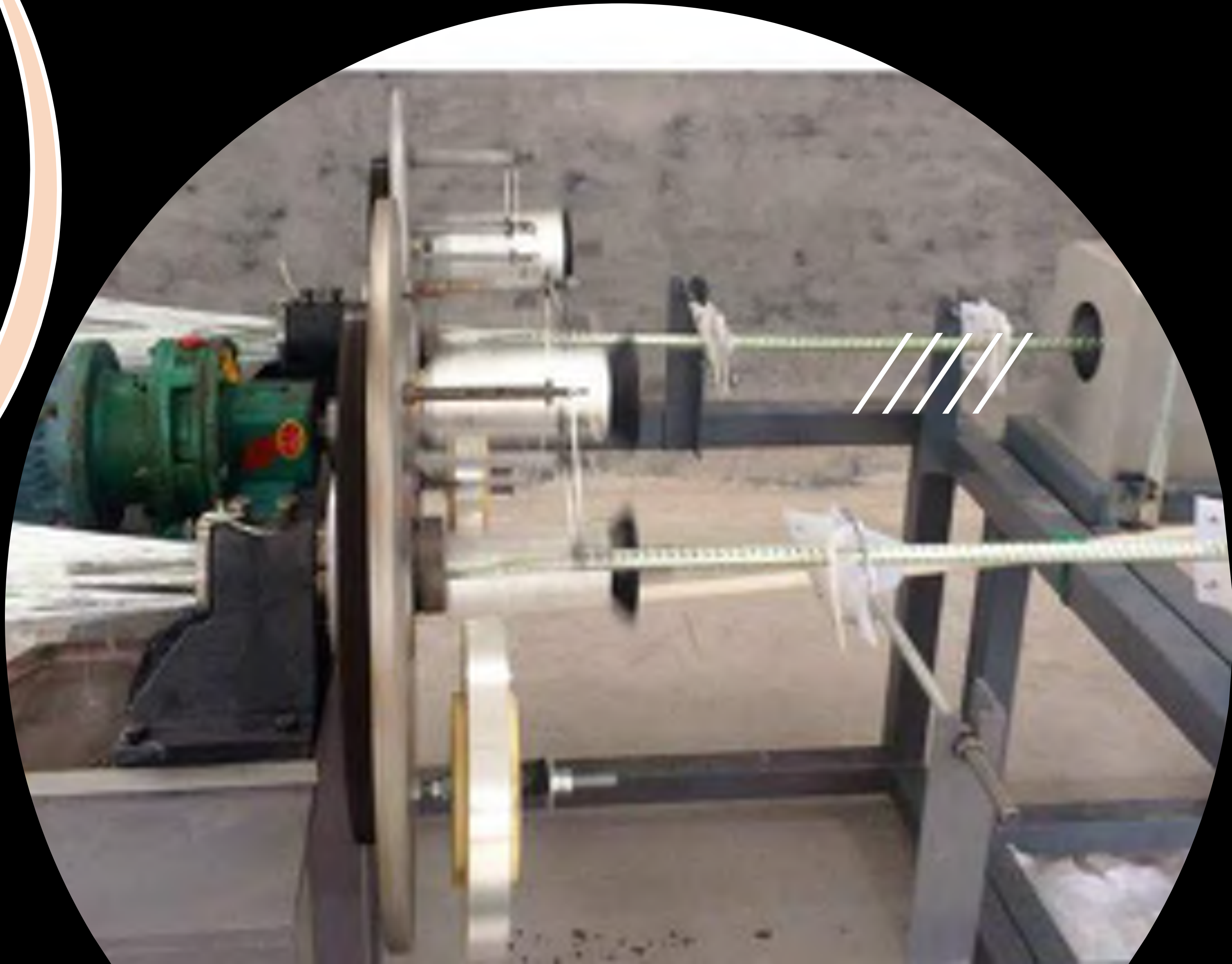
What Educational needs are missing?

- ➢ Relevant design codes
- ➢ Practical design examples
- ➢ Design tools
- ➢ Pre-Engineered solutions
- ➢ **Design & Training….**

What Educational needs are missing?

- Design & Training….
  - College Level
  - Junior Engineers
  - Senior Engineers
  - **Owners and District officials**
  - **Specifiers**

Manufacturing



What Manufacturing needs are missing?

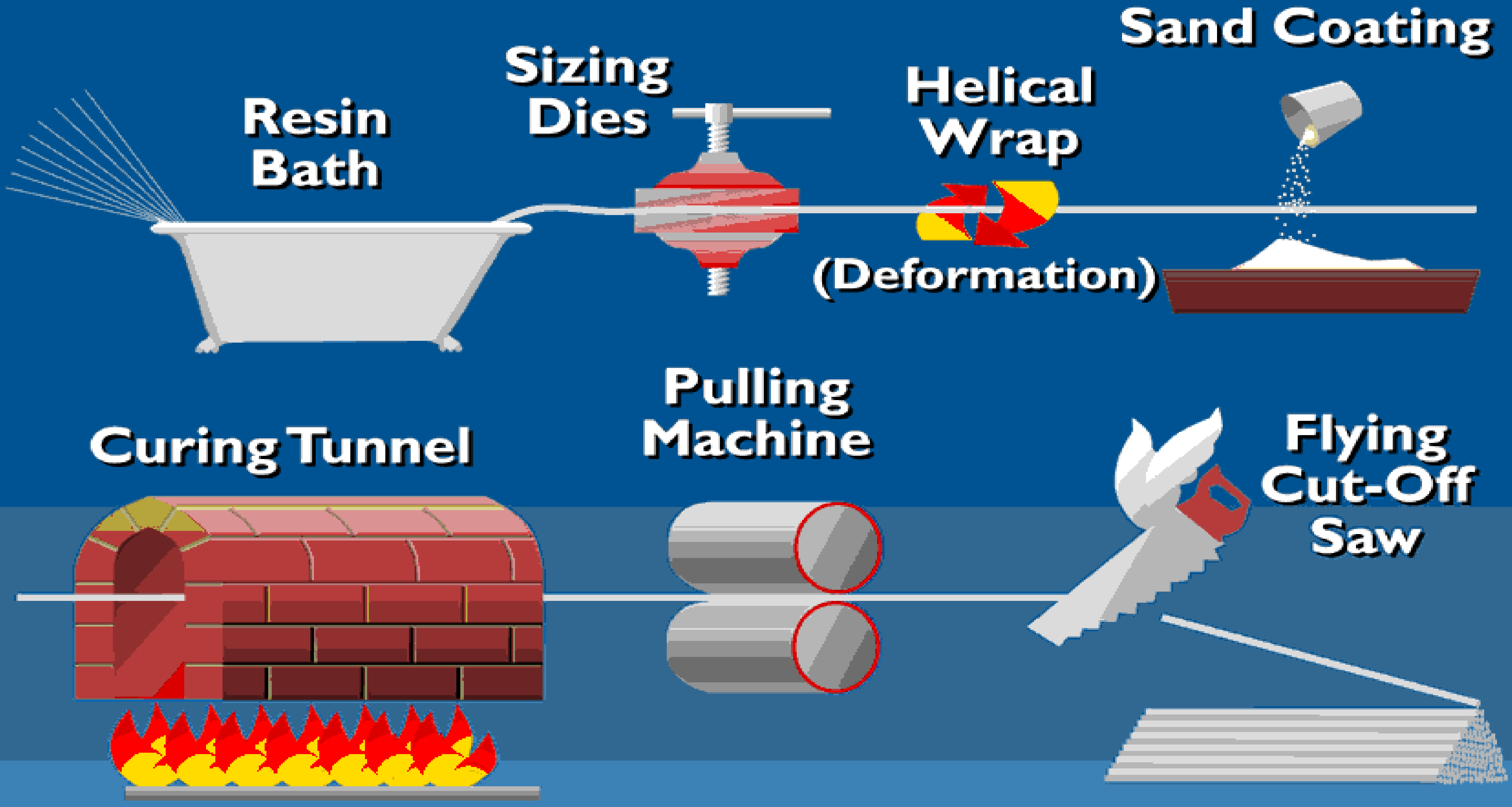
- **Economies of scale**
- QC/QA standardization
- Materials (resin/fiber)
- Bendability
- Commodity?

Center for Integration of Composites into Infrastructure

What Manufacturing needs are missing?

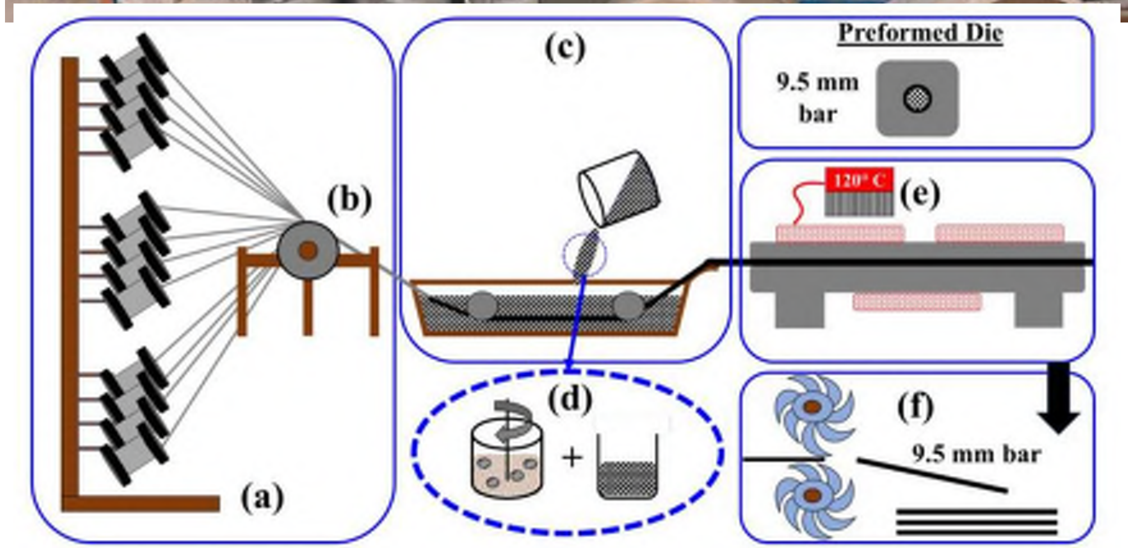
- ➢ Economies of scale
- ➢ **QC/QA standardization**
- ➢ Materials (resin/fiber)
- ➢ Bendability
- ➢ Commodity?

PRODUCTION PROCESS



What Manufacturing needs are missing?

- ➢ Economies of scale
- ➢ QC/QA standardization
- ➢ **Materials (resin/fiber)**
- ➢ Bendability
- ➢ Commodity?



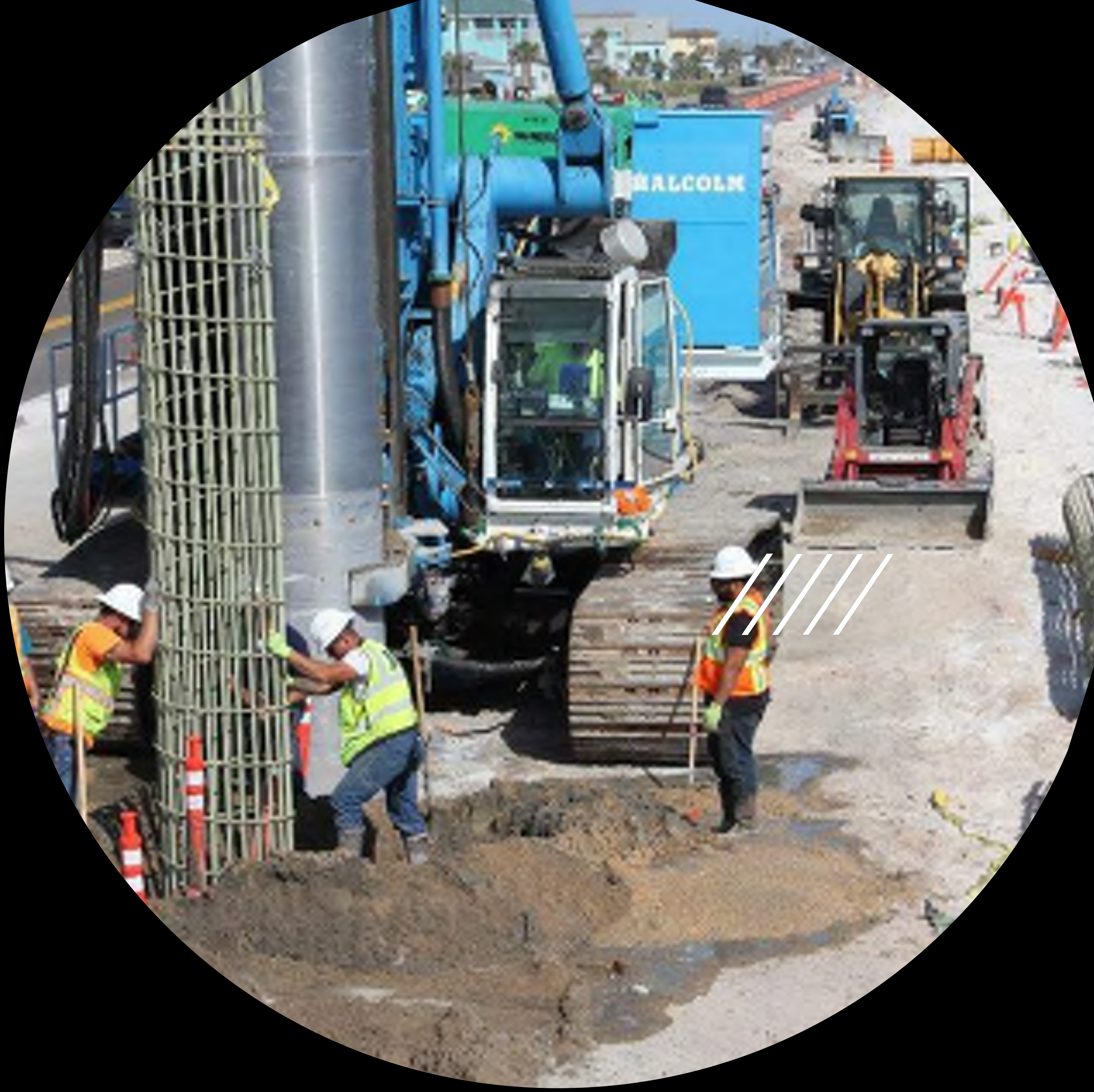
What Manufacturing needs are missing?

- Economies of scale
- QC/QA standardization
- Materials (resin/fiber)
- **Bendability**
- Commodity?

What Manufacturing needs are missing?

- Economies of scale
- QC/QA standardization
- Materials (resin/fiber)
- Bendability
- **Commodity?**

Construction



What Construction needs are missing?

- **Construction guide & detailing**
- Detection
- Inspection
- Repair
- Technical gaps…
  - Grips (PC)
  - Couplers

TRANSPORATION

- Fit more than twice the material in one shipment
- Use lighter mechanical equipment to unload truck

HANDLING

- Half number of trips from storage to site
- More durable than epoxy coating

INSTALLATION

- Faster placement due to lightweight
- Reduce rework with labeling

SAFETY

- Reduced risk score for lifting activities
- Reduced number of slips, trips, falls

What Construction needs are missing?

- Construction guide, detailing
- **Detection**
- Inspection
- Repair
- Technical gaps…
  - Grips (PC)
  - Couplers

Center for Integration of Composites into Infrastructure

What Construction needs are missing?

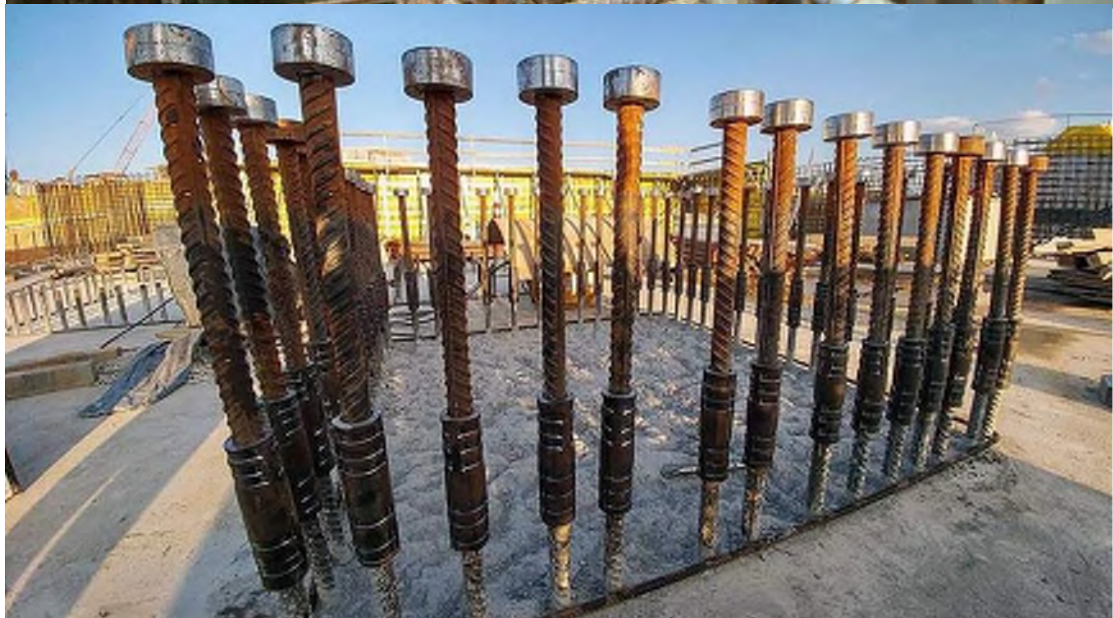
- Construction guide, detailing
- Detection
- **Inspection**
- Repair
- Technical gaps…
  - Grips (PC)
  - Couplers

What Construction needs are missing?

- ➢ Construction guide, detailing
- ➢ Detection
- ➢ Inspection
- ➢ **Repair**
- ➢ Technical gaps…
  - ▪ Grips (PC)
  - ▪ Couplers

What Construction needs are missing?

- Construction guide, detailing
- Detection
- Inspection
- Repair
- **Technical gaps…**
  - Grips (PC)
  - Couplers / headcoup

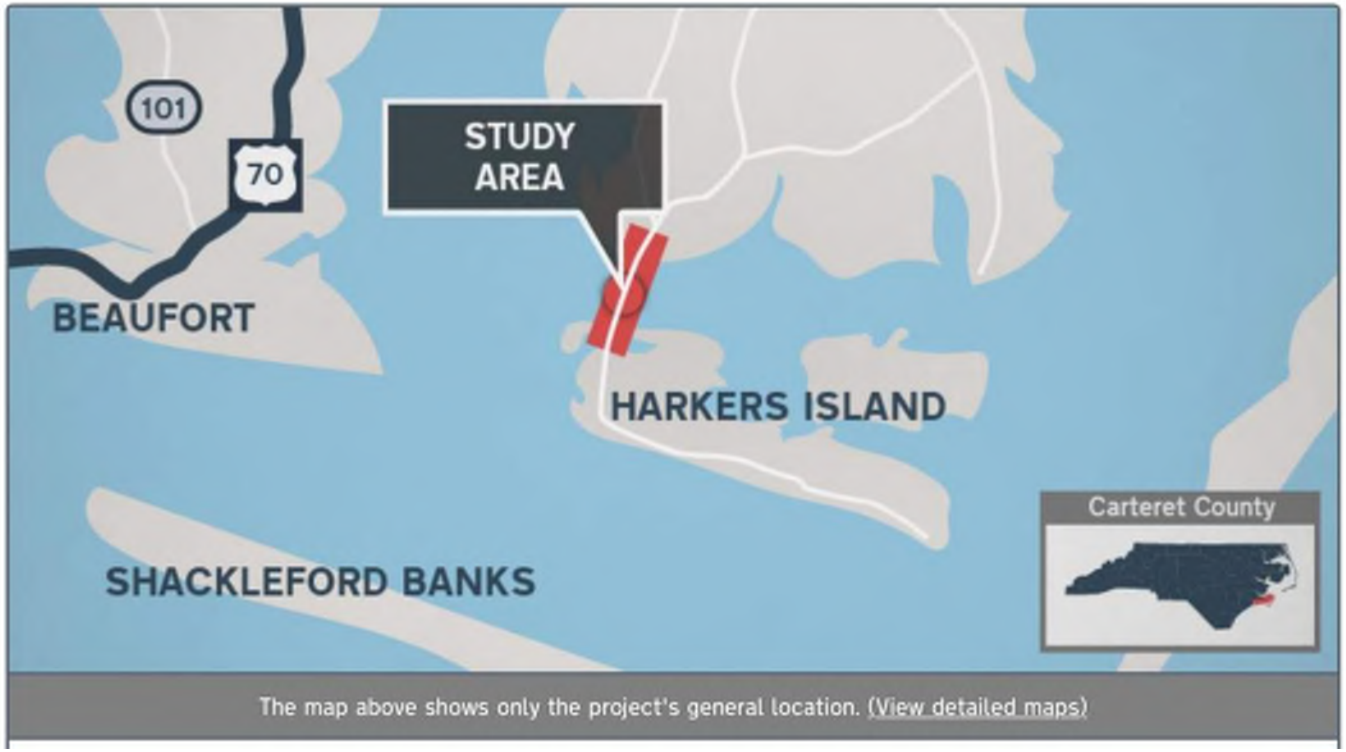


What Construction needs are missing? ****BONUS****

- QC/QA testing – sampling?

Harkers Island Bridge Replacement, North Carolina

County:	Carteret
Status:	In Development
STIP Number:	B-4863
Estimated Cost:	$47.9 million
Start Date:	Fall 2021
Completion Date:	2025




HAVANA
VISIT
CUBA

Other technical research needs…

- FRP bar surface, standardization?
- FRP adhesive anchors
- Deep beams
- Fire behavior and design
- Large FRP diameter bar (congestion)
- …


THANK

WHAT IS MISSING? FRP-RC/PC RESEARCH NEEDS

Francisco De Caso
Principal Scientist, University of Miami
fdecaso@miami.edu

SPxRSB-2023

1st Southeastern Peer Exchange for Resilient & Sustainable Bridges

Mobile, Alabama
Tuesday, August 8th 2023

What EDUCATIONAL needs do YOU think are needed to accelerate FRP-RC/PC?

What
MANUFACTURING
needs
do YOU think are
needed to accelerate
FRP-RC/PC?

What CONSTRUCTION needs do YOU think are needed to accelerate FRP-RC/PC?

1st Southeastern Peer Exchange for Resilient & Sustainable Bridges – Part 5

Session 1 (12pm – 1:30pm):

- **Part 1**: Round table discussion of goals and commitments (24-minutes)
- **Part 2a: Technical presentations of State of the Art in member states (30 minutes)**
- **Part 2b**: Technical presentations of State of the Art in member states (30 minutes)

**** Breakout (120 minutes) ****

**** Coffee, Tea, Lemonade & Beignets 3:00-3:30pm ****

Session 2 (3:30pm-6:00pm)

- **Part 3: Technical presentations of Manufacturer & Materials Acceptance (60-min)**
- **Part 4: Technical presentation and discussion on Research Needs**
- **Part 5: Technical presentation Open Topics (30-min)**
- **Part 6**: Final Q&A, Wrap Up assignment of Follow-up Tasks and Champions. (20 minutes)

Participants & Sponsors

NORTH CAROLINA
Department of Transportation

AASHTO Product Evaluation and Audit Solutions
Composite Concrete Reinforcements (CCR) Overview

W. Cabell Garbee, II, PE
NCDOT Manufactured Products Engineer
CCR Technical Committee Vice-Chair
August 2023

AASHTO
Product Evaluation & Audit Solutions

- *Formerly:*
  National Transportation Product Evaluation Program (NTPEP)

  AASHTO Product Evaluation & Audit Solutions Program combines the professional and physical resources of the AASHTO member departments in order to **evaluate materials, products, and devices of common interest for use in highway and bridge construction.** The primary goal of the program is to **provide cost-effective evaluations** for the State DOTs by **eliminating duplication of testing and auditing** by States and duplication of effort by manufacturers that provide products for evaluation.

  24 Technical Committees
  42 States Participated at the 2023 Annual Meeting

  https://transportation.org/product-evaluation-and-audit-solutions/

CCR Committee

June 2023 Annual Meeting

Membership

- Matt Bluman, AASHTO Liaison
- Joe Stillwell, Maine DOT Chair
- Cabell Garbee, North Carolina DOT Vice Chair
- Representatives from 18 State Departments of Transportation (DOT)
- Eight Manufacturers
- Testing Facility and Aud
  - Contracted to AASHTO
- Industry Association
  - FRP Institute for Civil Infrastructure

- Note
  - State DOT each have a voting member, all other members are non-voting

Composite Concrete Reinforcements (CCR)

Timeline

- 2021/2022 Task Force and Committee
  - Judge Interest, Develop Workplan
- 2023 Committee
  - Work Plan Approved
    - Participating Materials
      - Glass Fiber Bars
      - Carbon Fiber Strands (upcoming)
    - Facility Required Components
      - Quality Management System
      - Facility Audit
      - Sampling and Testing

Quality Management System

Minimum Components

- Quality Manual
- Standard Specifications
- Training and Competency Evaluation Records
- Equipment Calibration Records
- Certificates of Analysis
- Raw Material Test Results
- Product Physical Test Results

Annual Facility Audits

Components

- Yard Inspection
- Manufacturing Process Evaluation
- Review of AASHTO/ASTM Test Methods
- Demonstration/Observation of Quality Control Tests
- Traceability of Final Product
- Collection of Split Samples for Third Party Testing

Sampling and Testing

Minimum QMS Requirements

Measurement/Test	Frequency: Minimum	Test Methods
Fiber Mass Content	Once per Lot	ASTM D2584
Glass Transition Temperature	Once per Lot	ASTM E1356
Ultimate Tensile Force	Once per Lot	ASTM D7205
Tensile Modulus of Elasticity	Once per Lot	ASTM D7205
Ultimate Tensile Strain	Once per Lot	ASTM D7205
Moisture Absorption (24hr)	Once per Lot	ASTM D570
Transverse Shear Strength	Once per Lot	ASTM D7617
Cross sectional Area	Once per Lot	ASTM D7205
Degree of Cure	Once per Lot	ASTM E2160
Alkaline Resistance*	Annually (one lot, #5 or #6 bar)	ASTM D7705 Pro.A
Bond Strength	Annually	ASTM D7913
Horizontal Shear	Once per Lot	ASTM D4475

Sampling and Testing

Audit Split Samples

Product Test Property	Test Methods
Ultimate Tensile Force	ASTM D7205
Tensile Modulus of Elasticity	ASTM D7205
Ultimate Tensile Strain	ASTM D7205
Transverse Shear Strength	ASTM D7913
Cross sectional Area	ASTM D7205
Horizontal Shear Strength	ASTM D4475

Manufacture Retainage for Audit

25 Different Lot Samples, Five 80” bars each lot

Audit Sample Obtained from Retainage

3 Different Lot Samples, Five 80” bars each lot

AASHTO Website

Datamine (restricted access)
- Audit Reports
- Sample Test Reports

Industry Document Repository (restricted access)
- Technical Information
  - Physical/Design Properties
- Environmental Product Declaration
- Buy America/BABA Documentation

Program Information
- https://transportation.org/product-evaluation-and-audit-solutions/

Questions?

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NCDOT Manufactured Products Engineer
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cgarbee@ncdot.gov

AERO AGGREGATES®

Ultra-lightweight Foamed Glass Aggregate

I-95 EMERGENCY REPAIR

Philadelphia, PA

Made in USA from 99% Recycled Container Glass

I-95 Emergency Repair

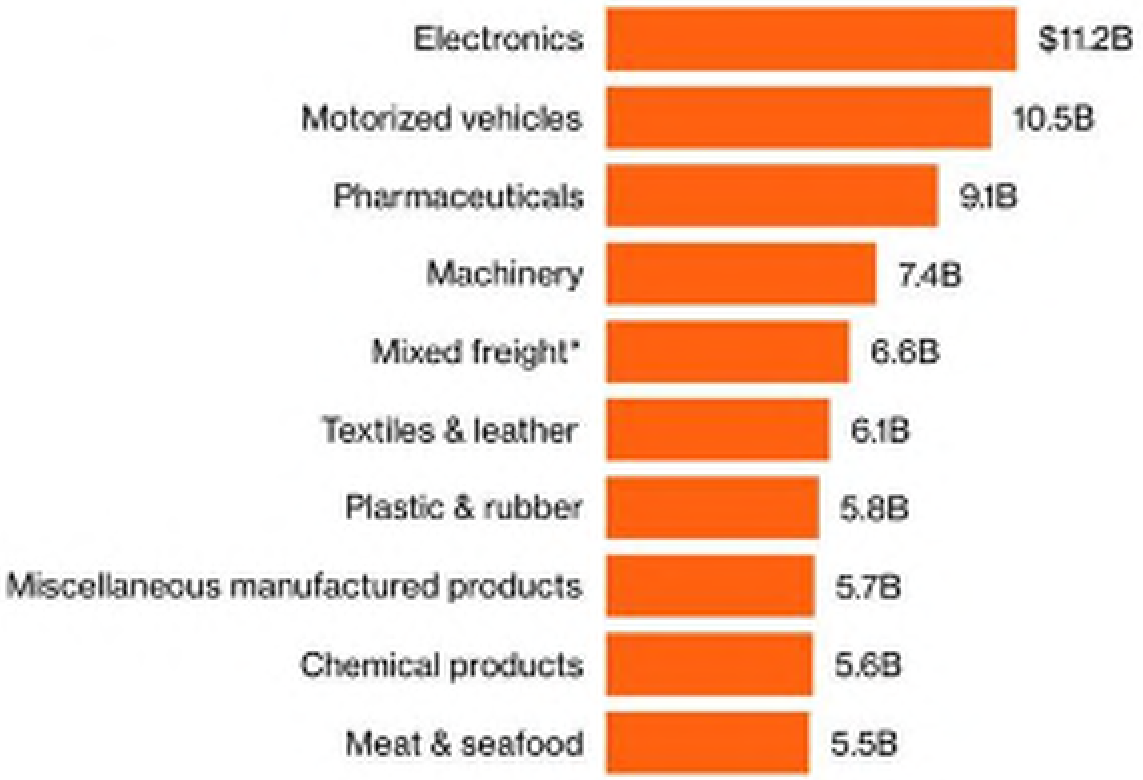
Philadelphia, PA

I-95 Emergency Repair

Philadelphia, PA

I-95 Carries Freight Through Northeast US

In 2021, trucks carried 21 million tons of freight worth $104 billion through the Philadelphia region, largely over I-95. The top categories:



Source: Bureau of Transportation Statistics
Note: Mixed freight includes office supplies, hardware, restaurant supplies, etc.

I-95 Emergency Repair

Philadelphia, PA

I-95 Emergency Repair

Philadelphia, PA

Solution for Rapid Repair

Philadelphia, PA

Solution for Rapid Repair

Philadelphia, PA

June 15th 4 days after collapse

Underground Utilities

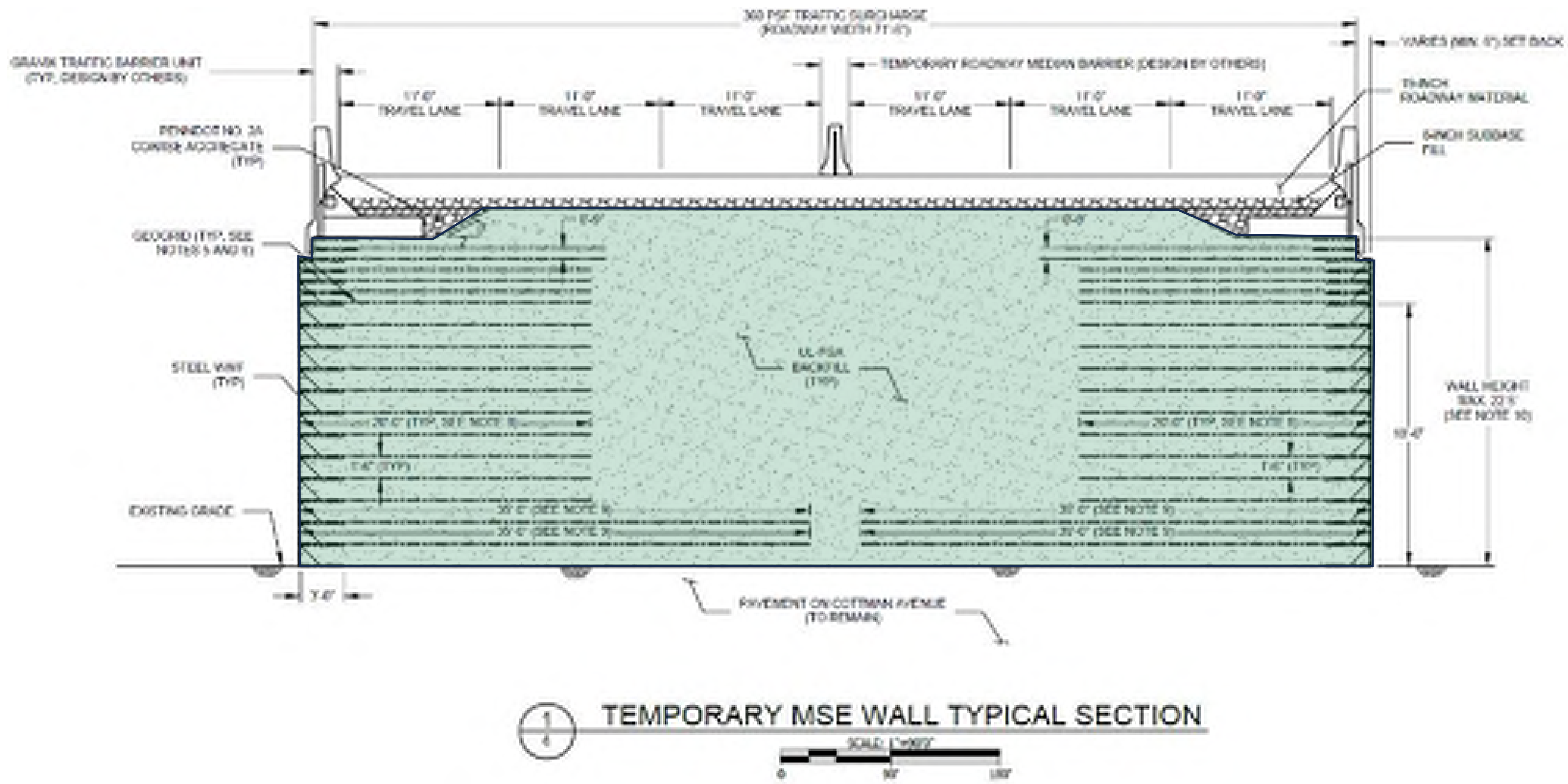
86” sewar line and 36” water Line

I-95 Emergency Repair

Philadelphia, PA

Aero Aggregates Briefing

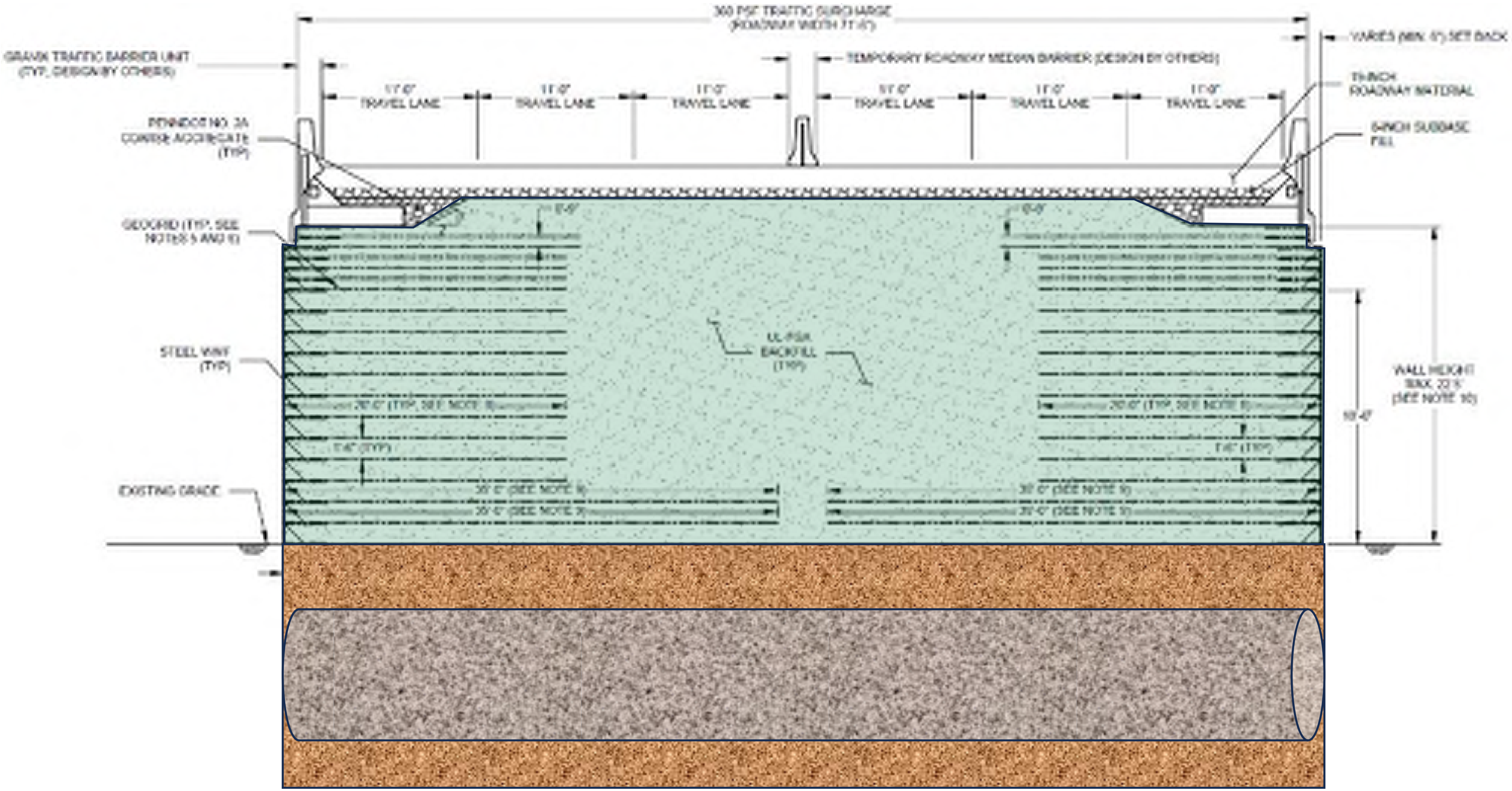
"Highest priority infrastructure project in the US"



- ✓ Protects the 86” dia. Sewer Main
- ✓ Fast Delivery and Construction
- ✓ No Weather Delays
- ✓ Permeable/ Minimize Stormwater Issues

I-95 Emergency Repair

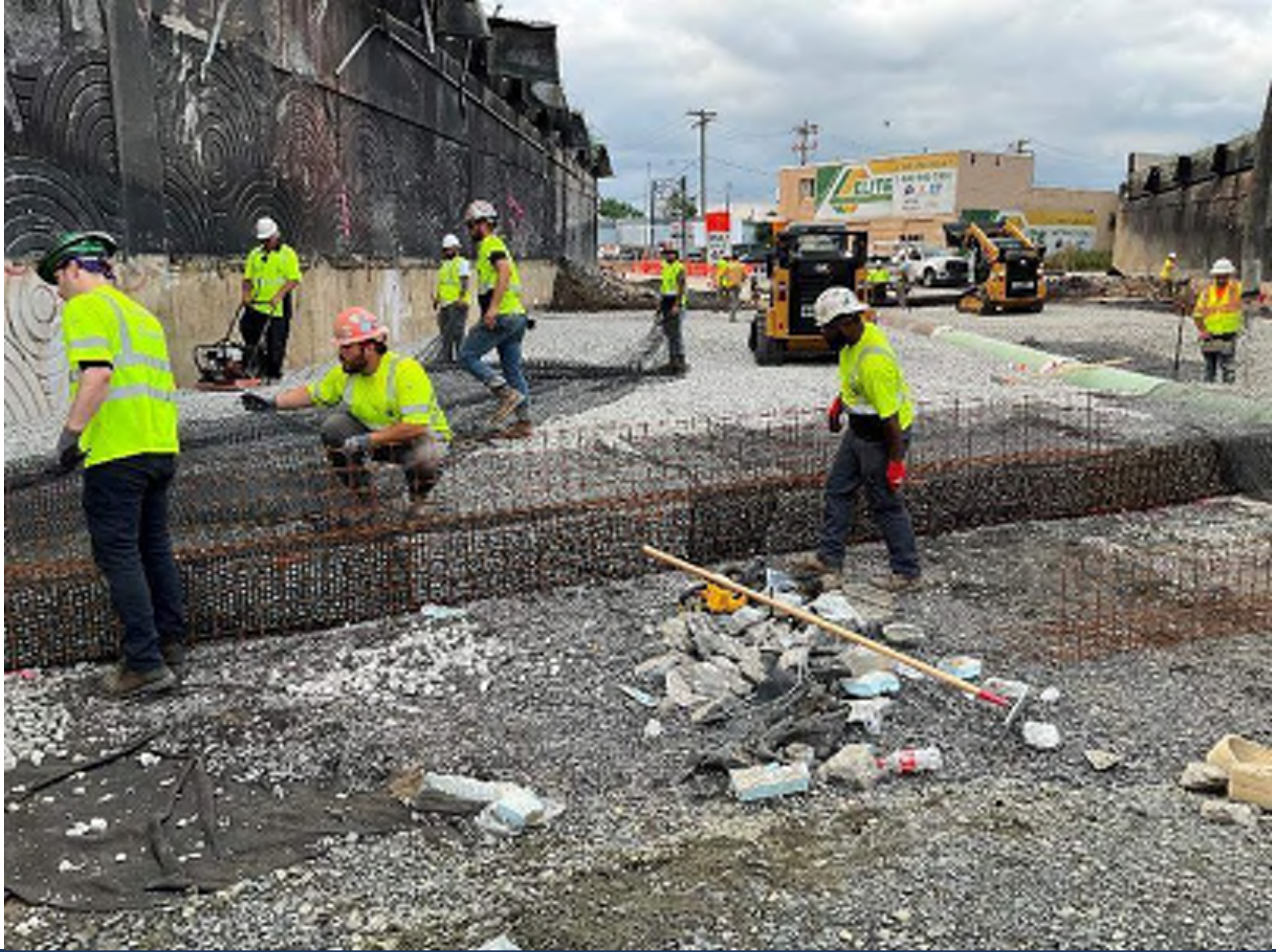
Philadelphia, PA



- ✓ Protects the 90” (2.3m) dia. Sewer Main
- ✓ Fast Delivery and Construction
- ✓ No Weather Delays
- ✓ Permeable/ Minimize Stormwater Issues

I-95 Emergency Repair

Philadelphia, PA



I-95 Emergency Repair

Philadelphia, PA

I-95 Emergency Repair

Philadelphia, PA

I-95 Emergency Repair

Philadelphia, PA

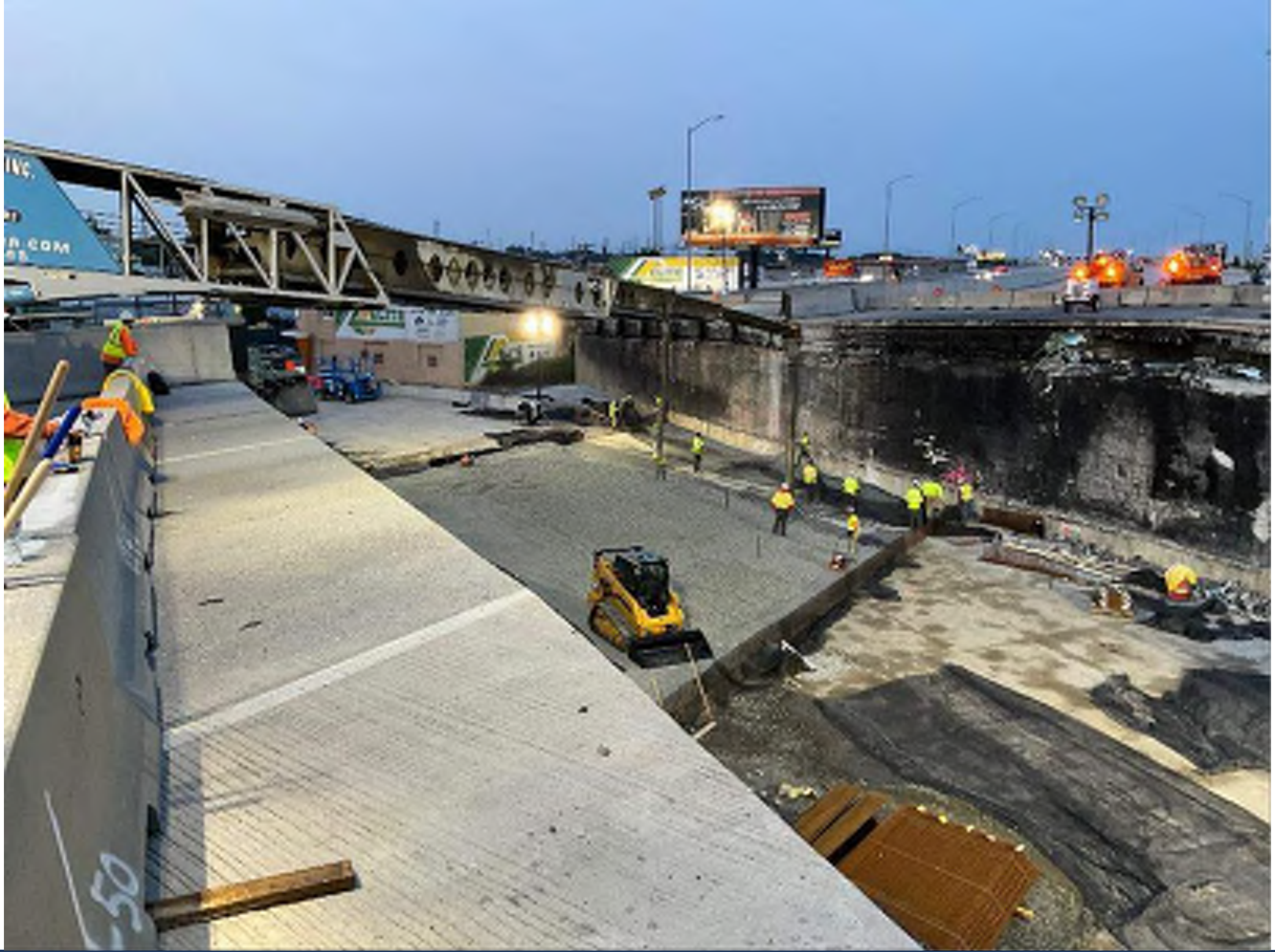
Geogrid Placement and Overlap

Philadelphia, PA


C-2H

Compaction

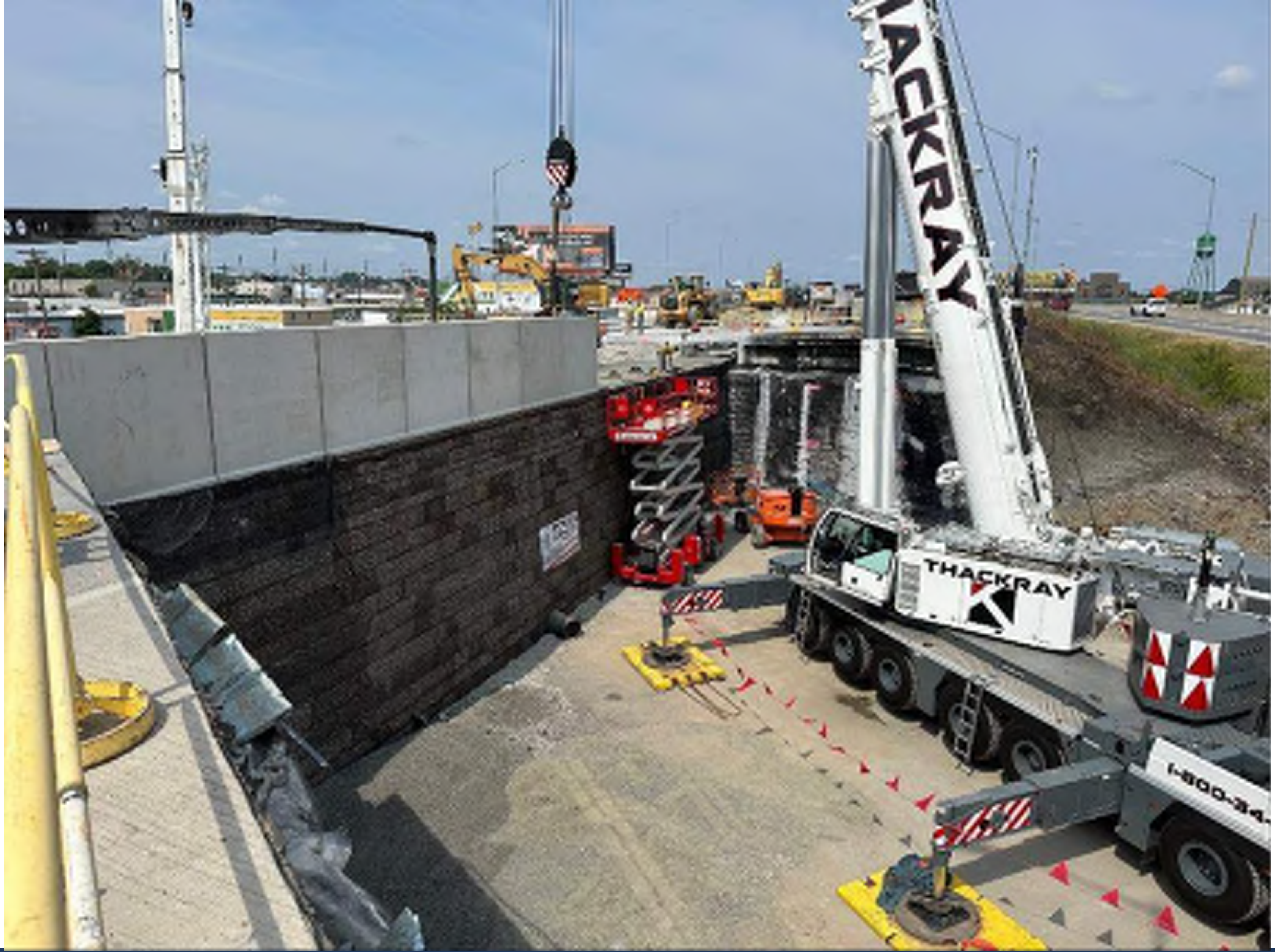
Skid Steer



First lifts of MSE Wall

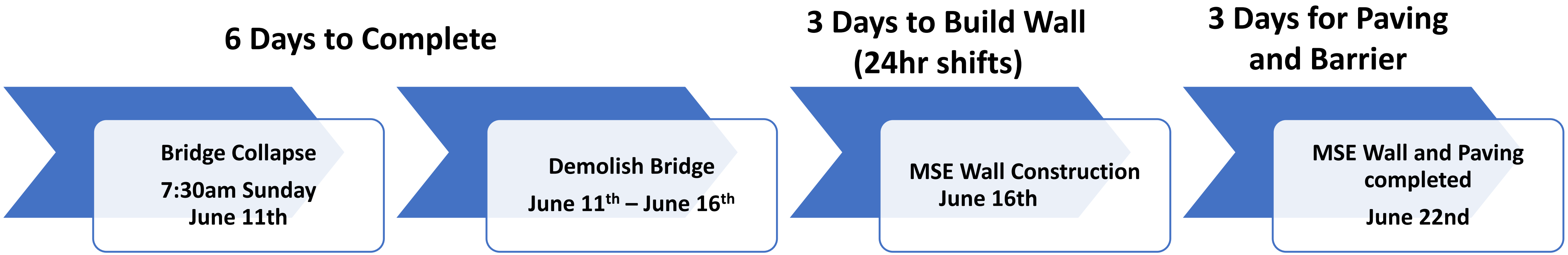
172
M·B·W
172
AP2000

I-95 Prior to subbase and paving



Precast Barrier

Timeline



All work completed in 11 days – I-95 Re-opened on 12th day

I-95 Emergency Repair

Philadelphia, PA

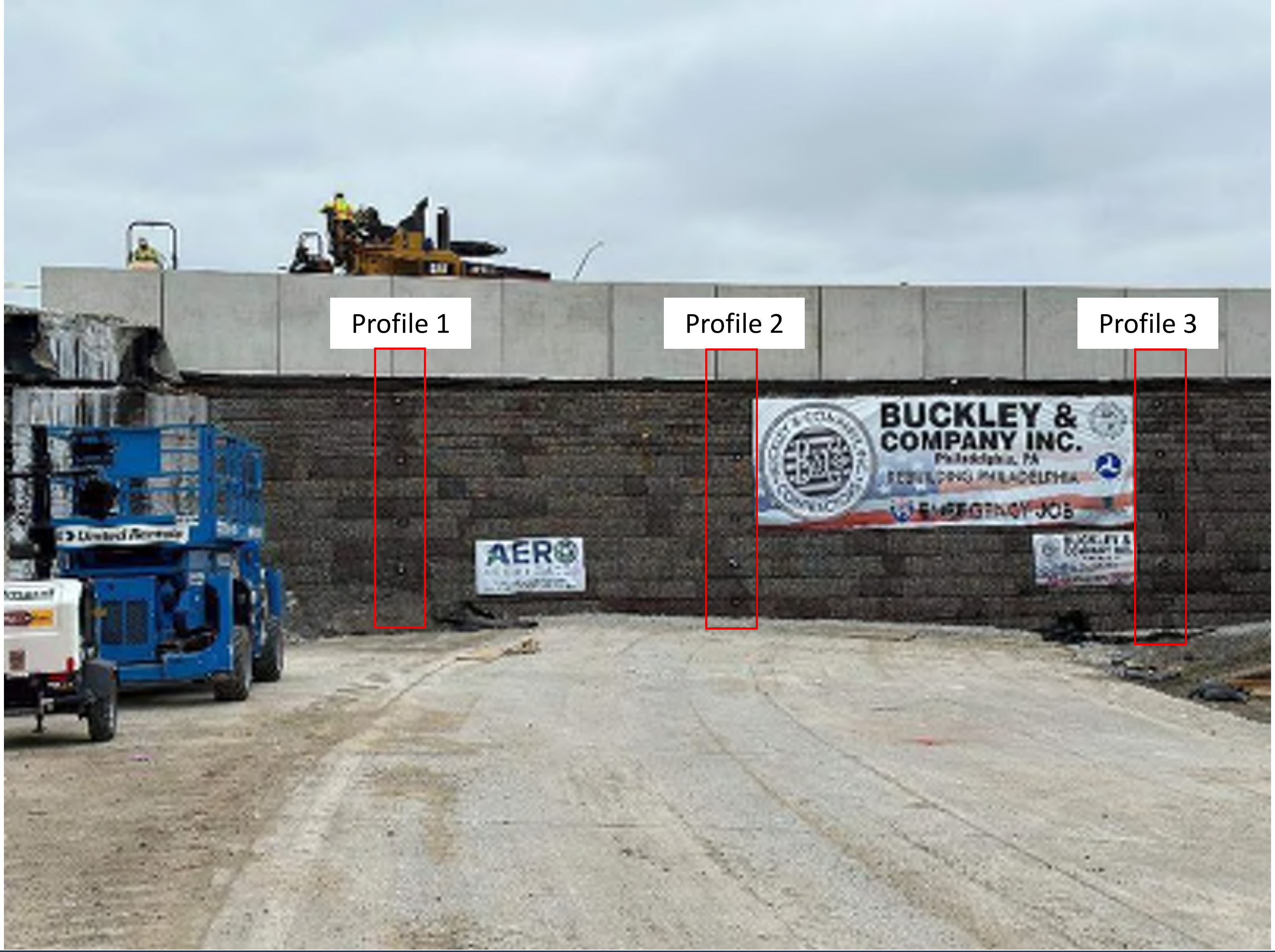
I-95 Emergency Repair

Philadelphia, PA


BUCKLEY &
COMPANY INC.
Philadelphia, PA
AER

LiDAR Monitoring

Philadelphia, PA



LiDAR Monitoring

Philadelphia, PA

Thank You!
Questions?

Archie Filshill, Ph.D., ENV SP
archie@aeroaggregates.com