Northeastern Peer Exchange for Resilient and Sustainable Bridges

August 7, 2024 – Buffalo, NY.

University at Buffalo

Institute of Bridge Engineering

WELCOME & INTRODUCTIONS

by Dr. Pinar Okumus (Chair) and Steve Nolan (Secretariat)

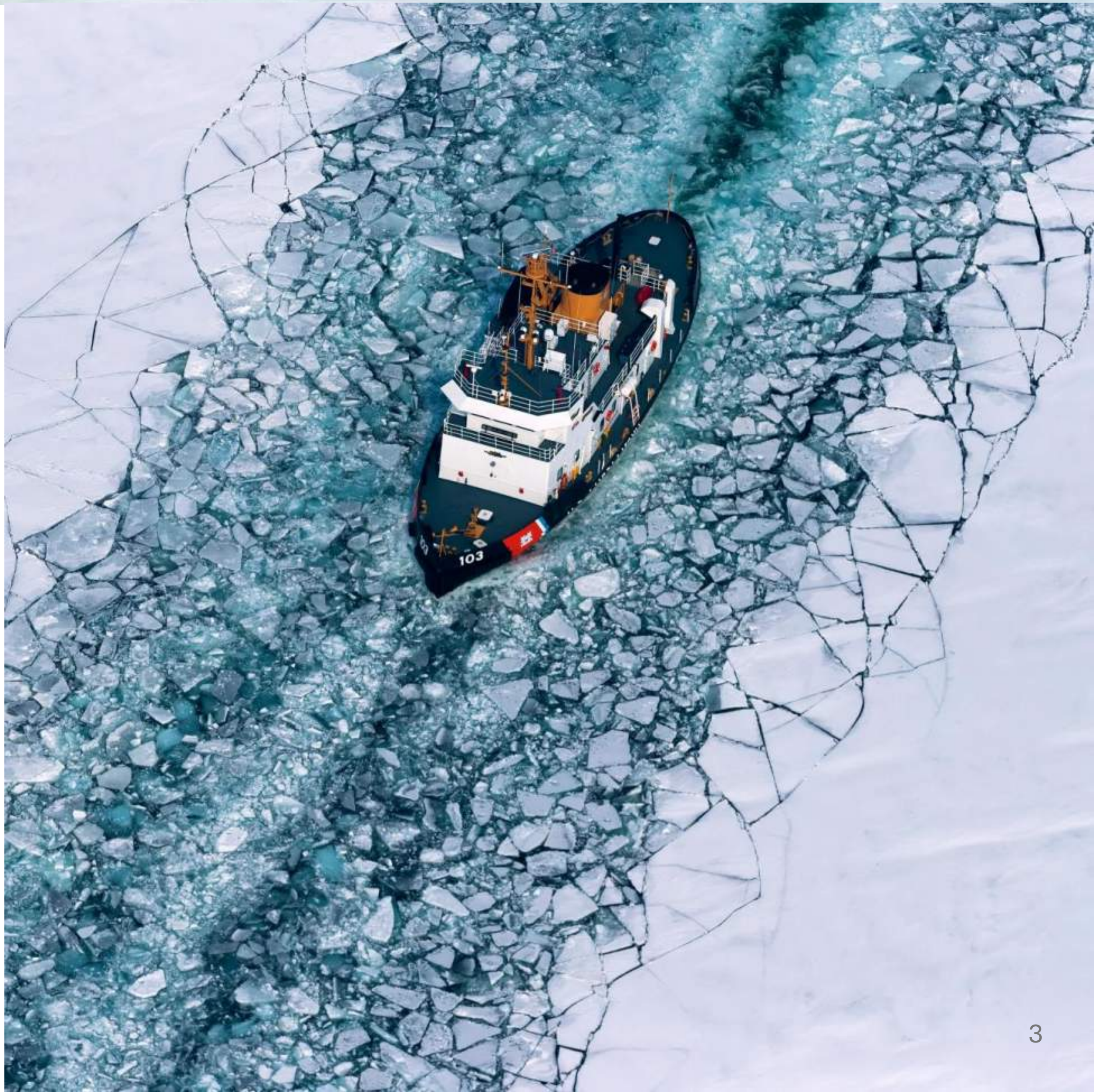
Resilient and Sustainable Infrastructure

- This in-person workshop is a regional collaboration promoting holistic resilient and sustainable infrastructure solutions with a focus on efficient highway and pedestrian bridges and structures.
- The goals of the workshop are increasing **RESILIENCE** (robustness, strength, durability, long service-life, and dynamic adaptability) using **SUSTAINABLE** (adaptable, lower embodied energy and GHG/CO_2 emissions, incorporating recycled, repurposed and upscaled materials, inclusive and diverse) structures, for **ECONOMICAL** (materials, fabrication, hauling, construction and design practices, low-maintenenence) solutions considering mature and emerging technologies.
- This will be achieved through the exchange of information on the latest advancements and practices for bridge design, construction, maintenance, and material science. Discussions will combine these topics to minimize asset life-cycle cost and owner's risk, while simultaneously reducing environmental impacts.

Ice Breaker

With your neighbors, please share:

- *two truths about your self and ,*
- *one wish for Resilience or Sustainability*



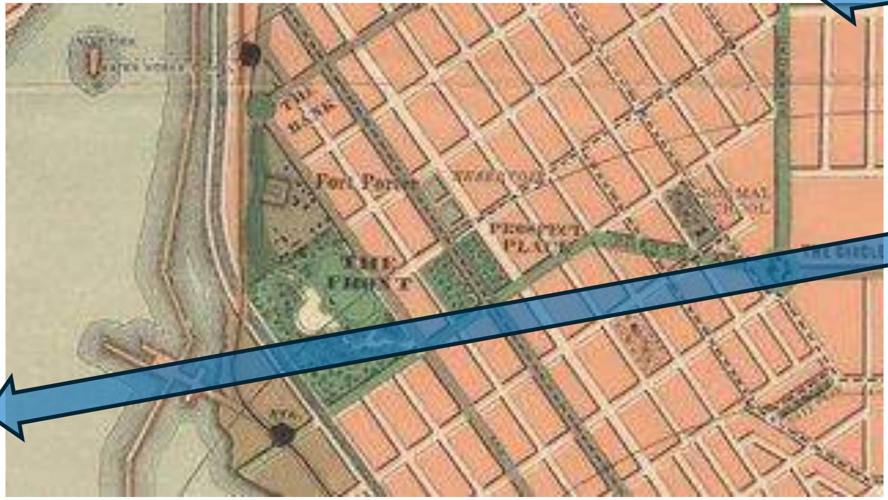
Inspiration - Local Context

Fredrick Law Olmsted (Landscape Architect) arrived in Buffalo in July 1868 to visit several potential park locations and select a site for a "central" park for the burgeoning city of Buffalo.

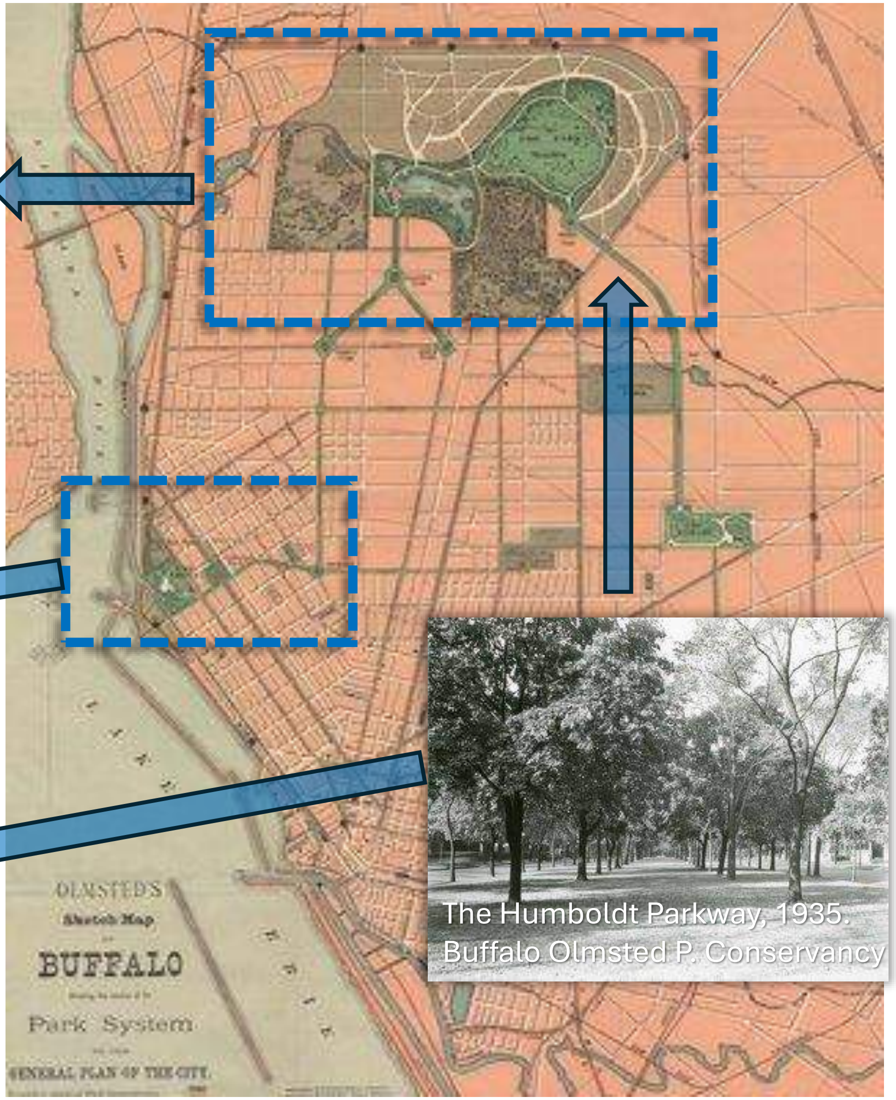
The Humboldt Parkway which linked Delaware Park and Martin Luther King Jr. Park was destroyed to build a sunken highway.

Formerly Humboldt Parkway, now the sunken Scajaquada Expressway 1960-present. *Buffalo Olmsted P. Conservancy*

Olmsted's map of The Park (Delaware Park), 1868. *National Parks Service*



Olmsted's map of The Front, 1868. *National Parks Service*



The Humboldt Parkway, 1935. Buffalo Olmsted P. Conservancy

Olmsted's sketch map of Buffalo showing the first three parks in the park system, 1868. *National Parks Service*

Return to Nature-based or -inspired Designs (NbiD)

Inspiration & Aspiration

"A regional collaboration promoting holistic resilient and sustainable infrastructure solutions with a focus on efficient highway and pedestrian bridges and structures"

The "Viele Map": Hand-colored map of Manhattan's waterways (1865). Library of Congress, Geography and Map Division.

Today, the world may admire and amplify Olmstead's vision, but New Yorkers live in the city that Viele imagined.

https://issues.org/viele-new-york-map-madhavan/

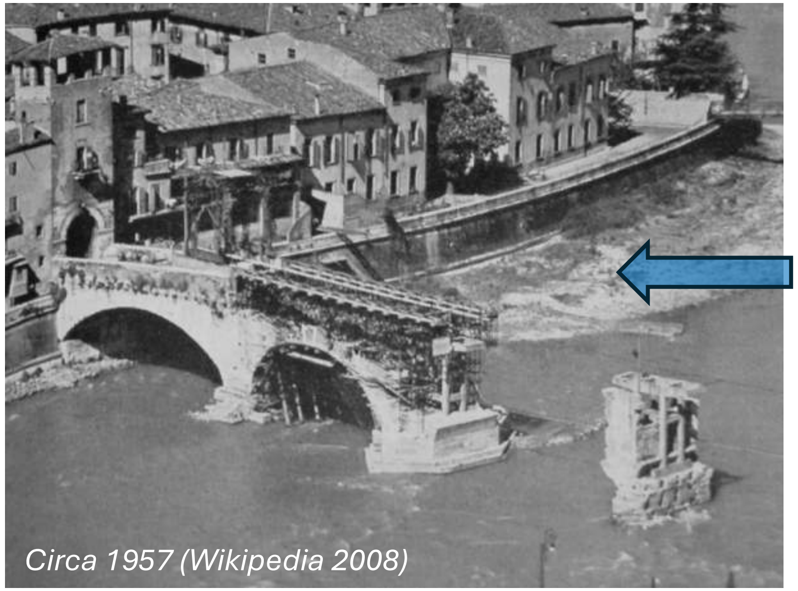
…**Fredrick Law Olmsted** *"wanted to create a planned city with an orderly hierarchy of nature and commerce. He imagined a city crystallized around a park where time stopped before the Industrial Revolution. It was a fantasy of pastoral hygiene—a contradiction that was at once idealistic and unrealistic for a polyglot city"*. English architect Calvert Vaux convinced the NYC Park commissioners to drop Viele's 1857 plan and teamed up with Olmstead in 1858 to oversee the development of Central Park.

Egbert Ludovicus Viele (West Point–trained engineer) was appointed as the first Chief Engineer of Central Park development in 1857. *"Viele envisioned that NYC might grow willy-nilly but in which peoples' lives could be improved by sanitation, by subways and elevated trains, and by canals. He lived in the real world—a working city with unruly aims and desires. Viele's New York was a protean space, relentlessly renovating and reconfiguring around its inhabitants and their needs. Today, the world may admire and amplify Olmstead's vision, but New Yorkers live in the city that Viele imagined."*

Guru Madhavan "Living in Viele's World", Perspectives, Issues in Science and Technology. Arizona State University , Vol. XL, No. 4, Summer 2024

Inspiration & Aspiration

"A regional collaboration promoting holistic resilient and sustainable infrastructure solutions with a focus on efficient highway and pedestrian bridges and structures"



Circa 1957 (Wikipedia 2008)

~~2100-Year-Old Bridge:~~

Ponte Pietra (Stone Bridge, Verona, Italy) was reconstructed several times since 100 BC. The arch nearest to the right bank of the Adige River was rebuilt in 1298 by Alberto I della Scala. Four arches of the bridge were blown up by retreating German troops in World War II, but rebuilt in 1957 with original materials

Source: American Society of Civil Engineers

2016 view from the right bank.
(Photo by S. Nolan)

Ponte Pietra (Verona, Italy)

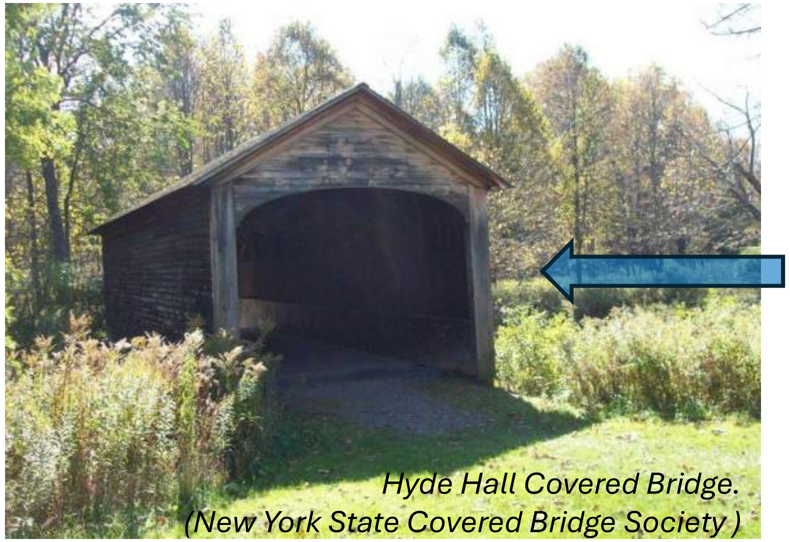
327-Year-Old Bridge:

Frankford Ave. Bridge (Philadelphia, PA) constructed in 1697. William Penn compelled each male member of the surrounding community to contribute a share of either labor or money. Originally 18-ft wide, to accommodate passing horse teams. It was widened in 1893 (~200-years) to accommodate trolley traffic and again in 1950 for vehicles (~250-years).

Source: American Society of Civil Engineers

Inspiration & Aspiration

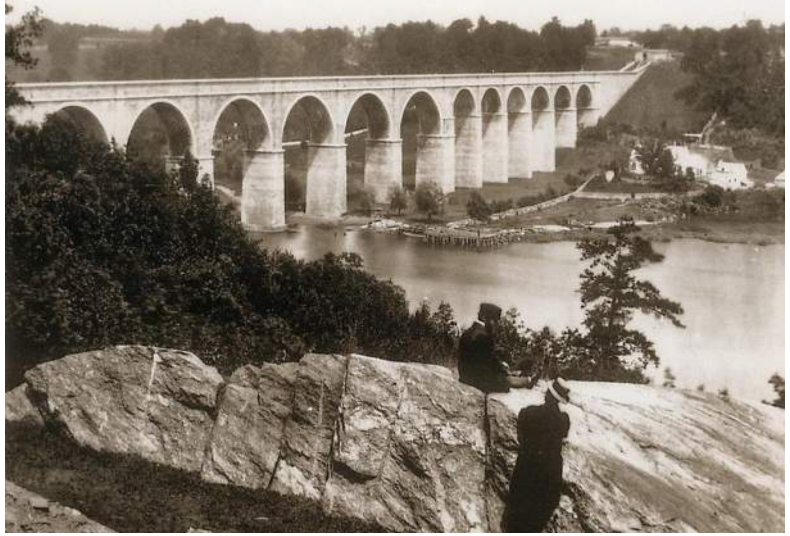
"A regional collaboration promoting holistic resilient and sustainable infrastructure solutions with a focus on efficient highway and pedestrian bridges and structures"



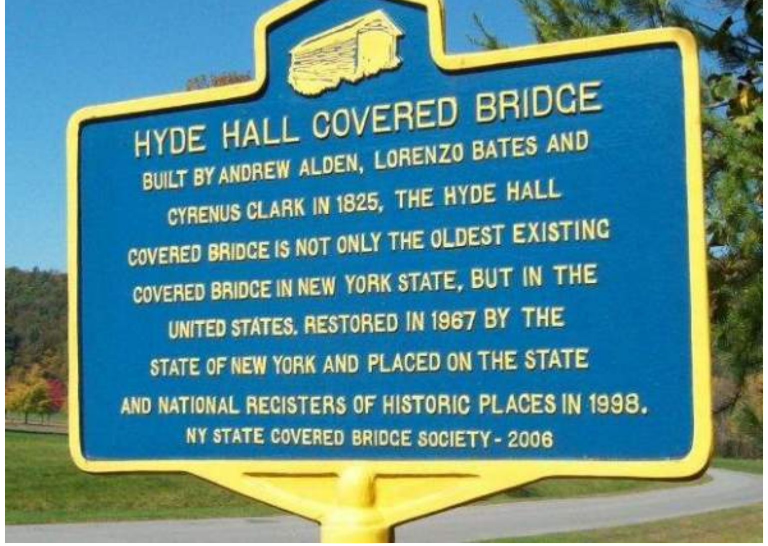
Hyde Hall Covered Bridge.
(New York State Covered Bridge Society)

200-Year Bridge: Hyde Hall Covered Bridge (NY-39-01): Built in 1823. It is single span of 53-ft crossing Shadow Brook in Glimmerglass State Park. Using a modified Burr Arch timber truss with X-bracing in place of a King-Posts. It was commissioned by George Clarke as part of a three-mile toll way providing access to Hyde Hall Mansion

Photo by William England, 1859.

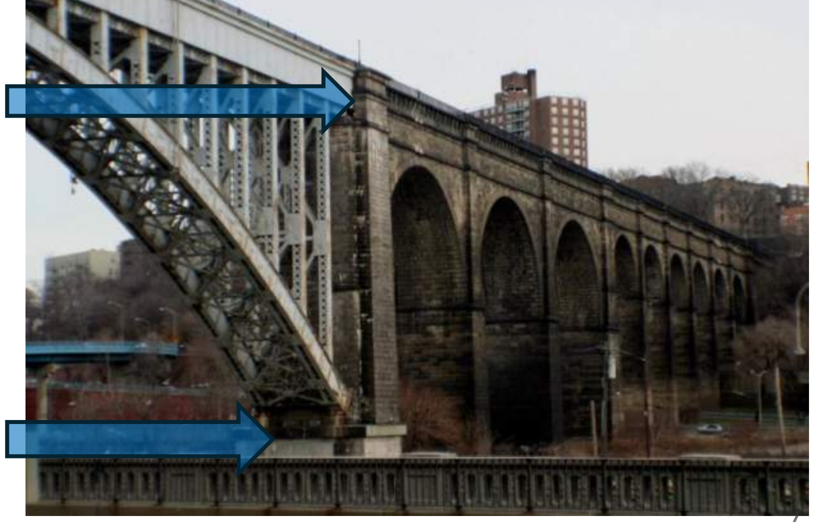


(Source: New York State Covered Bridge Society)

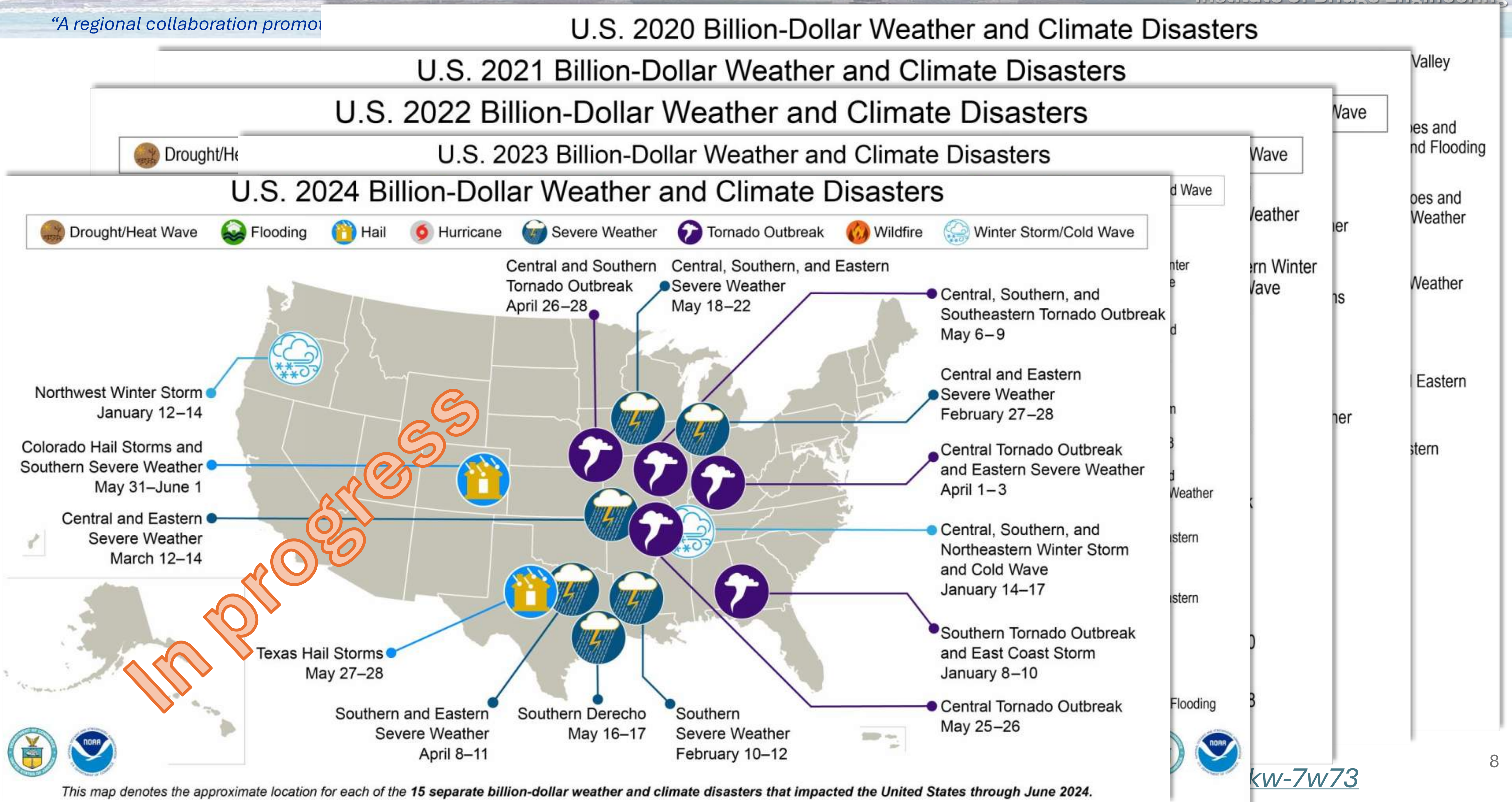


~180-Year Bridge:
The High Bridge (Bronx-Manhattan) was constructed from 1837 to 1848 as part of the Croton Aqueduct. Never used for vehicle, a walkway was added in 1864, however, the bridge was never used for vehicles. In 1928, 5 masonry arches spaning the Harlem River were demolished and replaced with a single 450-ft steel arch to improve navigation.

Wikipedia 2006.



Data for Motivation



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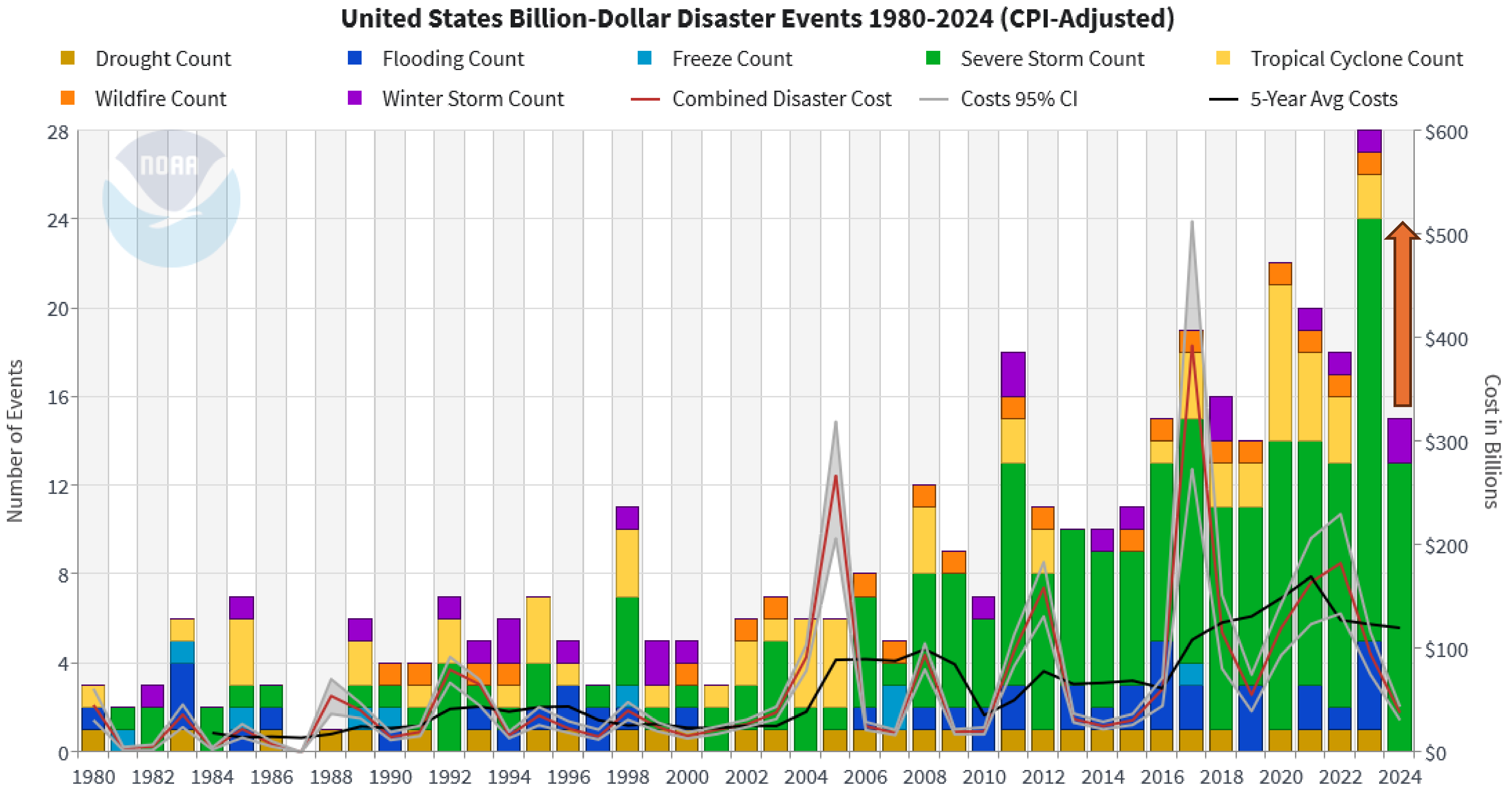
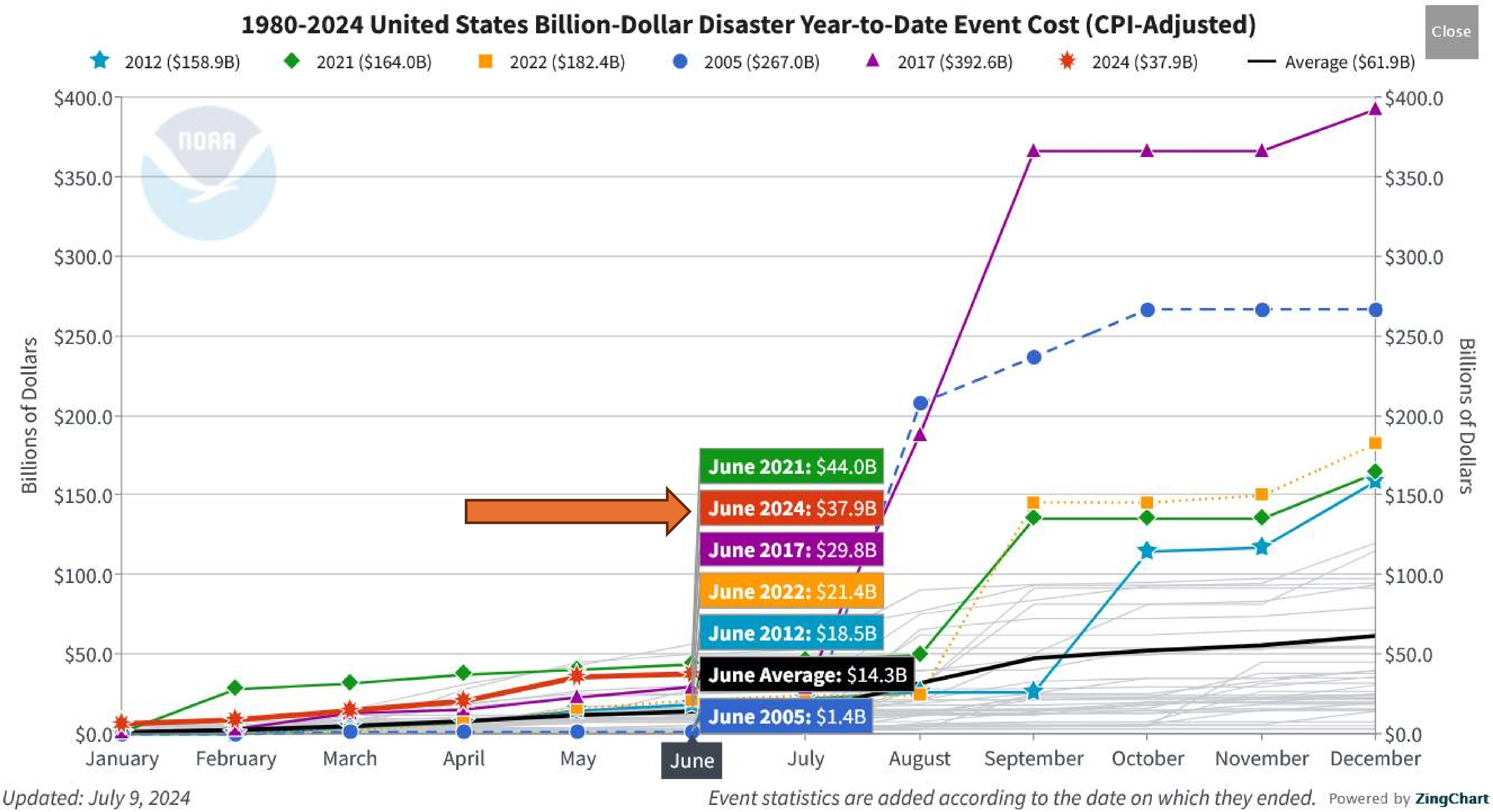


Updated: July 9, 2024

Data for Motivation



Agenda

Wednesday, August 7 | 110 Knox Hall | North Campus

Time	Topic	Speaker(s)
10:00 - 10:15 am	**Part 1: Icebreaker - Roundtable discussion of goals and commitments**	
	Part 2: Technical presentations of State-of-the-Art in Owners and Engineers	
10:15 - 10:30 am	**Resiliency & Sustainability in NYSDOT's Bridge Policies**	**Alan Zack**, New York State Department of Transportation
10:30 - 10:45 am	**NCDOT–Harkers Island & Alligator River Coastal Bridges**	**Cabell Garbee**, North Carolina Department of Transportation
10:45 - 11:00 am	**Evaluation of FRP Pedestrian Truss Bridges with Timber Decks**	**Dr. Hota GangaRao**, West Virginia University
11:00 - 11:15 am	**FDOT-Advancing Reinforced Concrete Design for Resilient & Sustainable Structures**	**Steven Nolan**, ACI 440C/243/CSAO
11:15 - 11:30 am	**I-Bridge: Innovative Corrosion Free Bridge**	**Dr. Franscisco De Caso**, University of Miami.
11:30 - 11:45 am	**Research and Developments on Improving FRP Rebar Sustainability - Manufacturing & Product Development to Meet Owner's Needs and Market Demand**	**Dr. Omar Alajarmeh**, University of Southern Queensland
11:45 a.m. - 12:00 pm	**Potential Applications Artificial Intelligence for Asset Management**	**Dr. Antonio De Luca**, Thornton Tomasetti
12:00 - 1:00 pm	**Lunch Break & Tour of the Structural Engineering and Earthquake Simulation Laboratory at the University at Buffalo**	

Agenda

Wednesday, August 7 | 110 Knox Hall | North Campus

Time	Topic	Speaker(s)
	Part 3: Technical presentations on Materials	
1:00 - 1:15 p.m.	**Allium Stainless-Clad Rebar for Resilient & Sustainable Reinforced Concrete Structures**	**Dr. Samuel McAlpine**, Allium Engineering
1:15 - 1:30 p.m.	**Innovative Composite Solutions for Sustainable Concrete Structures**	**Pierre Hofmann**, Dextra Group
1:30 - 1:45 p.m.	**GFRP Bars for More Resilient & Sustainable Bridges**	**Borna Hajimiragha**, MST Bar
1:45 - 2:00 p.m.	**Ground-Glass Pozzolan as a Sustainable Supplementary Cementitious Material for Portland Cement Concrete**	**Dr. Prasad Rajarangu**, Clemson University ****** REMOTE ******
	Part 4a: Technical presentations and/or discussion on Research Gaps	
2:00 - 2:10 p.m.	**Machine Learning for Evaluating In-Service Concrete Bridges**	**Dr. Pinar Okumus**, University at Buffalo
2:10 - 2:20 p.m.	**3D-Printed Ductile Concrete Covers for Improving Durability of Prestressed Concrete Bridge Girders**	**Dr. Ravi Ranade**, University at Buffalo
2:20 - 2:30 p.m.	**Post-Fire Assessment and Resilience Design of Reinforced Concrete Bridges**	**Dr. Negar Elhami-Khorasani**, University at Buffalo
2:30 - 2:45 p.m.	**Coffee Break**	

Agenda

Wednesday, August 7 | 110 Knox Hall | North Campus

Time	Topic	Speaker(s)
	Part 4b: Technical presentations and/or discussion on Research Gaps (cont.)	
2:45 - 3:00 p.m.	**The Response of Fiber Reinforced Polymer Composite Material Under Fire and Its Mitigation Methods**	**Dr. Ray Liang**, Western Virginia University
3:00 - 3:15 p.m.	**Analyzing Shear Strength of the Lightweight Concrete Reinforced with Glass Fiber Reinforced Polymer (GFRP) Bars**	**Dr. Saeid Haji Ghasemail**, State University of New York Canton
3:15 - 3:30 p.m.	**Life Cycle CO_2 Emissions Assessment for GFRP and Steel Structural Components and Systems**	**Md Ala Uddin and Faysal Ahamed**, West Virginia University
3:30 - 3:45 p.m.	**Puncture and Impact Responses of FRP Composite Jacketing for Railway Tank Car**	**Dr. Chao Zhang**, West Virginia University
3:45 - 4:00 p.m.	**Final Q&A, Wrap up, Summary of Outcomes**	

Announcements – Publication Opportunity

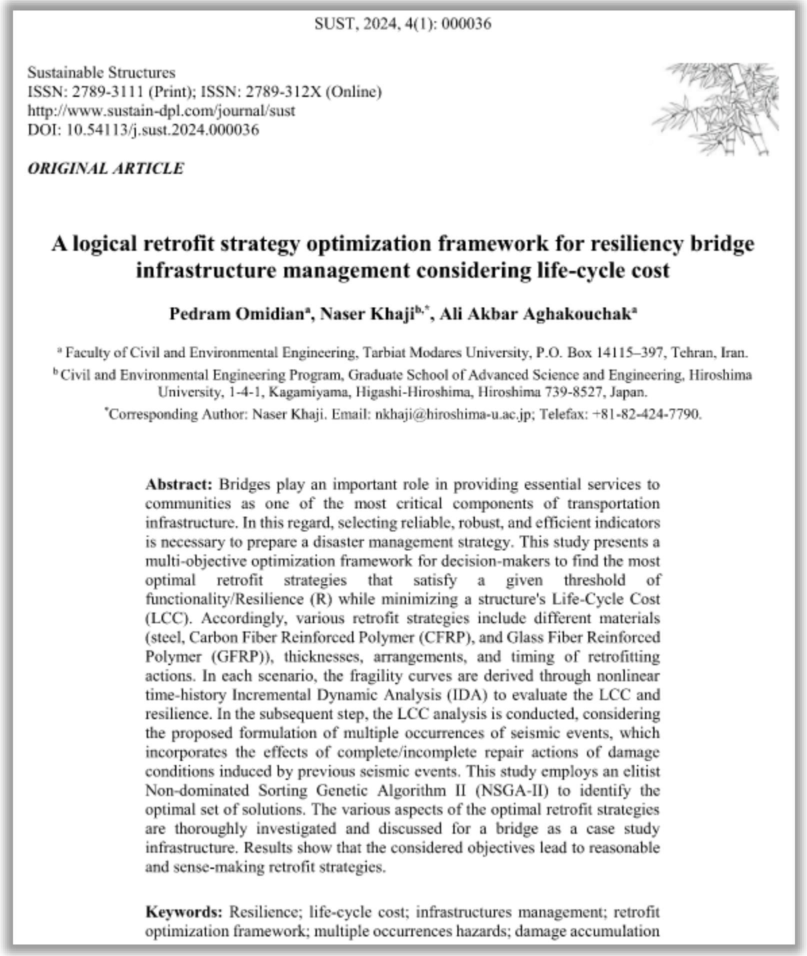
Speakers from *SPxRBS-2023* and *NPxRBS-2024* are encouraged to submit their technical manuscripts following the workshop to the **"Sustainable Structures"** journal. Accepted manuscripts will be compiled in Special Issue titled **"Resilient-Sustainable Bridges & Structures,"** containing 10 to 15 papers. This special issue is scheduled for publication December 2024.

Sustainable Structures Journal (SuSt)

Editor-in-Chief, Americas: Prof. Ruifeng (Ray) Liang, West Virginia University, Morgantown, WV.

Guest Editors:

- Dr. Pinar Okumus, Associate Professor, University at Buffalo, Institute of Bridge Engineering, NY.
- Prof. Prasad Rajarangu, Clemson University, SC.
- Steven Nolan, P.E., Senior Structures Design Engineer, Florida Department of Transportation, FL.



SUST, 2024, 4(1): 000036

Sustainable Structures
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http://www.sustain-dpl.com/journal/sust
DOI: 10.54113/j.sust.2024.000036

ORIGINAL ARTICLE

A logical retrofit strategy optimization framework for resiliency bridge infrastructure management considering life-cycle cost

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[b] Civil and Environmental Engineering Program, Graduate School of Advanced Science and Engineering, Hiroshima University, 1-4-1, Kagamiyama, Higashi-Hiroshima, Hiroshima 739-8527, Japan.
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Abstract: Bridges play an important role in providing essential services to communities as one of the most critical components of transportation infrastructure. In this regard, selecting reliable, robust, and efficient indicators is necessary to prepare a disaster management strategy. This study presents a multi-objective optimization framework for decision-makers to find the most optimal retrofit strategies that satisfy a given threshold of functionality/Resilience (R) while minimizing a structure's Life-Cycle Cost (LCC). Accordingly, various retrofit strategies include different materials (steel, Carbon Fiber Reinforced Polymer (CFRP), and Glass Fiber Reinforced Polymer (GFRP)), thicknesses, arrangements, and timing of retrofitting actions. In each scenario, the fragility curves are derived through nonlinear time-history Incremental Dynamic Analysis (IDA) to evaluate the LCC and resilience. In the subsequent step, the LCC analysis is conducted, considering the proposed formulation of multiple occurrences of seismic events, which incorporates the effects of complete/incomplete repair actions of damage conditions induced by previous seismic events. This study employs an elitist Non-dominated Sorting Genetic Algorithm II (NSGA-II) to identify the optimal set of solutions. The various aspects of the optimal retrofit strategies are thoroughly investigated and discussed for a bridge as a case study infrastructure. Results show that the considered objectives lead to reasonable and sense-making retrofit strategies.

Keywords: Resilience; life-cycle cost; infrastructures management; retrofit optimization framework; multiple occurrences hazards; damage accumulation

Announcements – August 2025 (Raleigh, NC)

2025 East Peer Exchange for Resilient and Sustainable Bridges (EPxRBS-2025)

Chair: Prof. Rudy Seracino
North Carolina State University
Department of Civil, Construction, and Environmental Engineering, https://ccee.ncsu.edu/
Director: Constructed Facilities Laboratory https://ccee.ncsu.edu/cfl/
Director: NSF I/UCRC Center for the Integration of Composites into Infrastructure, https://ccee.ncsu.edu/cici/
P: 919-515-7695
E: rseraci@ncsu.edu

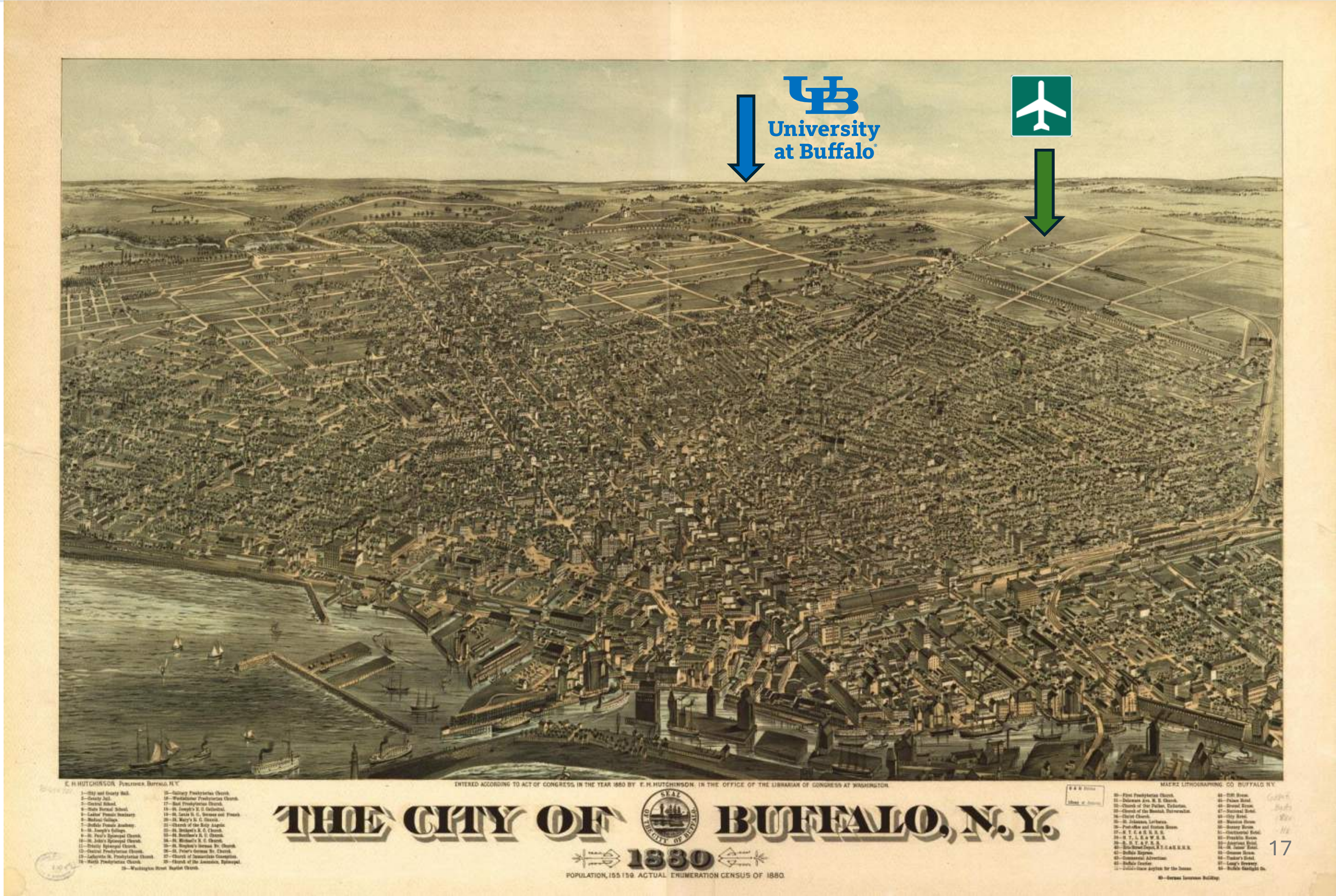
Secretariat: Steven Nolan, P.E.
Senior Structures Design Engineer
Florida Department of Transportation
P: 850-414-4272 E: steven.nolan@dot.state.fl.us

Announcements – Open Call

Questions?

Pinar Okumus, Ph.D. (Chair)
Associate Professor
University at Buffalo
pinaroku@buffalo.edu
716-645-4356

Steven Nolan, P.E. (Secretariat)
Senior Structures Design Eng.
Florida Department of
Transportation
steven.nolan@dot.state.fl.us
850-414-4272



Resiliency and Sustainability in NYSDOT's Bridge Policies

2nd Regional Peer Exchange for Resilient-Sustainable Bridges and Structures

August 7th, 2024

Alan Zack, P.E.
NYSDOT Office of Structures

Alan Zack, P.E.

SUNY Buffalo – BS Civil Engineering, 2010.

Worked in the private sector for 7 years

Obtained NYS Professional Engineering License, 2018

Employed by NYSDOT April 2018-Present

Project Engineer / Squad Leader – Buffalo Satellite Squads 7 & 10, Structures Design Bureau

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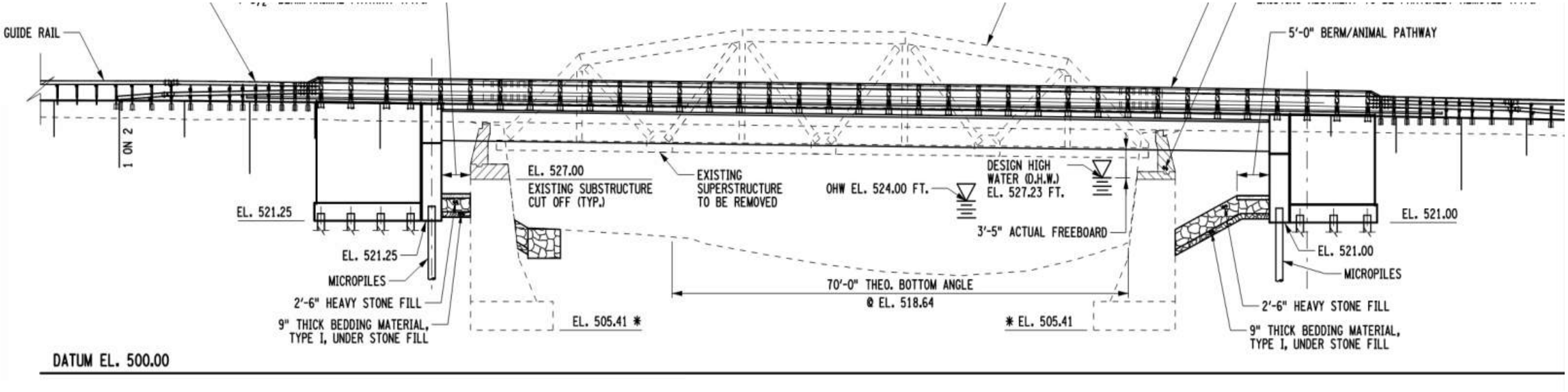
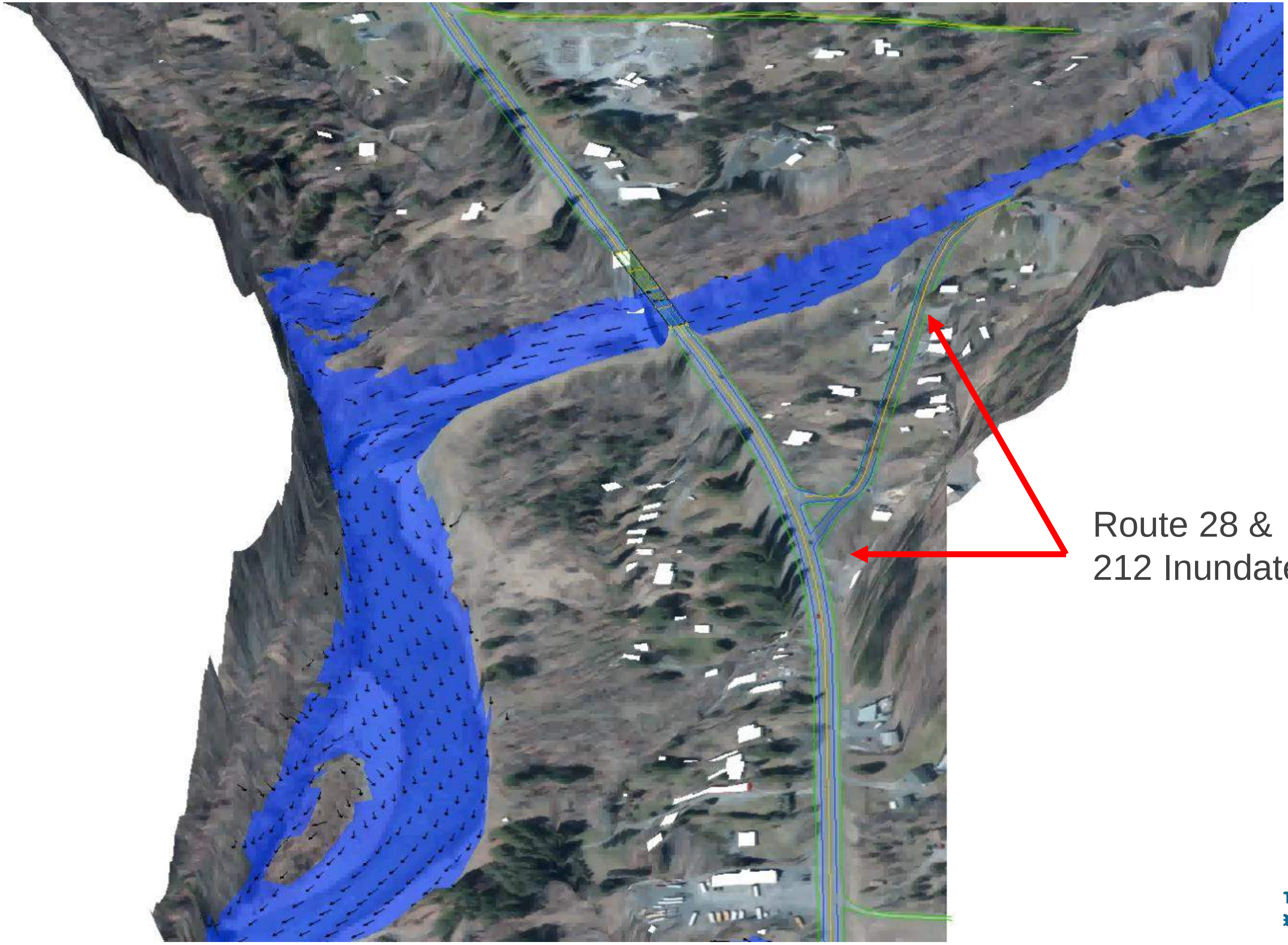
Agenda

- Hydraulic Design Policies
- Available Reinforcement Options and Policies
- Jointless Details – New Construction
- Jointless Details – Rehabilitations
- Superbox Project

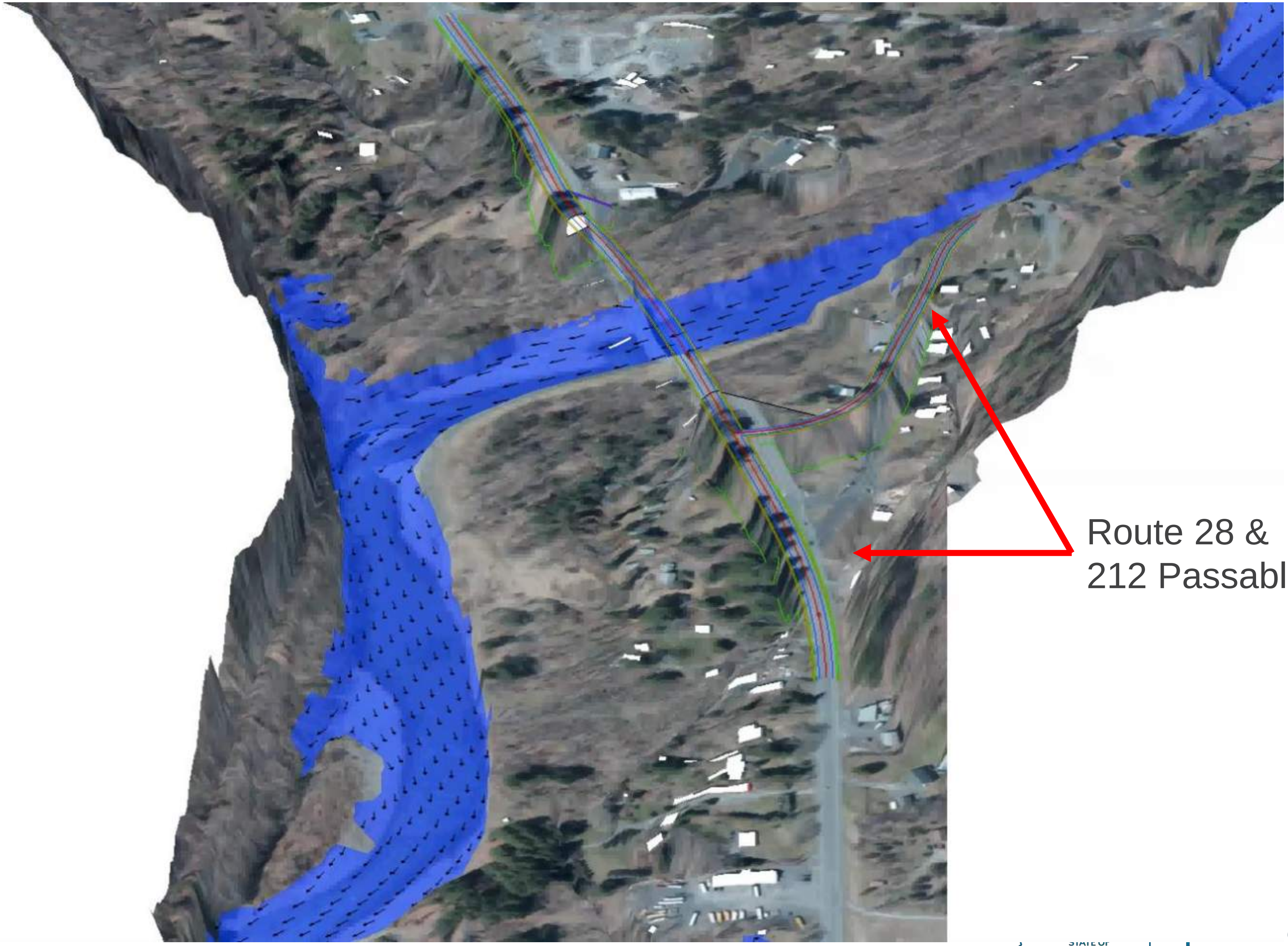
Hydraulic Design Policies

- Current peak flows shall be increased by 10% or 20%.
- Proposed structure shall not raise water surface elevations for both Q50 and Q100 events.
- 2’-0” of freeboard for projected Q50. Critical bridges require 3’-0” of freeboard for Q50.
- Q100 shall pass below the low chord without touching it.
- Proposed low chord shall not be lower than existing.





Route 28 &
212 Inundated



Route 28 &
212 Passable

Concrete Reinforcement

- Stainless Steel
- Chromium Steel
- Dual – Coated
- Hot-Dip Galvanized
- Epoxy Coated
- Plain

Bar Protection Type	***In-Place Cost Ratio***
Stainless Steel	*2.5*
Chromium Steel	*1.5*
Dual-Coated	*1.3**
Hot-Dip Galvanized	*1.2*
Epoxy-Coated	*1.1*
Plain	*1.0*

*Assumed costs based on a limited number of projects.

Table 15-2
Approximate Reinforcement Cost Comparison

Bar Protection Type	***Expected Service Life (years)***
Stainless Steel	*125+*
Chromium Steel	*75+*
Dual-Coated	*50+*
Hot-Dip Galvanized	*50*
Epoxy-Coated	*50*
Plain	*20*

Table 15-3
Expected Service Life

Concrete Reinforcement

Chromium Reinforcement

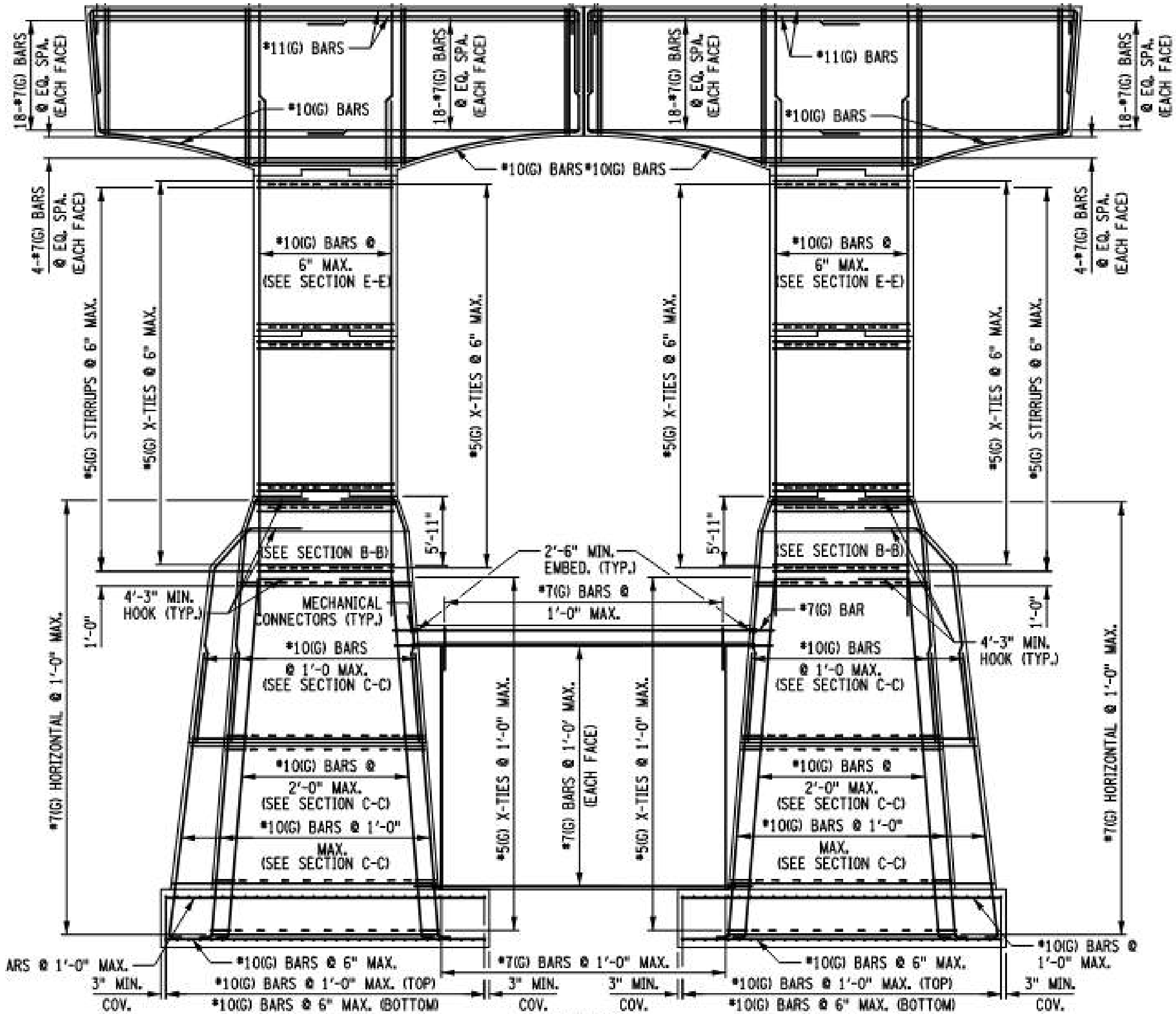
- Standard grade – 100ksi
- Used in areas of high tensile stresses where Grade 60 reinforcement would result in insufficient spacing between bars.

Stainless Steel

- Standard grade – 75ksi
- Used in areas of high traffic volumes (2-way AADT 50,000+/-, 1-way AADT 25,000+/-)
- Repair work would result in high user costs
- Used in cap beams under joints
- 8½" Deck (*NYSDOT standard deck thickness is 9 ½")

Concrete Reinforcement

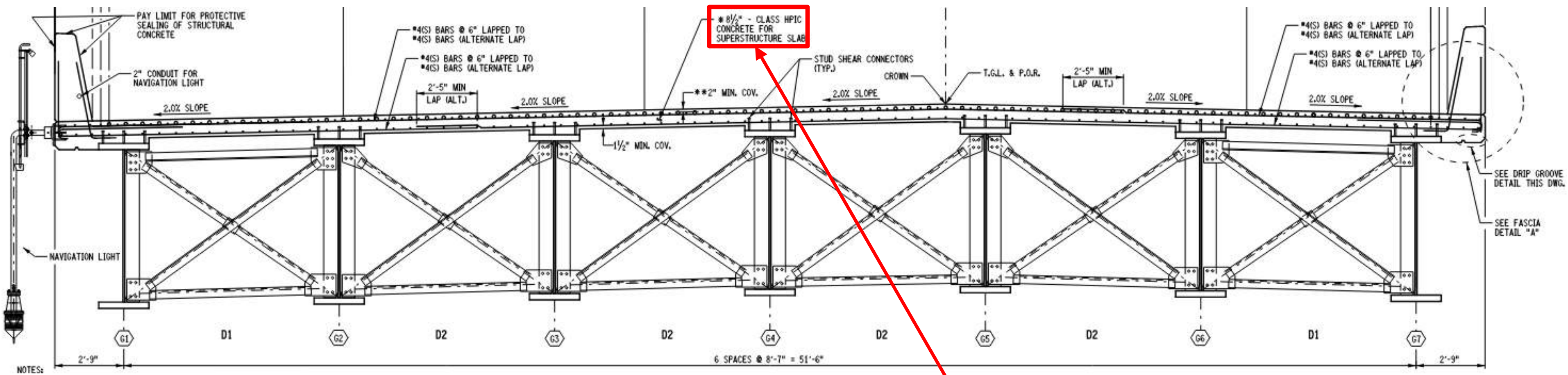
Galvanized



ELEVATION
(PIER 1 SHOWN - PIERS 2 AND 3 SIMILAR)

Concrete Reinforcement

Stainless Steel



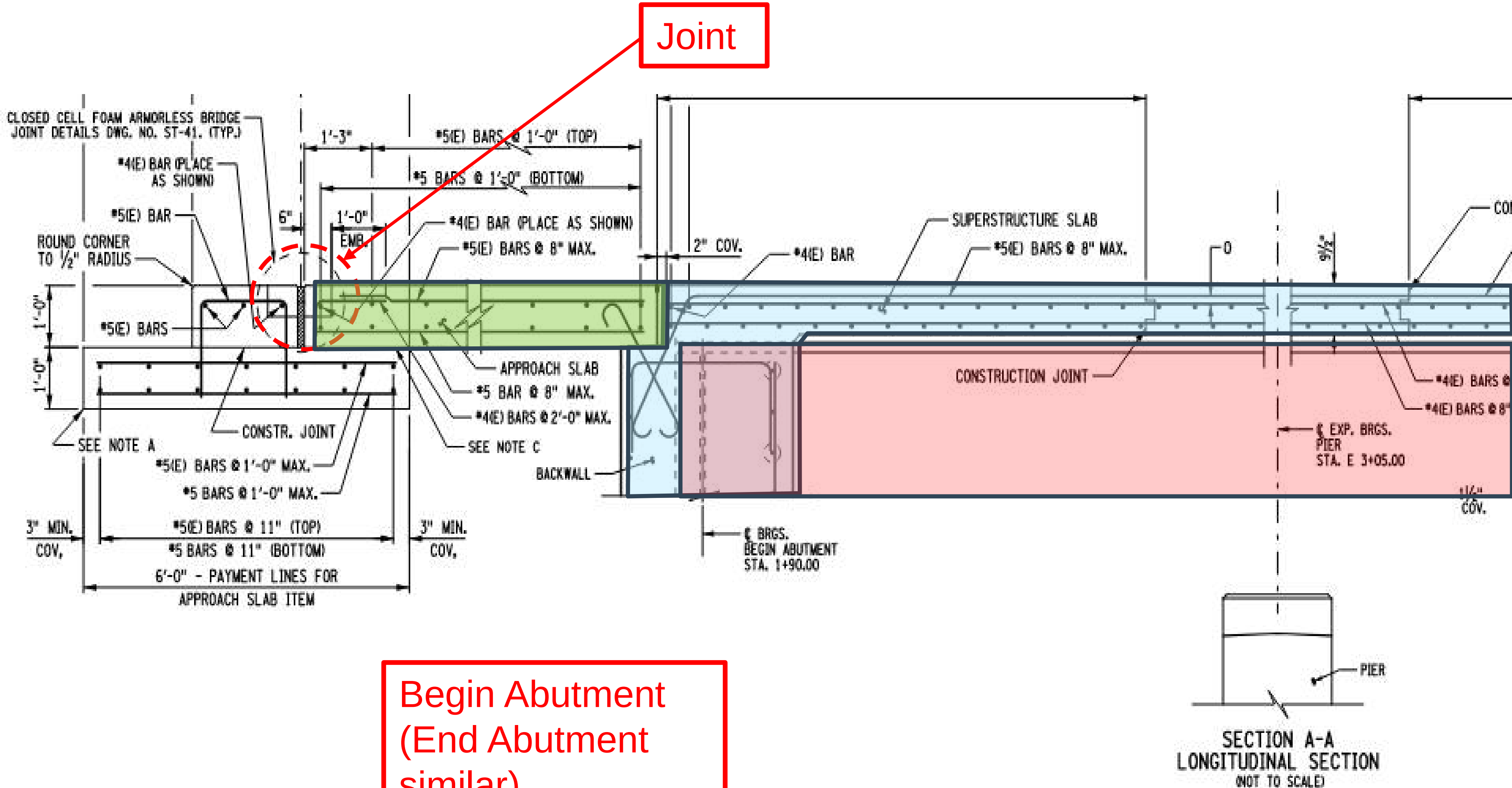
*NYSDOT standard deck thickness is 9 ½"

✱8½" - CLASS HPIC CONCRETE FOR SUPERSTRUCTURE SLAB

Jointless Details

Jointless Details – New Construction

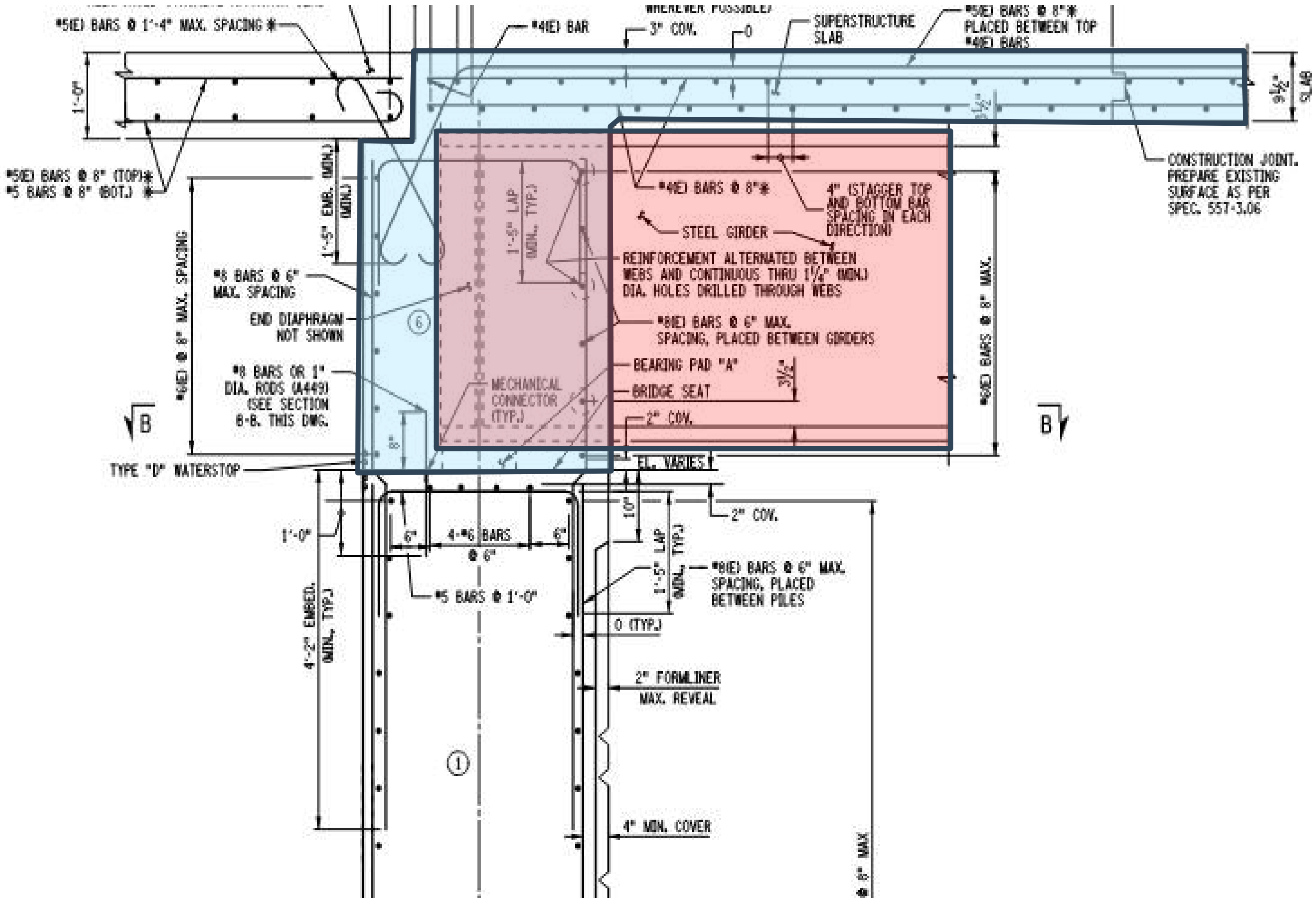
Integral Abutment



Begin Abutment (End Abutment similar)

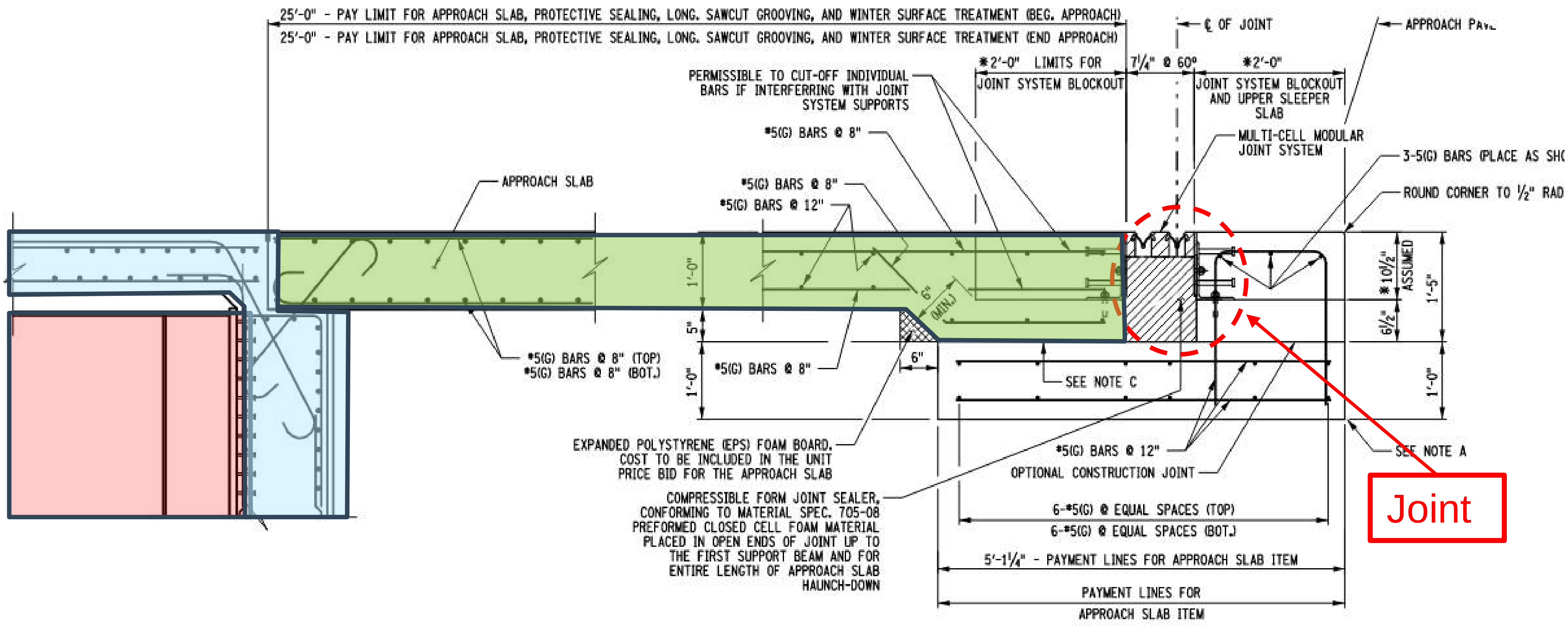
Jointless Details – New Construction

Integral Abutment



Jointless Details – New Construction

Semi-Integral Abutment



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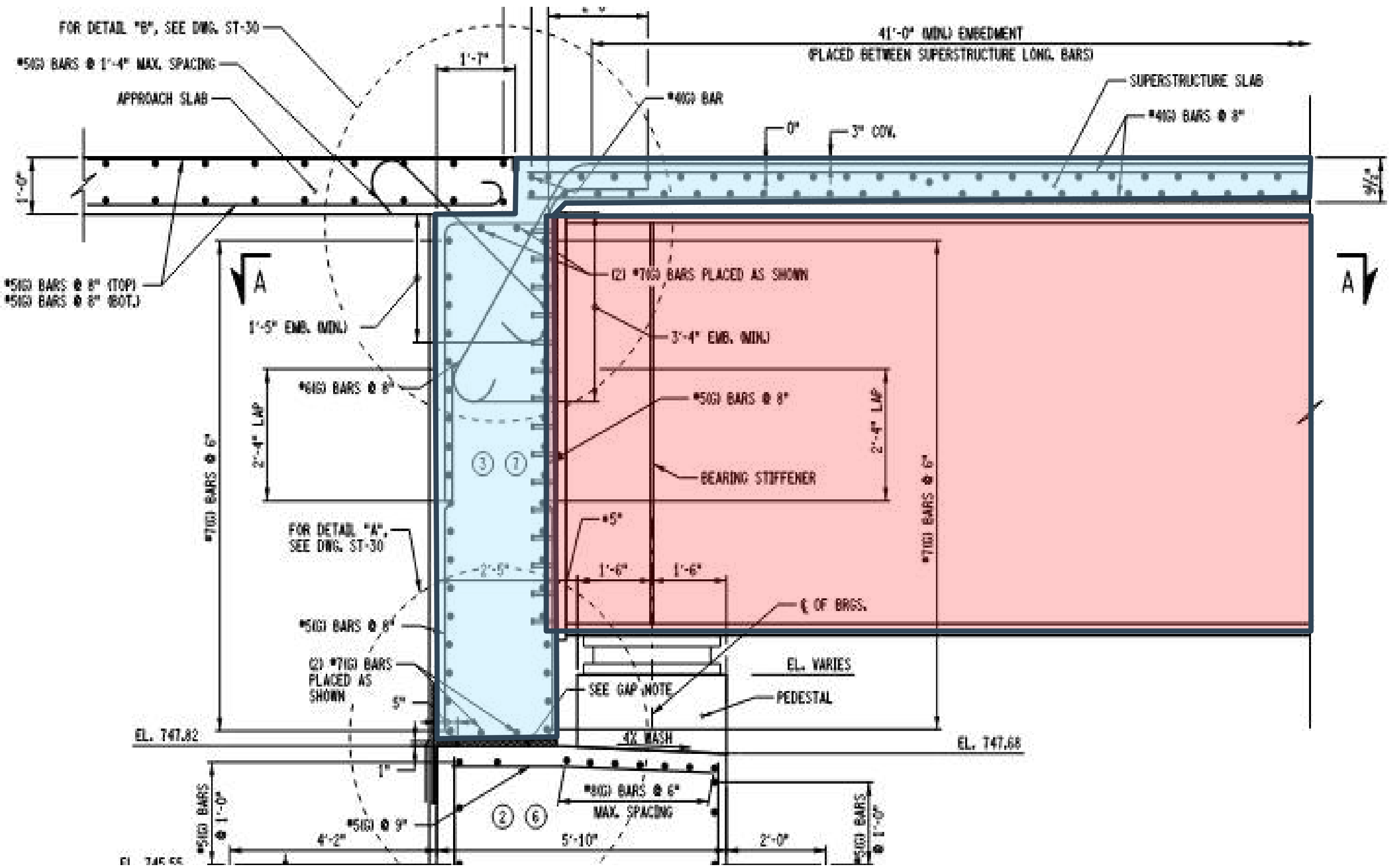
Jointless Details – New Construction

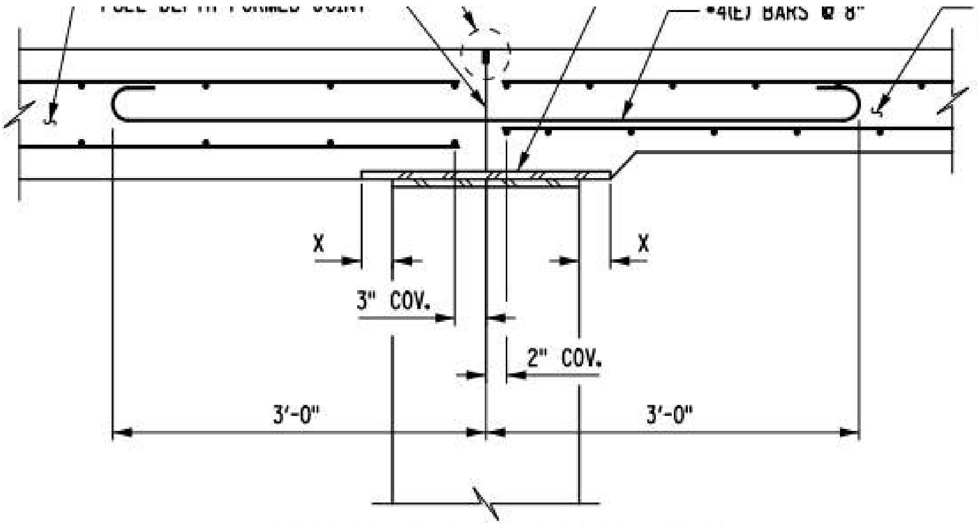
Semi-Integral Abutment



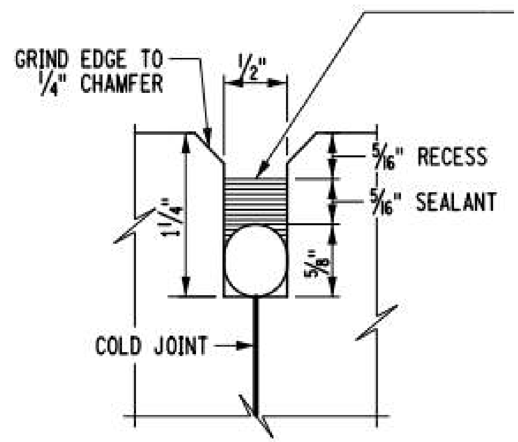
Jointless Details – Rehabilitations

Conventional Detail:

- Can be done during full deck replacements or localized deck replacement.
- Partial backwall removal to facilitate jointless detail.
- Build new backwall up to the underside of the deck and approach slabs.



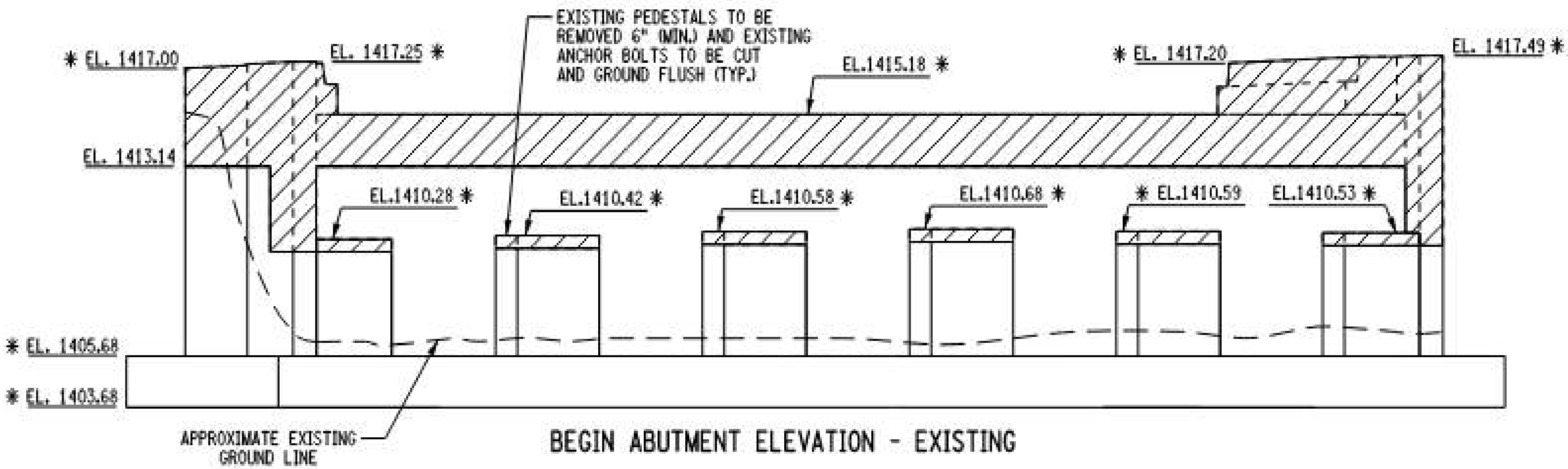
REINFORCEMENT DETAIL FOR JOINTLESS ABUTMENTS



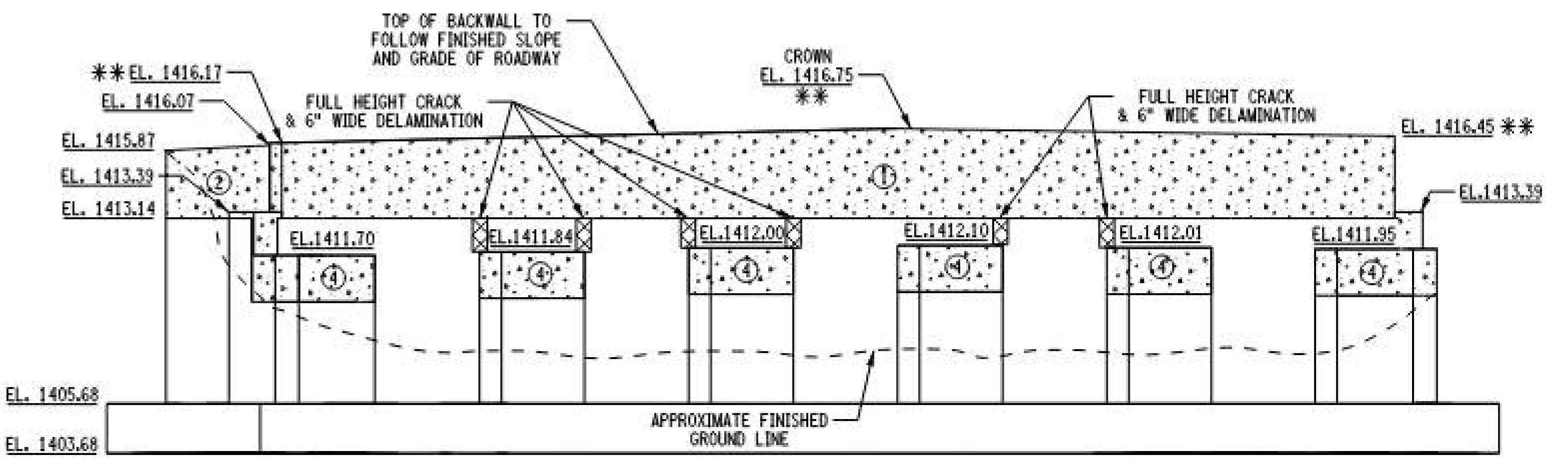
JOINT RECESS DETAIL

Jointless Details – Rehabilitations

Conventional Detail:



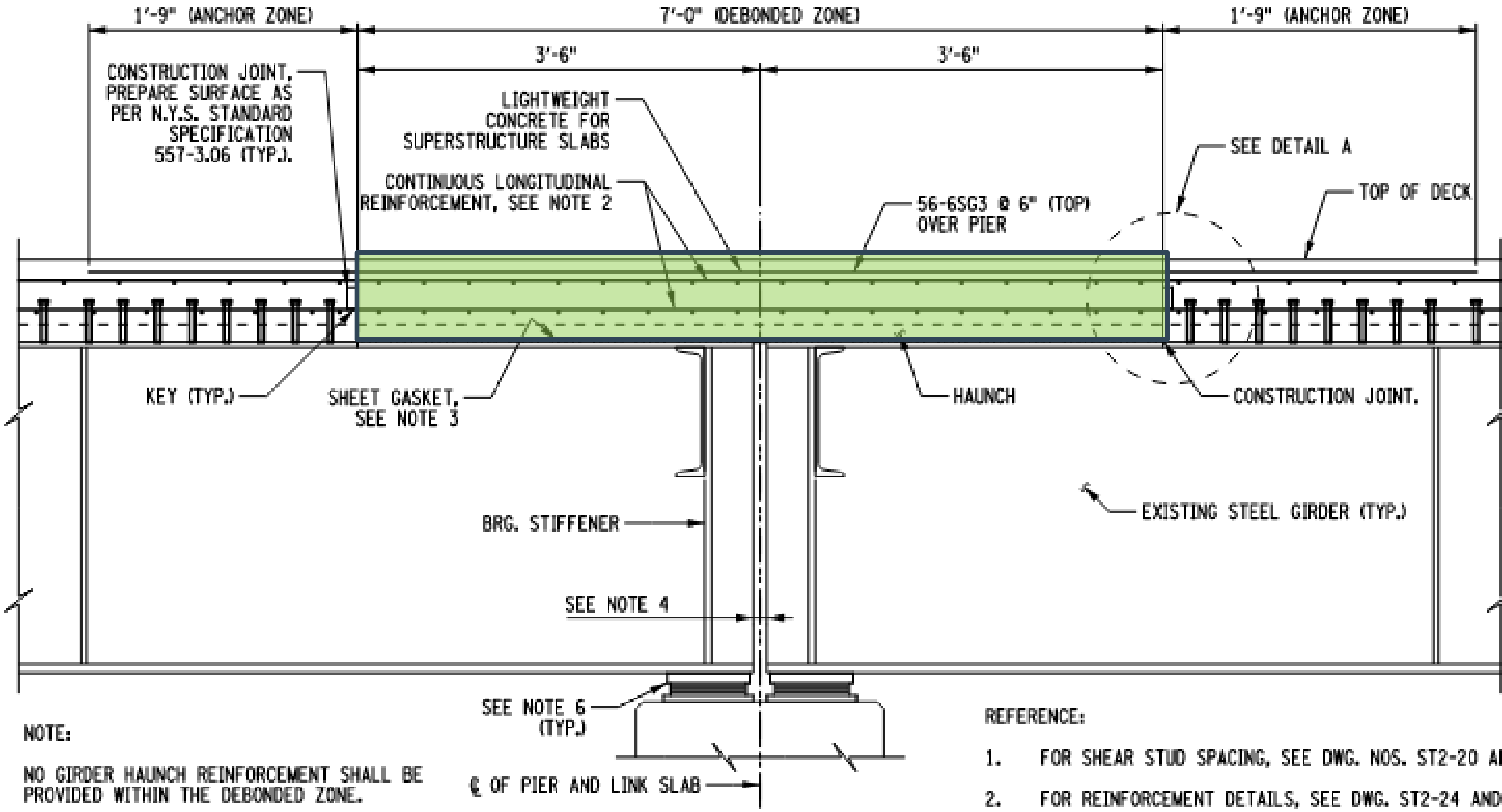
BEGIN ABUTMENT ELEVATION - EXISTING



BEGIN ABUTMENT ELEVATION - PROPOSED

Jointless Details – Rehabilitations

Link Slabs:



CONVENTIONAL LINK SLAB DETAIL

NOTE:

NO GIRDER HAUNCH REINFORCEMENT SHALL BE PROVIDED WITHIN THE DEBONDED ZONE.

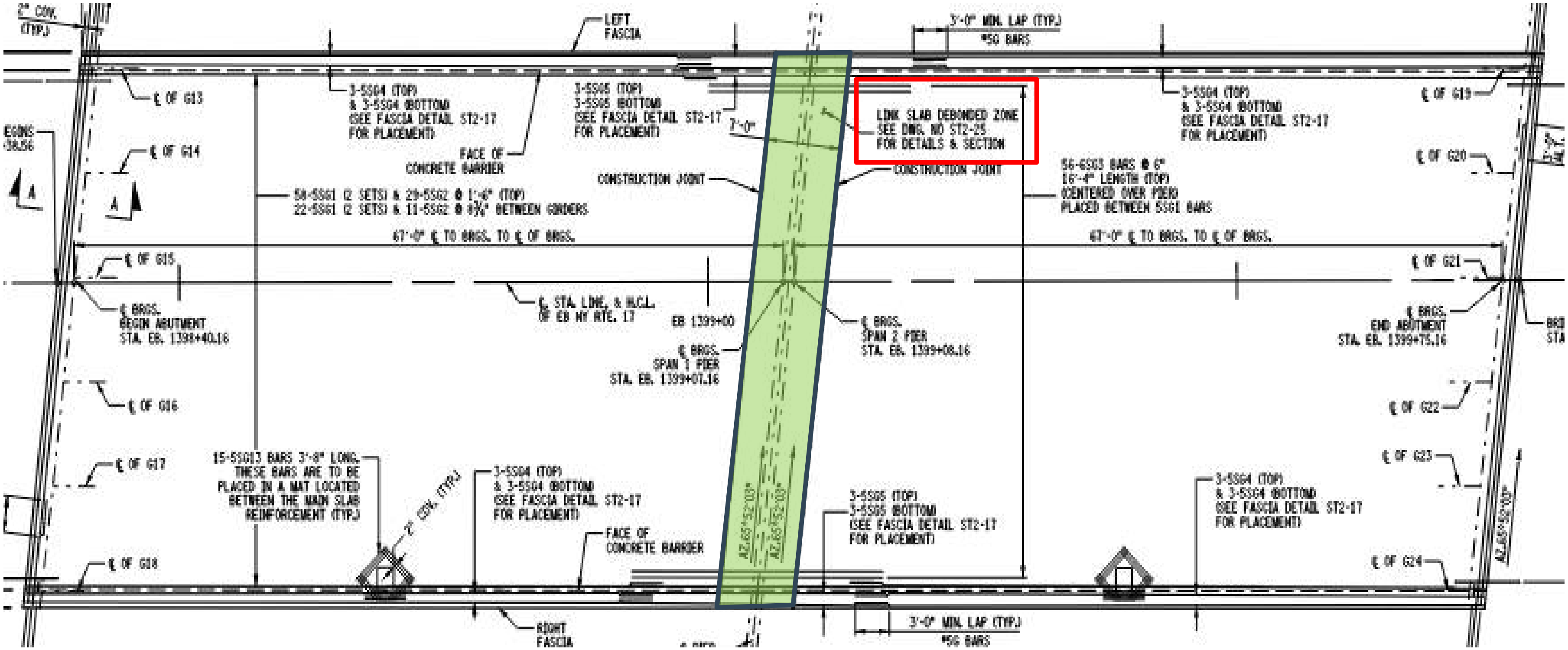
TRANSVERSE BARS NOT SHOWN FOR CLARITY

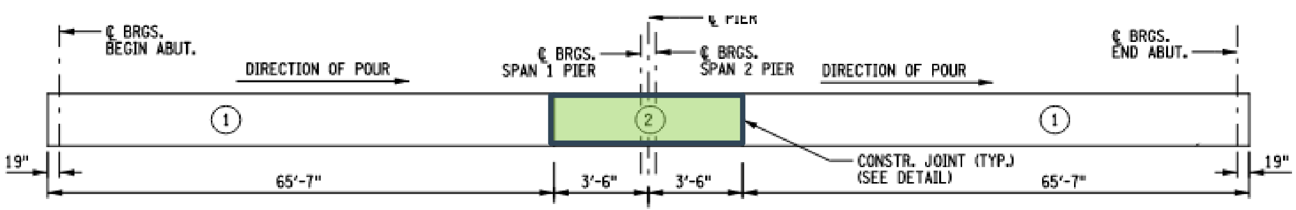
REFERENCE:

1. FOR SHEAR STUD SPACING, SEE DWG. NOS. ST2-20 AND ST2-21
2. FOR REINFORCEMENT DETAILS, SEE DWG. ST2-24 AND ST2-26

Jointless Details – Rehabilitations

Link Slabs:





SLAB PLACEMENT SEQUENCE

Superbox

GOAL: Have NYSDOT act faster and more efficiently to reconnect communities and areas affected from culvert failures

Pre-fabricated & Stockpiled Box Culverts

Structurally Hefty

Hydraulically Robust

Majority of Culverts in NYS

Superbox

Finding Information:

Size (Span Length):
- Majority of Culverts are 16' or less in span
- Over 400 Culverts with clear span > 18'
- Max Box Culvert Clear Span = 24'

Height of fill:
- Average 4' of fill
- Ranges from 0'-92'

Skew:
- Average = 24°
- Over 1,500 Culverts with Skew > 30°

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Superbox

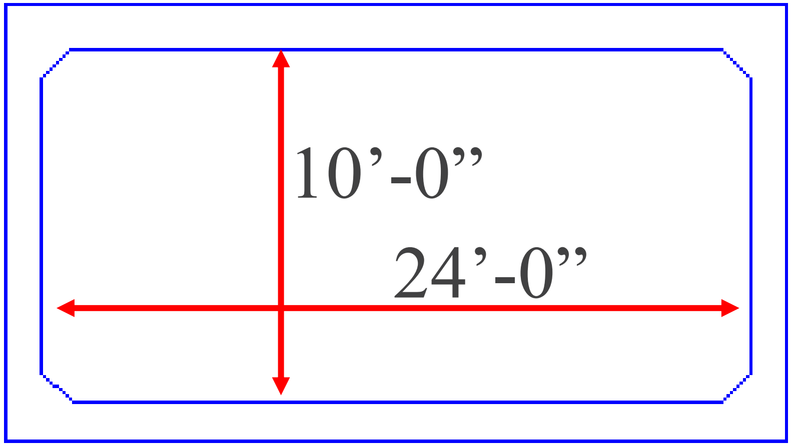
Design Parameters for Fabricator:

<u>Slab Thickness</u>

20” - 0’-17’ of fill

18” – 0’-15’ of fill

16” – 0’-12’ of fill

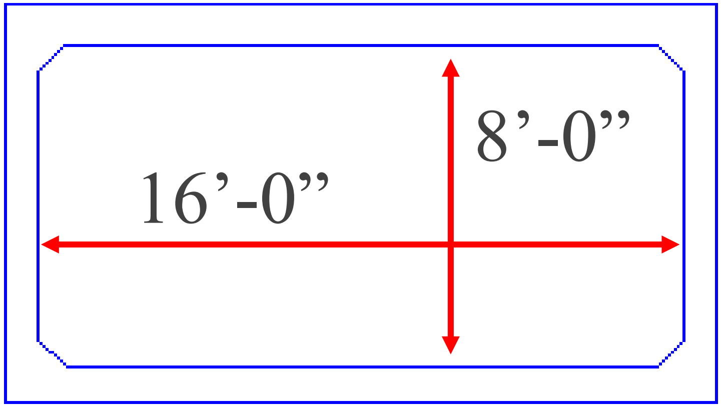


<u>Slab Thickness</u>

18” - 0’-26’ of fill

16” – 0’-22’ of fill

14” – 0’-18’ of fill



Superbox

Design Parameters for Fabricator:

Final Design Parameters

24’ Superbox	**16’ Superbox**
Any skew	Any skew
0’-17’ of fill	0’-20’ of fill

Superbox

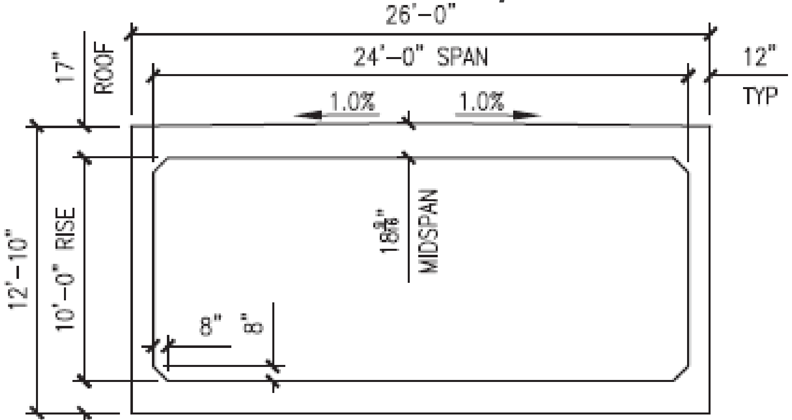
Fabricated and Stockpiled

BOX CULVERT DESIGN DATA	
CLEAR SPAN, ft.	24'-0"
STRUCTURE RISE, ft.	10'-0"
* MIN. FILL HEIGHT, ft.	0'-4"
* MAX. FILL HEIGHT, ft.	17'-0"
SKEW ANGLE ⊥ TO ℄ OF ROADWAY, DEG.	VARY FROM 0° TO 45° FOR STRENGTH 30° ASSUMED FOR DETERMINING BARREL LENGTH
LIVE LOAD	HL-93 WITH MINIMUM LRFR INVENTORY RATING OF 1.2
RAILING / BARRIER TEST LEVEL	N.A.

REQUIRED LOAD RATINGS			
MAX. FILL HEIGHT	MIN. FILL HEIGHT	SKEW < 15 DEGREES	SKEW > 15 DEGREES
23 INCHES	4 INCHES	(CONDITION 1)	(CONDITION 2)
17 FEET	15 FEET	(CONDITION 3)	(CONDITION 4)

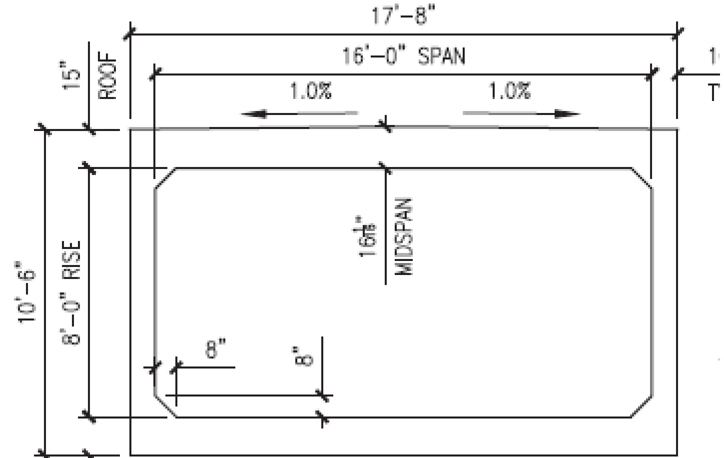
Superbox

Fabricated and Stockpiled



24'X10' TYPICAL CULVERT SECTION

NOTE: APPLIES TO MK#'S C1–C3



16'X8' TYPICAL CULVERT SECTION

NOTE: APPLIES TO MK#'S C4–C6

24'x10' CULVERT DESIGN NOTES:

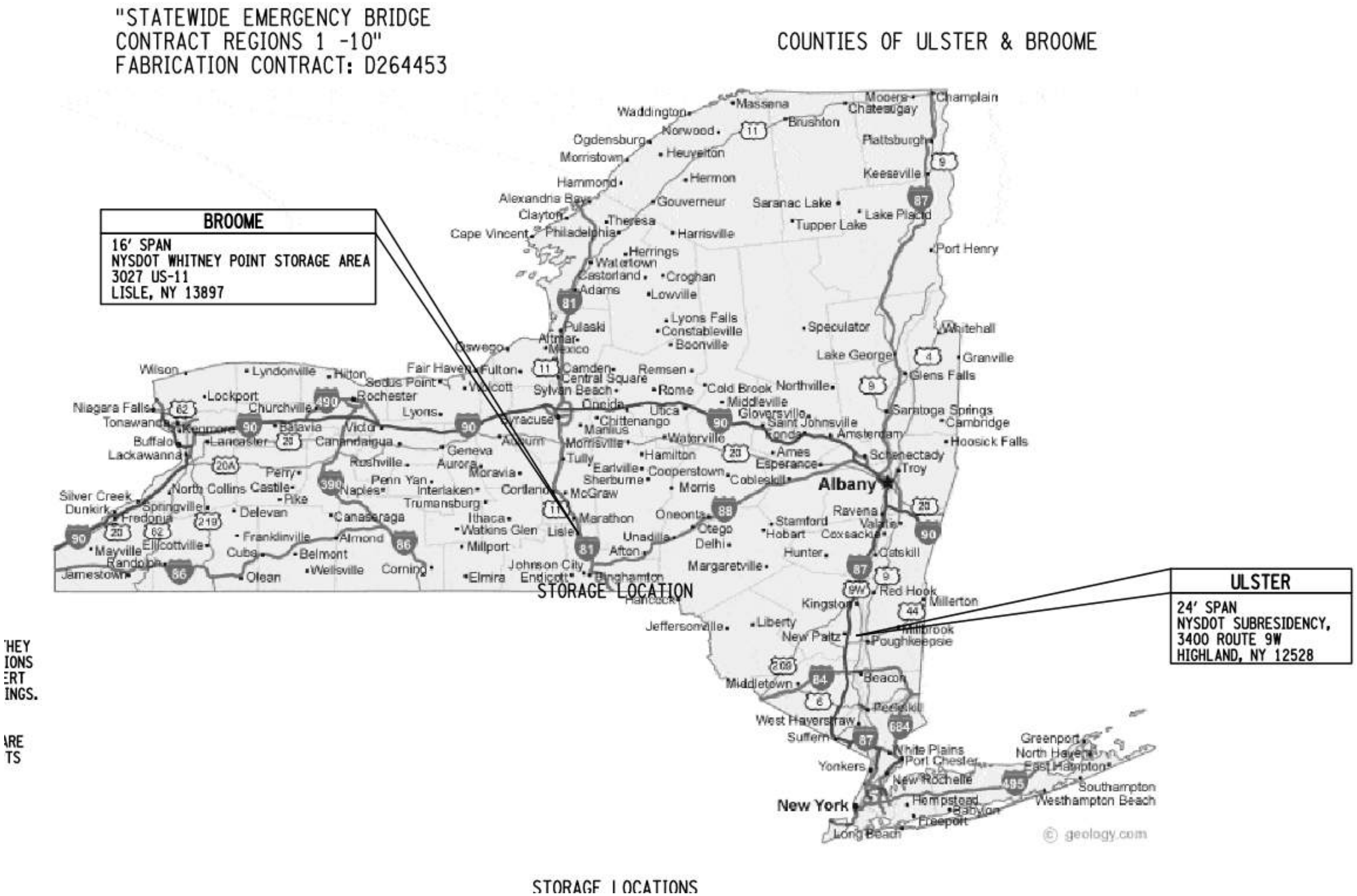
1. ASSUMED EARTH COVER = 0.33 FT (MIN) TO 17 FT (MAX)
2. CONCRETE CULVERT UNITS C1 – C3 CONCRETE STRENGTH SHALL BE 7,000 PSI AT 28 DAYS
3. DESIGN LOAD = HL–93 LIVE LOAD
4. MIN. LIFTING (STRIPPING) STRENGTH = 3,500 PSI.
5. SKEW ANGLE PERPENDICULAR TO ℄ OF ROADWAY = 45° MAX

16'x8' CULVERT DESIGN NOTES:

1. ASSUMED EARTH COVER = 0.33 FT (MIN) TO 20 FT (MAX)
2. CONCRETE CULVERT UNITS C4 – C6 CONCRETE STRENGTH SHALL BE 6,000 PSI AT 28 DAYS
3. DESIGN LOAD = HL–93 LIVE LOAD
4. MIN. LIFTING (STRIPPING) STRENGTH = 3,500 PSI.
5. SKEW ANGLE PERPENDICULAR TO ℄ OF ROADWAY = 45° MAX

Superbox

Fabricated and Stockpiled



Superbox

Route 7 over Hoosic River

Superbox

Route 7 over Hoosic River

Superbox

Route 7 over Hoosic River

Superbox

Route 7 over Hoosic River

- *Does the Superbox work?*

Existing Site:

1) Clear Opening = 24'

2) Depth of Fill = 8.5'

3) Skew = 45°

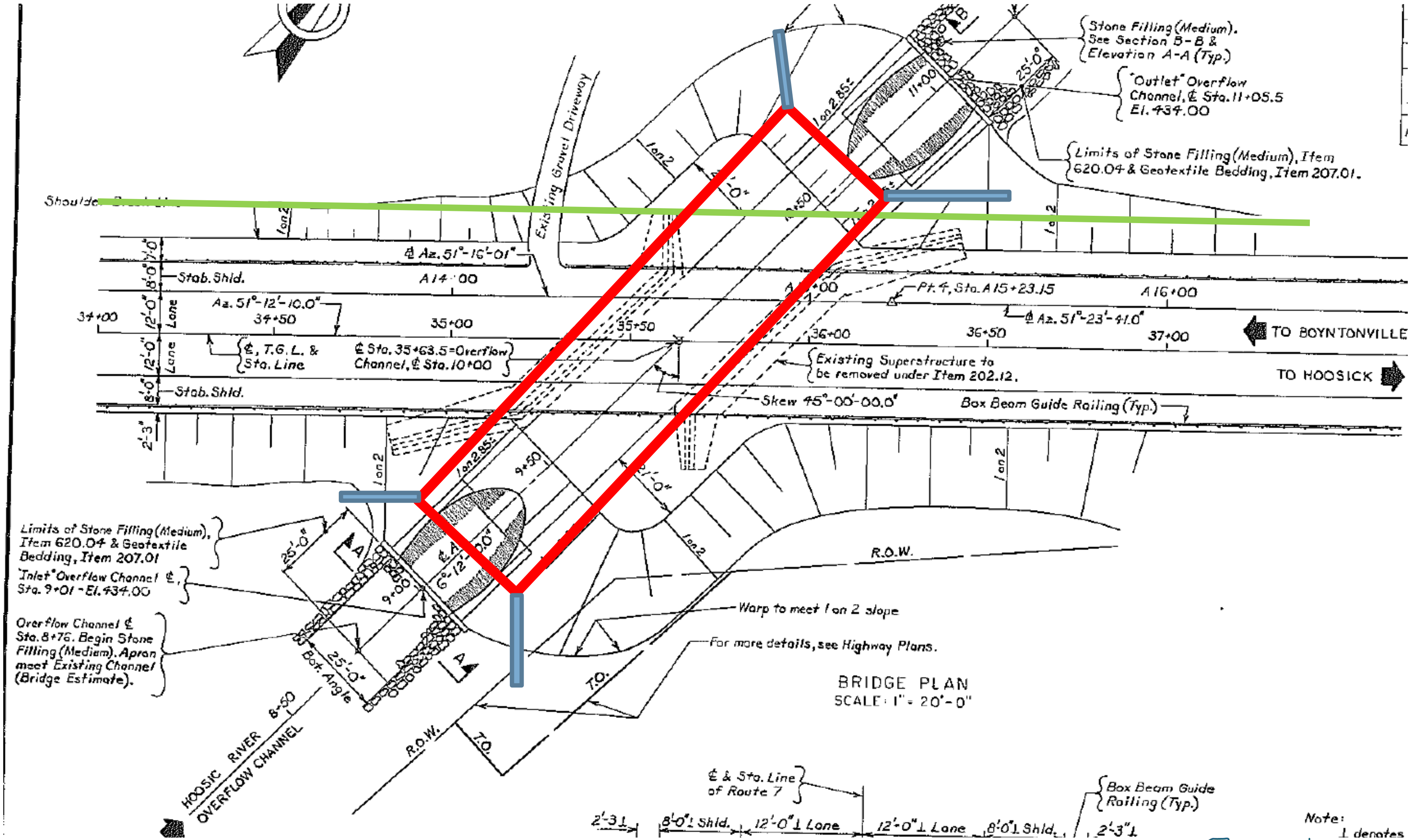
BOX CULVERT DESIGN DATA	
CLEAR SPAN, ft.	24'-0"
STRUCTURE RISE, ft.	10'-0"
* MIN. FILL HEIGHT, ft.	0'-4"
* MAX. FILL HEIGHT, ft.	17'-0"
SKEW ANGLE ⊥ TO ℄ OF ROADWAY, DEG.	VARY FROM 0° TO 45° FOR STRENGTH 30° ASSUMED FOR DETERMINING BARREL LENGTH
LIVE LOAD	HL-93 WITH MINIMUM LRFR INVENTORY RATING OF 1.2
RAILING / BARRIER TEST LEVEL	N.A.

Superbox

Route 7 over Hoosic River

KEY

= PROPOSED RETENSION WALL
= PROPOSED CULVERT LAYOUT
= EXISTING OVERHEAD UTILITY



Superbox

Route 7 over Hoosic River

Superbox

Route 7 over Hoosic River

Superbox

Route 7 over Hoosic River

January 2023

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

www.a-printable-calendar.com

Design Process

Began Jan. 13th

Ended Jan. 20th

1 Week

Construction

Began Jan. 13th

Ended Feb. 3rd

3 Weeks

Thank You

Alan Zack – Project Engineer
Alan.Zack@dot.ny.gov
(716) 847-3489

NEW YORK STATE OF OPPORTUNITY. Department of Transportation

Evaluation of Fiber Reinforced Polymer (FRP) Composites Truss Bridges with Timber Decks

Hota V.S. Gangarao, Jack Wykle and Chao Zhang

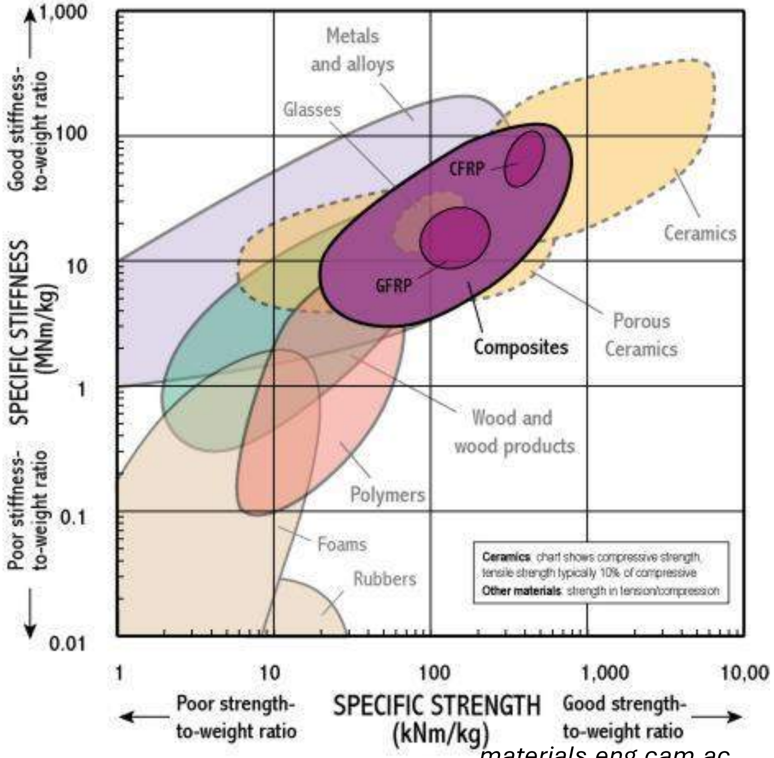
Constructed Facilities Center (CFC) and Center for the Integration of Composites into Infrastructure (CICI),

West Virginia University, Morgantown, WV 26506, USA

Prof. Hota V. S. GangaRao, Ph.D., P.E., F.ASCE, F.SEI

- **Maurice A. & JoAnn Wadsworth Distinguished Professor of CEE**
- **Director, NSF's Center for Integration of Composites into Infrastructure**
- **Director, Constructed Facilities Center**

Prof. GangaRao has chaired/co-chaired numerous professional committees under ASCE, ACMA, ACI, PIANC, and ICERP. He co-authored a draft FRP composites specification for construction, holds 14 US patents, and has published over 400 refereed papers. His work on timber bridges has been adopted by AASHTO, leading to the construction of over 100 timber bridges in the US and the rehabilitation of many railroad timber bridges with FRP composites. He teaches timber design at WVU and received ACMA's 'Professor of the Year' award in 2022.



materials.eng.cam.ac.uk

Glass Fiber (GFRP) Carbon Fiber (CFRP) Basalt Fiber (BFRP)

From internet

- **Fiber Reinforced Polymers (FRP) Composites are made of a polymer matrix reinforced with fibers.**
- **2 to 8 times stronger than mild steel based on fiber type on unit weight basis (specific strength)**
- **More flexible than steel, but some carbon composite are 3 times stiffer than steel**

Corrosion Resistance to chemicals and water

Sustainable
Expected life of 50 to 75 years and even longer (100+ years)
No Maintenance

Prefabricated Large Structures

Simpler installation
Faster installation
Less expensive installation

Light Weight for Accelerated Construction

80% lighter than concrete decking
Reduced cost of substructure

Architectural/Structural Features Molded into Structure

Many surface finish options
Crowns, cross slopes, scuppers, curbs, etc..

Design Flexibility

High strength; high energy absorption
Size, shapes, structural properties

Introduction - Composites

- **Strong, stiff fibers surrounded by tough environmentally resistant polymers**
- **FRP Composites are orthotropic materials, i.e.,**
  - **Properties are different along each axis.**
  - **Designer can tailor thermal-mechanical properties in each direction.**
- **Deflection generally drives the design**
  - **L/240, L/360 or L/500**
  - **Results in high strength safety factors**

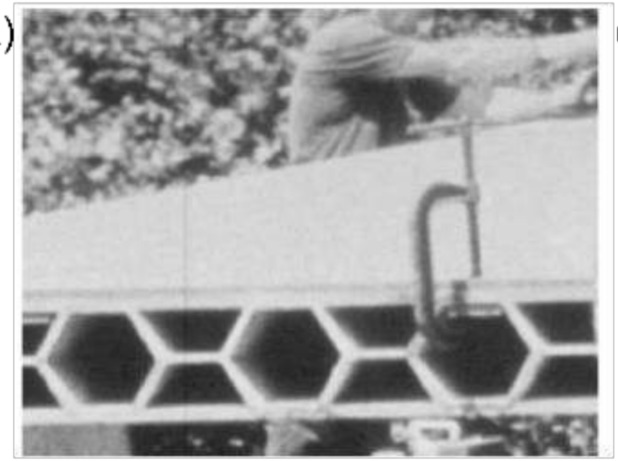
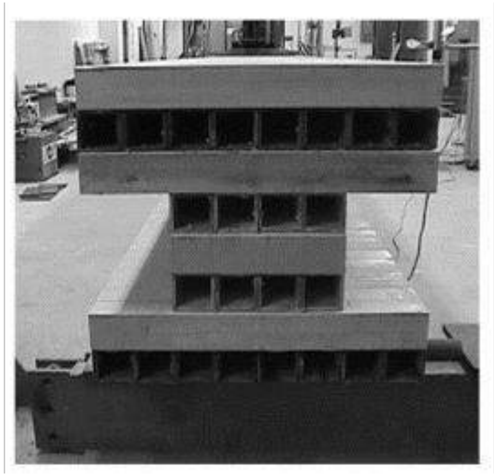
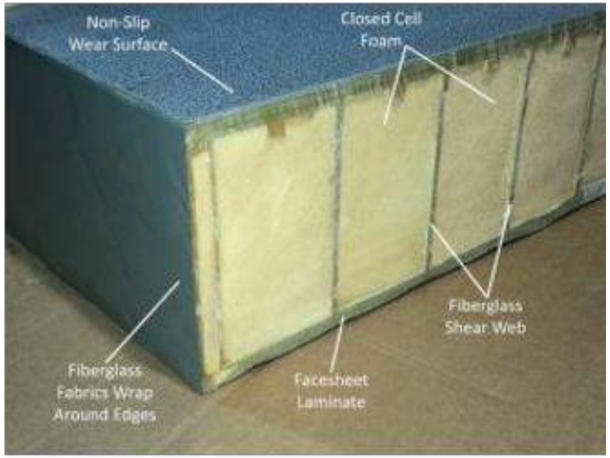
FRP pedestrian bridge (Johansen et al., 1997)

FRP Pedestrian Decks

- **Light weight (5 to 10 psf)**
- **Fast installation**
- **Eliminate maintenance**
- **Increase usable life**

FRP Pedestrian Decks

- Key design parameters
  - Support span
  - Vehicle load
  - Deflection limit
  - Installation plan

(a)

(b)

(c)


(a) shear-key mechanism (b) cross-section of the bridge deck (Nanni et al., 2004), and (c) FRP cross-section (Reeve, 2019) .

Introduction - FRP Design

FRP Decks

Bolted connections

Adhesive bonding

70` long Swartzheidle bridge was built in 4 hours by using the modular concept and bolted connections and adhesive bonding.

FRP Truss Bridge Installation

- Standard pultruded profiles are bolted to create the truss
- Delivered assembled or as a kit
- Kits as modules are easy to install in remote locations; pieces can be carried to the site; and assembled in 1-2 days

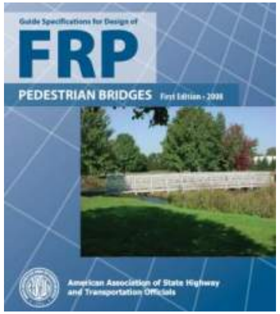
World's Longest FRP Truss Bridge

Creative Composites Group

Creative Composites Group

- Bermuda Railway Trail
- 152 ft long, 8 ft wide

Introduction – Benefits of FRP Bridges and Decks



In 2008, American Association of State Highway and Transportation Officials (AASHTO) developed "Guide Specifications for Design of FRP Pedestrians Bridges" based on Johansen`s work

Design loads	Design details
• Pedestrian live load (85 lb/sq. ft) • Wind loads • Vehicle load • No fatigue check	• Deflection • Vibration limit • Allowable stress • Minimum thickness of material • Connections (bolted-torque & creep limit etc.) • Loaded Half-through truss spans

Deflection and vibration limit are the most critical aspects in a FRP pedestrian bridge design and construction.

FRP Pedestrian Testing

- GFRP pedestrian bridges with up to 70' length and 8.5' width constructed at WVU-CEE/CFC lab using C- and rectangular sections using appropriate FRP and metal connectors.
- Truss-bridge elements consisted of:
  - top & bottom-chord members
  - transverse members
  - vertical posts
  - diagonal members
  - outriggers

70` long single-span FRP pedestrian bridge being tested at CFC-WVU lab

FRP Pedestrian Testing

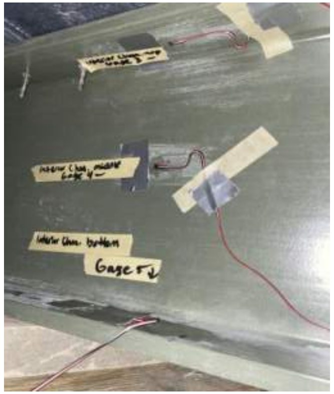
- Static loading (H5 vehicular loads and uniformly distributed loads/UDL, wind) and dynamic excitation tests conducted on FRP pedestrian bridges
- Differing torques (10 to 40 ft-lbs) used on connections to measure creep effects.
- Over 100 sensors used including strain gages, LVDTs, dial gages and accelerometers

H5 loading at four locations of wheels

loading for 100 PSF UDL loading

lateral loading (wind loading).

Dynamic tests



Over 100 sensors for monitoring

FRP Pedestrian Testing

FRP Decks

3" thick timber deck planks (1`x8`)

FRP Pedestrian Testing

Deflection under UDL LOADING (100 PSF)

	Location	Max. deflection
1	MIDDLE-Mid-Longitudinal Center	1.498
2	MIDDLE-Exterior-Transverse Channel	1.462
3	MIDDLE-Free-Edge Transverse	1.301
4	Center-Center of Bridge	1.495
5	Middle-of Transverse (SUPPORTED BY BOTTOM BRACE)	1.008
Design Consideration **Truss member vertical deflections**: 1.498" (no bolt-friction loss values included)		

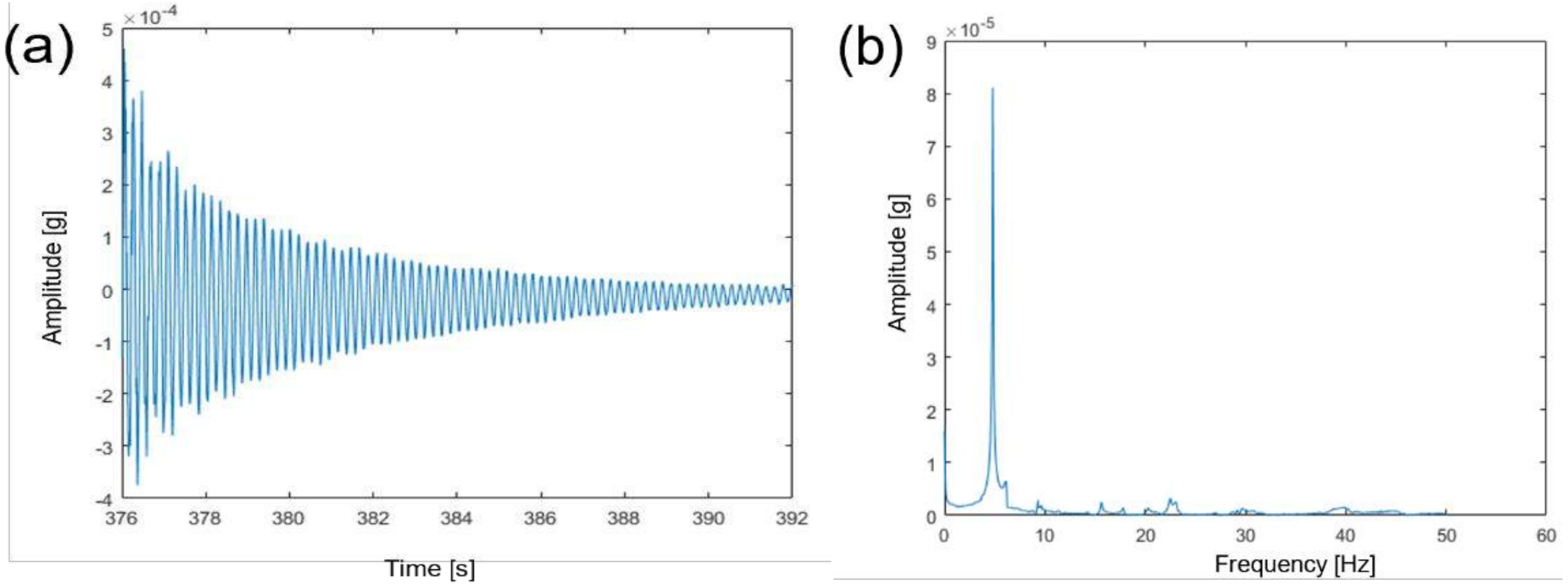
The residual deflections and those related to frictional loss were as high as 1 ¼" at the mid-span after all the load removal with respect a horizontal line from end-to-end of the supports.

FRP Pedestrian Testing

#	Member Category	Factor of Safety (FS)		
		T* (ε, μs)	C* (ε, μs)	FS**
1	Bottom-Chord	-	-351	>5
2	Top-Chord	56	-3,310	>4.5
3	Transverse Beams	235	-497	>8
4	X/Horizontal Braces	2,811	-3,444	>4.5
5	Side Posts	1,604	--3,076	>4.5
6	Outriggers	641	-381	>8
7	Plates: Metal	162	-45	>8
	FRP	540	-829	>8
8	Deck Panels	1605	-617	>8

*T-Tension; C-Compression **FS for a coupon failure strain of ~15,000μs

FRP Pedestrian Testing



Time vs amplitude

Amplitude vs. Frequency

Fast Fourier Transformed (FFT) dynamic excitation data

Conclusions

- Strain and deflection responses for all load types (UDL, H5, equestrian, & wind) were found to be within allowable limits (less than 2,000$\mu\varepsilon$ in most members compared to typical coupon failure strains of 10,000-20,000$\mu\varepsilon$).
- Deflection values of span/360 (2.33") to span/500 (1.68") for different load types satisfy the applicable specifications.
- Vertical (4.82 Hz) and lateral (5.14 Hz) frequencies conform to the AASHTO suggested ~5 Hz frequency.
- Safety factors were far above 3.5 for different types of loads and members.
- Experimental results regarding stresses and deformations validate the analytical work and finite element (FE) analyses corresponding to safety factors.
- GFRPs will serve as the future generation of infrastructure materials that are rapidly manufactured and field constructed with high quality control.

Summary

- The AASHTO guide specifications (2008) and evaluations were developed for FRP pedestrian bridge under static loading and dynamic response. However, the limitation in specifications need to be addressed in term of torque limit per bolt, creep limit state, adhesion system, fire guidance, and vibration/fatigue limit states.
- The demonstration projects of FRP pedestrian bridges (FRP truss) will inspire and develop the potential application of various FRP composites, including glass fiber, basalt fiber, and carbon fiber, in the bridge constructions.
- Optimization of cross sectional shapes must be carried out in addition to developing longer span (500`-1000`) pedestrian bridges using FRP cable stays & other suspension systems.

Guide Specifications for FRP pedestrian bridges

Suggestions to modify "Guide Specifications for Design of FRP Pedestrians Bridges", based on major strides made in FRP composites technologies

- ❑ Standard fatigue provisions
- ❑ Specific provisions for bolted connections
- ❑ Creep under sustained loads as a function of minimum/maximum torque (foot-pounds per bolt) levels
- ❑ Guidance for adhesive bonding of joints
- ❑ Guidance for fire protection like fire retardants and intumescent coatings
- ❑ Shape optimization as a function of span

Acknowledgement

"A regional collaboration promoting holistic resilient and sustainable infrastructure solutions with a focus on efficient highway and pedestrian bridges and structures"






Northeastern Peer Exchange for Resilient and Sustainable Bridges

August 7, 2024 – Buffalo, NY.

University at Buffalo
Institute of Bridge Engineering

FDOT's Resilience Policies and Proposed Practices for Transportation Infrastructure

- Focusing on Bridges and Coastal Structures

Photo: Courtesy of Fox News 4 (Hurricane Ian[redacted] Sanibel Island, FL., 2022)

Old Seven Mile Bridge, Florida Keys (2023)

Photo: Courtesy of GettyImage[redacted] (Francis Scott Key Bridge[redacted] Baltimore, 2024)

Presented by: Steven Nolan, P.E.

Advancing Reinforced Concrete Design For Resilient And Sustainable Structures

Revised

Recent publication and further development of several design and construction specifications are helping to advance the durability and sustainability of reinforced concrete structures. ACI CODE-440.11-22 now provides a model code for international adoption in design of reinforced concrete structures. ASTM Committee D30.10 has been actively developing FRP internal reinforcement testing and materials specifications with Glass and Basalt FRP reinforcing specifications under D7957-22 and ASTM D8505-23 with several new specifications under development for Carbon FRP and grid/mesh products. ACI Committees 239 and 243 are also developing guide documents for UHPC and Seawater Concrete, respectively. While Committee 323 recently released the Model Code for low-carbon concrete. In combination these specifications and guides provide engineers with valuable tools for design and construction of buildings, bridges, and waterfront structures with improved resilience and sustainability.

Speaker Bio.

Steve Nolan has been a Professional Engineer in Florida since 2003. He is the technical lead coordinator for Florida DOT for implementation of Fiber-Reinforced Polymer reinforcing and prestressing, stainless-steel prestressing, and UHPC for structural applications. 10-years' experience with development of design guidance for FRP, 30-years' experience with concrete design and construction including 25-years with bridge design specification and standards development. Current member of ***TRB*** committee **AKB10**-Innovative Highway Structures, ***ACI*** 440C & CSAO, ***ASCE***-Structural Engineering Institute, Bridge Engineering Institute, and ***fib*** *(International Federation for Structural Concrete)*.

FDOT's Resilience Policies and Proposed Practices for Transportation Infrastructure

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 such as pavement markings, roundabouts, high mast lighting, 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, will be shared with the audience to encourage consideration and refinement of similar action by other state DOTs.

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)

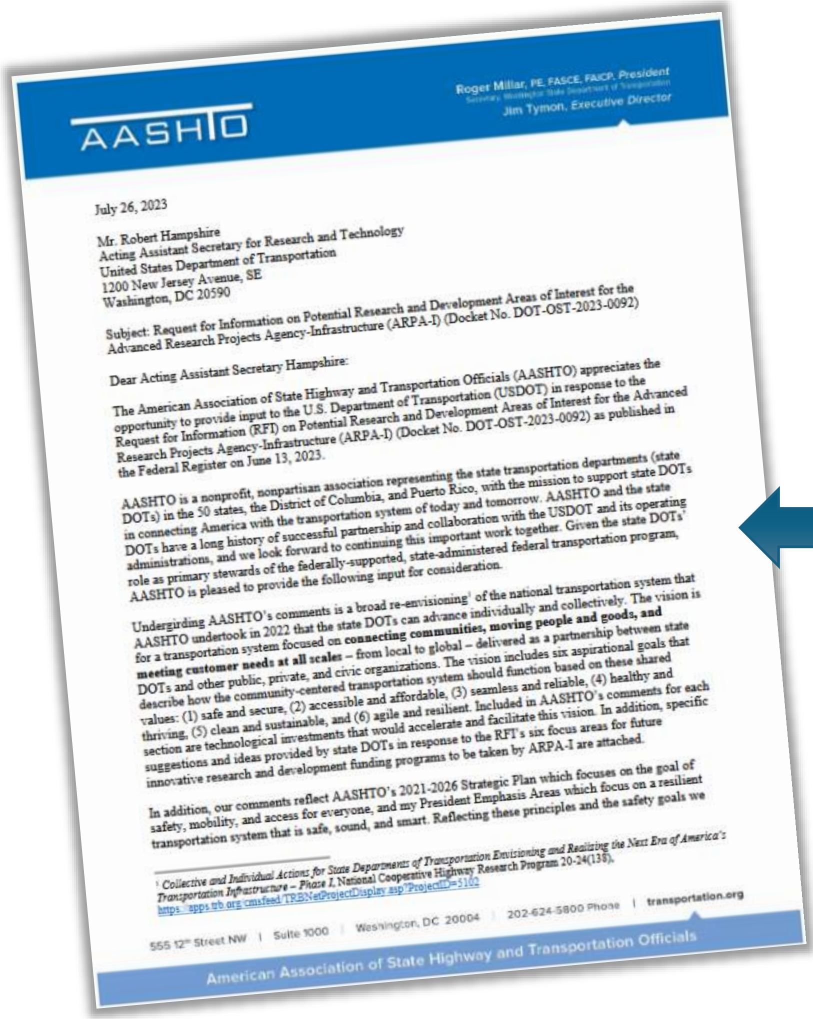
USDOT/FHWA (Pavements)

"...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 Interest



AASHTO

Roger Millar, PE, FASCE, FAICP, President
Jim Tymon, Executive Director

July 26, 2023

Mr. Robert Hampshire
Acting Assistant Secretary for Research and Technology
United States Department of Transportation
1200 New Jersey Avenue, SE
Washington, DC 20590

Subject: Request for Information on Potential Research and Development Areas of Interest for the Advanced Research Projects Agency-Infrastructure (ARPA-I) (Docket No. DOT-OST-2023-0092)

Dear Acting Assistant Secretary Hampshire:

The American Association of State Highway and Transportation Officials (AASHTO) appreciates the opportunity to provide input to the U.S. Department of Transportation (USDOT) in response to the Request for Information (RFI) on Potential Research and Development Areas of Interest for the Advanced Research Projects Agency-Infrastructure (ARPA-I) (Docket No. DOT-OST-2023-0092) as published in the Federal Register on June 13, 2023.

AASHTO is a nonprofit, nonpartisan association representing the state transportation departments (state DOTs) in the 50 states, the District of Columbia, and Puerto Rico, with the mission to support state DOTs in connecting America with the transportation system of today and tomorrow. AASHTO and the state DOTs have a long history of successful partnership and collaboration with the USDOT and its operating administrations, and we look forward to continuing this important work together. Given the state DOTs' role as primary stewards of the federally-supported, state-administered federal transportation program, AASHTO is pleased to provide the following input for consideration.

Undergirding AASHTO's comments is a broad re-envisioning[1] of the national transportation system that AASHTO undertook in 2022 that the state DOTs can advance individually and collectively. The vision is for a transportation system focused on **connecting communities, moving people and goods, and meeting customer needs at all scales** – from local to global – delivered as a partnership between state DOTs and other public, private, and civic organizations. The vision includes six aspirational goals that describe how the community-centered transportation system should function based on these shared values: (1) safe and secure, (2) accessible and affordable, (3) seamless and reliable, (4) healthy and thriving, (5) clean and sustainable, and (6) agile and resilient. Included in AASHTO's comments for each section are technological investments that would accelerate and facilitate this vision. In addition, specific suggestions and ideas provided by state DOTs in response to the RFI's six focus areas for future innovative research and development funding programs to be taken by ARPA-I are attached.

In addition, our comments reflect AASHTO's 2021-2026 Strategic Plan which focuses on the goal of safety, mobility, and access for everyone, and my President Emphasis Areas which focus on a resilient transportation system that is safe, sound, and smart. Reflecting these principles and the safety goals we

[1] *Collective and Individual Actions for State Departments of Transportation Envisioning and Realizing the Next Era of America's Transportation Infrastructure – Phase I*, National Cooperative Highway Research Program 20-24(138), https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=5102

555 12th Street NW | Suite 1000 | Washington, DC 20004 | 202-624-5800 Phone | transportation.org

American Association of State Highway and Transportation Officials

USDOT/ARPA-I

RFI: Potential Research and Development Areas of Interest for the Advanced Research Projects Agency - Infrastructure

(Posted by the **Department of Transportation** on Jun 13, 2023)

77 Public Comments received, including:

- *AASHTO:* **Posted** Jul 27, 2023: Link to comment DOT-OST-2023-0092-0026.
- *U. Maine – Advance Structural Composites Center (200+ Bridge):* **Posted** Jul 28, 2023: Link to comment DOT-OST-2023-0092-0042.
- *ASCE:* **Posted** Aug 9, 2023: Link to comment DOT-OST-2023-0092-0054.
- *Virginia DOT:* **Posted** Aug 10, 2023: Link to comment DOT-OST-2023-0092-0056.

Resilience Interest

AASHTO Response to USDOT/ARPA-I 2023 RFI

2) ADVANCED CONSTRUCTION MATERIALS AND METHODS

… focus on new materials that are stronger, lighter, and more durable than existing materials, construction methods that improve efficiency, and new technologies that can be used to monitor and maintain infrastructure [such as]…

Ultra-lightweight foamed glass aggregate for use as fill material:

- *The recent use of this material on the I-95 emergency in Pennsylvania*

Concrete technologies

- *Fiber reinforced polymers in precast concrete.*
- *Carbon-negative cement is an emerging area of innovation for potential use in the building industry to reduce and absorb carbon emissions.*
- *Alternative/supplementary cementitious materials that can replace fly ash.*
- *Use of recycled materials (such as wind tower blades) in concrete production.*

5) CLIMATE AND RESILIENCE

….

Hardening of infrastructure

- *Make coastal communities more resilient.*

Greenhouse gas emissions reduction technologies

- *Methods for optimizing GHG uptake on transportation right-of-way including carbon capture, urban heat island mitigation, utility transmission, storm water capture, and air quality improvements.*
- *Enhanced roadsides with pollinator and wildlife habitat.*

Extreme weather resilient materials

- *Research is needed into materials that can withstand extreme weather events including flood-resistant and heat-resistant materials to address pavement rutting, spreading, deformation, structure fatigue, and material transformation.*

FDOT Resilience Policy & Plan

Resiliency Policy (2020)

FDOT

Florida Department of Transportation

RON DESANTIS
GOVERNOR

605 Suwannee Street
Tallahassee, FL 32399-0450

KEVIN J. THIBAULT, P.E.
SECRETARY

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.

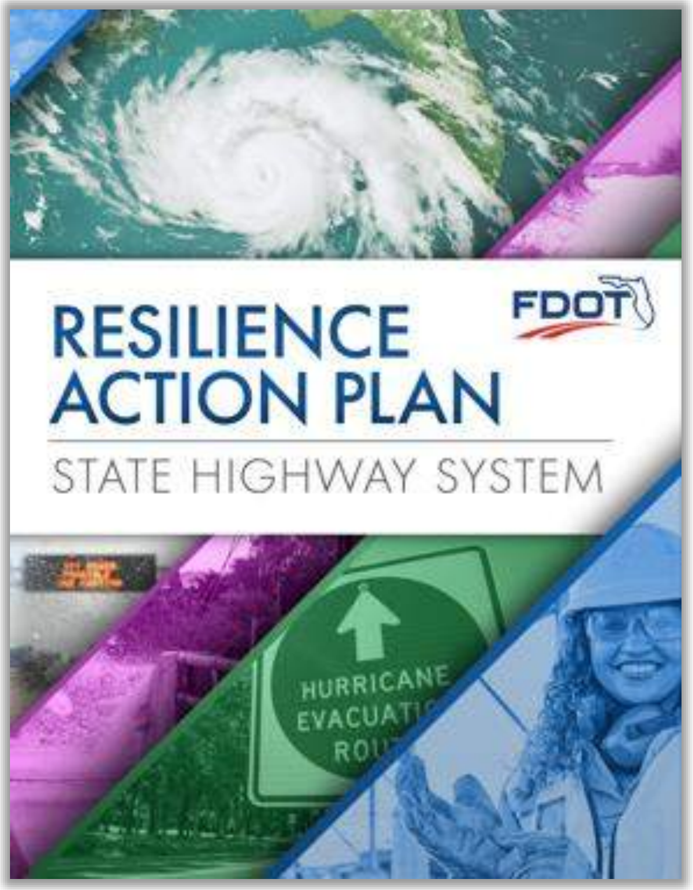
This policy will be implemented through the Department's long-range and modal plans; work program; asset management plans; research efforts; and internal manuals, tools, guidelines, procedures, and related documents, guiding planning, programming, project development, design, construction, operations,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

DocuSigned by:

Kevin J. Thibault, P.E.
Secretary

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

Resilience Action Plan (RAP-2023)

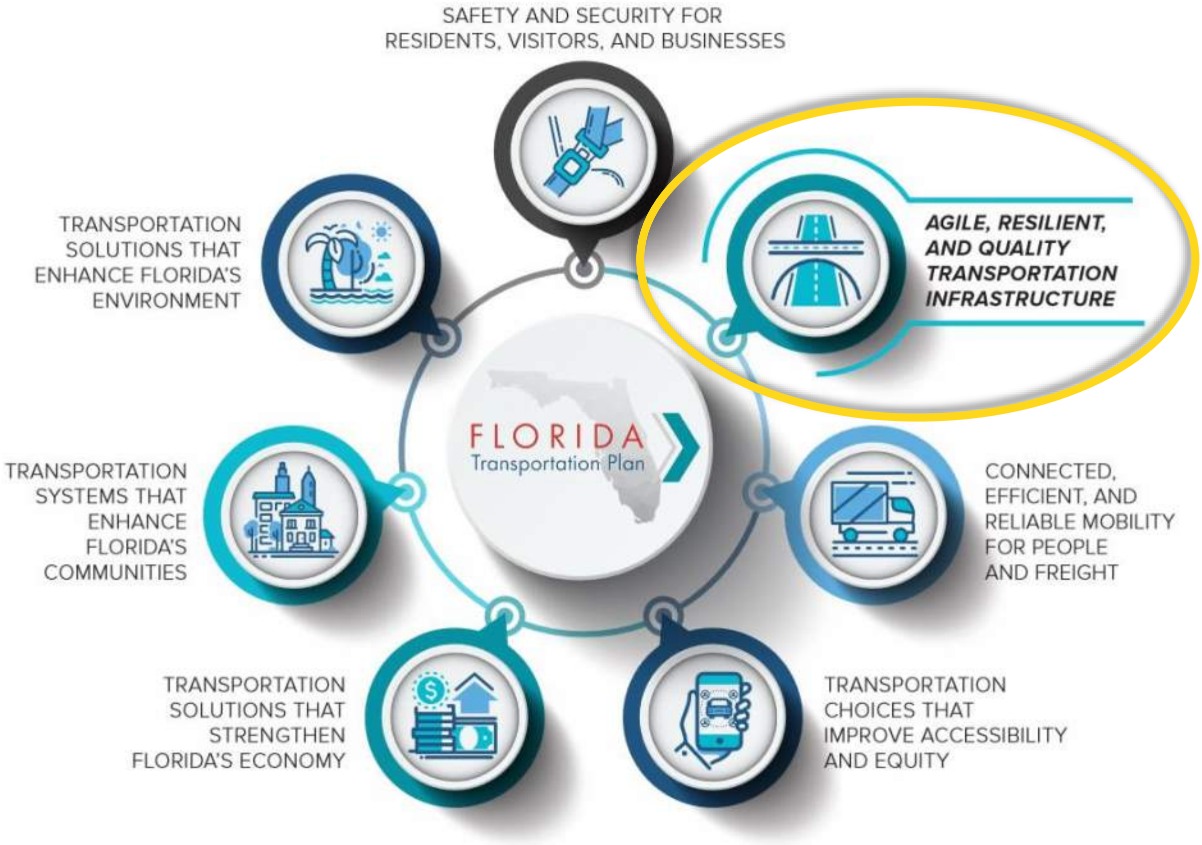


https://www.fdot.gov/planning/policy/resilience/resilience-action-plan

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/

Sustainability Goals

FDOT

- Although no formal definition has been established, FDOT has used sustainable practices for decades:
  - Recycle Asphalt Pavement (RAP)
  - Recycle Concrete Aggregate (RCA)
  - 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/

What Others Are Doing – **IABSE on Resilience**

IABSE

HOME ABOUT ▸ MEMBERSHIP ▸ COMMITTEES ▸ NATIONAL GROUPS ▸ EVENTS ▸ ELEARNING PUBLICATIONS ▸ MEDIA ▸

Task Group 6.1

Effects of Climate Change on Infrastructures

Mission Statement/Objectives

According to IPCC climate change predictions, countries around the world will likely face dramatic climate changes in the near future. More floods, drier summers and wetter winters are expected, along with the rise of sea levels and increase of wind speeds. The operational issues imposed on civil engineering structures by the change in temperature, precipitation, sea level etc. are already recognized. The goal of this Task Group is to characterize not only the severity of impacts but also give recommendations for mitigation and remediation strategies for buildings, bridges and other civil engineering structures. More specifically, the project promotes the technical discussion of topics related to:

- the main effects of climate change and their consequences on structural performance, in the context of evolving loads, load frequencies or loading scenarios
- mitigation and remediation solutions to enhance resilience of infrastructures to extreme weather events in the short, medium and long-term
- the development of cost-benefit analysis, risk assessment methodologies, modelling, engineering design, technology, asset management, optimization under uncertainty where the cost of loss or remediation following the hazard impact is compared to the cost of applied mitigation

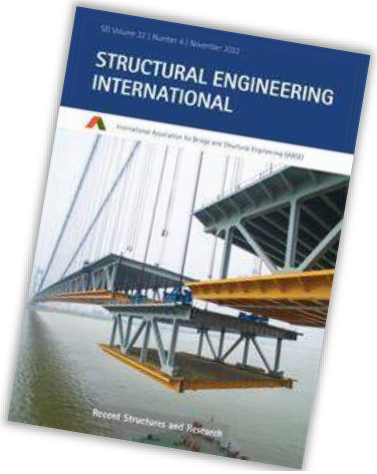
Chair
André Orcesi, *France*

Vice Chair
Alan O'Connor, *Ireland*

Members
Mitsuyoshi Akiyama, *Japan*
Abdul Kadir Alhamid, *Japan*
Angel Aparicio, *Spain*
Jorge Ballester, *Spain*
Edgar E. Bastidas-Arteaga, *France*
Thomas Bles, *Netherlands*
Joan Ramon Casas, *Spain*
Dimitris Diamantidis, *Germany*
Matilda Djidara, *Germany*
Andrew Foster, *United Kingdom*
Lara Hawchar, *Ireland*
Boulent Imam, *United Kingdom*
Katerina Kreislova, *Czech Republic*
Yue Li, *USA*
Olga Markogiannaki, *Greece*
Panagiotis Michalis, *Croatia*
Maria Pregnolato, *United Kingdom*
Xin Ruan, *China*
Paraic C. Ryan, *Ireland*
Babak Salarieh, *USA*
Abdullahi M. Salman, *USA*
Franziska Schmidt, *France*
Franck Schoefs, *France*
Mark Stewart, *Australia*
Miroslav Sýkora, *Czech Republic*
Solomon Tesfamariam, *Canada*
Sudip Talukdar, *Canada*
Teng Wu, *USA*
Ana Margarido Bento, *Portugal*

What Others Are Doing – IABSE TG6.1

André Orcesi Dr, Alan O'Connor Prof., Dimitris Diamantidis Prof, Miroslav Sykora Dr, Teng Wu Dr, Mitsuyoshi Akiyama Prof., Abdul Kadir Alhamid, Franziska Schmidt Dr, Maria Pregnolato Dr, Yue Li Prof., Babak Salarieh, Abdullahi M. Salman Prof, Emilio Bastidas-Arteaga Prof, Olga Markogiannaki Dr & Franck Schoefs Prof. (2022). "**Investigating the Effects of Climate Change on Structural Actions**," *Structural Engineering International*, 32:4, 563-576, DOI: 10.1080/10168664.2022.209889



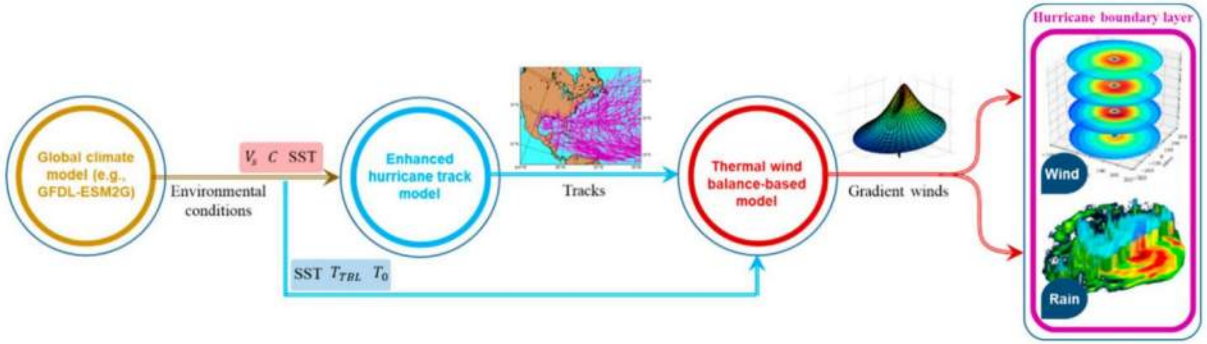


Fig. 1: UB climate-dependent stochastic simulation framework for TC wind and rain hazards[74] (Note: Vs is wind shear, C is convective instability, T_{TBL} is temperature at the top of the atmospheric boundary layer, and T_0 is outflow temperature)

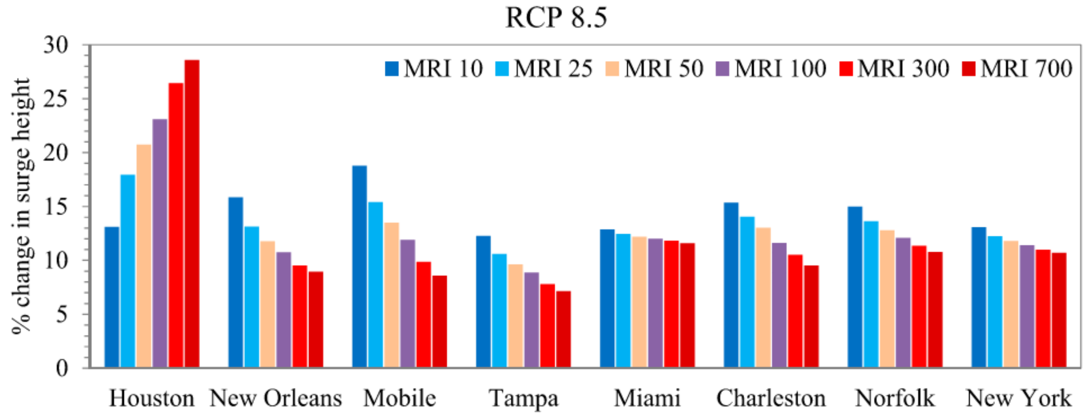
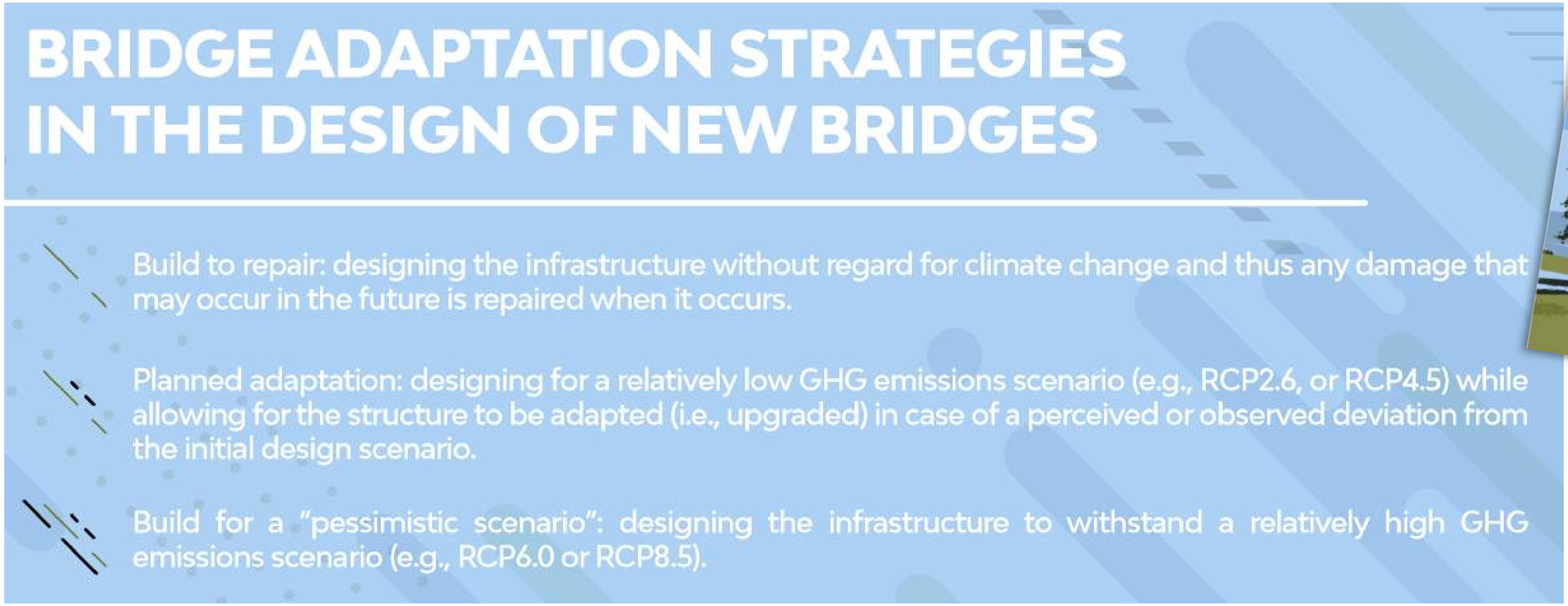


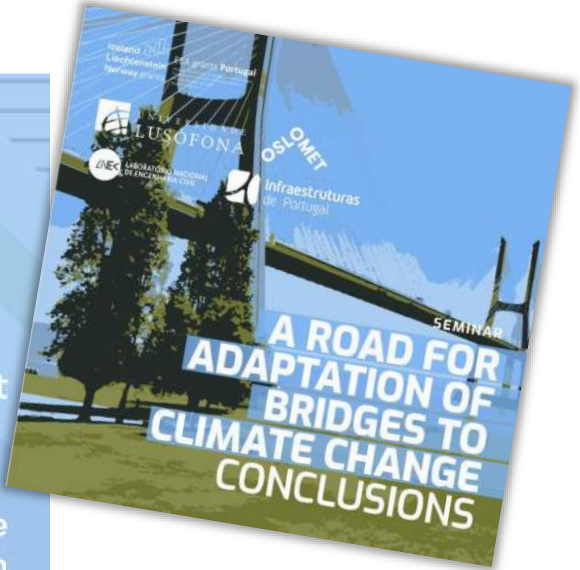
Fig. 2: Changes in storm surge hazard from 2020 to 2100 for different Mean Recurrence Intervals (MRI) under RCP 8.5

What Others Are Doing – Adaption in **Portugal**

"**A road for adaptation of bridge to climate change**" was held in Lisbon (September 27, 2022) under the *ClimaBridge Project* funded by EEA Grants. This seminar brought together experts from the bridge engineering field and academia, climatologists, bridge authorities, and decision makers to understand the impacts of climate change on the health of bridges and to propose cost-effective adaptation strategies.

https://www.eeagrants.gov.pt/en/programmes/bilateral-relations/news/seminar-a-road-for-adaptation-of-bridges-to-climate-change/



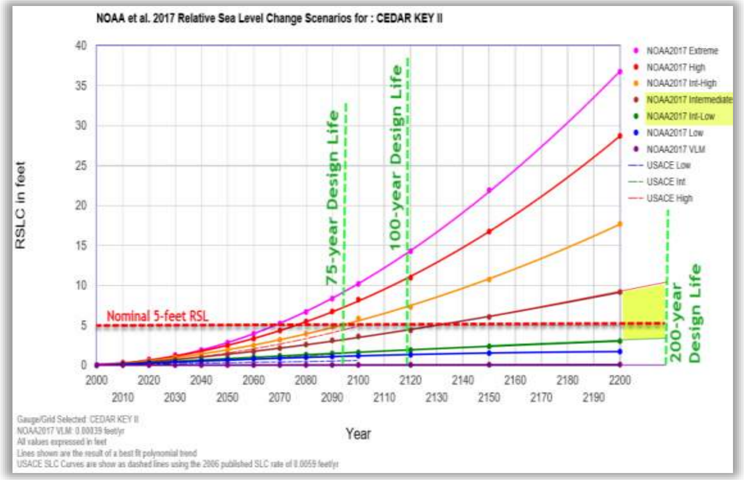


→ Focusing on Structures: LRFD Design Practice

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)*

Existing Standards (constantly evolving)



RESISTANCE (Strength & Durability)

- 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)*

Existing Standards (constantly evolving)

→ Aspirations for Structures – **RA Design Goals**

RESILIENCE

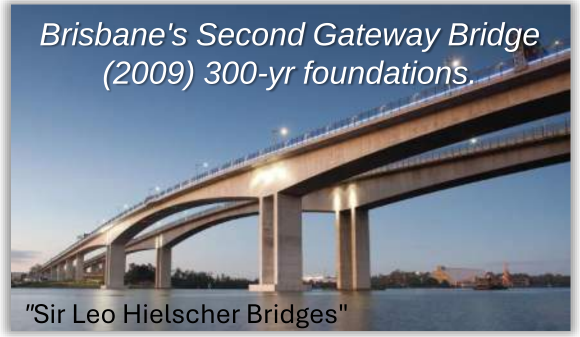
- **Robustness** *(Bend don't break)*
- **Durability:** Inert or Regenerative materials *(Ultra-durable, Self-healing, or easily replaceable)*
- Rapid **Repair &/or Replacement** *(component upgrade, periodic replacement)*

Needed Standards

Ponte Pietr[redacted] Bridge, post-WWII

...born 100 BC (Verona, Italy)

Photo: Nolan (2016) from IABSE-NYC 200-year Bridge Workshop



Brisbane's Second Gateway Bridge (2009) 300-yr foundations.

"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)*

Needed Standards

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

+

Structures <u>RA</u> Design Goals

=

Load & Resistance Factor Design

with Resilience & Adaptability

(LRFD+RA)

Digging deeper (example) → **Durability:**
Corrosion Protection & Mitigation Strategies

Decreasing Level of Protection

- Form & Function *(Compression vs. Flexural & Tension elements)*
- Inert Members/Regenerative Materials? *(Plain Concrete, Synthetic FRC, FRP / Crack Self-Healing)*
- xCR[1] FRP Rebar & Strand *(Fibers: Glass, Basalt, Aramid, Carbon; Resins: Thermoset vs. Thermoplastic)*
- xCR[1] SS Rebar & Strand (Duplex--> 316 --> Low-Cr.)

- 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)*

Decreasing Level of Mitigation

[1] *xCR = extremely Corrosion-Resistant*

Standards Development – ANSI

The means, methods, and design procedures for any innovative material should follow the "**twelve globally accepted principles for standards development**", as defined in the **ANSI** *2020 United States Standards Strategy*[1] :

- transparency
- openness
- impartiality,
- Effectiveness and relevance
- consensus
- performance based
- coherence
- due process
- technical assistance
- flexible
- timely
- balanced

[1] *https://share.ansi.org/Shared Documents/Standards Activities/NSSC/USSS-2020/USSS-2020-Edition.pdf*

FDOT Resilience: Resilience Action Plan (RAP)

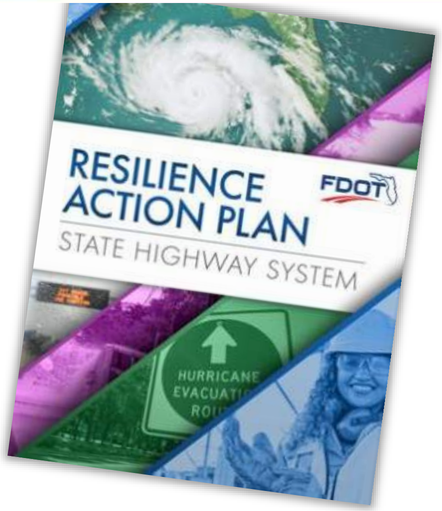
Project List

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

Prioritization Tier	Centerline Miles Exposed	% of SHS	Bridges Exposed	% of SHS Bridges
High	57	0.5%	446	9%
Medium	709	6%	536	11%
Low	1,781	15%	1,499	31%

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 (	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	Medium	No	SR 64 (MANATEE AVE) FROM FLAMINGO DR TO [illegible]	Unfunded	$ 32,300,000	ROADWAY ELEVATION
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)

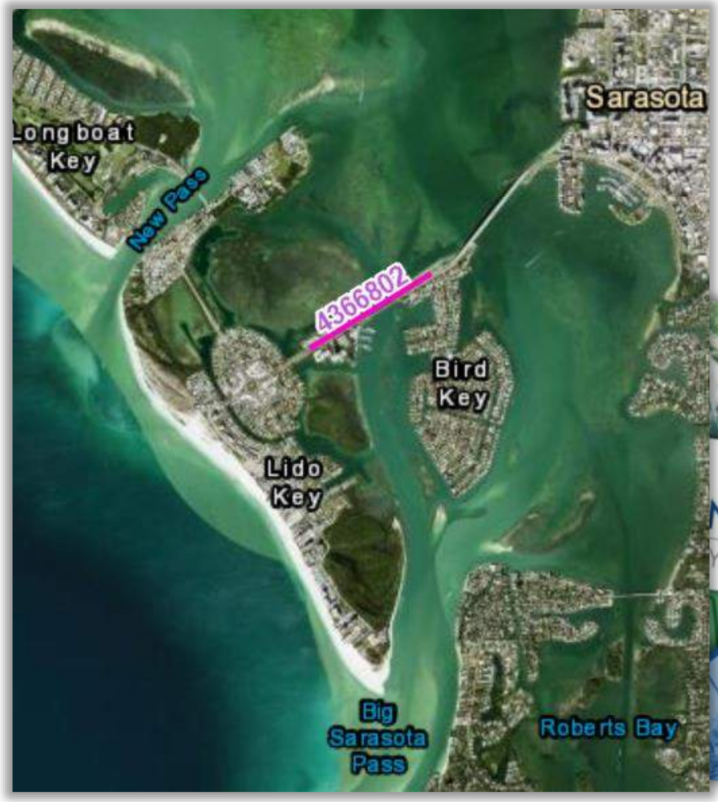
District 4, 6, & 8

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 Available	[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 Resilience:
Where Are the Bridges of Interest (D1)?

The #1 District 1 Opportunities

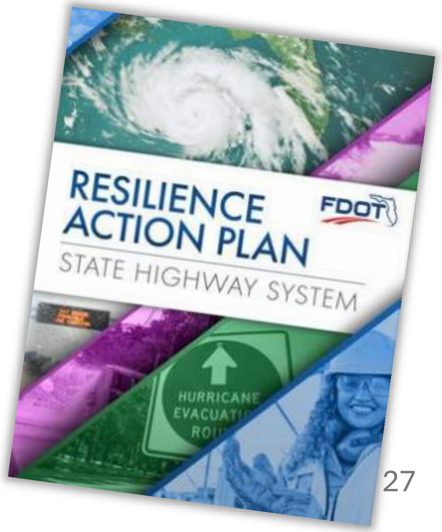
- Little Ringling Bridge *(2027-28, DBB FIN# 446680-2)*
- Hernando Desoto Bridge *(2026 Design/Build FIN# 442630-2)*
- Anna Maria Island *(2026, DBB FIN# 408185-3)*
- Cortez Bridge *(2025, DBB FIN# 430204-2)*



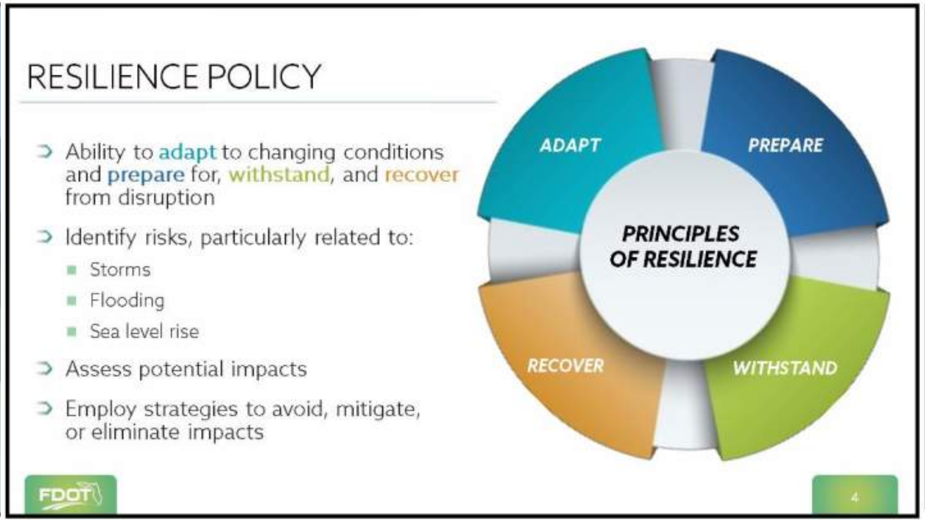
FDOT Resilience:
Where Are the Bridges of Interest (D2 & D3)?

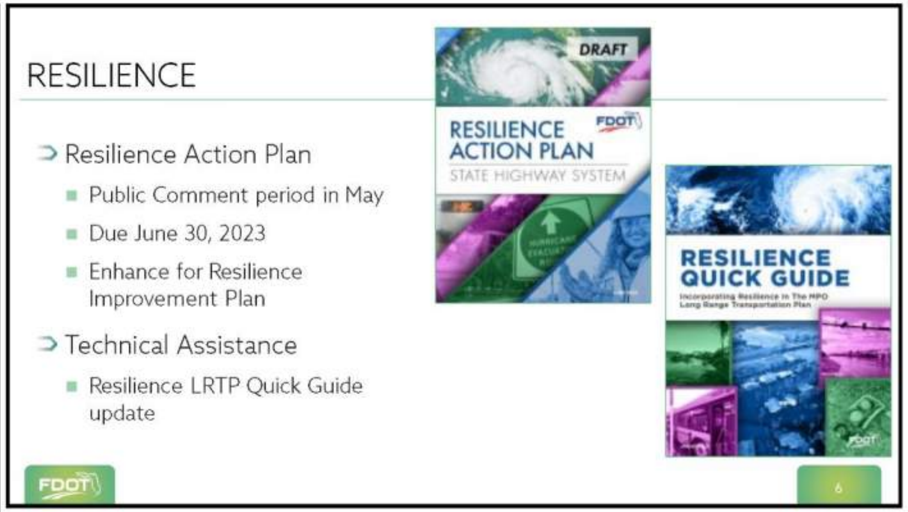
The #1 District 2 Opportunities

- CR-357 over Shired Creek *(2025, DBB FIN# 4-2)*
- SR-388 over Burnt Mill Creek *(2029+, DBB FIN# 424464-6)*
- Dupont Bridge Replacement *(2024 Design/Build FIN# 442667-1)*

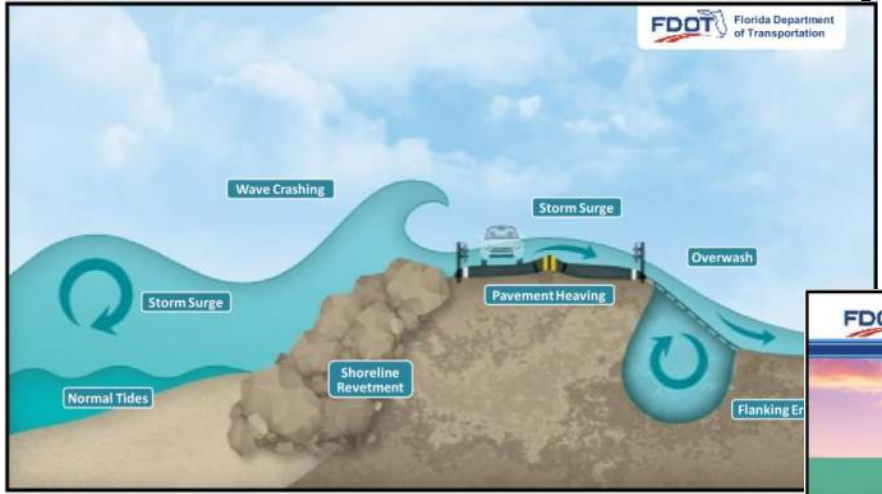


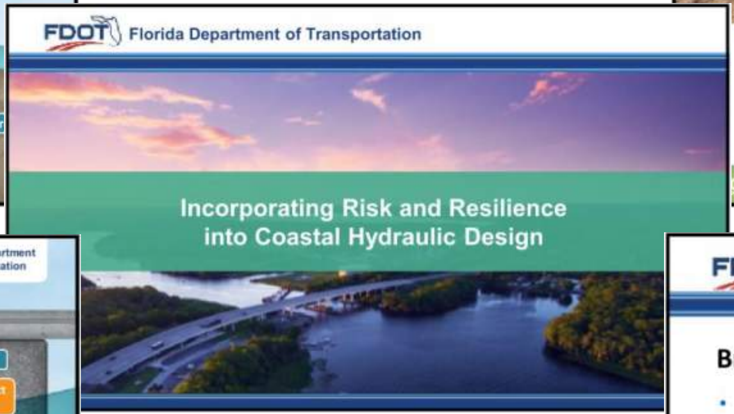
FDOT Statewide Resilience Training: for Planners & Designers

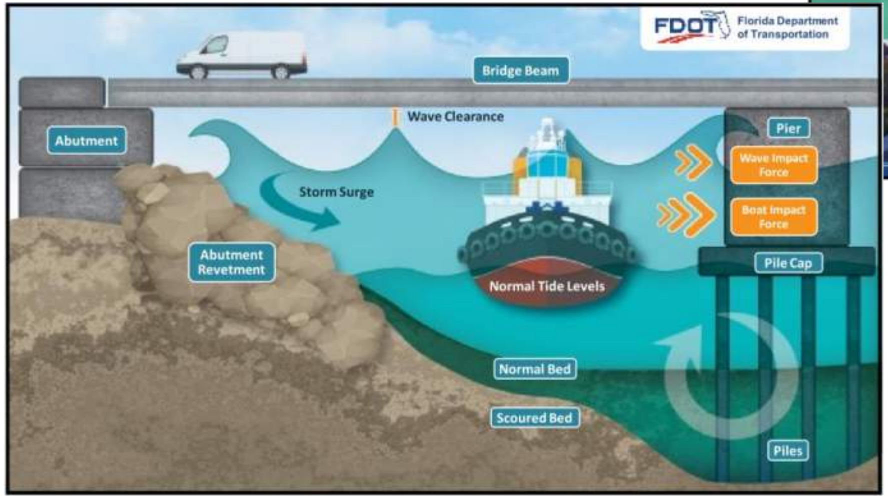




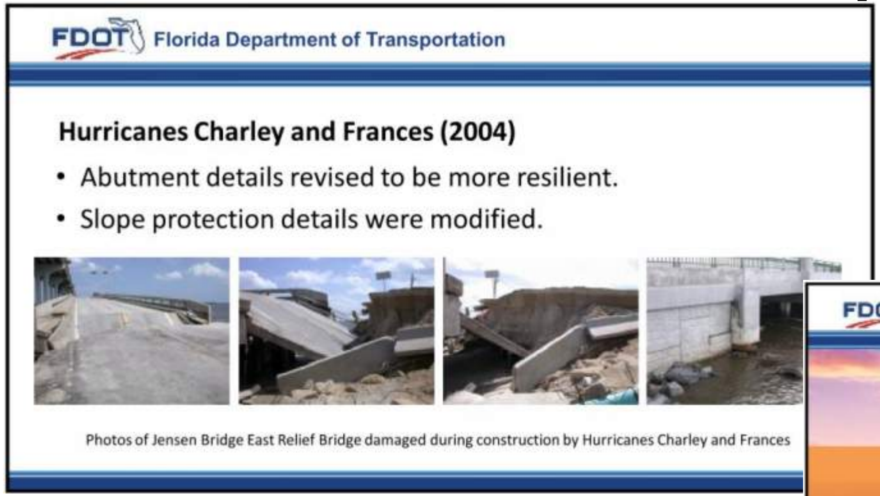
FDOT Statewide Resilience Training: Structures Examples

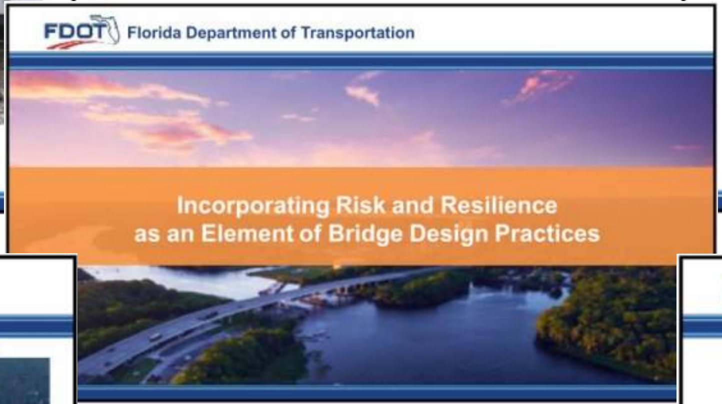


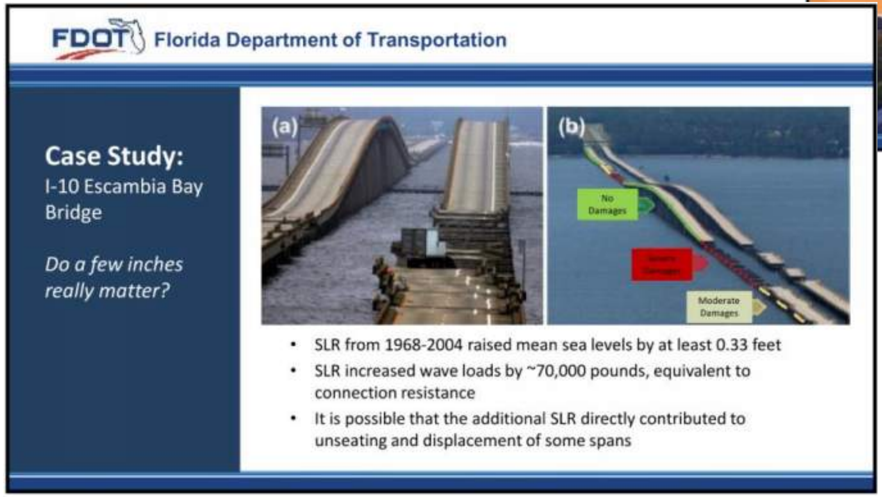


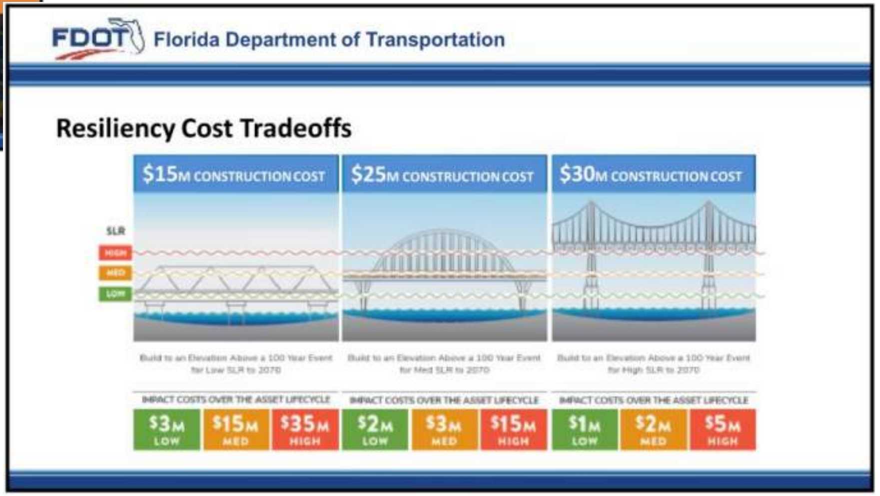


FDOT Statewide Resilience Training: Structures Examples









Thank you for your attendance and participation!

QUESTIONS ?

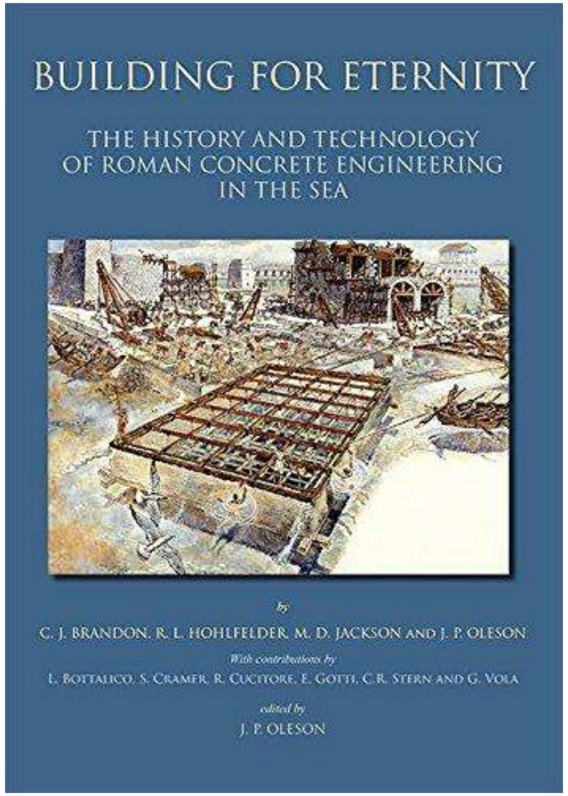
Contact Information:

Steven Nolan, PE.
Senior Structures Design Engineer
Florida Department of Transportation
Tel: 850.414.4272
Email: steven.nolan@dot.state.fl.us

Extra Slides
(not presented)

Resilient Design and Adaptability

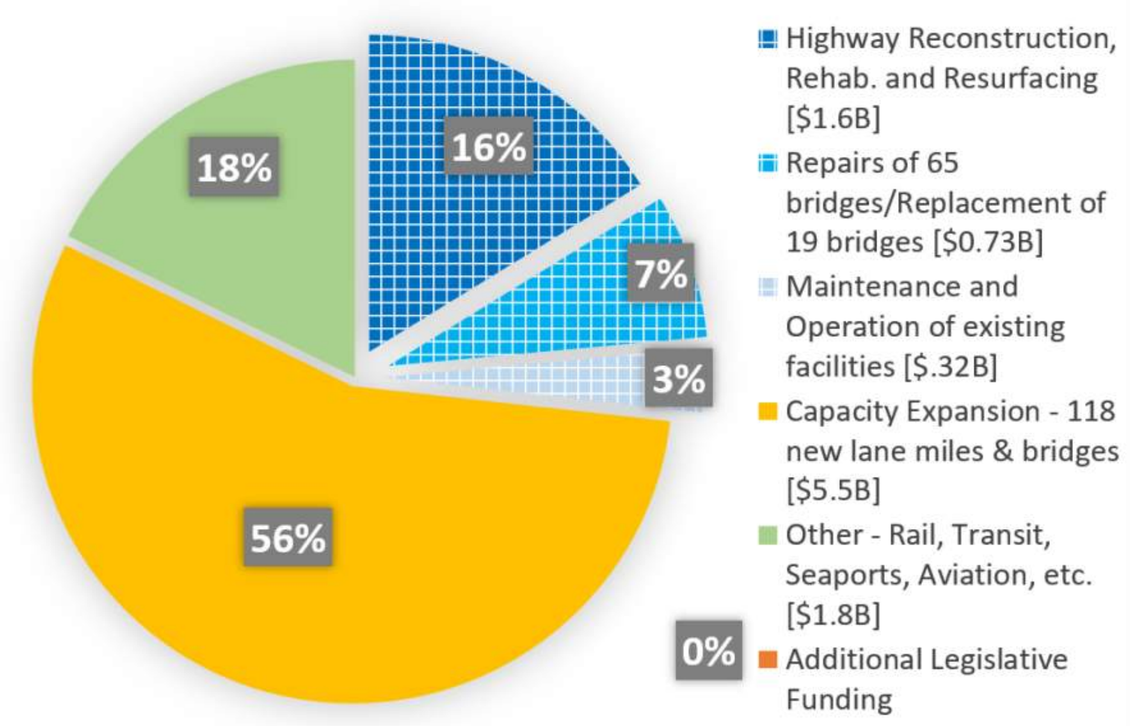
Ponte Pietra Bridge. Born 100 BC



Condition in 2016 (Verona, Italy)

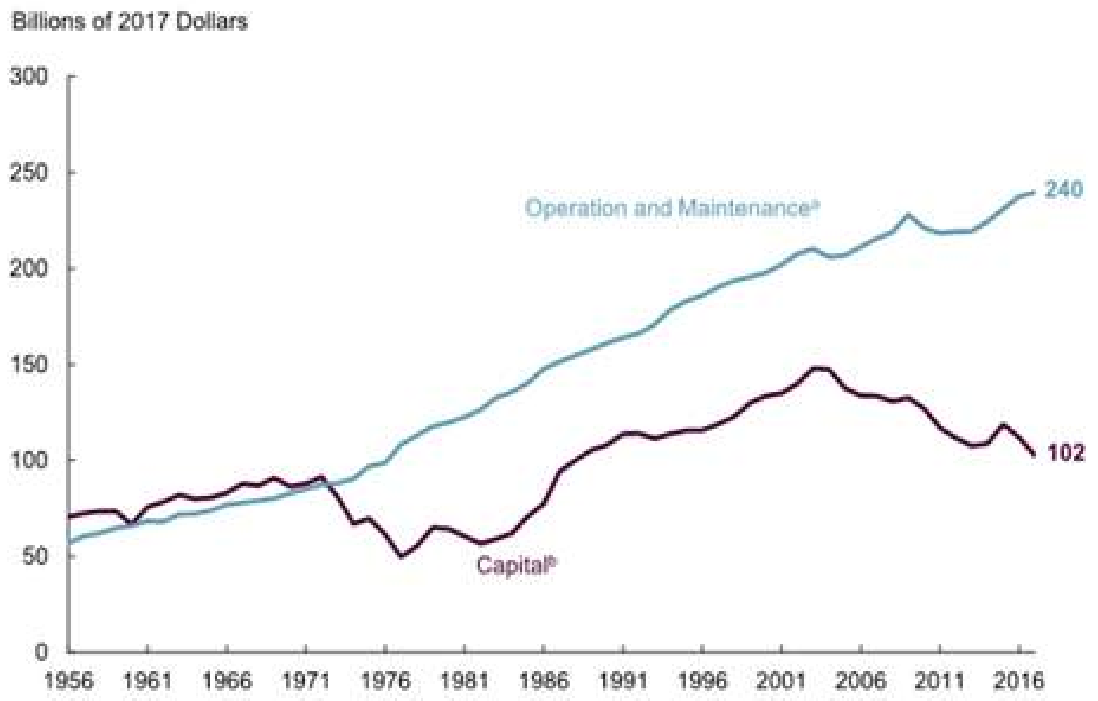
Durable Design Needs & Strategies

Cost of Ownership



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

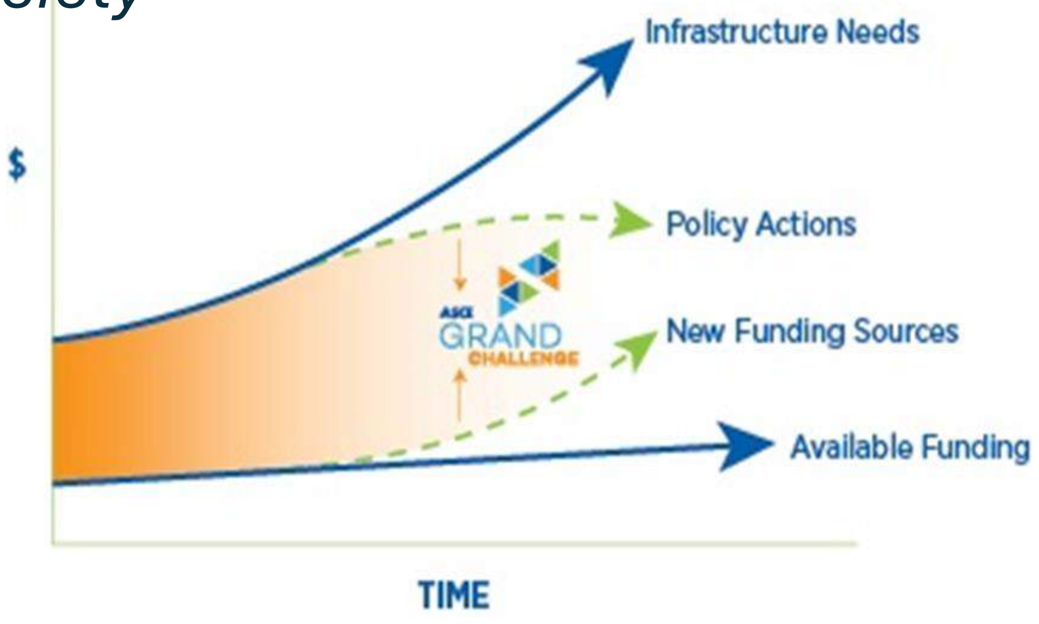
Increasing Maintenance & Rehab. Liability



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

ASCE Grand Challenge

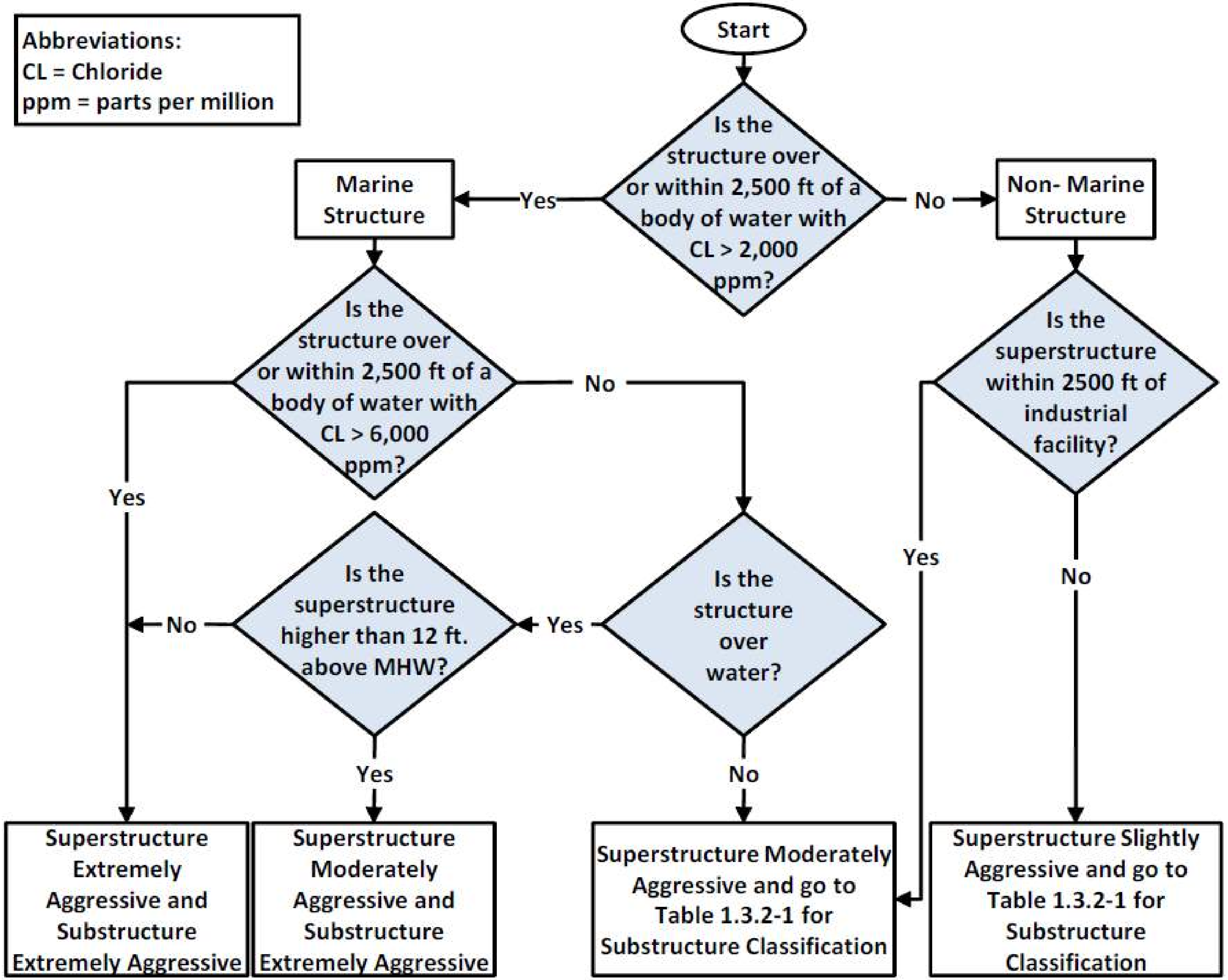
"Reduce the life cycle cost of infrastructure by 50 percent by 2025 and foster the optimization of infrastructure investments for society"



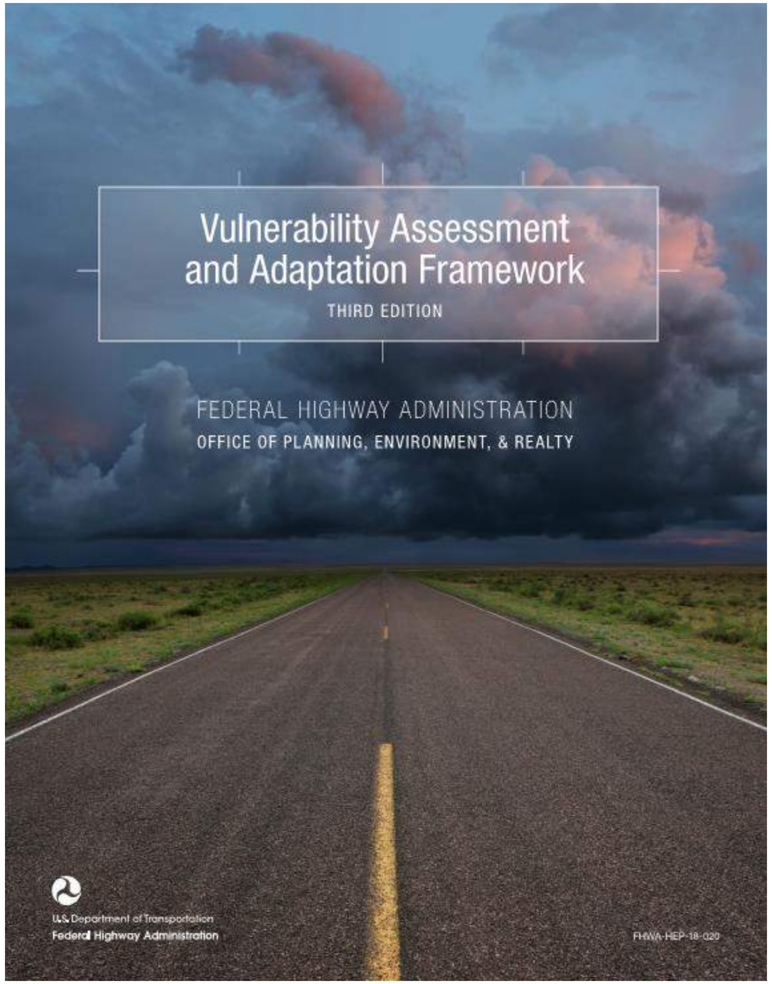
Increasing Maintenance & Rehab. Liability

Together we can close the infrastructure gap!

Flow Chart for SDG Environmental Classification of Structures



Predicting Future Use & Impacts



Bridge Builders Look for Better Ways at International Conference

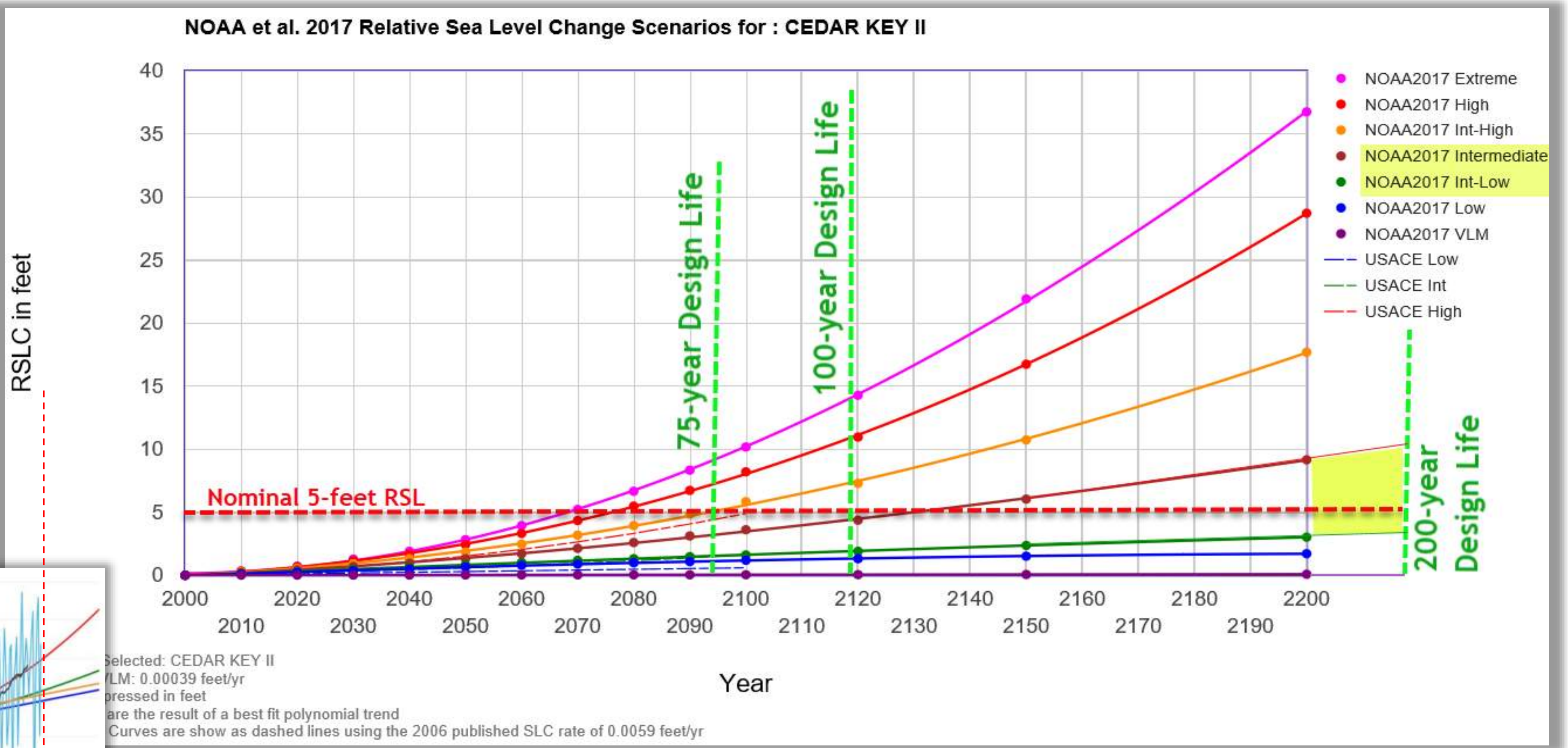
July 8, 2019

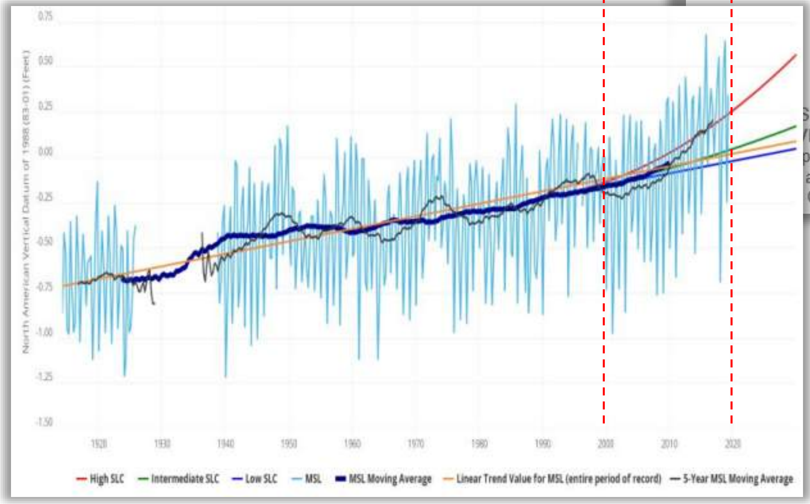
ENR
Engineering News-Record

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



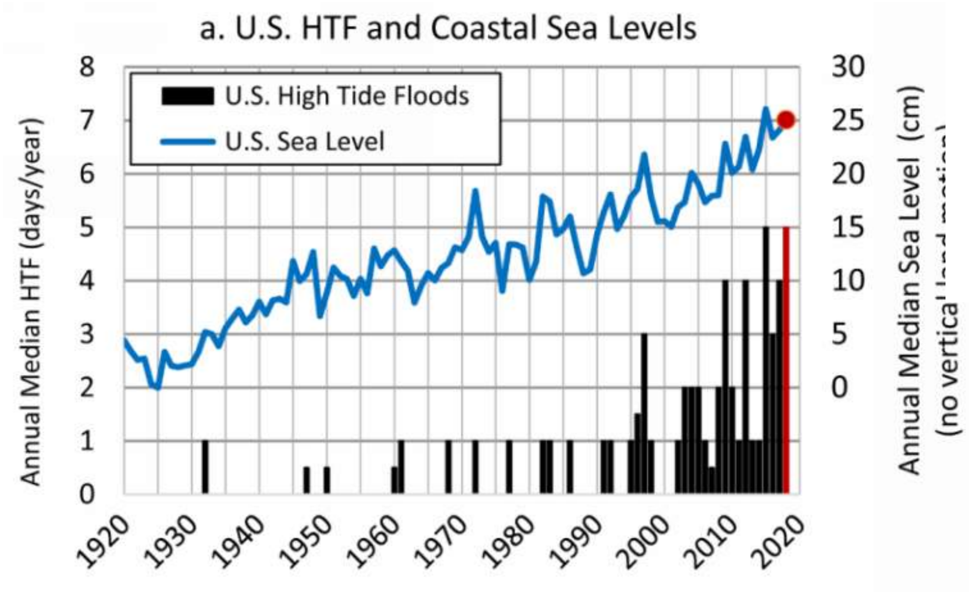


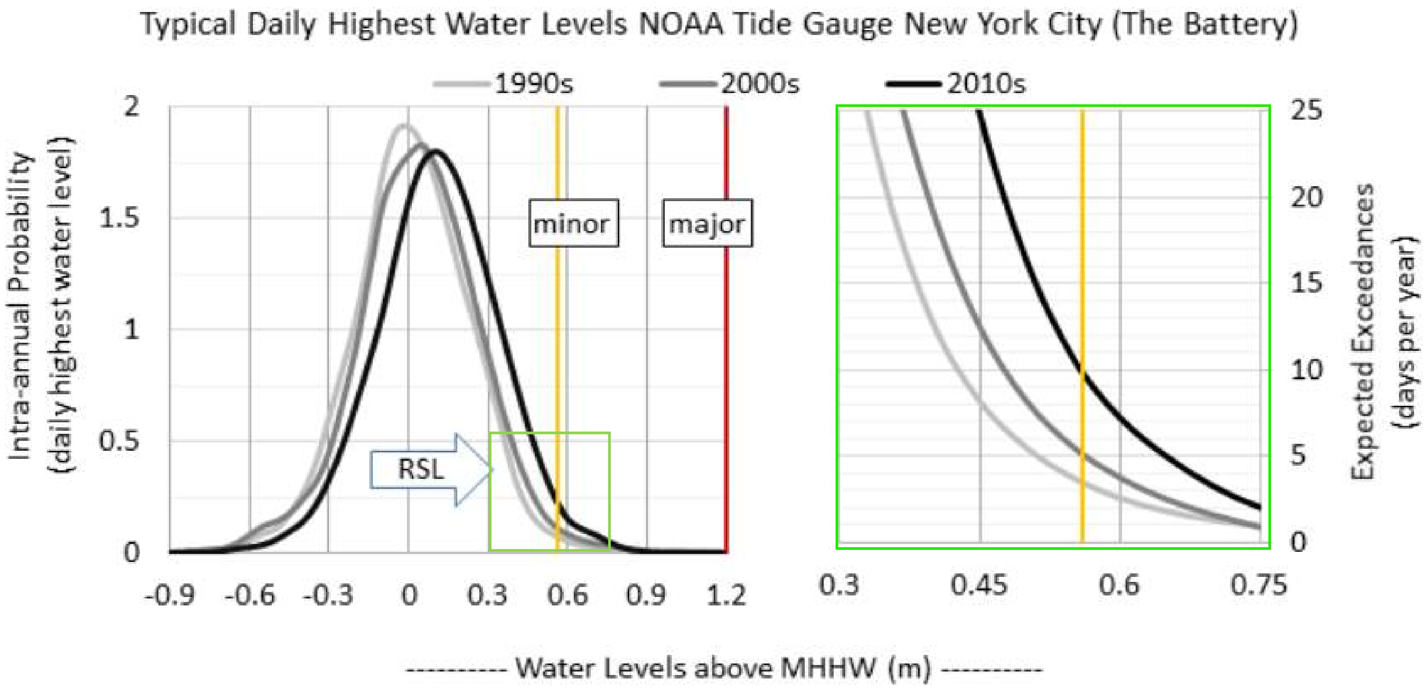
SLC Scenarios for Cedar Key, FL (Gauge 8727520)
https://climate.sec.usace.army.mil/slr_app/

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

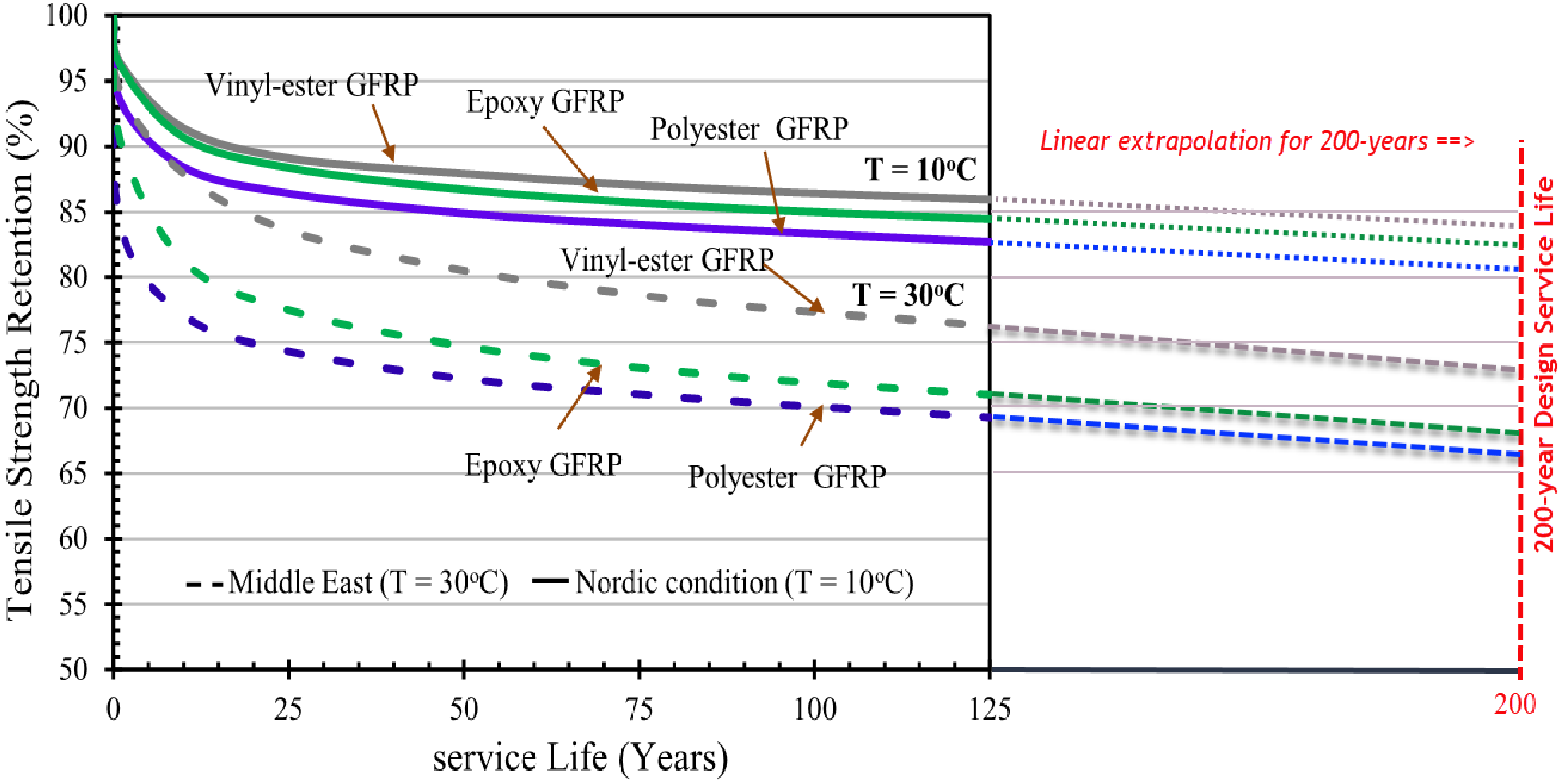




Above: Decadal empirical probability distributions for daily highest water levels in New York City (NOAA tide gauge The Battery) during the 1990s, 2000s, and 2010s changing due to relative sea level RSL

Design Criteria

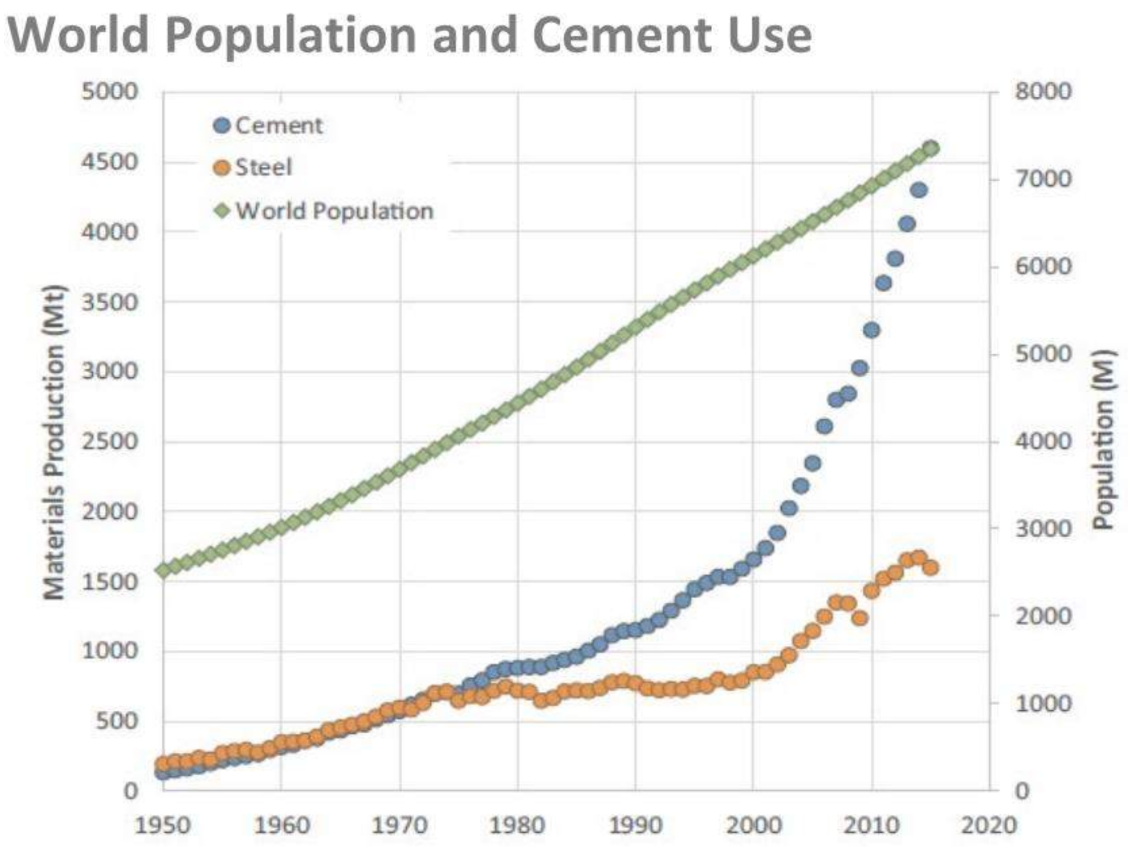
- FRP Reinforcing and Prestressing….
- Stainless-steel Reinforcing and Prestressing….



Tensile strength retention of GFRP Rebar

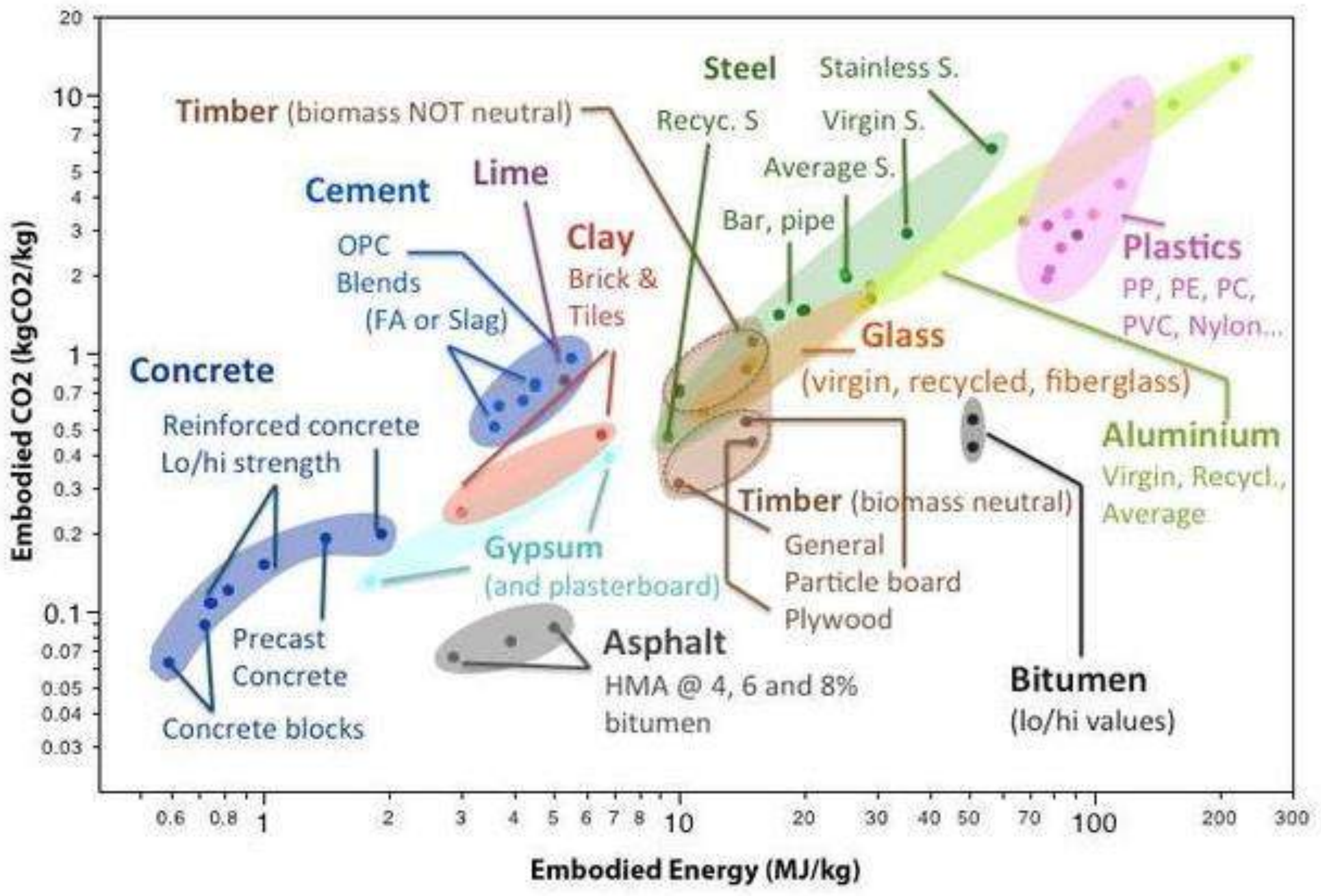
Shows performance for different resin compositions at mean annual temperatures of 10°C and 30°C

Sustainability



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

Sustainability



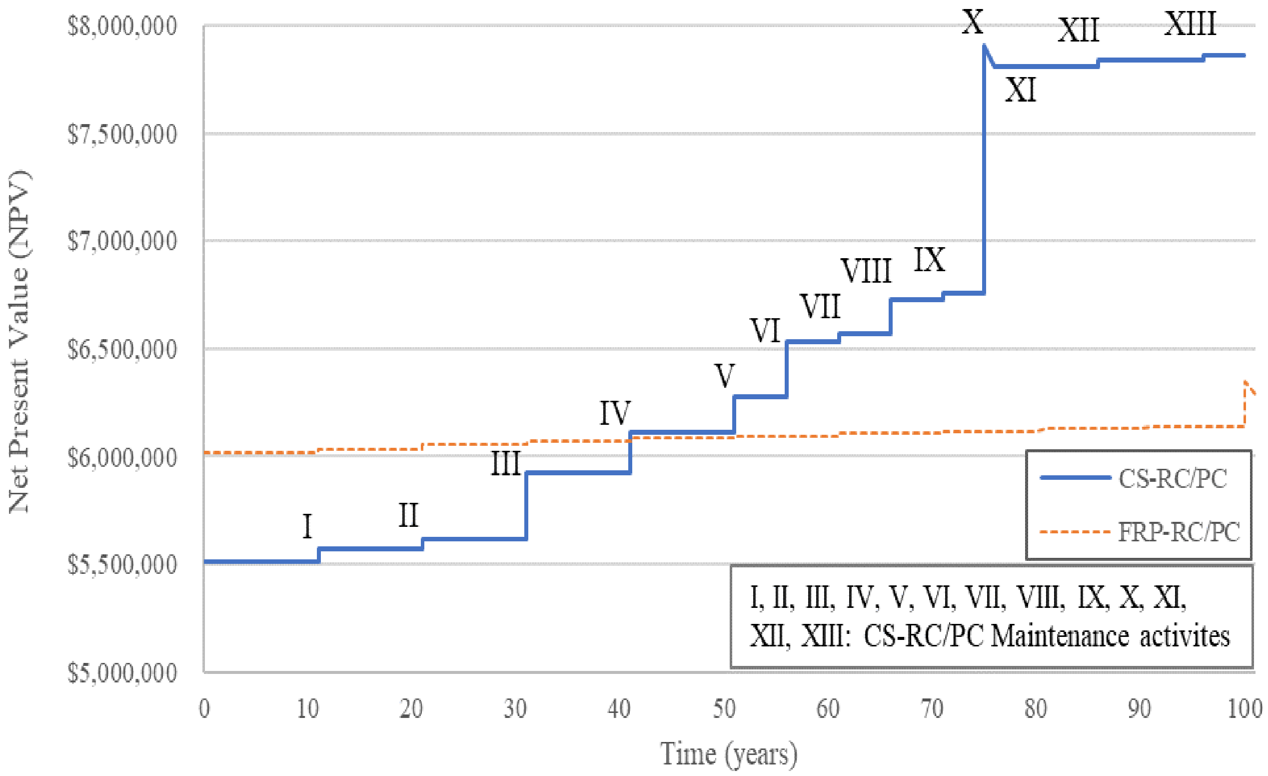
Cement and Carbon Emissions

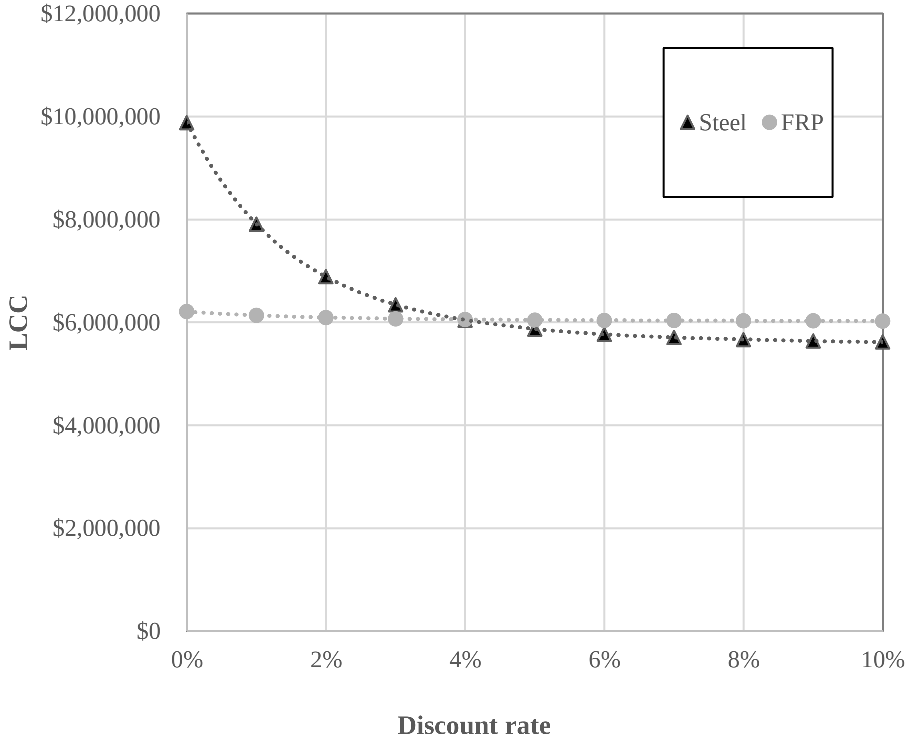
Laurent Barcelo[1,2], John Kline[1], Gunther Walenta[2] & Ellis Gartner[2]

[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.

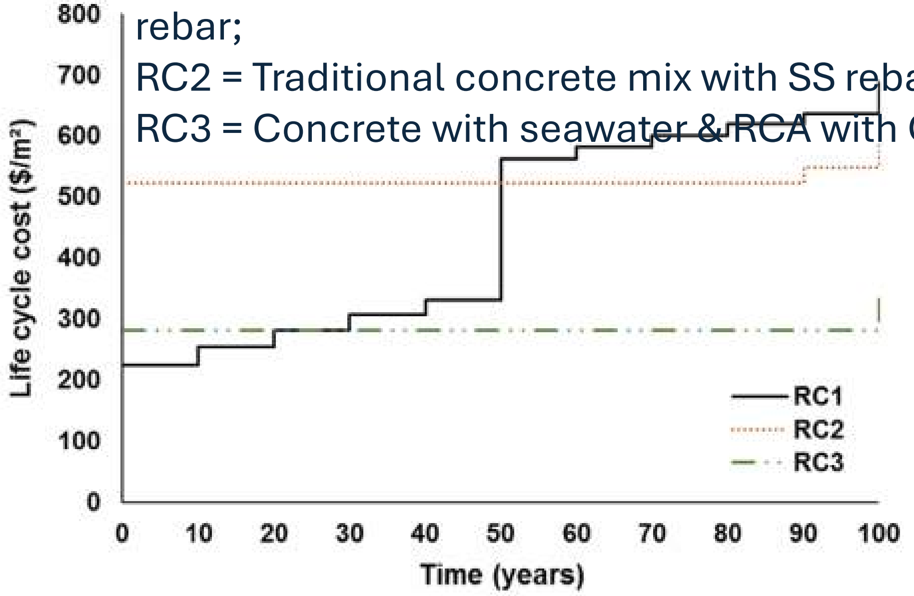


Fig. 5. Life cycle cost results (considering the baseline scenario where $r = 0.7\%$ and $C = 150\%$ of M).

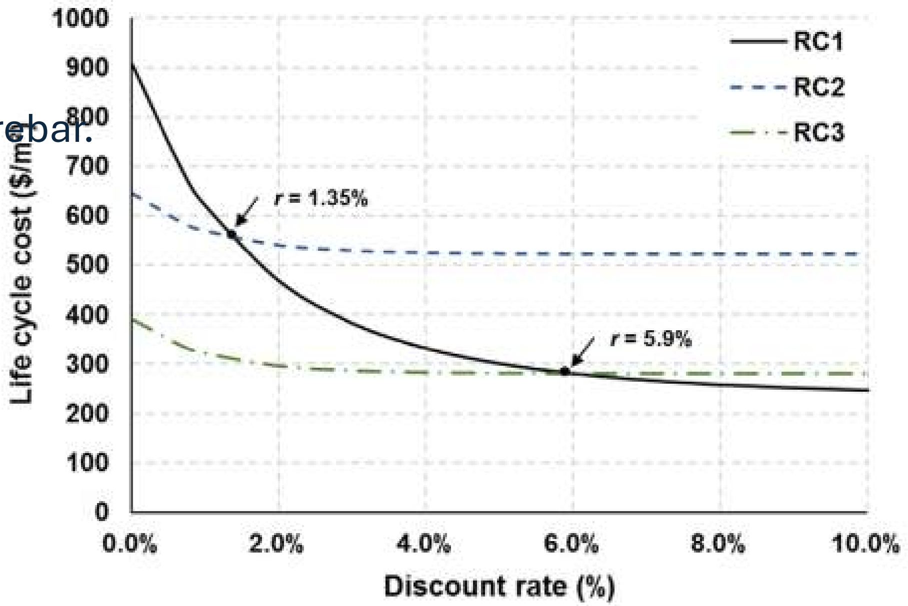


Fig. 6. Sensitivity of LCC results to the discount rate (while C is fixed at $1.5M$).

"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.

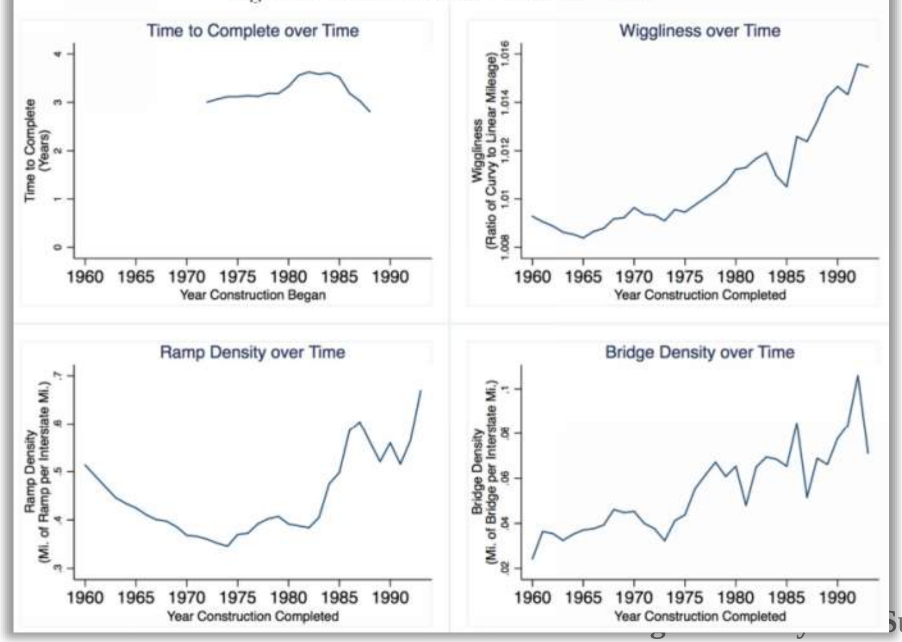
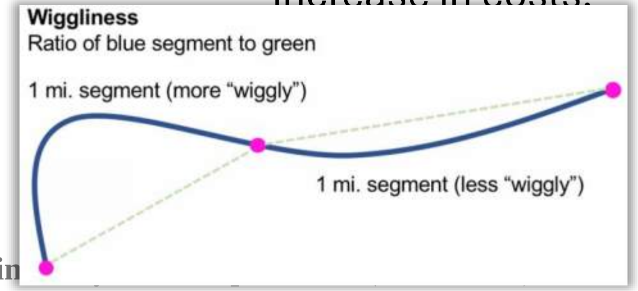


Figure 5. Time Trends in Interstate Attributes

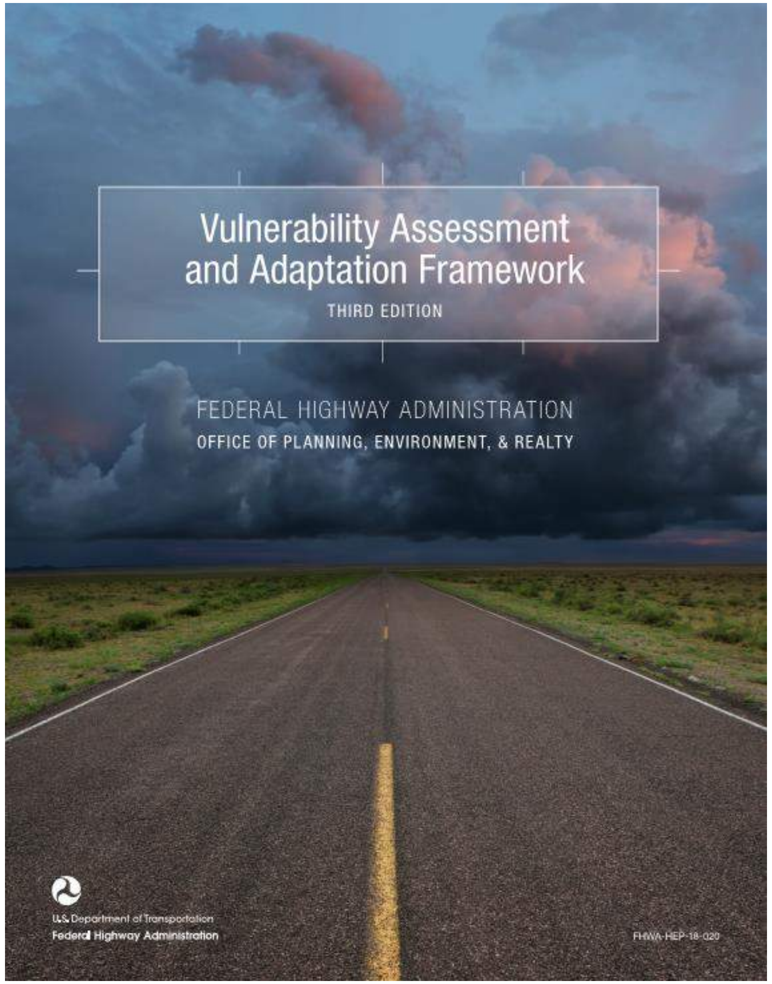
The cost of building one mile of interstate highway in the 1980s was three times what it cost in the 1960s, adjusted for inflation, Leah Brooks of The George Washington University and Zachary Liscow of Yale University find in a paper prepared for the 2019 Municipal Finance Conference (July 15-16, 2019)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

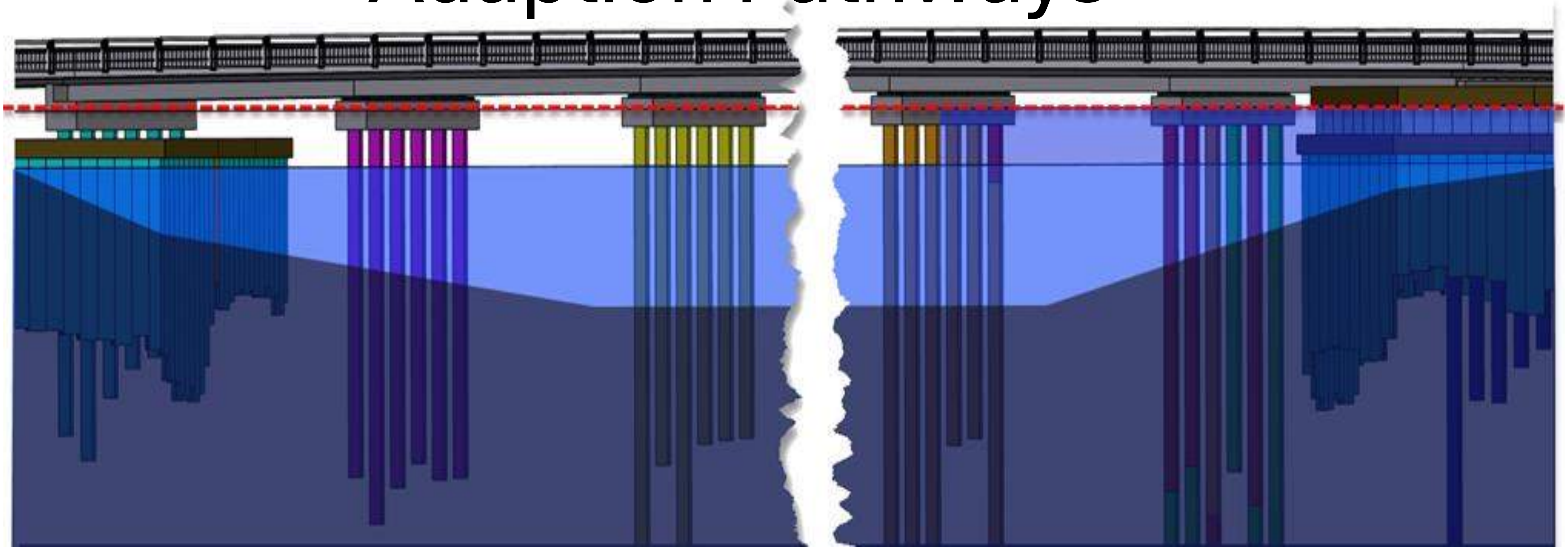
Adaption Pathways



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

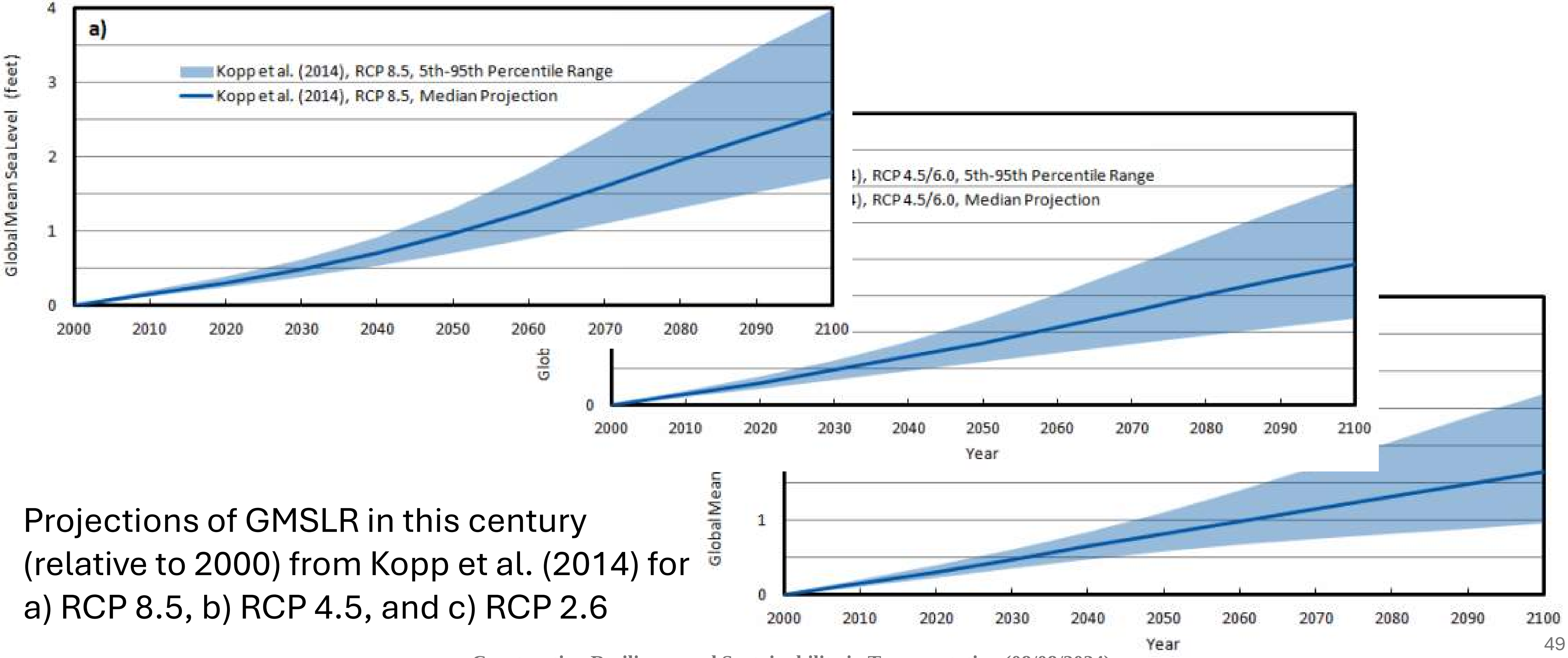


Halls River Bridge showing the impact of a 6-foot RSL

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

California 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.

Reflections:

"Weights and measures may be ranked among the necessaries of life to every individual of human society. They enter into the economical arrangements and daily concerns of every family. They are necessary to every occupation of human industry; to the distribution and security of every species of property; to every transaction of trade and commerce; to the labors of the husbandman; to the ingenuity of the artificer; to the studies of the philosopher; to the researches of the antiquarian; to the navigation of the mariner, and the marches of the soldier; to all the exchanges of peace, and all the operations of war. The knowledge of them, as in established use, is among the first elements of education, and is often learned by those who learn nothing else, not even to read and write. This knowledge is riveted in the memory by the habitual application of it to the employments of men throughout life." [1]

- John Quincy Adams, from the Report on Weights and Measures by the Secretary of State, made to the Senate on February 22, 1821

[1] https://share.ansi.org/Shared Documents/Standards Activities/NSSC/USSS-2020/USSS-2020-Edition.pdf

I-BRIDGE:
INNOVATIVE CORROSION FREE BRIDGE

Francisco De Caso, PhD., LEED A.P.

University of Miami

College of Engineering, Structures and Materials Lab

Principal Scientist

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UNIVERSITY OF MIAMI

Center for Integration of Composites into Infrastructure

I-BRIDGE:
INNOVATIVE CORROSION FREE BRIDGE

Abstract:
The University of Miami deliberately chose to construct the ‘iBridge’ or innovation bridge; a pedestrian passage spanning over a canal using concrete elements solely reinforced and prestressed with fiber-reinforced polymer (FRP) composites.

In addition to showcasing concrete reinforcing bars made of basalt and glass FRP and tendons made of carbon FRP, this bridge is the first of its kind. It features unique basalt FRP forms such as continuous close stirrups used in the pier-caps and curbs; as well as prefabricated basalt FRP cages for the auger-cast piles. The elements of the bridge were instrumented with vibrating-wire gages to monitor the structural performance over time, and load tests conducted on one of the prestressed concrete girders at the precast yard and a at the completion of the project. This presentation discusses the material technologies used to reinforce the iBridge, as well as the unique design features and construction methods, while providing load test data to support the design methodologies. The iBridge sets a course for the new construction of robust, durable corrosion free infrastructure.

Speaker Bio

Applied research work is focused on resilient material and structural systems for the built infrastructure; as well as the decarbonization of the concrete and cement industry to reach carbon neutrality by 2050. He is actively involved in technology transfer as Managing Director of the Center for Integration of Composites into Infrastructure (CICI), and Manager of the Structures and Materials Laboratory, an ISO 17025 accredited laboratory, and ISO 17020 inspection body.

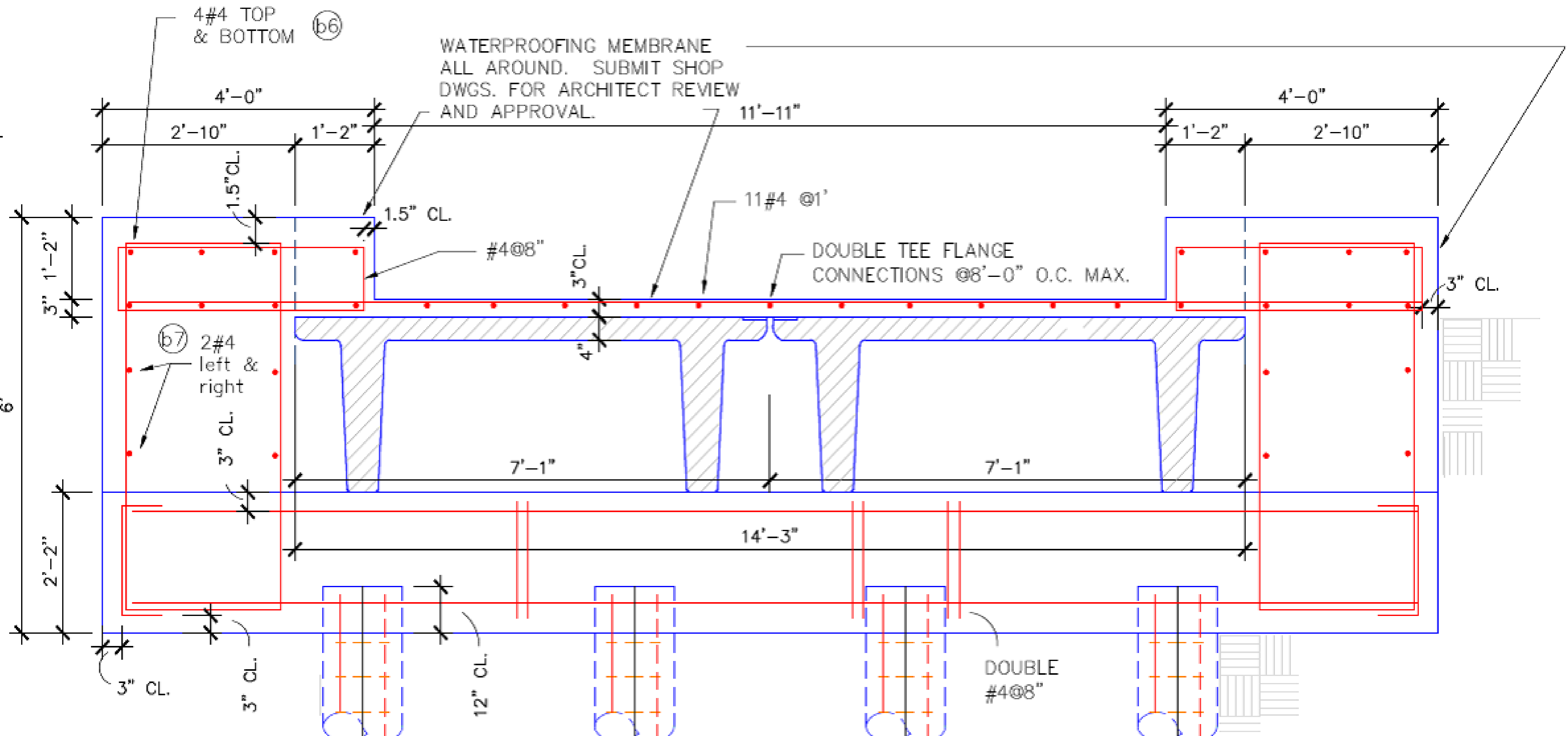
Chair of ASTM D30.10 committee on Composites for Civil Structures, involved with International Code Council (ICC), American Society of Civil Engineers (ASCE); and most recently was appointed member in the Committee on Codes and Standards Advocacy and Outreach (CSAO) of the American Concrete Institute (ACI). Dr. De Caso is actively engaged in sponsored research from federal, state agencies, and private industry

I-BRIDGE: INNOVATIVE CORROSION FREE BRIDGE

Bridge Overview:

- University of Miami (UM) pedestrian bridge: single-span, 70 ft.-long .
- Construction from November 2015 - May 2016.
- Not a single pound of “black” steel.
- Reinforcement and tendons made of FRP composites: basalt FRP (BFRP), glass FRP (GFRP), carbon FRP (CFRP).
- Novel composite manufacturing technologies: continuous close stirrups and preassembled pile cages

I-BRIDGE:
INNOVATIVE CORROSION FREE BRIDGE



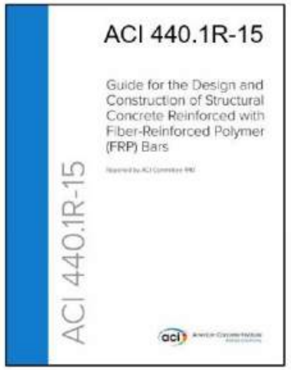
I-BRIDGE: INNOVATIVE CORROSION FREE BRIDGE

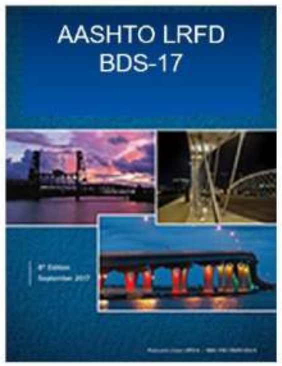
Materials:

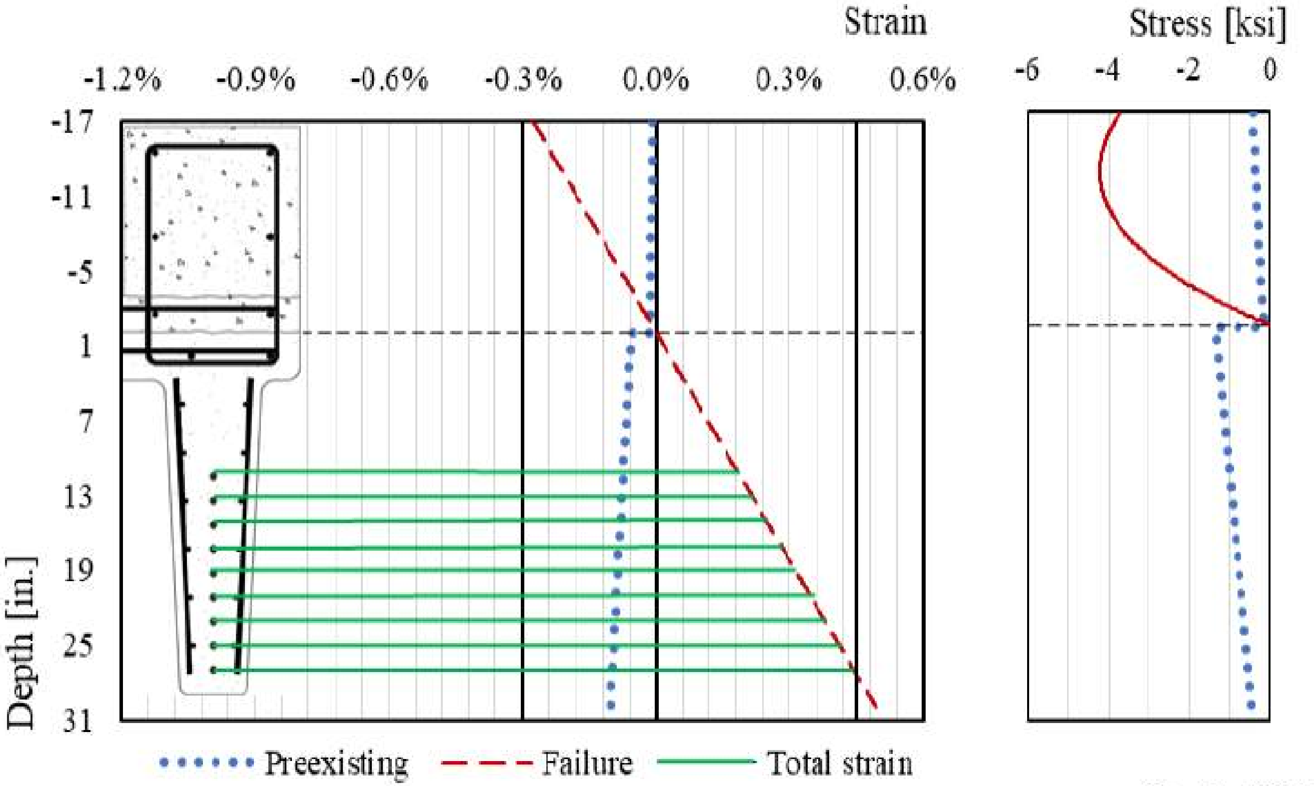
- Carbon FRP pre-stress strands (7-wire)
- Basalt FRP bars
- Glass FRP 'L' bends

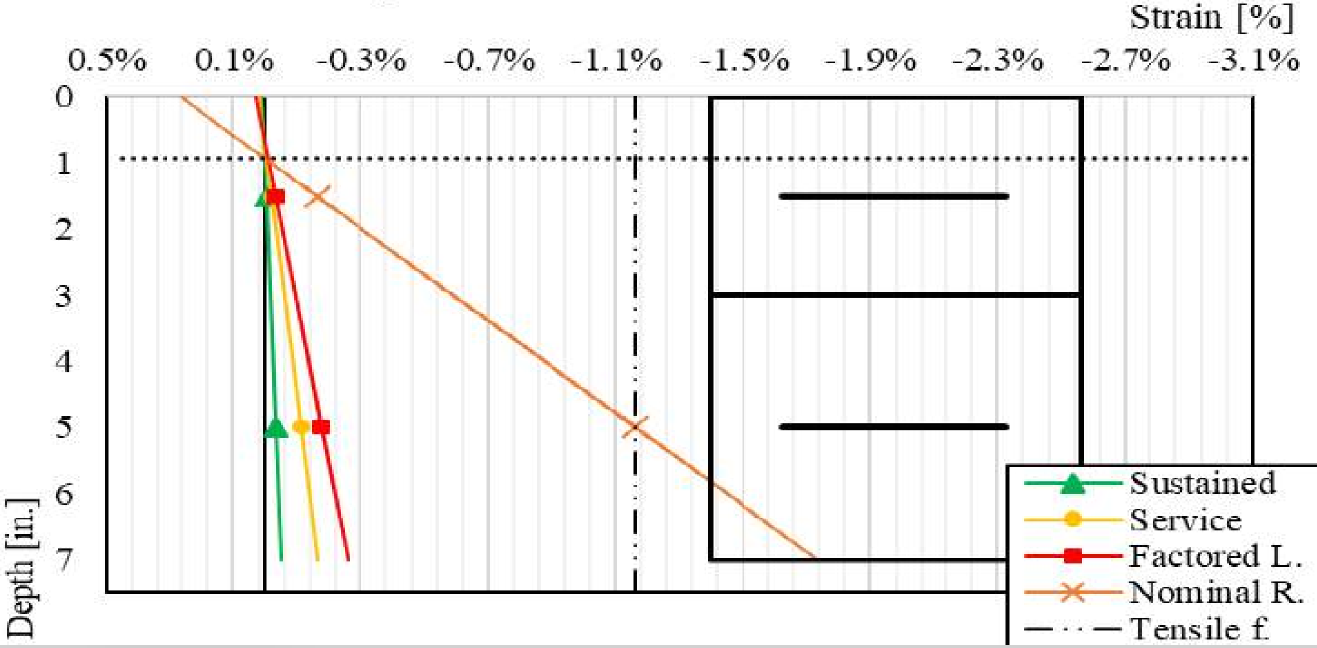
Design:

- Unified approach for RC & PC.
- Traditional methods.
- Consistent with AASHTO BDS
- Service may govern the design









I-BRIDGE:
INNOVATIVE CORROSION FREE BRIDGE

Bridge concrete elements:

1) Auger-cast piles 40' long, pre-assembled cages delivered to site.
2) Cast-in-place pile caps, side blocks and back walls.
3) Precast prestressed girders.
4) Cast-in-place deck topping and curbs.



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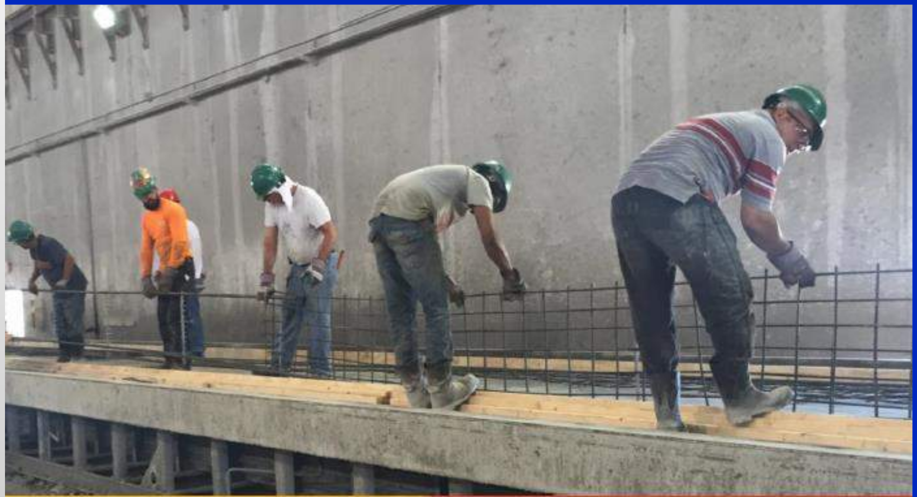


OVERSIZE
OVERSIZE LOAD
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I-BRIDGE:
INNOVATIVE CORROSION FREE BRIDGE

Instrumentation:

- 16 vibrating gages (stain of concrete and FRP)
- 10 dial gauges (deflection of girders)
- 5 survey target (deflection and camber monitoring)

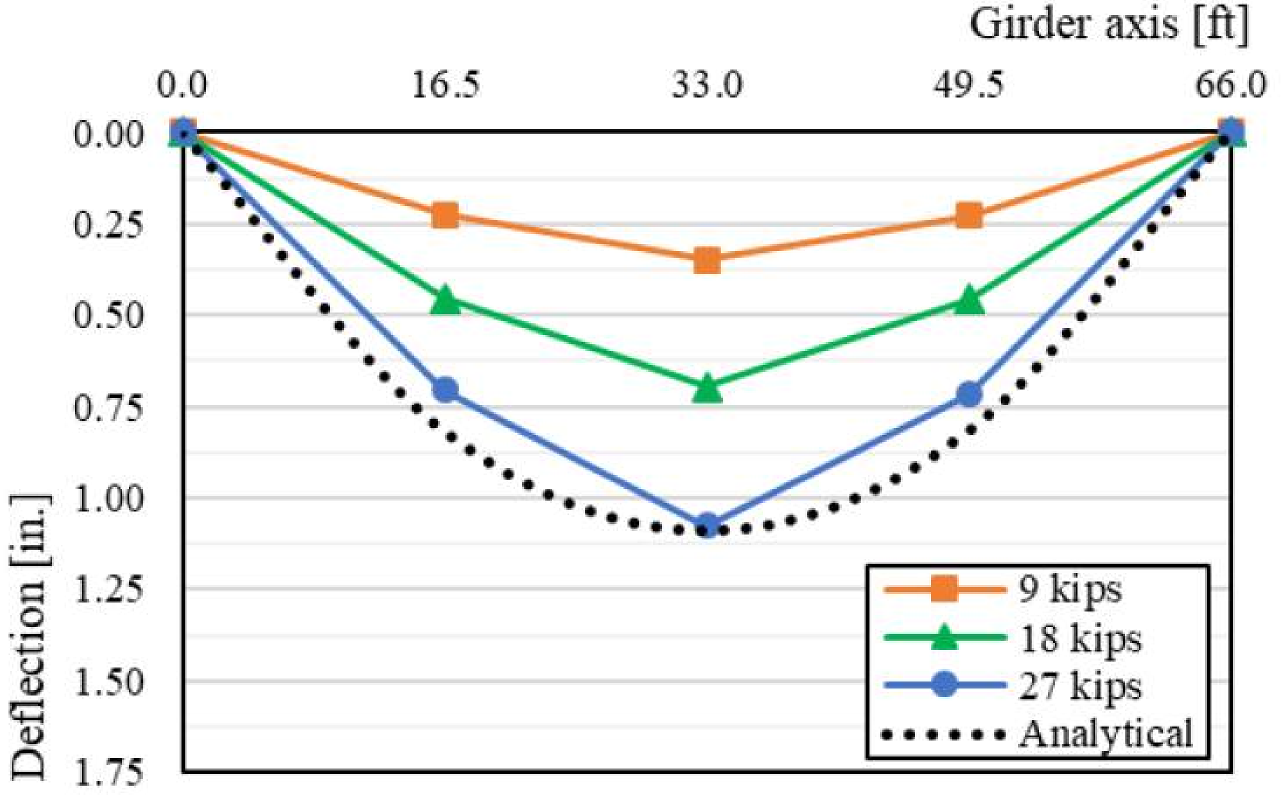
Load Tests:

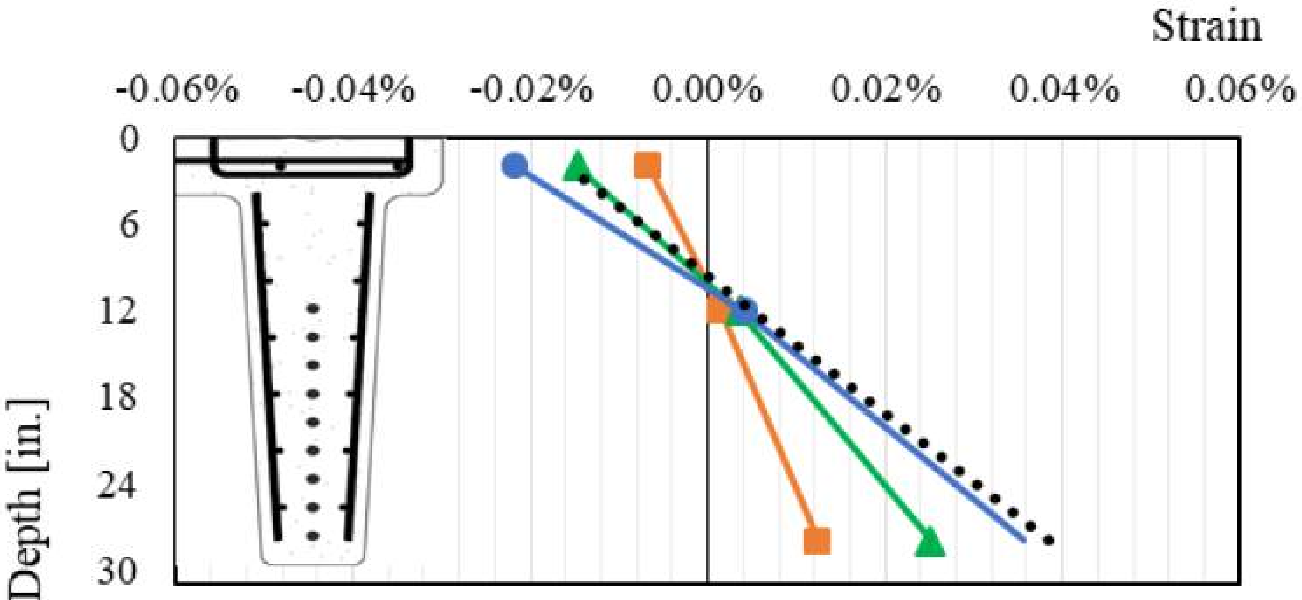
- Girder load test (28 days)
- Concrete Poring (deck during construction)
- Post construction:
  - ✓ 156 days
  - ✓ 519 days

I-BRIDGE: INNOVATIVE CORROSION FREE BRIDGE

Girder load test (28 days):

- 27 kip point load
- 85 % cracking moment
- Simply supported

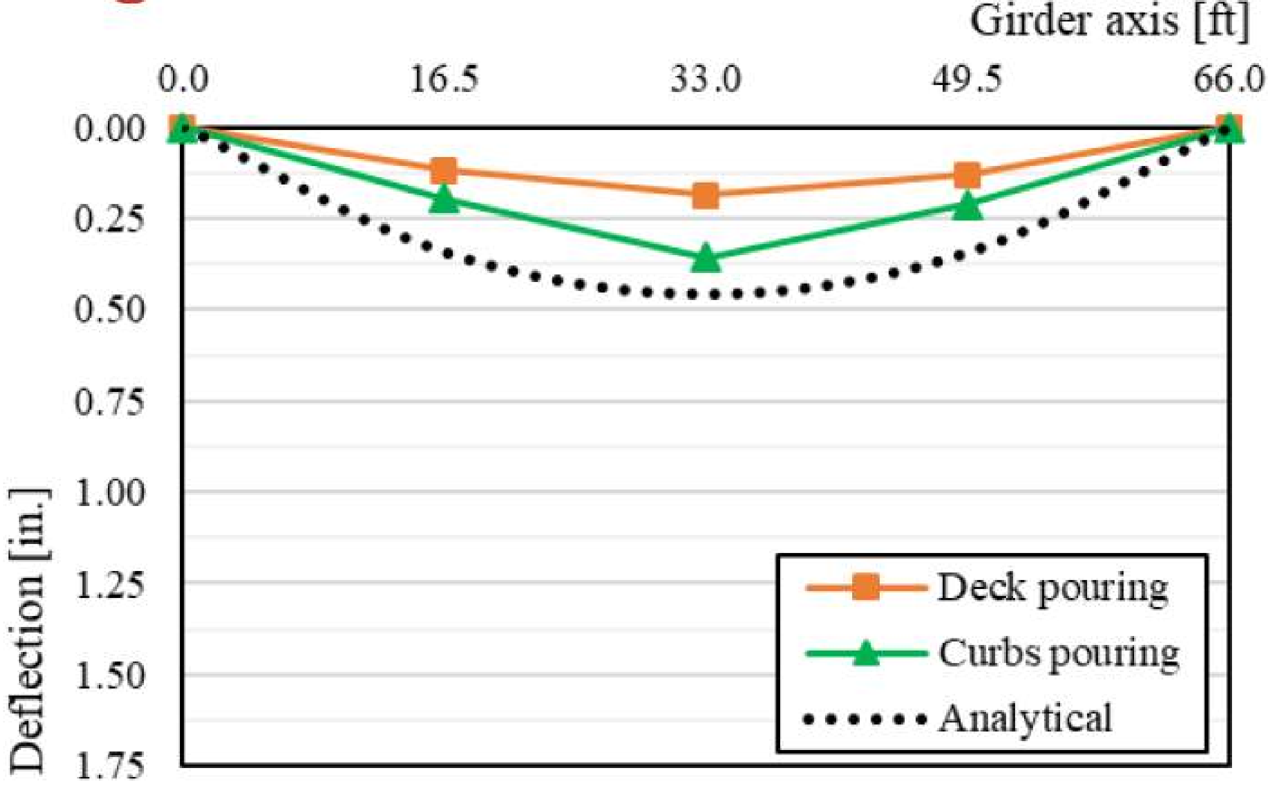


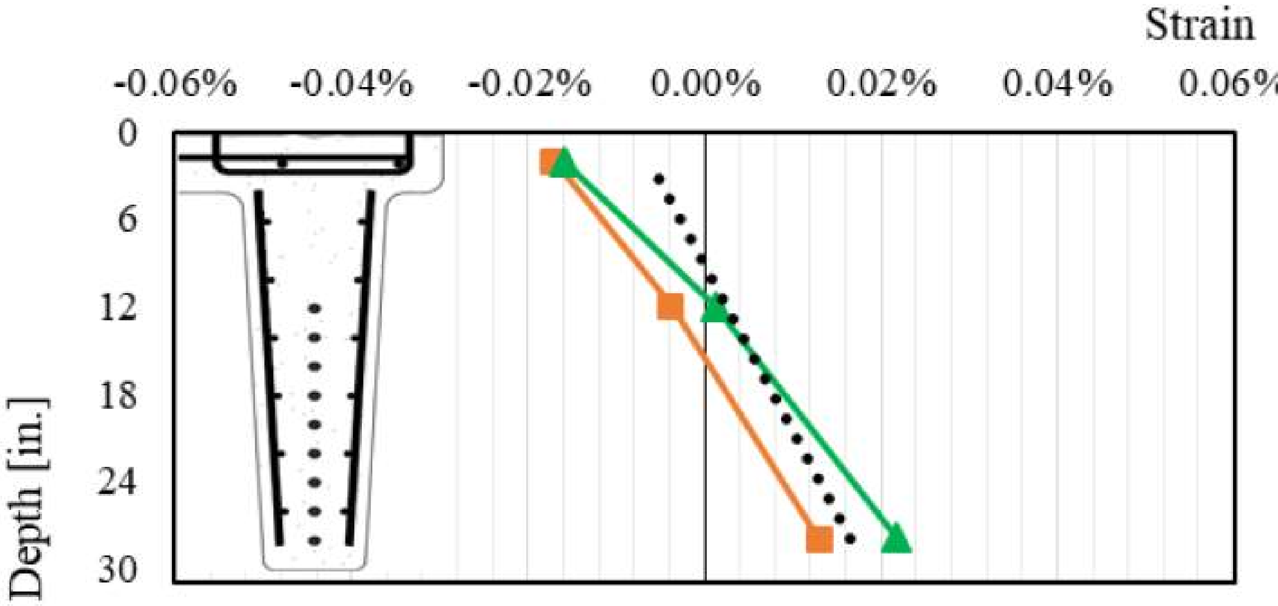


I-BRIDGE: INNOVATIVE CORROSION FREE BRIDGE

Concrete Poring (deck during construction):

- ➢ 0.5 kip/ft distributed load
- ➢ 60 % cracking moment
- ➢ Simply supported (during construction)

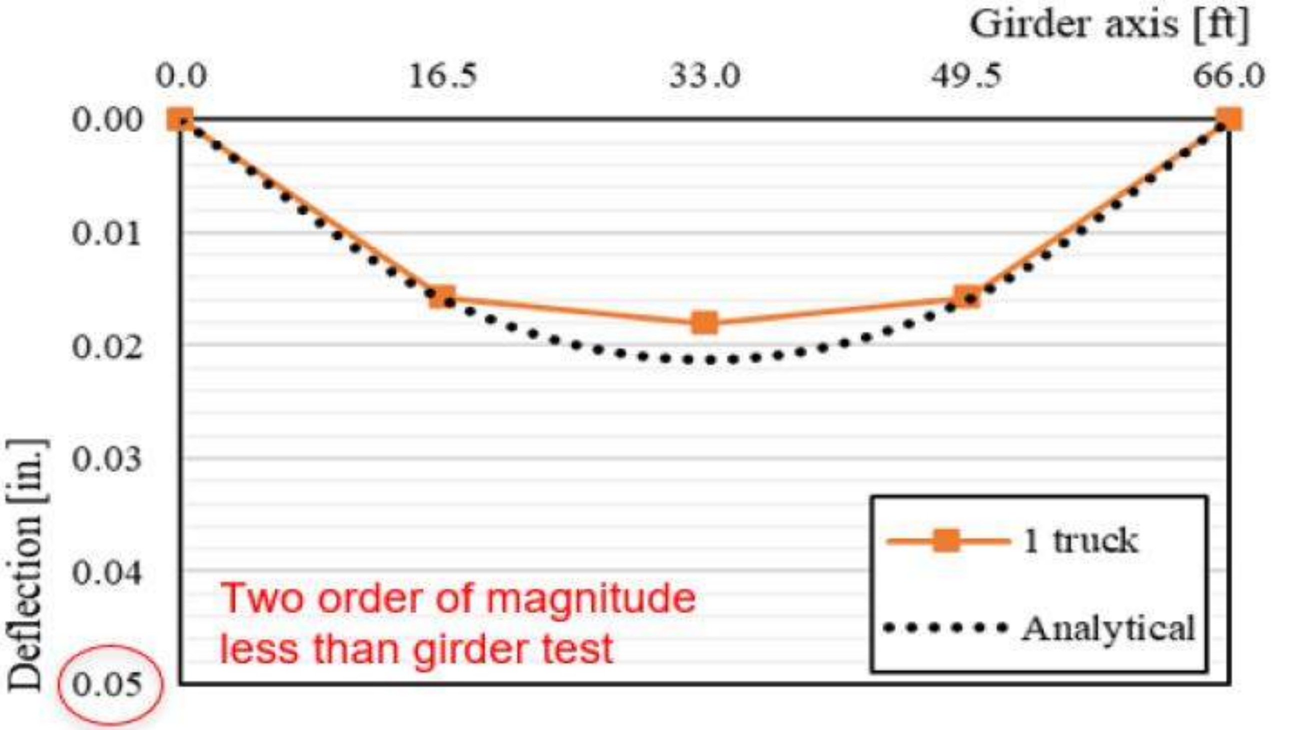




I-BRIDGE: INNOVATIVE CORROSION FREE BRIDGE

Post Construction – 156 days:

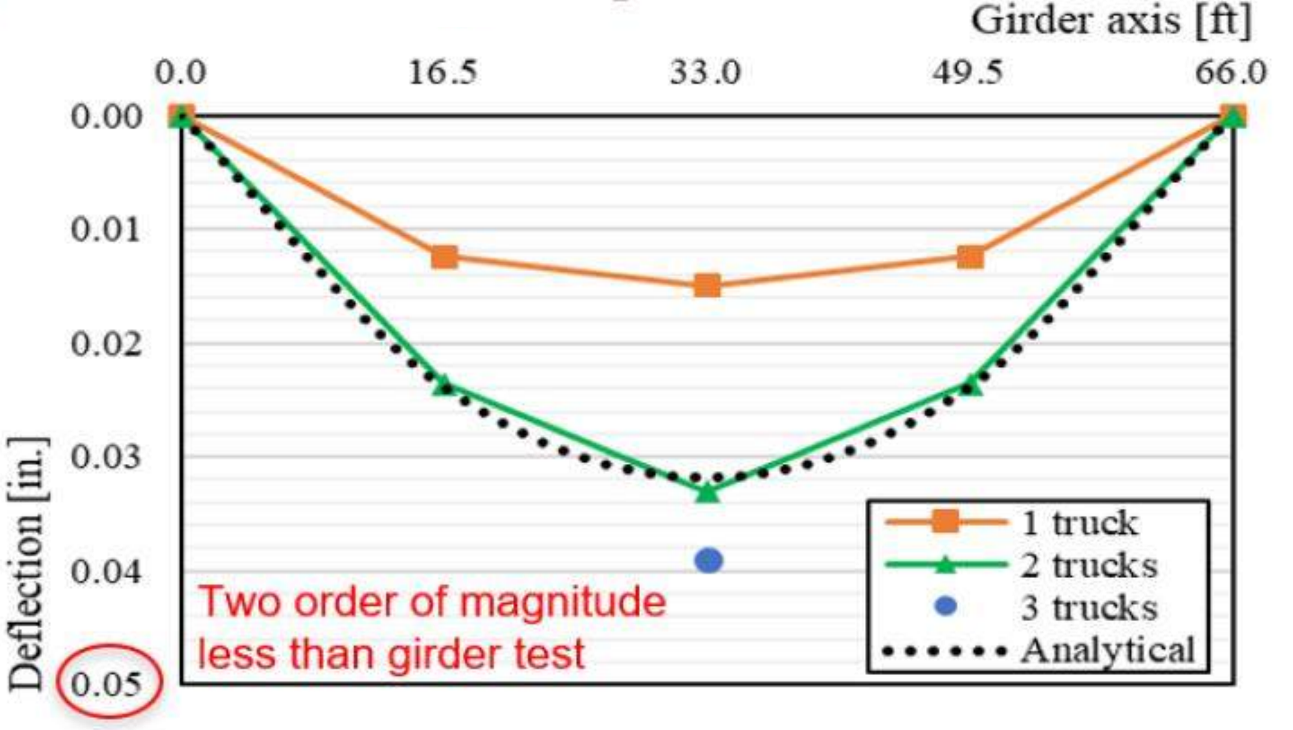
- 6 kip over two points (One Truck)
- 63 % cracking moment
- Fix ends (as built)

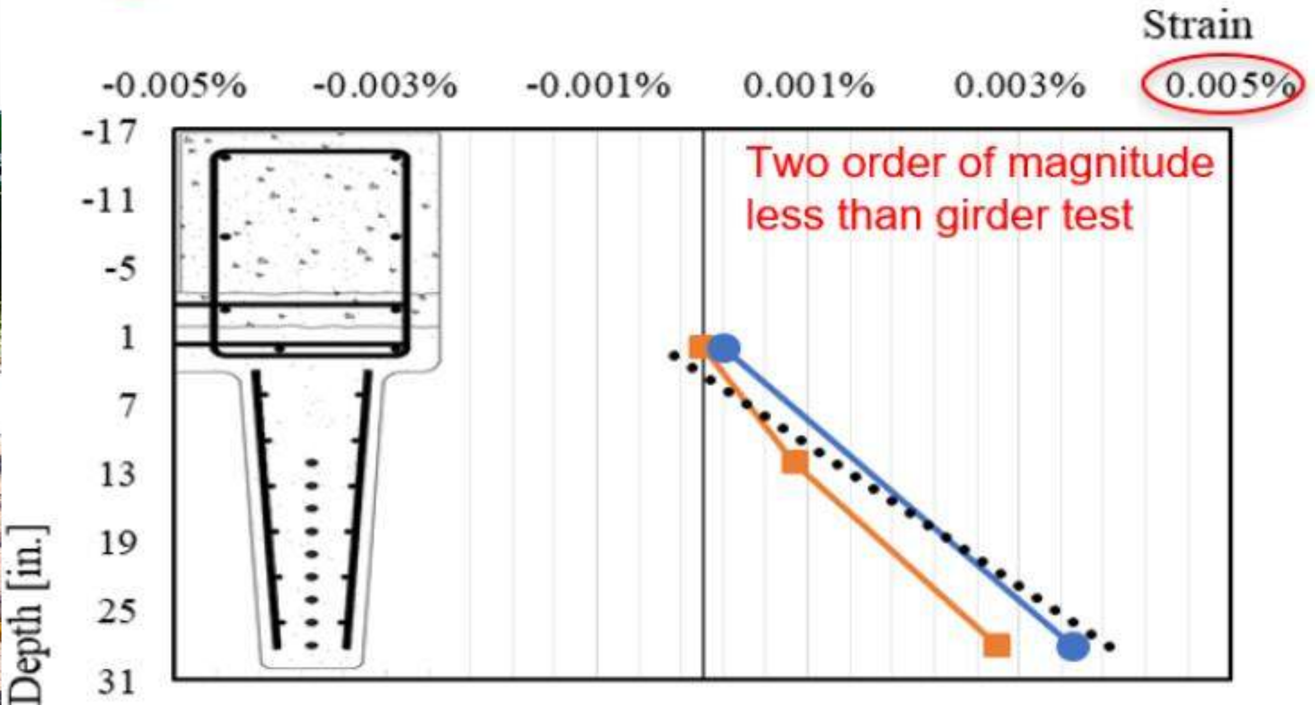


I-BRIDGE: INNOVATIVE CORROSION FREE BRIDGE

Post Construction – 519 days:

- 12 kip over six points (Three Truck)
- 65 % cracking moment
- Fix ends (as built)





I-BRIDGE:
INNOVATIVE CORROSION FREE BRIDGE

Conclusions:

- FRP: Durable, Safer, Cost Efficient.
- Pre-stressing of CFRP posses challenges.
- Labor savings during site construction handling FRP
- First entirely FRP RC/PC pedestrian bridge:
  - ✓ First BFRP RC deployment in infrastructures.
  - ✓ First FRP RC deployment in bridge substructure.
  - ✓ First auger cast BFRP pile.
- Experimentally validated:
  - ✓ 4 load tests on girder and entire structure as built structure
- Synergies: SEACON & FDOT Innovation Challenge.

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Questions

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UNIVERSITY OF MIAMI

Center for Integration of Composites into Infrastructure

University at Buffalo

Northeastern Peer Exchange for Resilient and Sustainable Bridges

August 7, 2024 – Buffalo, NY.

Institute of Bridge Engineering

RESEARCH AND DEVELOPMENTS ON IMPROVING FRP REBAR SUSTAINABILITY: MANUFACTURING & PRODUCT DEVELOPMENT TO MEET OWNER'S NEEDS AND MARKET DEMAND

Dr Omar Alajarmeh

Centre for Future Materials – University of Southern Queensland – Australia

Centre for Future Materials – University of Southern Queensland

- Established in 1995
- One of the leading research centres in Australia for engineered fibre composites
- Delivering R&D to Reality
  - Working closely with industry partners
  - Development of advanced/sustainable materials & manufacturing
  - Application in resilient structures
  - From research laboratory to real-life applications
- +100 industrial partners
- +70 researchers

"In the field of Composite Materials, we name USQ as Australia's top research institution, with most citations in the top 20 journals in the field in the last five years."

RESEARCH SPECIAL REPORT
SEPTEMBER 2020, THE AUSTRALIAN

THE AUSTRALIAN

Industry Partners

Total of more than 850 publications from 2016 to 2023

Centre for Future Materials – University of Southern Queensland

Advanced Composites Manufacturing

- Filament Winding
- Pultrusion and Braiding
- Repair
- Infusion Processing

Functional Materials

- Flame Retardant
- Morphing Material
- Energy Material
- Environmental Material
- Geopolymer

Civil Composites

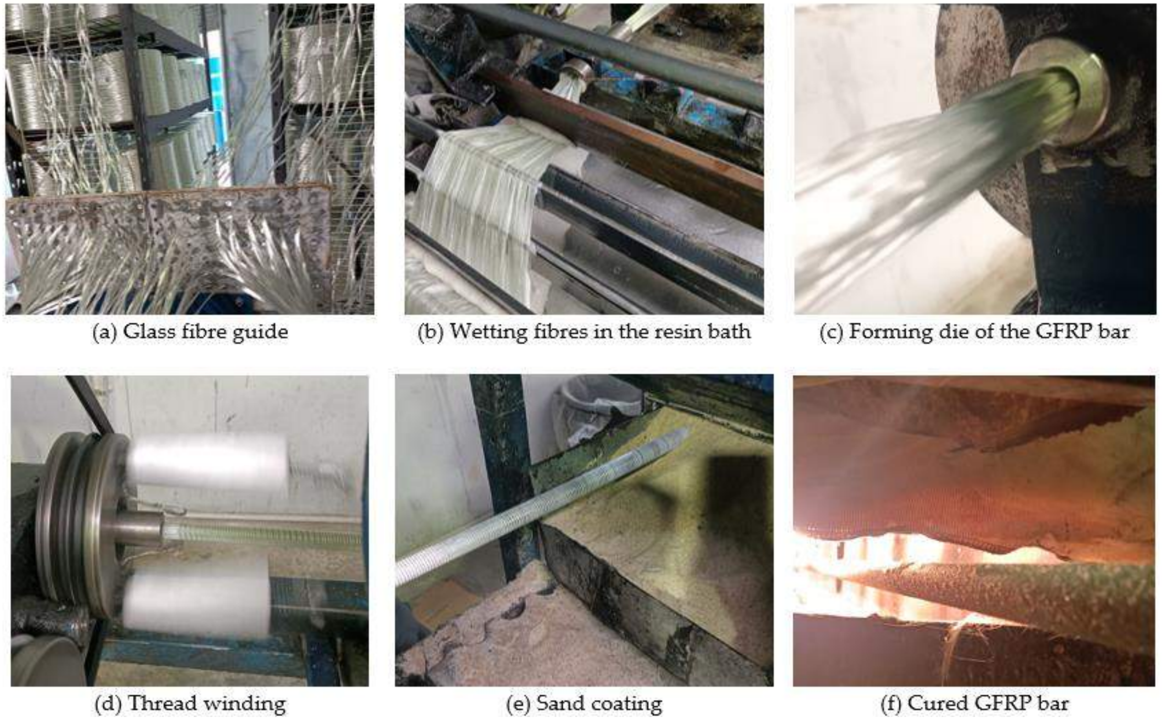
- FRP Bar
- Rock Bolt
- Bio-epoxy and recycled thermoplastic resins
- Repair/Rehabilitation
- High Performance Concrete

Sustainable Industry Design

- Circular Economy Modelling
- Materials Recycle & Reuse
- Microprocessing
- System Design

Sustainable resilient reinforcing system

Issue: Chloride attach corrosion



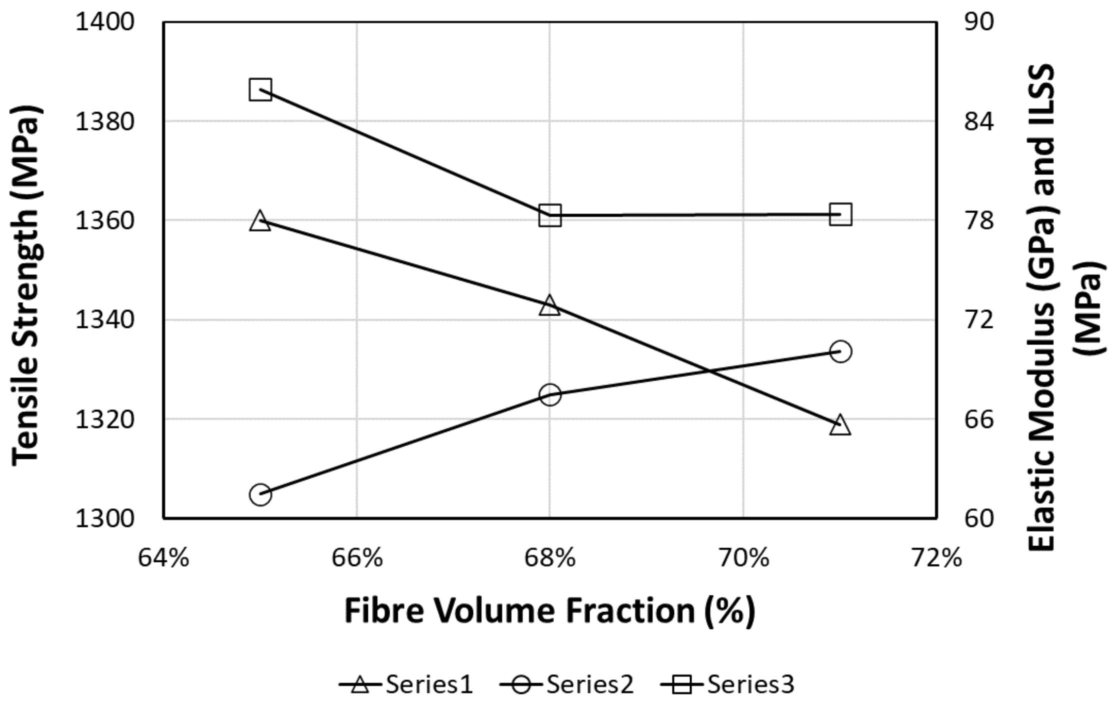
Solution: GFRP bars

Outcomes:
- ✓ High strength; Light weight
- ✓ Non-corrosive; Non-conductive
- ✓ 50% Less manufacturing power
- ✓ 45% Less CO2 emission
- ✓ 400% less transport expenses

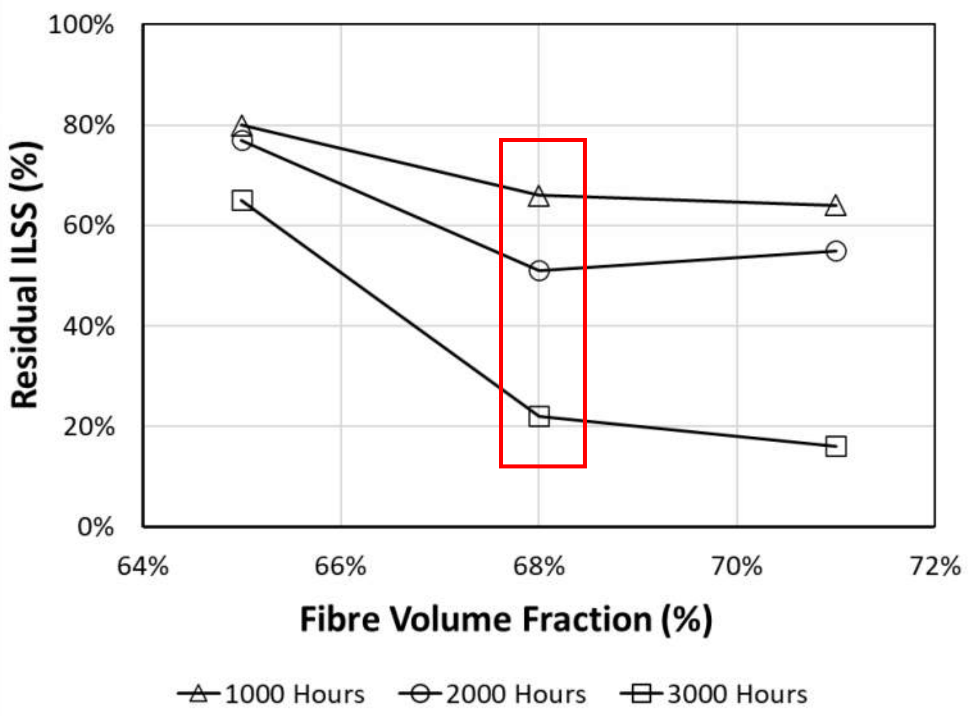
Are GFRP rebars limited to Grade III ?!

Sustainable resilient reinforcing system

- Effect of fibre content (fibre volume 65%, 68%, 71%)

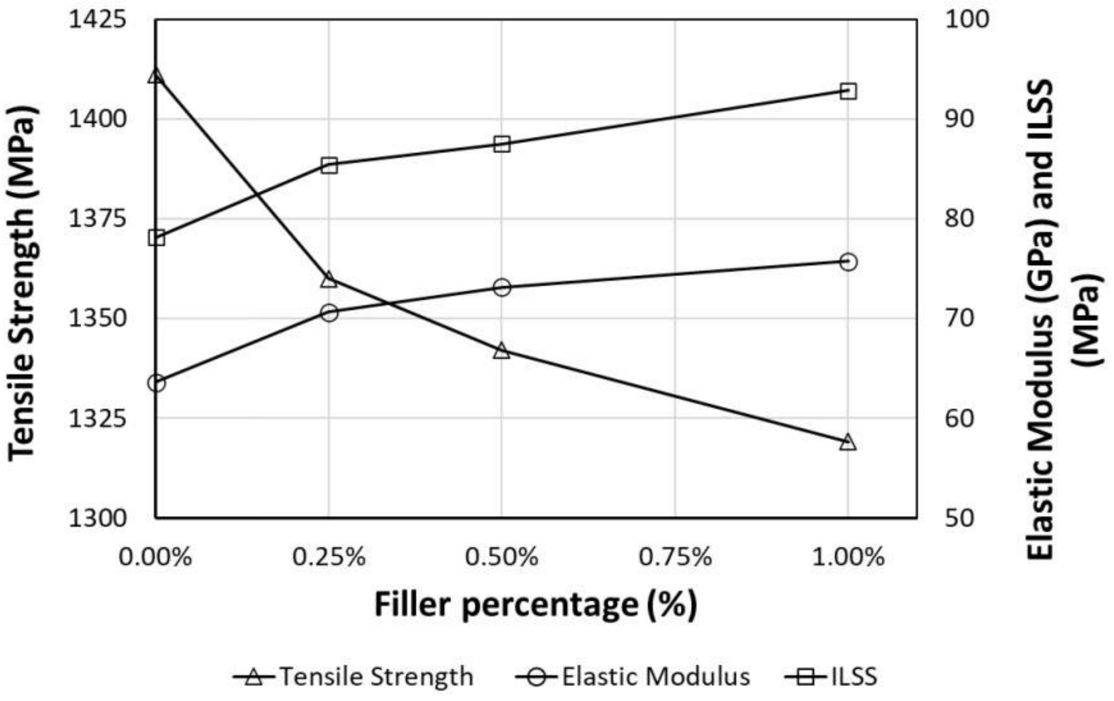


Durability (Alkaline Conditioning)



Sustainable resilient reinforcing system

- Effect of additive manufacturing (Graphene nanoplatelets)



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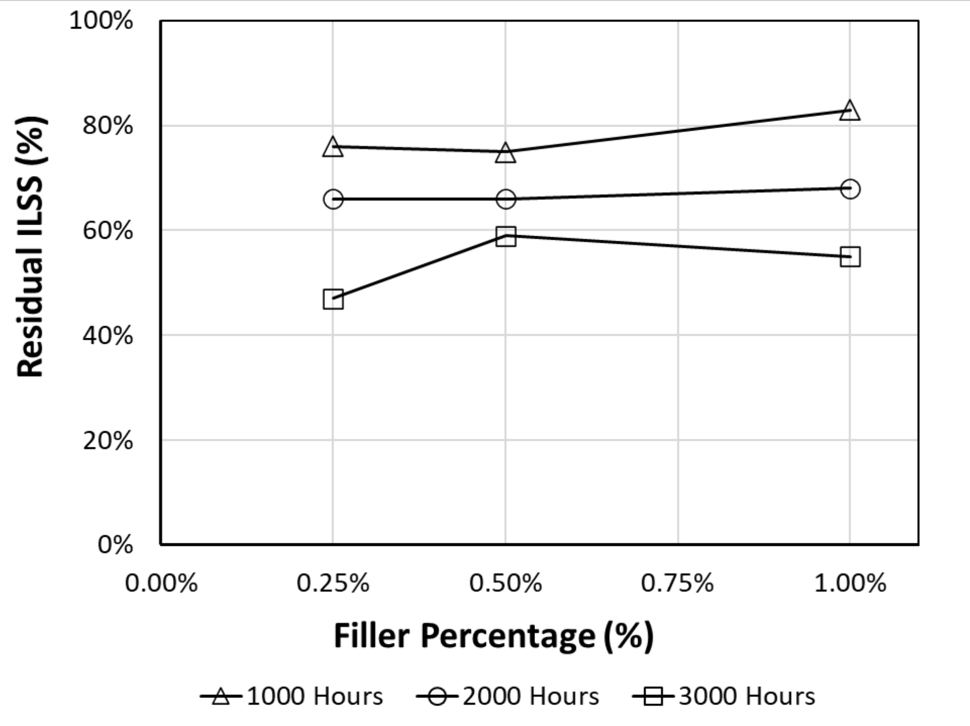


Development of new resin systems

- Sustainable Bio-based resin system

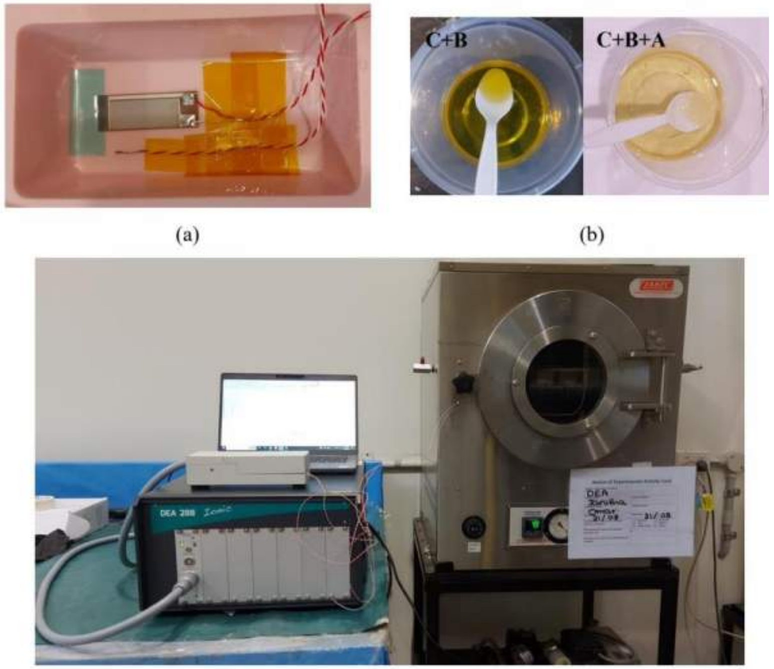
Project: New development of Bio-epoxy resin system

Partners: Incomat and Climate Change

Diglycidyl ether Bisphenol A (DGEBA)

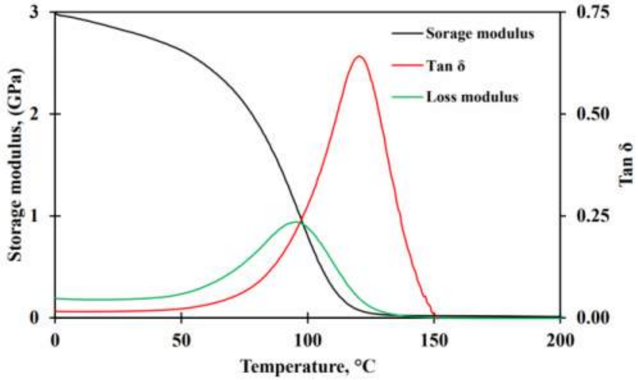
↓

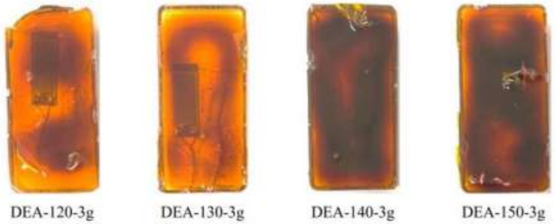
Bio-based epoxy resin system: glycerol core



(a) (b)

(c)





Outcomes:

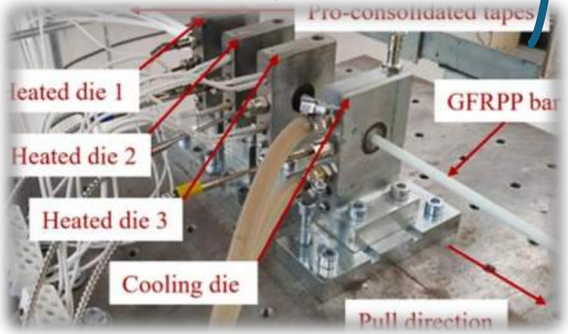
- ✓ Produce new novel Bio-epoxy resin reliable for pultrusion manufacturing
- ✓ Reducing at least 80% of CO_2 emission at production
- ✓ Pultrude new version of environmental-friendly pultruded products

Development of new resin systems

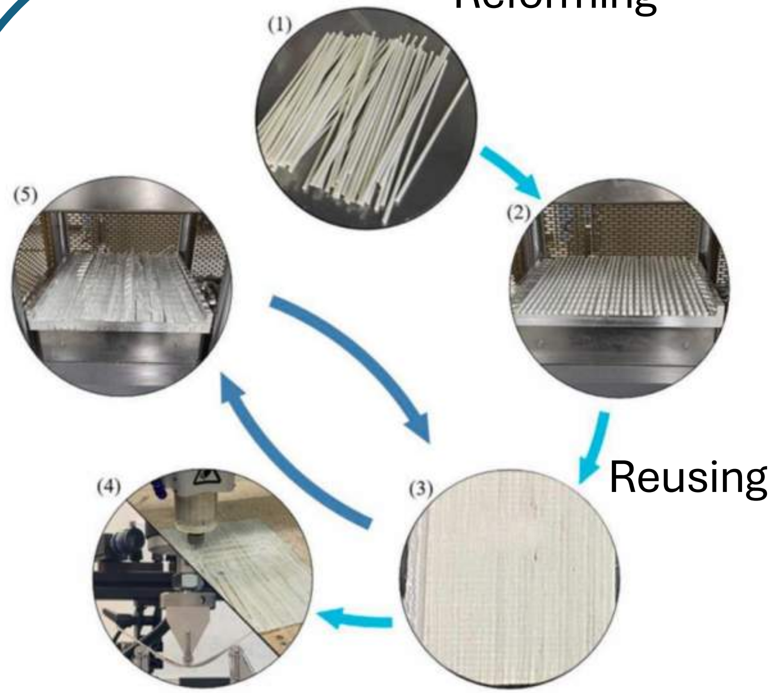
- Recyclable thermoplastic reinforcing system

Project: New development of Thermoplastic GFRP rebars

Partners: Beyond Materials Group



Reforming



Reusing

- ➢ Recycled Polyproplene (PP)
- ➢ Recycled Polyethylene terephthalate (PET)
- ➢ Recycled High-density polyethylene (HDPE)

Outcomes:

- ✓ Producing recycled thermoplastic GFRP rebar through pultrusion
- ✓ Pultrude new version of environmental-friendly pultruded products

Contact

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Tel: +61 7 4631 5516
Mob:+61497394088

www.youtube.com/c/USQCentreforFutureMaterials

More Information on
https://composites.usq.edu.au/research/facilities/

CRICOS : QLD00244B NSW02225M TEQSA:PRIV12081

Northeastern Peer Exchange for Resilient and Sustainable Bridges

August 7, 2024 – Buffalo, NY.

University at Buffalo

Institute of Bridge Engineering

POTENTIAL APPLICATIONS OF ARTIFICIAL INTELLIGENCE/ MACHINE LEARNING IN BRIDGE MAINTENANCE

Antonio De Luca, PhD, PE, SE[1]

Rolan Duvvury, PE[2]

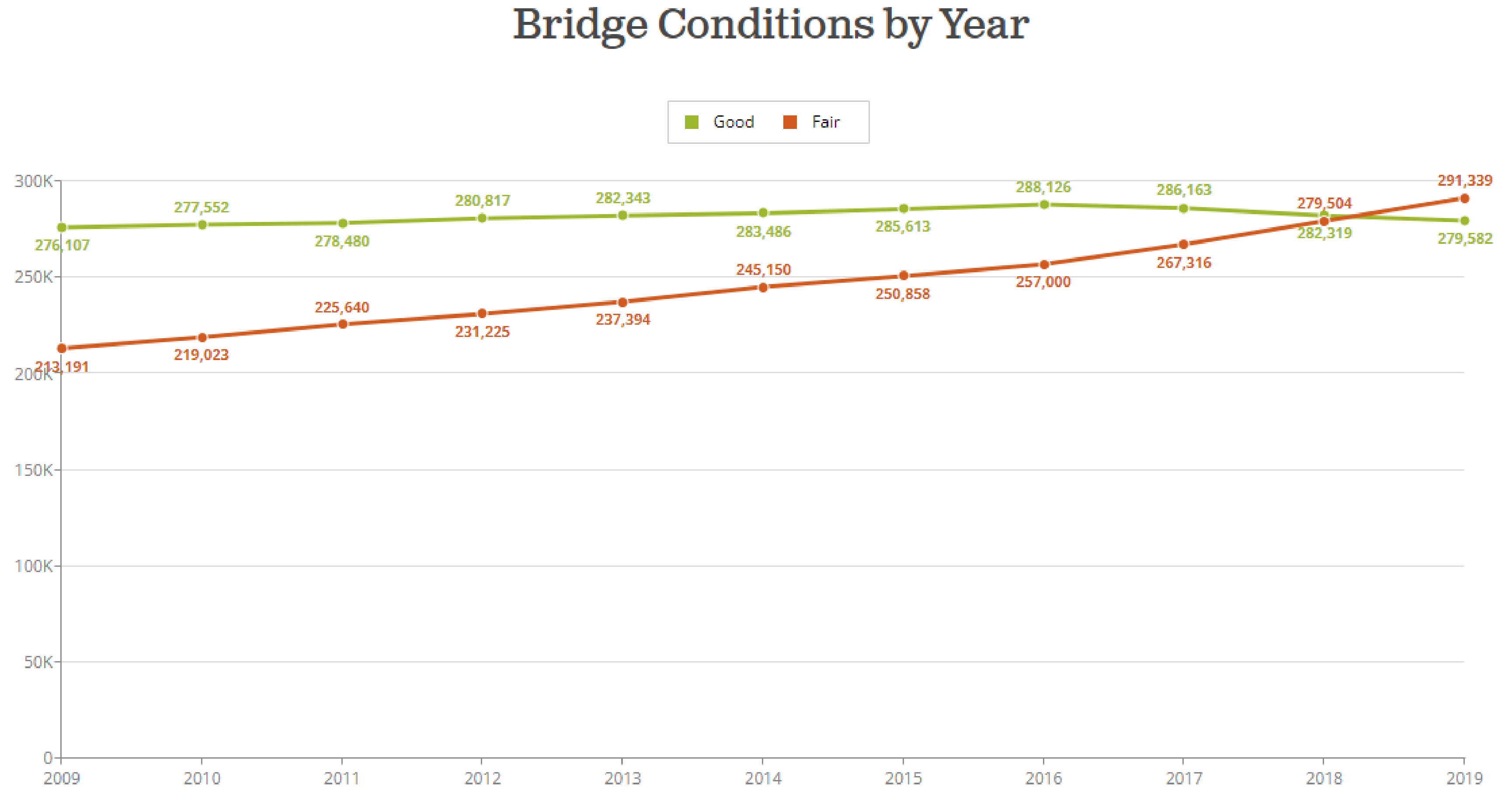
[1]Senior Associate – Forensics, Thornton Tomasetti, Fort Lauderdale, FL

[2]Senior Project Engineer – Transportation, Thornton Tomasetti, New York, NY

OUTLINE

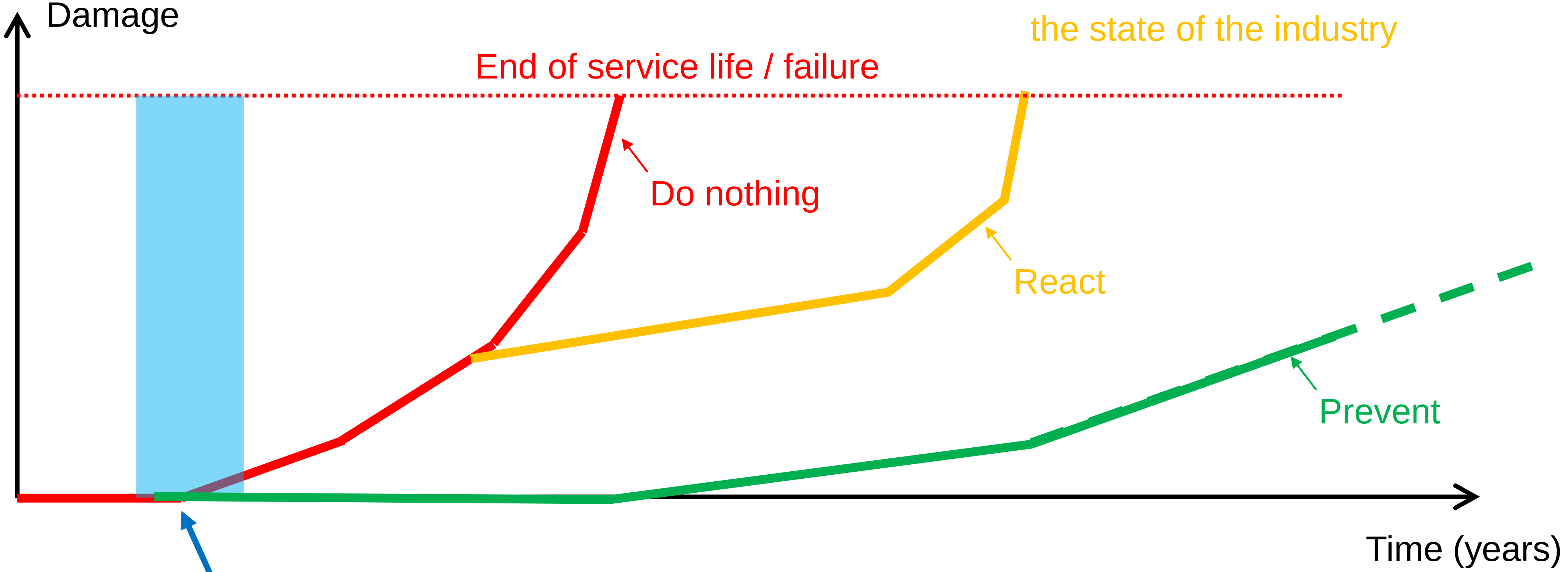
- Introduction & Background
- Potential applications of AI/ML for bridge management
- Discussion on how AI/ML may impact future of bridge monitoring
- Conclusions

2021 ASCE REPORT CARD

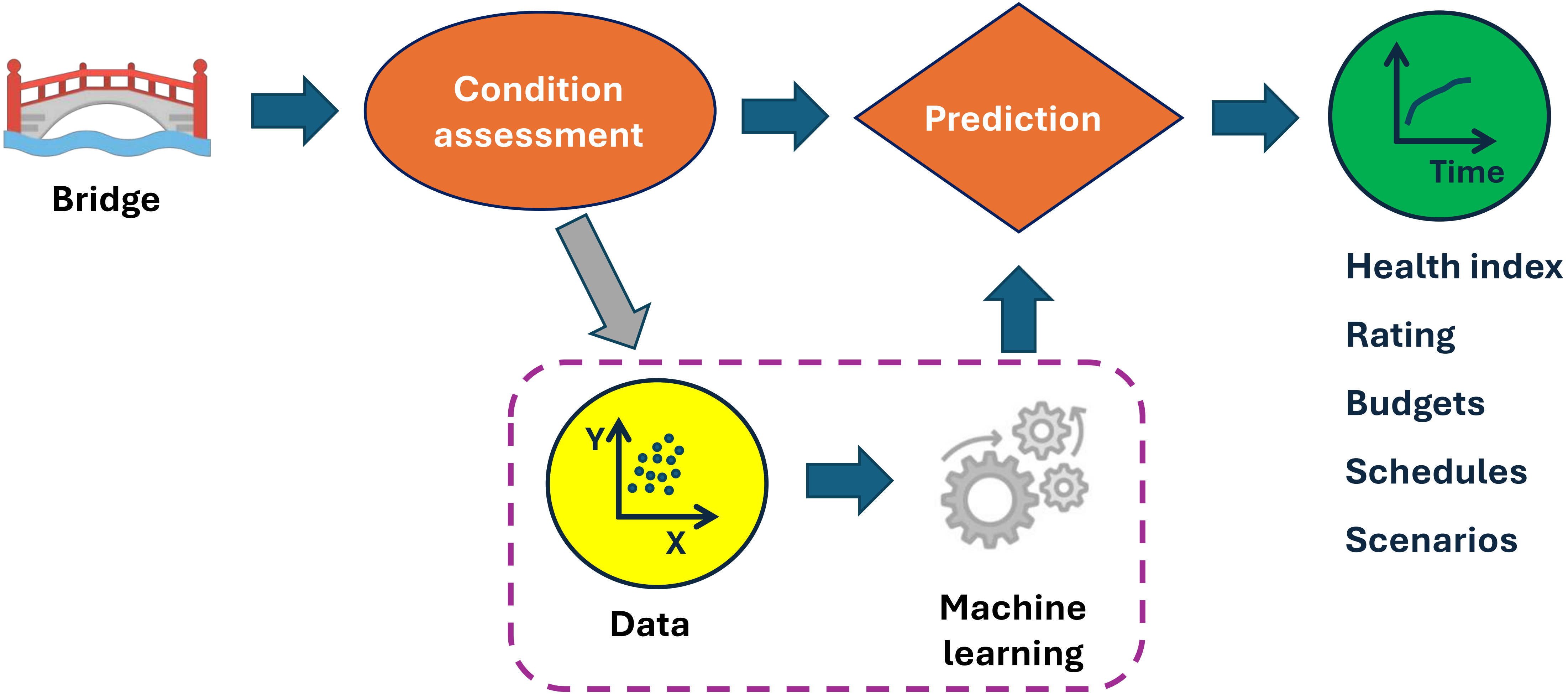


Source: U.S. Department of Transportation, Federal Highway Administration, InfoBridge: Data: https://infobridge.fhwa.dot.gov/Data/Dashboard

PREVENT RATHER THAN REACT



DATA-DRIVEN PREVENTIVE MAINTENANCE



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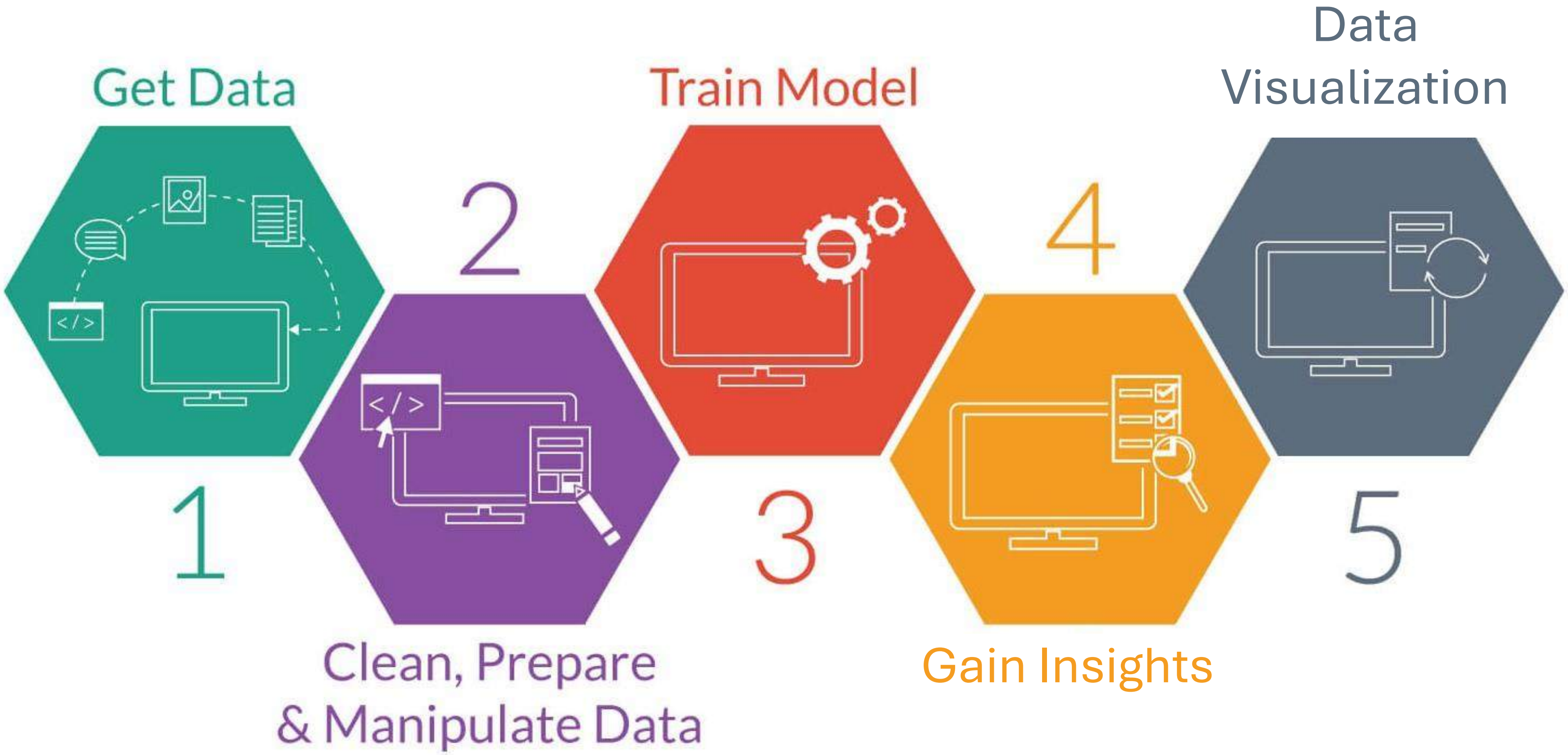
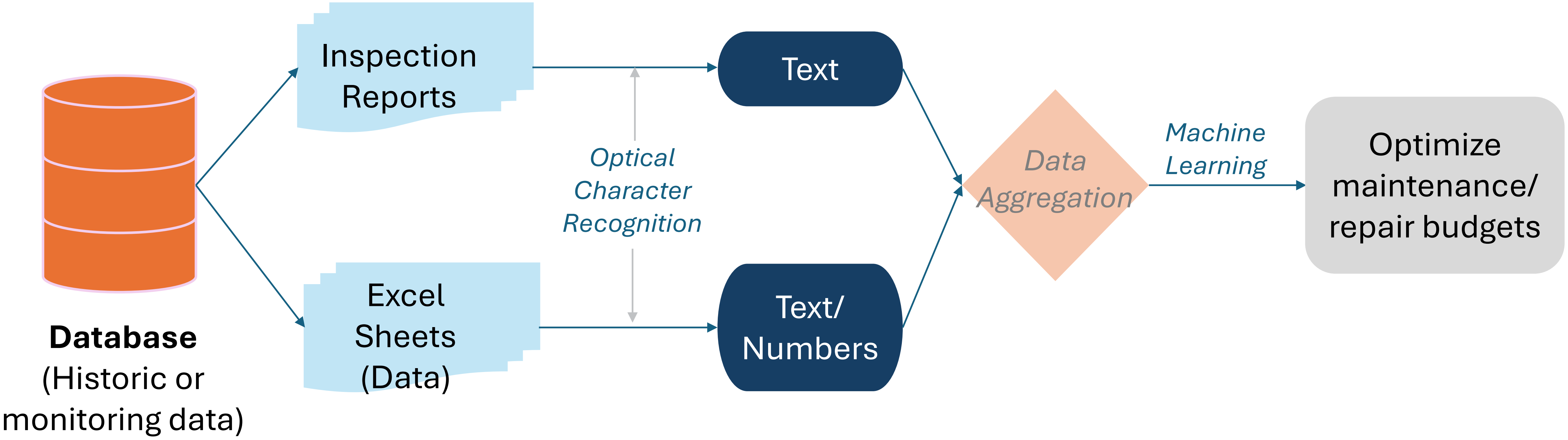
AI/ML PROCESS



POTENTIAL PIPELINE



FLORIDA BRIDGE INVENTORY

Florida Bridge Information

DISTRICT	COUNTY	OWNER	BRIDGE	STRUCTURE NAME	ROADWAY	ADT	FACILITY CROSSED	YEAR BUILT	RECONSTRUCTED	LAST INSPECTION	SUFFICIENCY RATING	HEALTH INDEX	NBI RATING
Central Florida	Brevard	State Highway Agency	700002	SR-405 WB - FECRR	SR-405 WB	7,550	FECRR	1969		11/9/2021	80.3	98.26	
Central Florida	Brevard	State Highway Agency	700003	3-7x4x110 CBC	US-1	15,236	Kid Creek	1964		4/3/2020	69	58.85	
Central Florida	Brevard	State Highway Agency	700006	US-1 - Crane Cr. & City St	US-1	37,000	City St. & Crane Creek	1959	1990	10/22/2021	65	94.61	FO
Central Florida	Brevard	State Highway Agency	700007	US-1 over Elbow Creek	US-1	49,000	Elbow Creek	1961	1990	11/4/2021	92.3	93.96	
Central Florida	Brevard	State Highway Agency	700008	US-1- Eau Gallie River	US-1	54,000	Eau Gallie River	1961	1990	11/3/2021	85	95.22	
Central Florida	Brevard	State Highway Agency	700012	US-1 - FECRR	US-1	19,700	FECRR	1936	1961	9/13/2021	91.9	99.77	
Central Florida	Brevard	State Highway Agency	700013	SR-50 WB - St Johns River	SR-50 WB	6,100	St. Johns River	1971		12/15/2021	88.5	86.88	
Central Florida	Brevard	State Highway Agency	700014	SR-528 WB - US-1 & FECRR	SR-528 WB	20,000	US-1 & FECRR	1963	1970	10/27/2021	76.8	98.71	FO
Central Florida	Brevard	State Highway Agency	700015	SR-528 WB - CR-515	SR-528 WB	21,579	CR-515 & Indian River	1963	2001	10/28/2021	78.7	91.53	
Central Florida	Brevard	State Highway Agency	700017	SR-528 WB over SR-3	SR-528	15,250	SR-3	1971		3/22/2022	83.9	99.28	FO
Central Florida	Brevard	State Highway Agency	700018	US-192 EB - Sawgrass Creek	US-192 EB	5,150	Sawgrass Creek	1967	2004	2/1/2021	99.7	94.81	
Central Florida	Brevard	State Highway Agency	700023	US-192 WB - St Johns Relief	US-192 WB	5,150	St Johns River Relief	1966	2004	3/1/2021	99.7	90.42	
Central Florida	Brevard	State Highway Agency	700025	SR-528 WB - Sykes Creek	SR-528	15,250	Sykes Creek	1963	2002	3/22/2022	78	77.65	FO
Central Florida	Brevard	State Highway Agency	700026	SR-528 WB - Banana R. Dr.	SR-528 WB	13,000	Banana River Drive	1963		1/27/2022	76.2	90.42	FO
Central Florida	Brevard	State Highway Agency	700027	SR-528 WB-Banana R. Rel.	SR-528	13,000	Banana River Relief	1963		1/31/2022	74.2	92.97	
Central Florida	Brevard	State Highway Agency	700028	SR-528 WB - Banana R.	SR-528	13,000	Banana River	1963		7/27/2020	66.5	87.81	FO
Central Florida	Brevard	State Highway Agency	700029	SR-405 WB - US-1	SR-405 WB	7,550	US-1	1964		12/21/2021	82.3	98.39	
Central Florida	Brevard	State Highway Agency	700030	SR-401 SB - Barge Canal	SR-401 SB	5,750	Service Rd & Canal	1963	2011	9/29/2021	68.8	90.08	FO
Central Florida	Brevard	State Highway Agency	700031	SR-401 SB - Barge Canal	SR-401 SB	4,600	Service Rd & Canal	1963		9/29/2021	77	93.47	FO
Central Florida	Brevard	State Highway Agency	700033	4-12x12x142 CBC	US-192	35,500	Crane Creek	1974		12/21/2021	81.8	94.86	
Central Florida	Brevard	State Highway Agency	700034	I-95 SB - Tillman Canal	I-95 SB	31,250	Tillman Canal	1964	2010	1/7/2021	95.6	91.47	
Central Florida	Brevard	State Highway Agency	700043	I-95 SB -Lake Washington Road	I-95 SB	45,500	Lake Washington Road	1964	2009	1/20/2021	94.5	95.72	
Central Florida	Brevard	State Highway Agency	700046	3-8x4x184 CBC	I-95	91,000	Milner's Canal	1964	1994	1/28/2022	83	95.69	
Central Florida	Brevard	State Highway Agency	700050	2-12x10x187 CBC	I-95	76,435	Rockledge Creek	1965		3/23/2021	72	33.97	
Central Florida	Brevard	State Highway Agency	700052	I-95 SB - SR-520	I-95 SB	41,250	SR-520	1966	2004	1/20/2021	96	96.55	
Central Florida	Brevard	State Highway Agency	700054	I-95 SB - SR-524	I-95 SB	5,100	SR-524	1966	2009	2/21/2022	71	97.28	SD
Central Florida	Brevard	State Highway Agency	700055	3-9x11x157 CBC	I-95	44,500	Santiago Canal	1964		1/19/2021	83	34.18	
Central Florida	Brevard	State Highway Agency	700056	3-10x5x168 CBC	I-95	46,500	Ross Creek	1965	2014	12/16/2020	83	92.43	
Central Florida	Brevard	State Highway Agency	700058	I-95 SB - SR-50	I-95 SB	20,250	SR-50	1965	2013	8/25/2021	97	98.21	
Central Florida	Brevard	State Highway Agency	700059	I-95 SB over SR-406	I-95 SB	20,000	SR-406	1963	2013	8/25/2021	96	98.46	
Central Florida	Brevard	State Highway Agency	700061	Hubert H Humphrey Bridge	SR-520 WB	28,500	Indian River	1966		11/12/2020	71	97.18	FO
Central Florida	Brevard	State Highway Agency	700064	3-8x6x158 CBC	I-95	31,492	Outfall	1967		12/15/2020	83	66.91	
Central Florida	Brevard	State Highway Agency	700065	3-8x8x158 CBC	I-95	31,492	Outfall	1967		12/15/2020	83	66.85	
Central Florida	Brevard	State Highway Agency	700066	I-95 SB - Aurantia Rd.	I-95 SB	15,746	Aurantia Rd.	1967	2014	12/15/2020	94.6	98.42	
Central Florida	Brevard	State Highway Agency	700072	Christa McAuliffe Bridge	SR-3	14,000	Barge Canal	1961	1998	6/24/2021	62.9	97.12	FO
Central Florida	Brevard	State Highway Agency	700074	SR-528 WB - SR-401	SR-528 WB	13,000	SR-401	1971	2001	10/28/2021	90.3	99.52	
Central Florida	Brevard	State Highway Agency	700075	US-1 SB - SR-404	US-1 SB	19,500	SR-404	1971	1997	10/22/2021	96.5	98.60	
Central Florida	Brevard	State Highway Agency	700076	SR-404 WB - Indian River	SR-404 WB	26,250	Indian River West Relief	1971		10/22/2021	96	89.84	
Central Florida	Brevard	State Highway Agency	700077	SR-404 WB - Indian River	SR-404 WB	26,250	Indian River	1971		5/19/2020	84	95.70	
Central Florida	Brevard	State Highway Agency	700078	SR-404 WB-Indian River	SR-404 WB	26,250	Indian River Relief East	1971		11/3/2021	96	91.74	
Central Florida	Brevard	State Highway Agency	700079	SR-404 WB over CR-3	SR-404 WB	26,250	CR-3	1971		9/17/2021	98	99.44	
Central Florida	Brevard	State Highway Agency	700080	SR-404 WB-Banana River	SR-404 WB	26,500	Banana River Relief West	1971		11/2/2021	98	92.83	
Central Florida	Brevard	State Highway Agency	700081	SR-404 WB - Banana River	SR-404 WB	26,500	Banana River	1971		5/14/2020	93.9	97.18	
Central Florida	Brevard	State Highway Agency	700082	SR-404 WB-Banana River	SR-404 WB	26,500	Banana River Relief East	1971		11/1/2021	96	86.95	
Central Florida	Brevard	State Highway Agency	700083	Max K. Rodes	SR-404 WB	26,500	SR-513	1972		10/22/2021	98	97.73	
Central Florida	Brevard	Turnpike	700084	SR-528 WB-St Johns River	SR-528	23,050	St Johns River	1973		8/6/2020	96.9	90.30	
Central Florida	Brevard	Turnpike	700085	SR-407 NB over SR-528 WB	SR-407 NB	4,800	SR-528	1973	1998	8/5/2020	97.3	99.23	
Central Florida	Brevard	Turnpike	700086	4 - 10x10x167 CBC	SR-528	36,500	Ryan's Canal	1973		8/18/2020	70	66.00	
Central Florida	Brevard	Turnpike	700087	SR-528 WB over Pine St.	SR-528 WB	18,250	Pine Street	1973	1997	8/5/2020	96	99.37	
Central Florida	Brevard	Turnpike	700089	SR-528 WB over Clear Lk/Inds Rd	SR-528 WB	15,050	SR-524	1973		8/4/2020	95.2	98.87	
Central Florida	Brevard	Turnpike	700090	SR-407 over Kings Road	SR-407	6,747	Kings Road	1973	1998	8/18/2020	93.8	99.04	
Central Florida	Brevard	Turnpike	700091	SR-407 over I-95	SR-407	6,747	I-95 (SR-9)	1972	1998	8/18/2020	92.5	98.11	

Friday, April 1, 2022

Page 1 of 226

NBI=National Bridge Inventory
ADT=Average Daily Traffic
SD=Structurally Deficient
FO=Functionally Obsolete

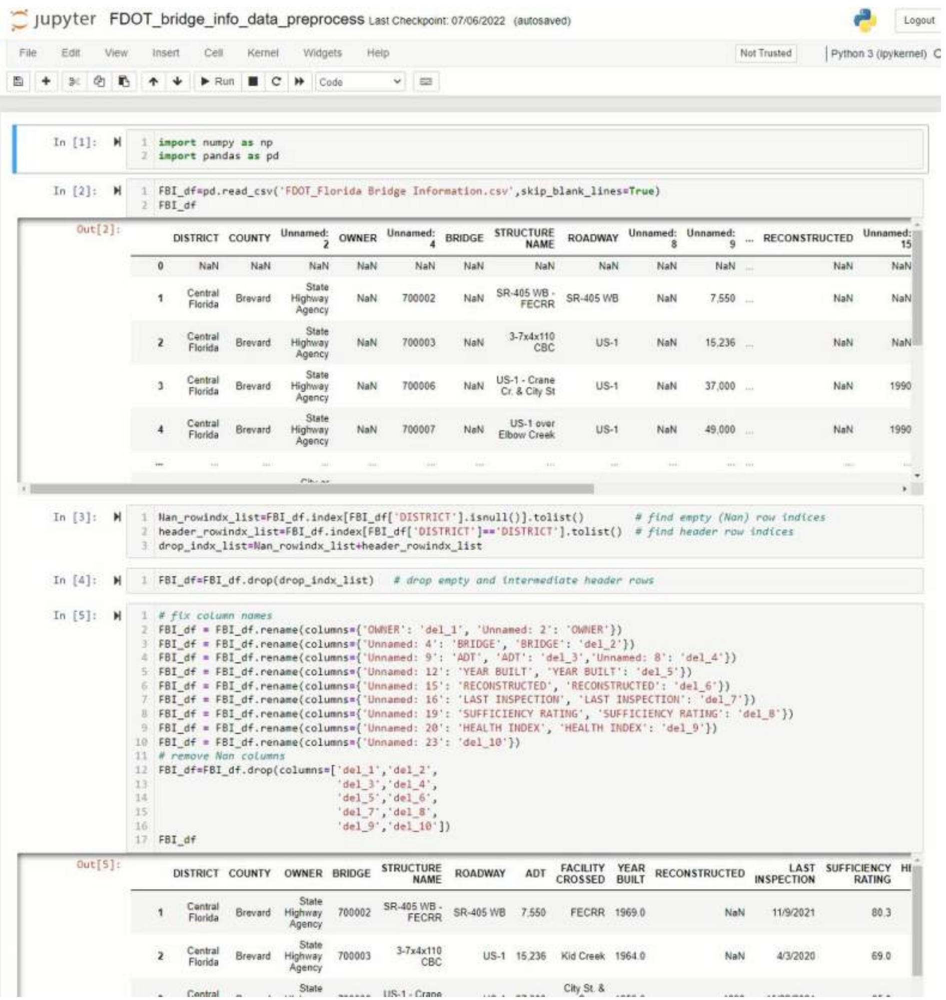
DATA CLEANING AND PREP

- 12620 records
- Preprocess raw data
  - Check for outliers and anomalies

    Remove records with NBI rating of Functionally Obsolete (FO) or structural deficient (SD)
  - Handle issues with missing data

    Some records missing certain information (e.g., year built, sufficiency rating, etc.)
  - Fix formatting issues

    "St. Johns" vs "Saint Johns" county
- Data augmentation for enhanced data analytics
  - Humidity
  - Precipitation
  - Temperature
  - Population density and growth



DATA MINING

USA.COM

Local Data Search

Search State, County, City, Zip Code, or Area Code | Search

USA.com / Ranks / Florida Average Temperature County Rank

Florida Average Temperature County Rank

A total of 67 results found. Show Results on Map.

Rank	Average Temperature ▼	County / Population
1.	75.60°F	Miami-Dade, FL / 2,600,861
2.	75.00°F	Broward, FL / 1,815,269
3.	74.96°F	Monroe, FL / 75,208
4.	74.17°F	Palm Beach, FL / 1,359,074
5.	74.06°F	Lee, FL / 647,554
6.	73.95°F	Collier, FL / 334,474
7.	73.73°F	Hendry, FL / 38,360
8.	73.21°F	Martin, FL / 149,658
9.	73.08°F	Sarasota, FL / 386,944
10.	73.06°F	Saint Lucie, FL / 283,988
11.	72.98°F	Manatee, FL / 335,840
12.	72.96°F	Polk, FL / 617,323
13.	72.93°F	Charlotte, FL / 163,151
14.	72.85°F	Hillsborough, FL / 1,279,668
15.	72.85°F	Indian River, FL / 140,918
16.	72.70°F	De Soto, FL / 34,785
17.	72.69°F	Osceola, FL / 289,449
18.	72.66°F	Pinellas, FL / 925,030
19.	72.65°F	Glades, FL / 13,190
20.	72.61°F	Okeechobee, FL / 39,398
21.	72.58°F	Hardee, FL / 27,549
22.	72.53°F	Highlands, FL / 98,261
23.	72.24°F	Brevard, FL / 548,891
24.	71.84°F	Orange, FL / 1,200,241
25.	71.65°F	Hernando, FL / 173,792
26.	71.63°F	Pasco, FL / 472,745
27.	71.29°F	Seminole, FL / 432,135
28.	70.98°F	Sumter, FL / 103,708
29.	70.90°F	Lake, FL / 305,010
30.	70.52°F	Volusia, FL / 498,981
31.	70.35°F	Flagler, FL / 98,843
32.	70.19°F	Citrus, FL / 139,771

Population of Counties in Florida (2022)

There are **67** counties in Florida.

As of 2018, Florida's Miami-Dade County is the most populous county in the Sunshine State, with 2,751,796 residents, representing a population growth of 10.2% since the last census. Miami-Dade is followed by Broward County(1,935,878), Palm Beach County (1,471,150), Hillsborough County (1,381,627), and Orange County (1,323,598) as the only other counties in the state with populations in excess of one million. Of these, Orange County has seen the highest population growth at an impressive 17.7%.

Florida Counties with Fewer Residents

The least populous Floridian counties are Liberty County, with 8,242 residents, closely followed by Lafayette County, with its population of 8,451. Both of these counties have seen their populations decline in recent years, with reductions of 1.5% and 4.7%, respectively. However, other counties with small populations, such as Franklin County (11,727) and Glades County (13,754), have had population increases (1.5% for Franklin County and 6.8% for Glades County).

Florida Counties with Rapid Growth

Sumter County boasts the highest growth rate in the state, with a substantial increase of 34% according to statistics for 2018, taking its total population to 125,165. Osceola County and St. Johns County also show impressive population growth, with increases of 31.1% and 28.3%, respectively. Bradford County, with its 2010 population of 28,520, has the biggest reduction in numbers – its population has reduced to 26,728, representing a negative growth of -5.2% in the last few years.

⤓ CSV ⤓ JSON

Name	2022 Population ▾	Growth Since 2010	Density (mi²)
Miami-Dade County	2,723,200	8.63%	1,434.33
Broward County	1,972,790	12.55%	1,634.42
Palm Beach County	1,538,450	16.23%	780.99
Hillsborough County	1,532,120	24.21%	1,501.62
Orange County	1,429,190	24.43%	1,582.16
Duval County	985,064	13.80%	1,291.66
Pinellas County	980,810	7.03%	3,582.30
Lee County	818,898	31.98%	1,044.05
Polk County	779,317	29.22%	433.77
Brevard County	622,159	14.37%	612.70

jupyter FDOT_bridge_info_data_preprocess Last Checkpoint: 07/06/2022 (autosaved)

File Edit View Insert Cell Kernel Widgets Help | Not Trusted | Python 3 (ipykernel)

In [1]:
```
import numpy as np
import pandas as pd
```

In [2]:
```
FBI_df=pd.read_csv('FDOT_Florida Bridge Information.csv',skip_blank_lines=True)
FBI_df
```

Out[2]:

	DISTRICT	COUNTY	Unnamed: 2	OWNER	Unnamed: 4	BRIDGE	STRUCTURE NAME	ROADWAY	Unnamed: 8	Unnamed: 9	...	RECONSTRUCTED	Unnamed: 15
0	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	...	NaN	NaN
1	Central Florida	Brevard	State Highway Agency	NaN	700002	NaN	SR-405 WB - FECRR	SR-405 WB	NaN	7,550	...	NaN	NaN
2	Central Florida	Brevard	State Highway Agency	NaN	700003	NaN	3-7x4x110 CBC	US-1	NaN	15,236	...	NaN	NaN
3	Central Florida	Brevard	State Highway Agency	NaN	700006	NaN	US-1 - Crane Cr. & City St	US-1	NaN	37,000	...	NaN	1990
4	Central Florida	Brevard	State Highway Agency	NaN	700007	NaN	US-1 over Elbow Creek	US-1	NaN	49,000	...	NaN	1990
...	...	...	...	...	...	...	...	...	...	...	...	...	...

In [3]:
```
Nan_rowindx_list=FBI_df.index[FBI_df['DISTRICT'].isnull()].tolist()        # find empty (Nan) row indices
header_rowindx_list=FBI_df.index[FBI_df['DISTRICT']=='DISTRICT'].tolist()  # find header row indices
drop_indx_list=Nan_rowindx_list+header_rowindx_list
```

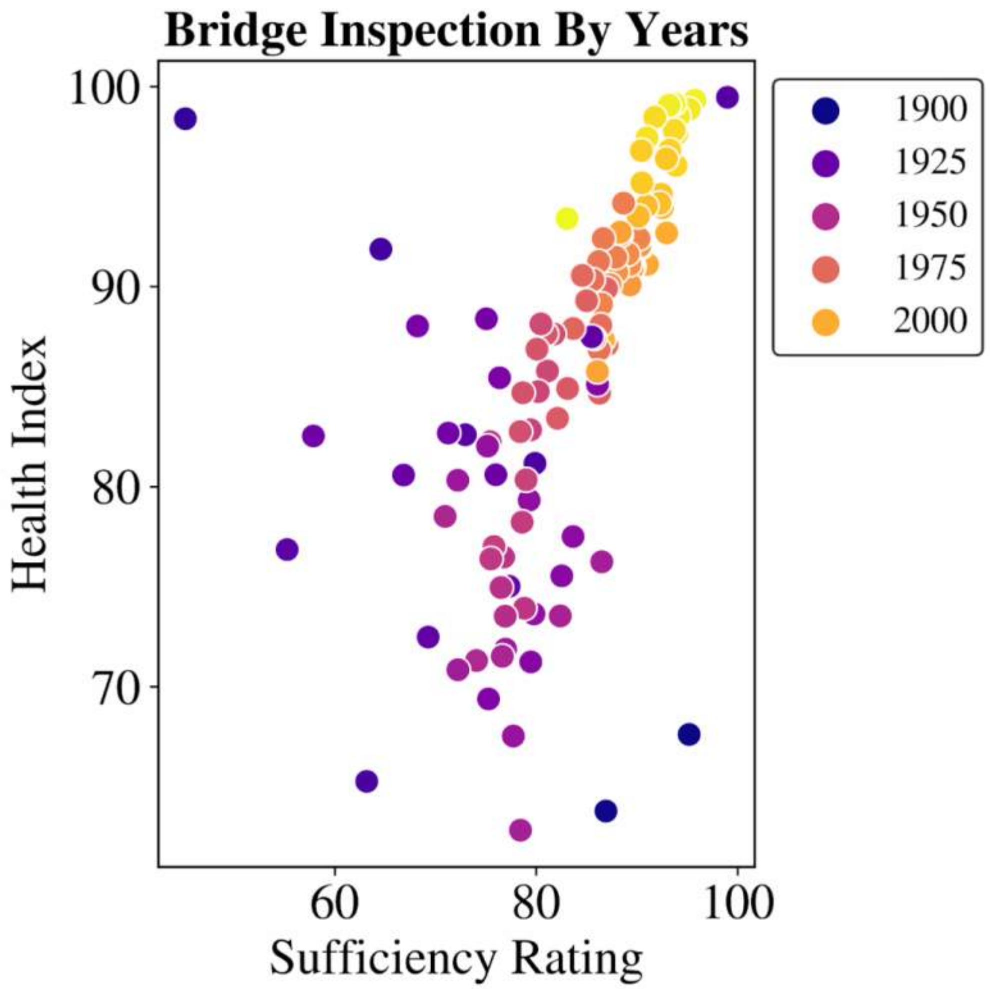
In [4]:
```
FBI_df=FBI_df.drop(drop_indx_list)   # drop empty and intermediate header rows
```

In [5]:
```
# fix column names
FBI_df = FBI_df.rename(columns={'OWNER': 'del_1', 'Unnamed: 2': 'OWNER'})
FBI_df = FBI_df.rename(columns={'Unnamed: 4': 'BRIDGE', 'BRIDGE': 'del_2'})
FBI_df = FBI_df.rename(columns={'Unnamed: 9': 'ADT', 'ADT': 'del_3','Unnamed: 8': 'del_4'})
FBI_df = FBI_df.rename(columns={'Unnamed: 12': 'YEAR BUILT', 'YEAR BUILT': 'del_5'})
FBI_df = FBI_df.rename(columns={'Unnamed: 15': 'RECONSTRUCTED', 'RECONSTRUCTED': 'del_6'})
FBI_df = FBI_df.rename(columns={'Unnamed: 16': 'LAST INSPECTION', 'LAST INSPECTION': 'del_7'})
FBI_df = FBI_df.rename(columns={'Unnamed: 19': 'SUFFICIENCY RATING', 'SUFFICIENCY RATING': 'del_8'})
FBI_df = FBI_df.rename(columns={'Unnamed: 20': 'HEALTH INDEX', 'HEALTH INDEX': 'del_9'})
FBI_df = FBI_df.rename(columns={'Unnamed: 23': 'del_10'})
# remove Nan columns
FBI_df=FBI_df.drop(columns=['del_1','del_2',
                            'del_3','del_4',
                            'del_5','del_6',
                            'del_7','del_8',
                            'del_9','del_10'])
FBI_df
```

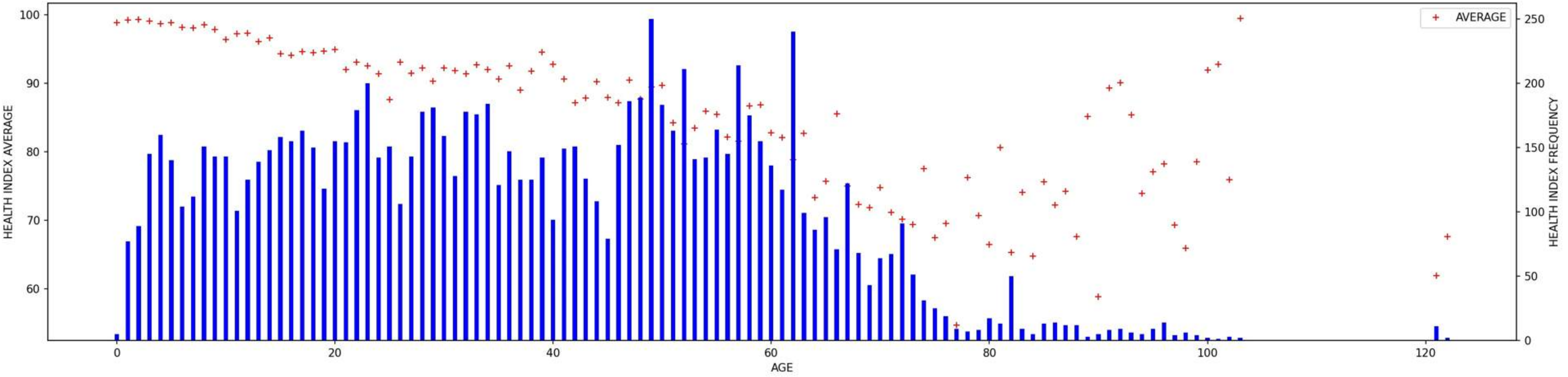
Out[5]:

	DISTRICT	COUNTY	OWNER	BRIDGE	STRUCTURE NAME	ROADWAY	ADT	FACILITY CROSSED	YEAR BUILT	RECONSTRUCTED	LAST INSPECTION	SUFFICIENCY RATING
1	Central Florida	Brevard	State Highway Agency	700002	SR-405 WB - FECRR	SR-405 WB	7,550	FECRR	1969.0	NaN	11/9/2021	80.3
2	Central Florida	Brevard	State Highway Agency	700003	3-7x4x110 CBC	US-1	15,236	Kid Creek	1964.0	NaN	4/3/2020	69.0

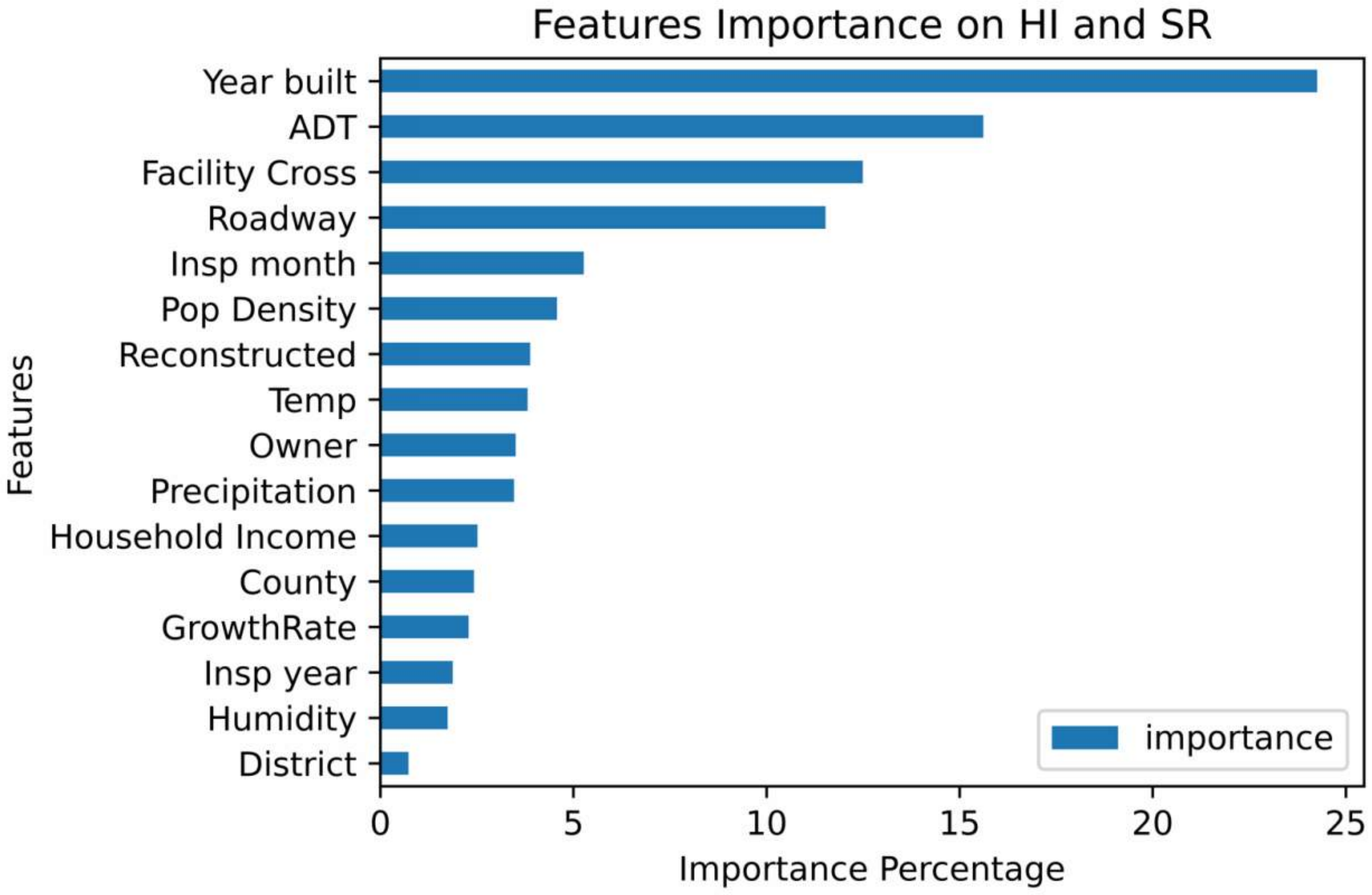
DATA VISUALIZATION



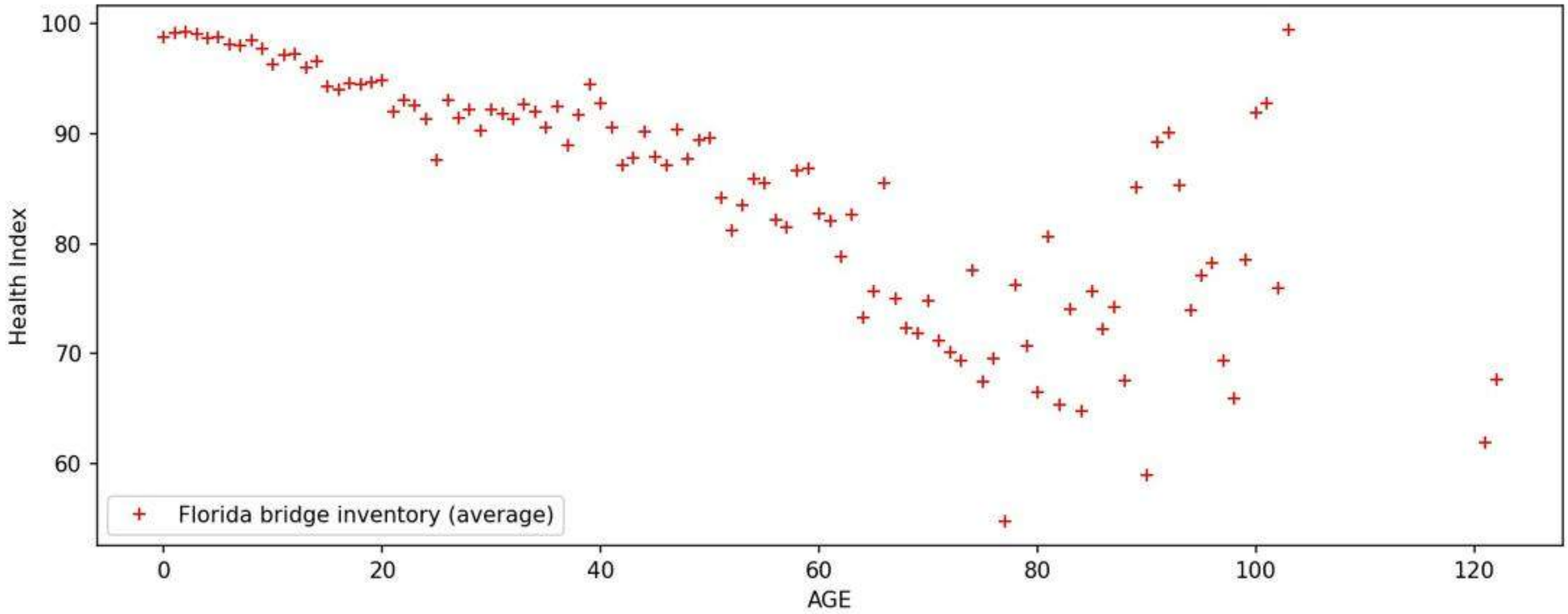
HEALTH INDEX VERSUS AGE OF BRIDGE



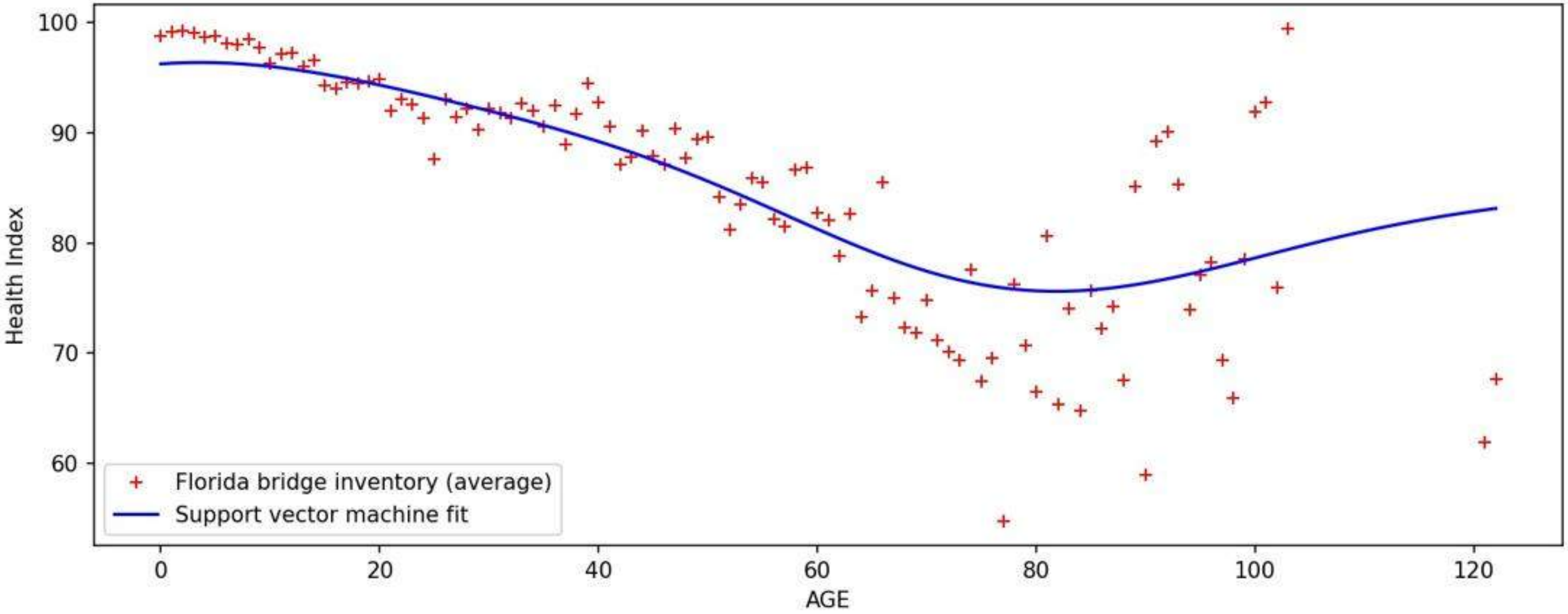
LEARNING FROM THE DATA



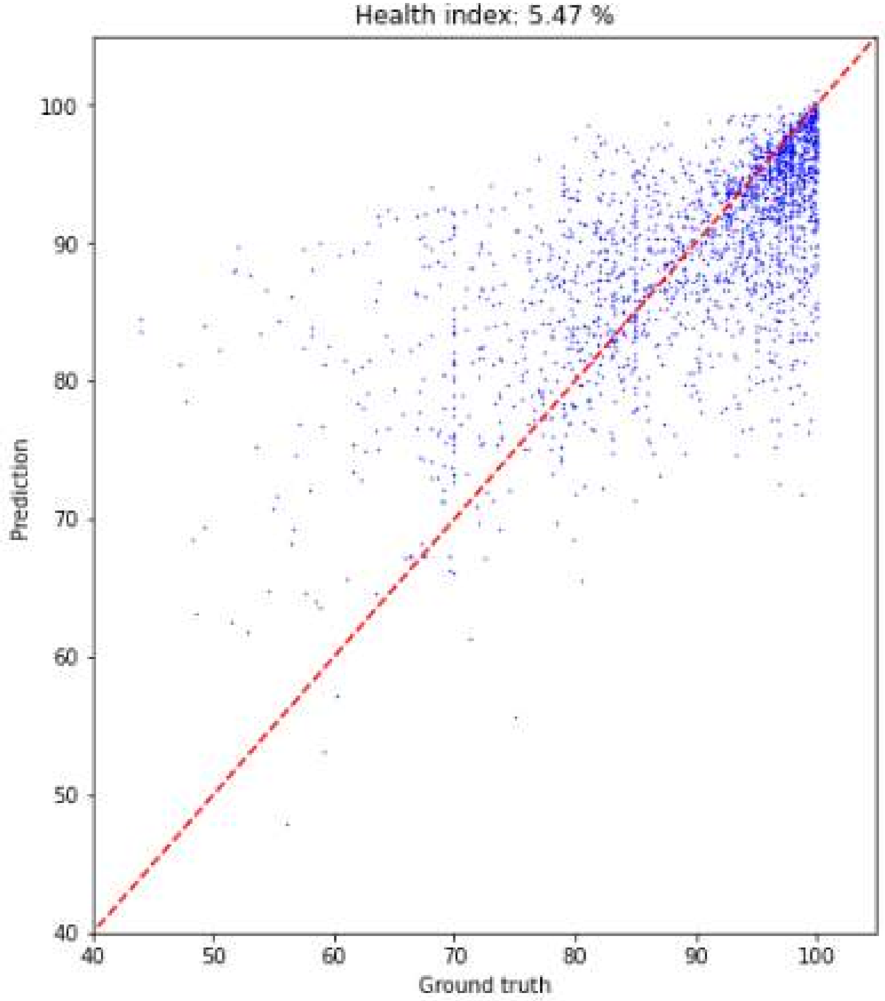
HEALTH INDEX VERSUS AGE OF BRIDGE



HEALTH INDEX PREDICTION



POTENTIAL FDOT ML APP



District: Central Florida
Owner: State Highway Agency
County: Baker
Roadway: SR-405 WB
Fac_cross: FECRR
ADT: 125000
Y_built: 1996
Y_recons: 1996
Insp_M: 11
Insp_Y: 2021
Pop_grow: 34
Pop_dens: 1065
Temp: 83
Humid: 75
Percp: 76
Income: 34

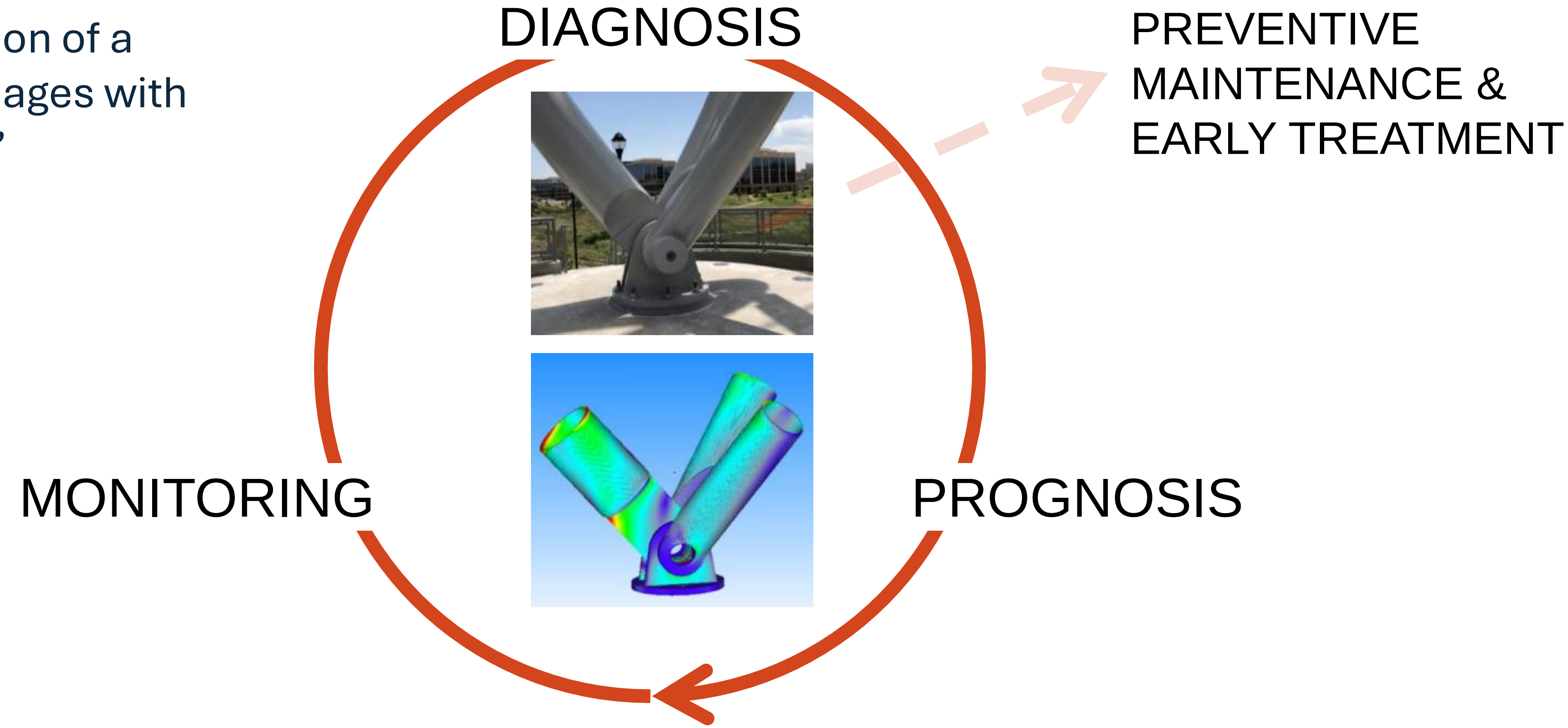
Sufficiency Rating: 93.56, Health Index: 80.56

OUTLINE

- Introduction & Background
- Potential applications of AI/ML for bridge management
- Discussion on how AI/ML may impact future of bridge monitoring
- Conclusions

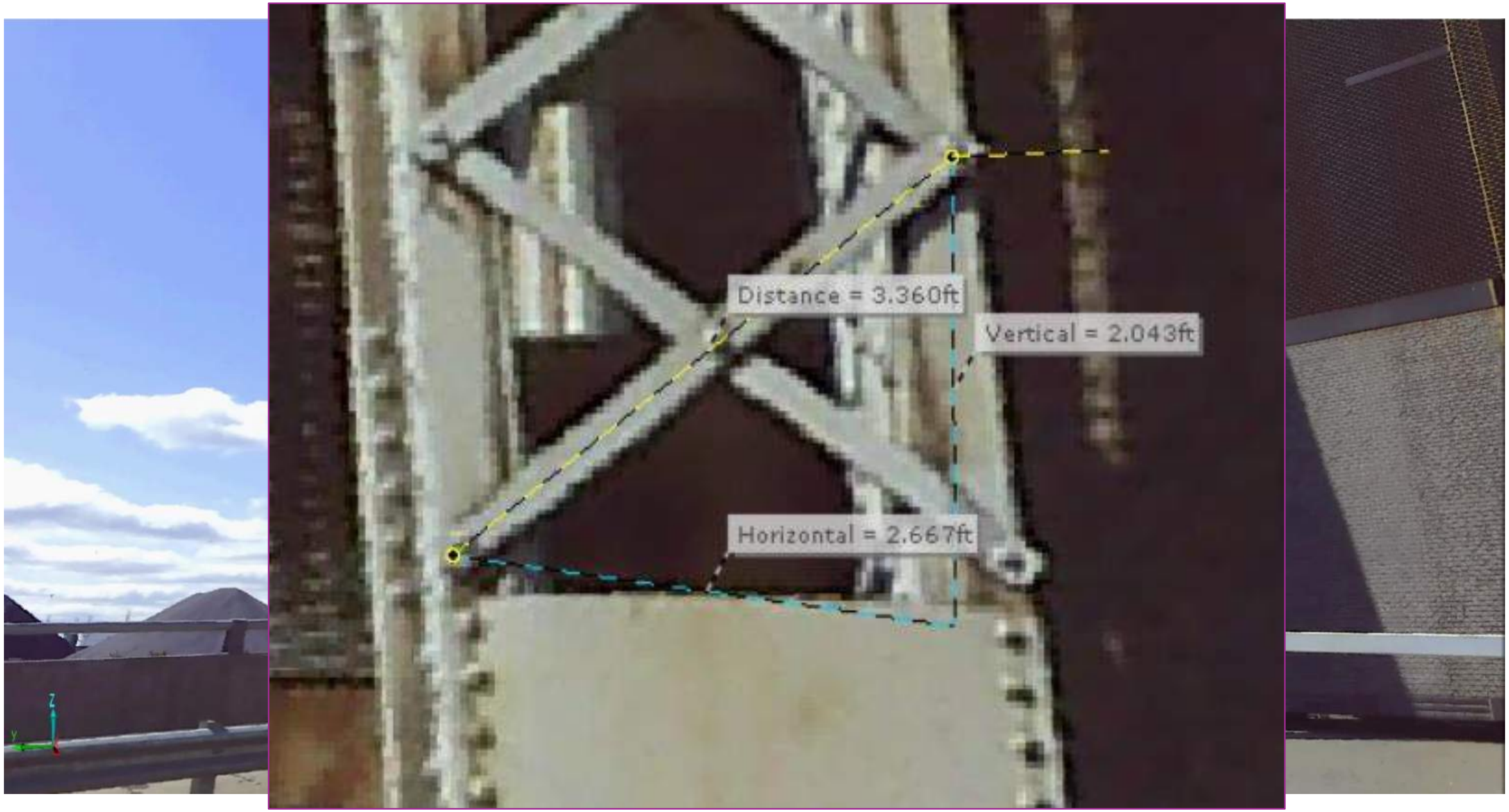
WILL BRIDGE DIGITAL TWINS BE THE FUTURE?

"Digital representation of a physical object that ages with the physical object."

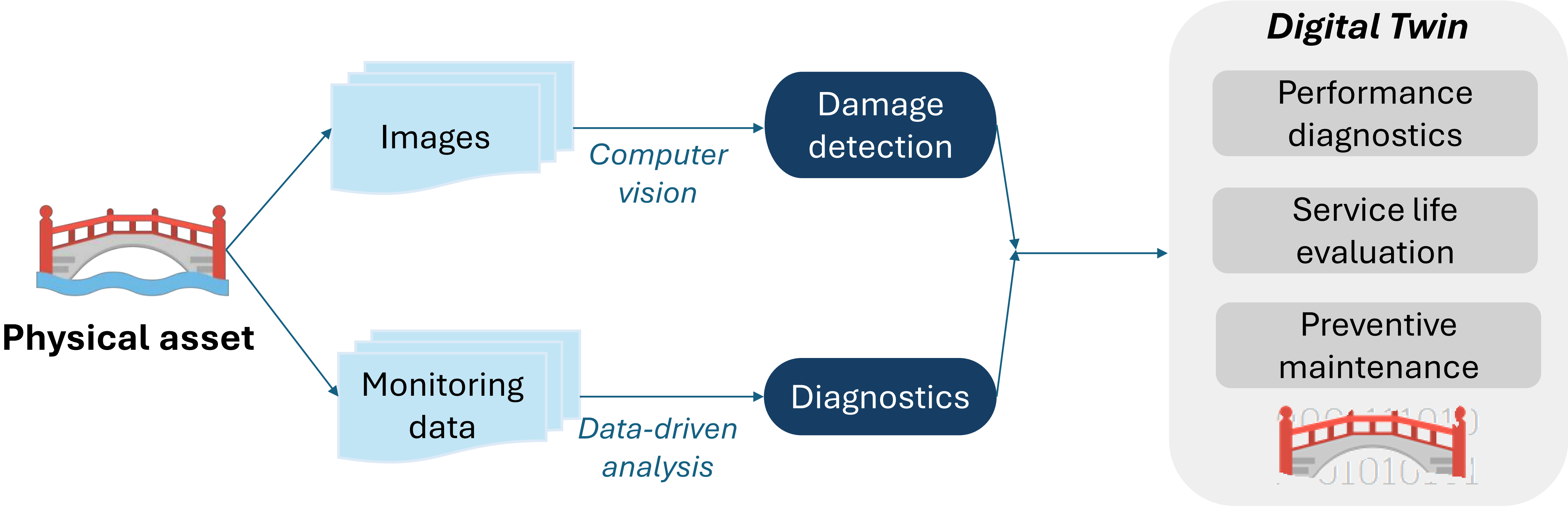


PHYSICS-BASED DIGITAL TWIN

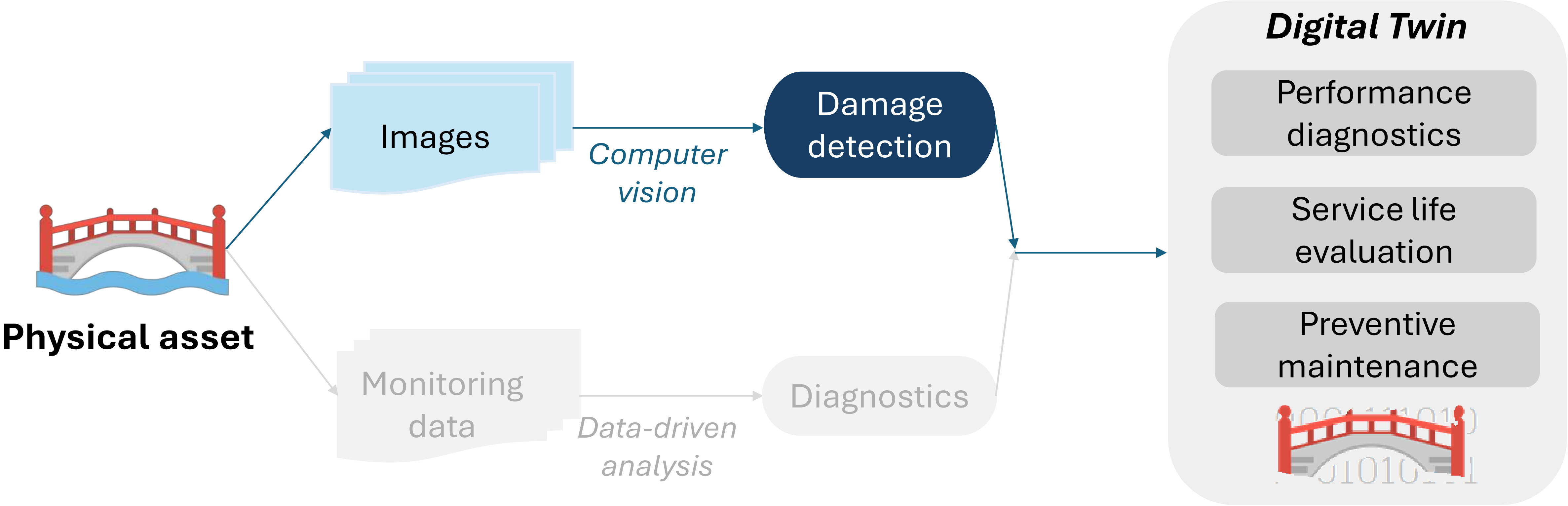
LASER SCAN-BASED DIGITAL TWIN



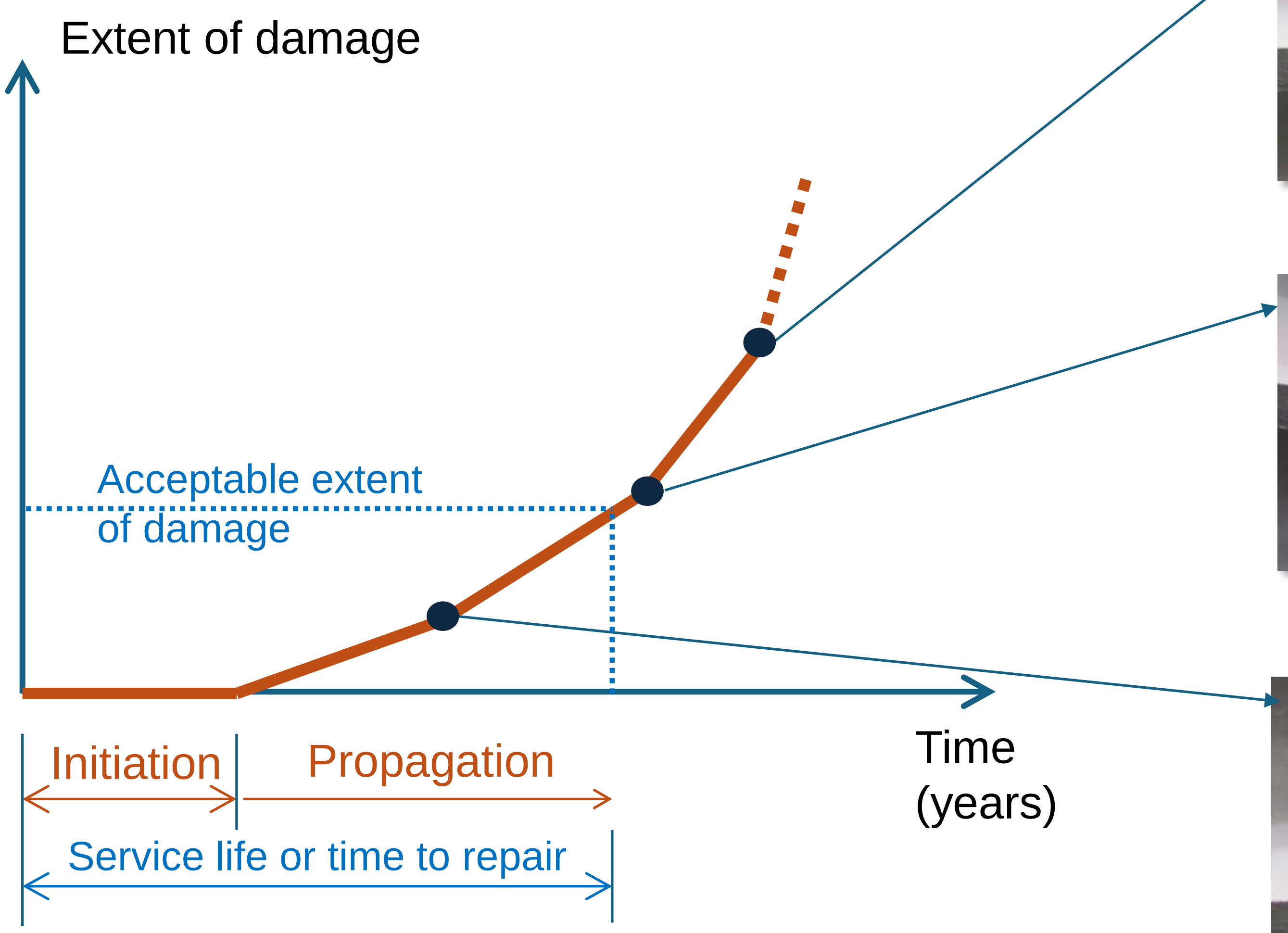
POSSIBLE FUTURE OF BRIDGE MONITORING



COMPUTER VISION

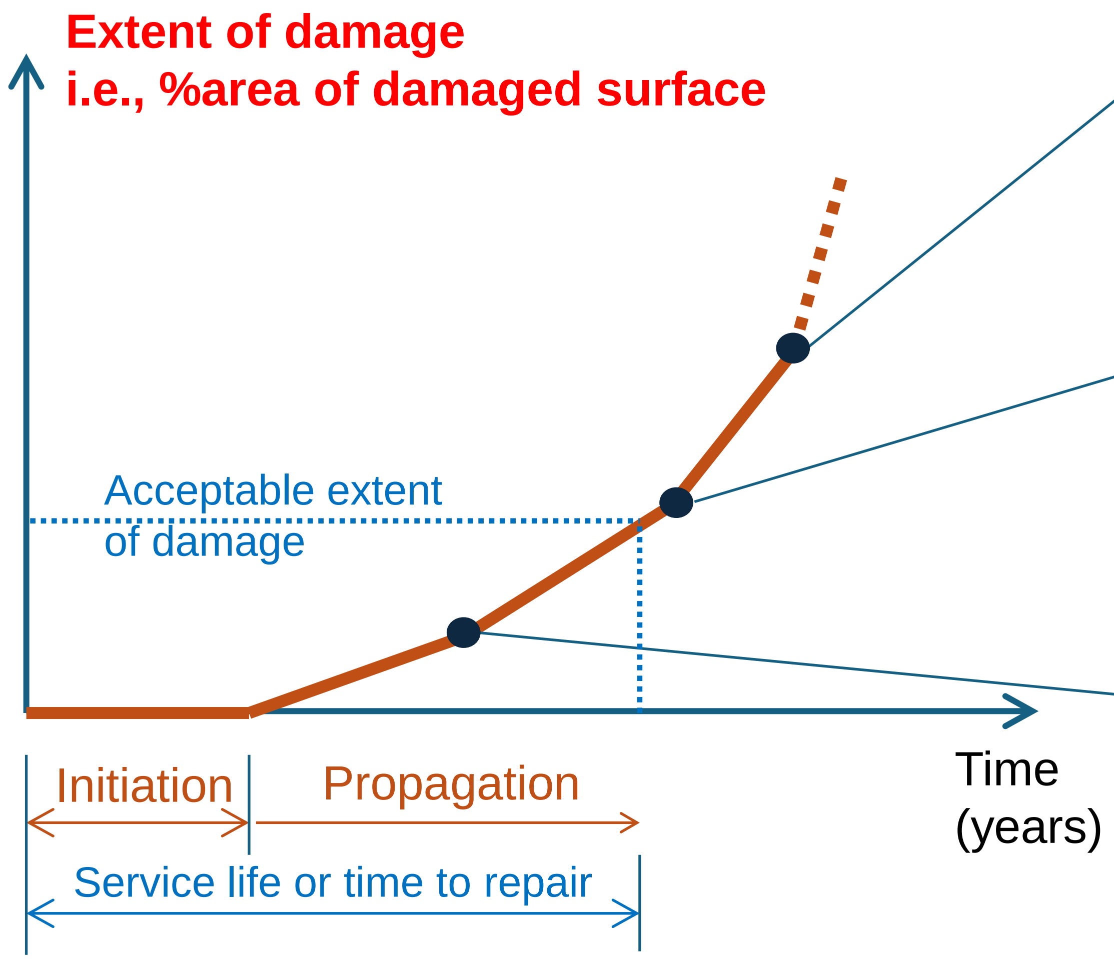


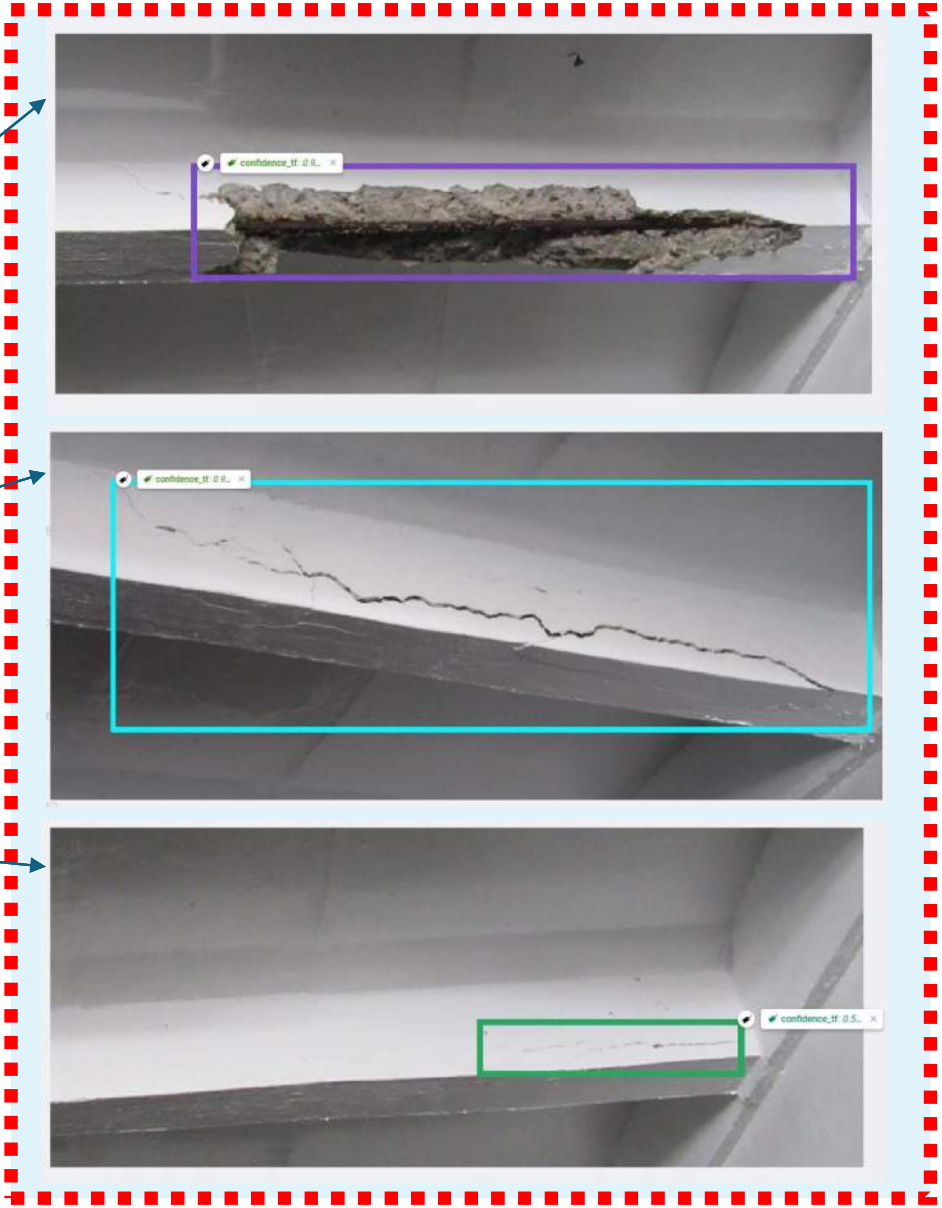
SERVICE LIFE MODELING



Tuutti, K., 1982, Corrosion of Steel in Concrete, Swedish Cement and Concrete Research Institute, Stockholm, Sweden

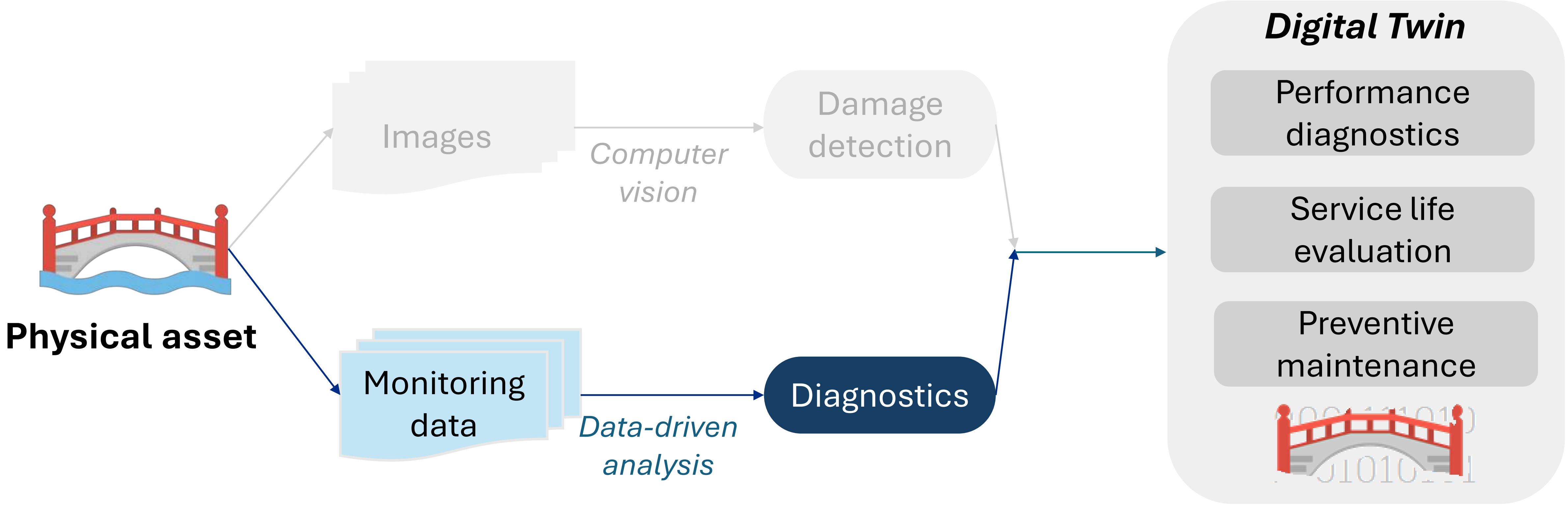
SERVICE LIFE MODELING



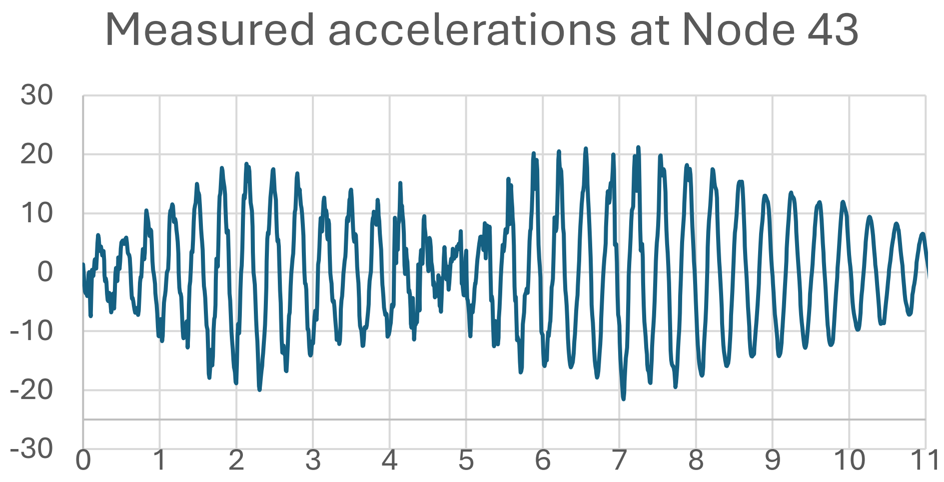


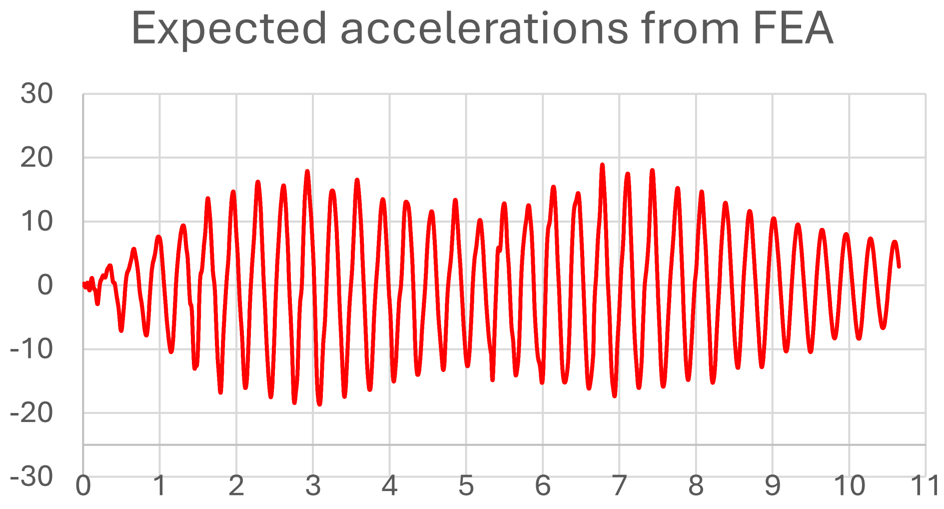
Computer vision

STRUCTURAL HEALTH MONITORING (SHM)



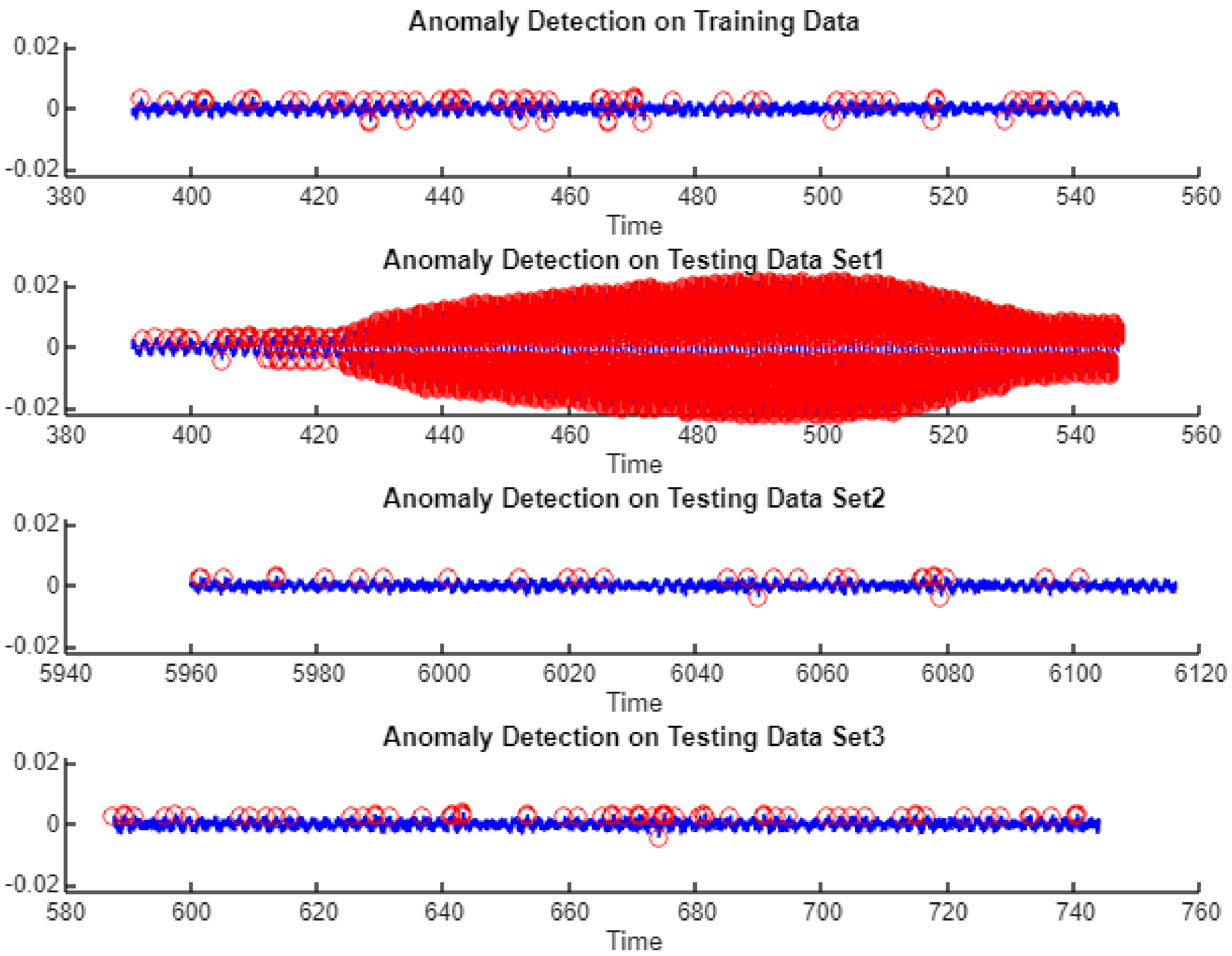
STATE-OF-THE-ART BRIDGE DIAGNOSTICS





AM/ML TO FLAG ANOMALIES

- Detected Anomalies (red circle)



OUTLINE

- Introduction & Background
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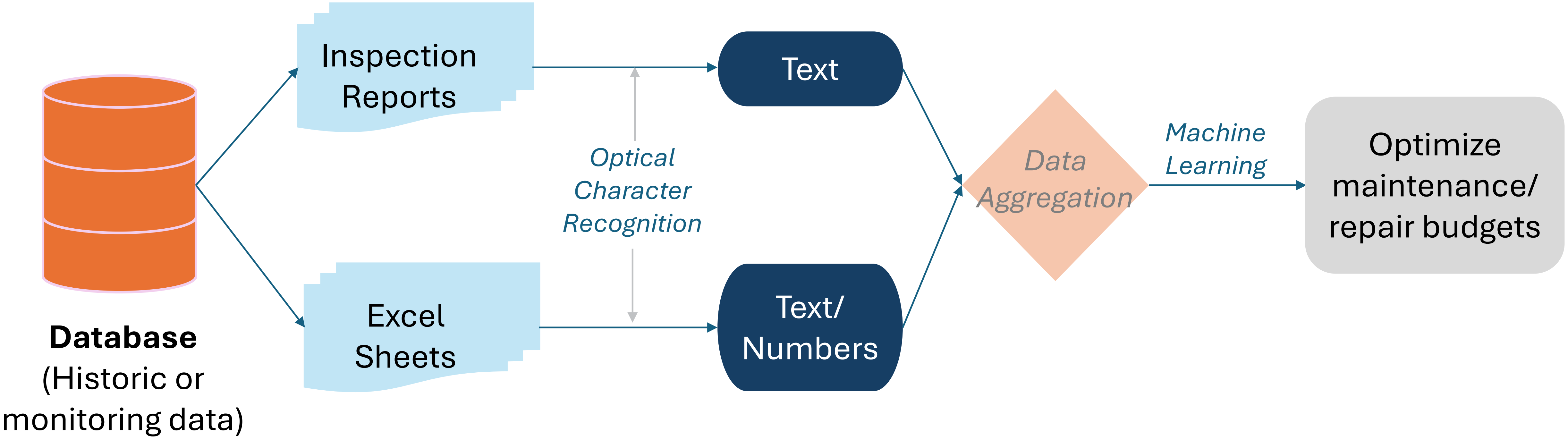
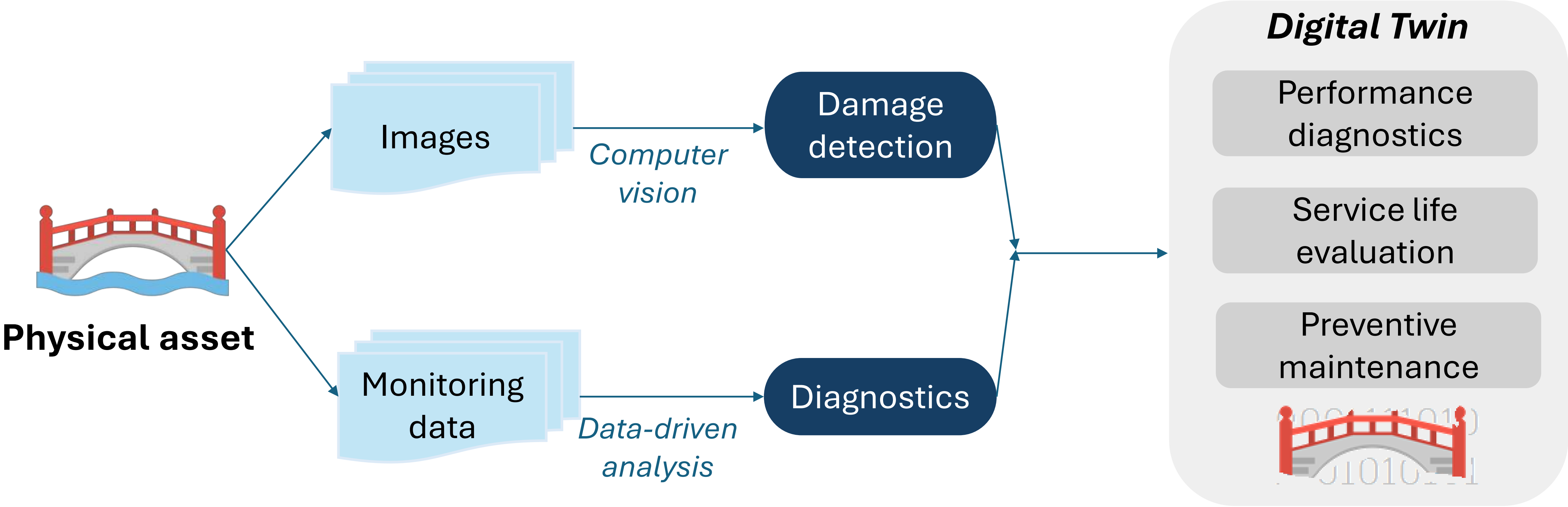
USE OF AI/ML: SHORT-TERM



USE OF AI/ML: LONG-TERM



QUESTIONS?

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  ADeLuca@ThorntonTomasetti.com
  Direct: +1 954-903-9331

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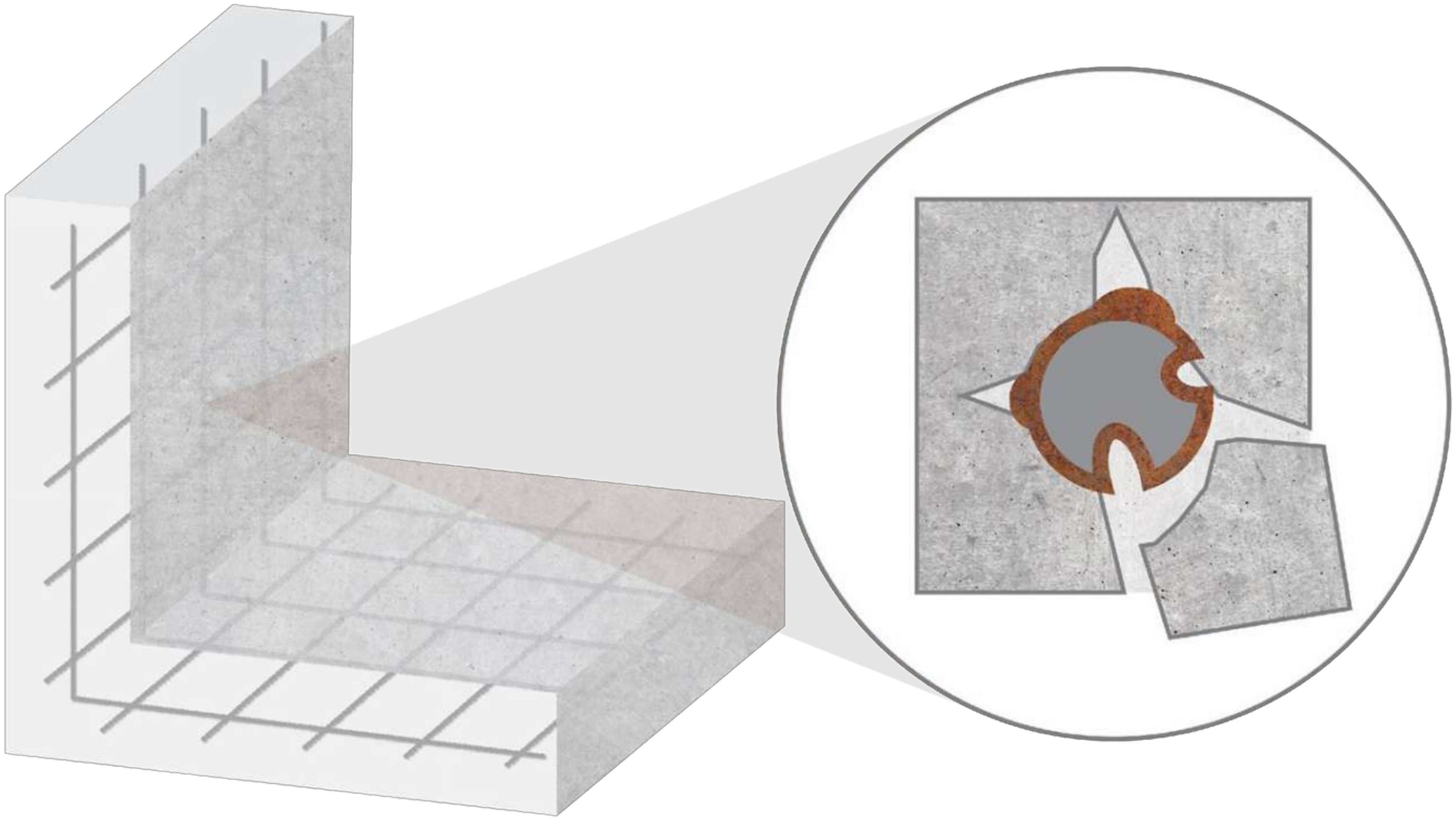
  Thornton Tomasetti | 120 Broadway, 15th Floor, New York, NY 10271
  RDuvvury@ThorntonTomasetti.com
  Direct: +1 212-367-2992

Stainless-Clad Rebar for Resilient & Sustainable Reinforced Concrete Structures

Allium Engineering, Inc.

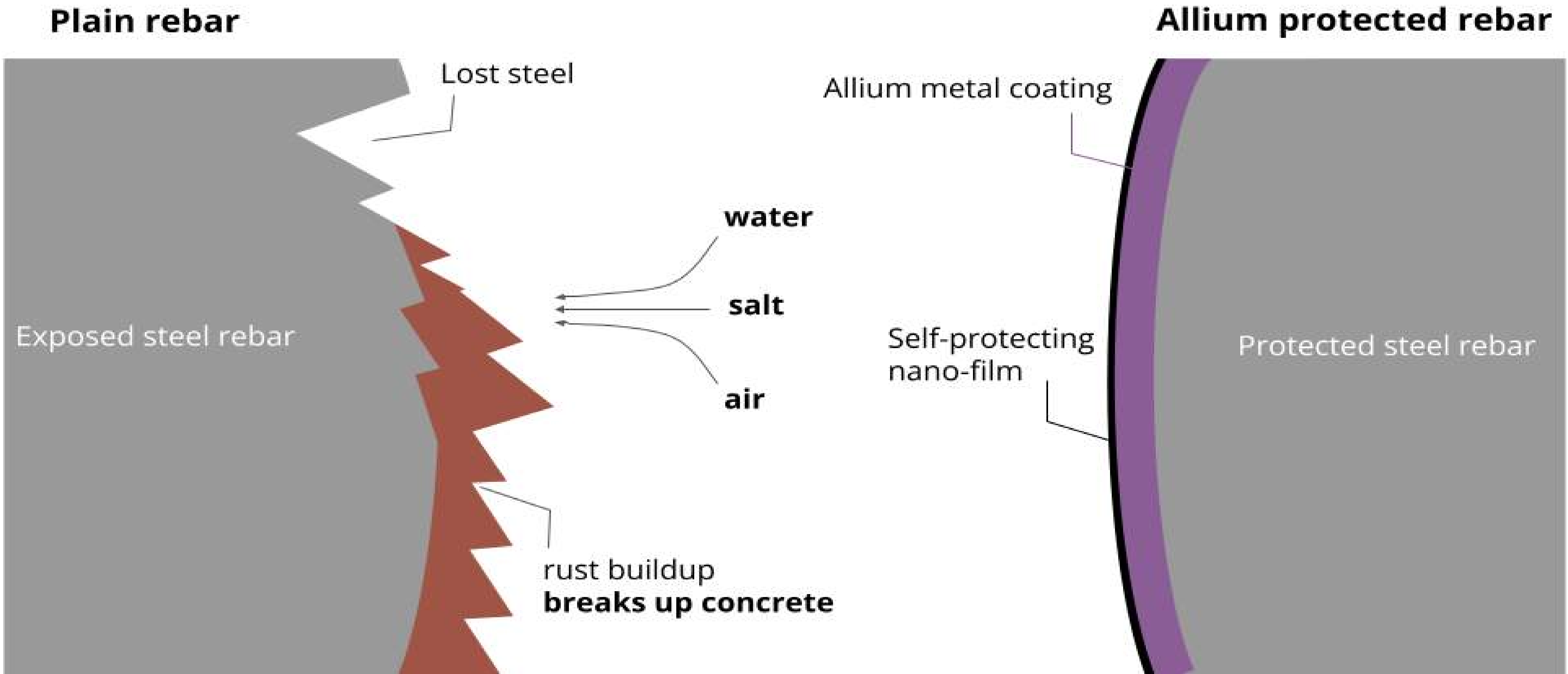
Sam McAlpine, PhD

Problem: Rebar corrosion causes failure



“A regional collaboration promoting holistic resilient and sustainable infrastructure solutions with a focus on efficient highway and pedestrian bridges and structures”

Solution: Our patented rebar coating prevents rust



New Manufacturing Approach

Steel mill integration

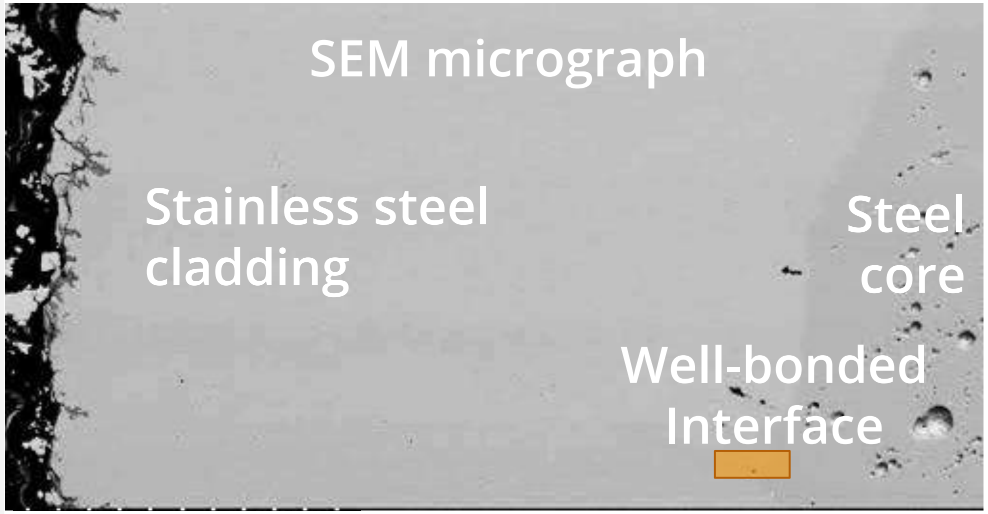
Steel mill (customer)
Produces large
steel billets

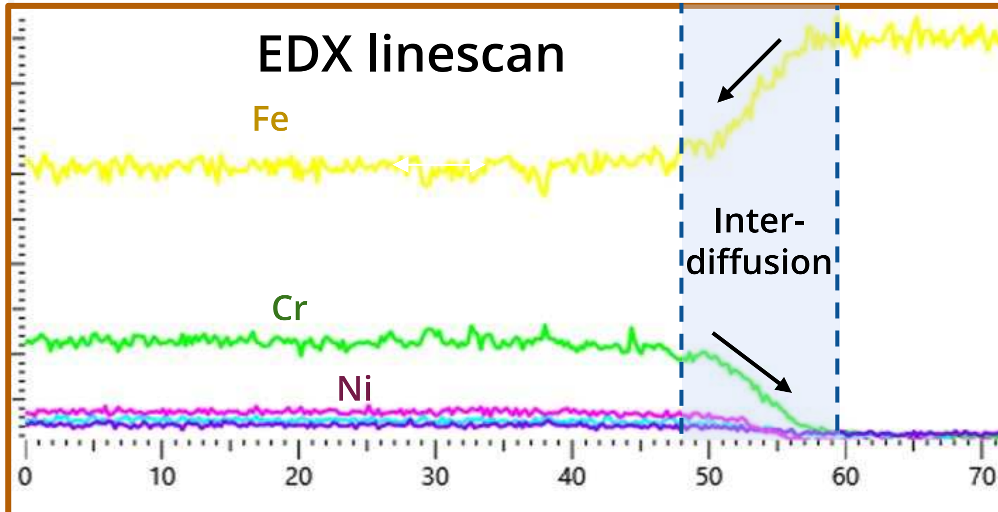
Allium solution
Clads large
outer surfaces

Steel mill hot rolls
into cladded rebar

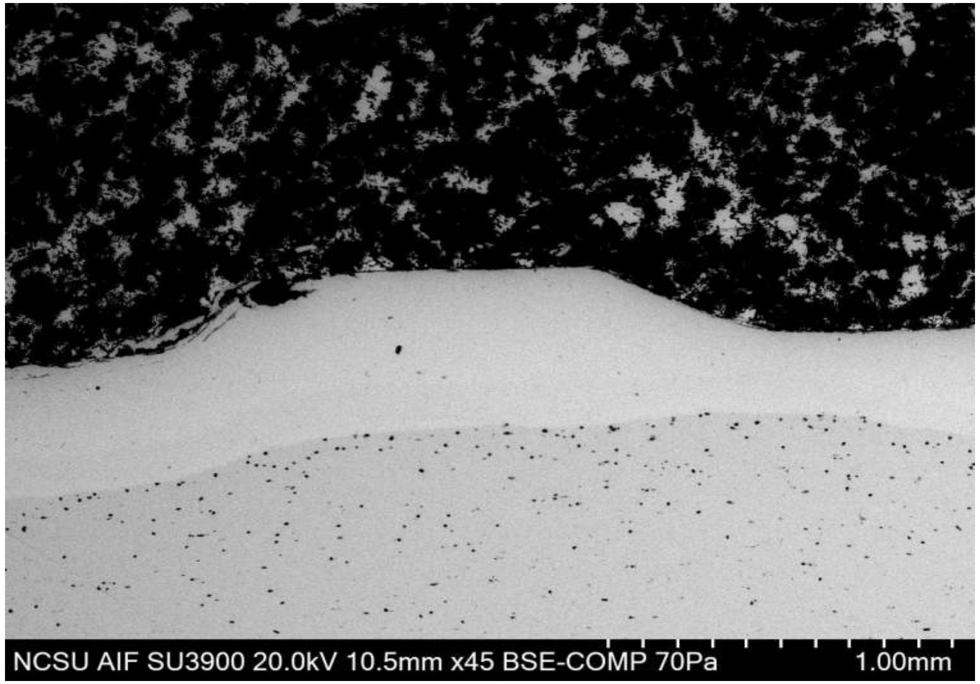
Diffusion & roll bonding

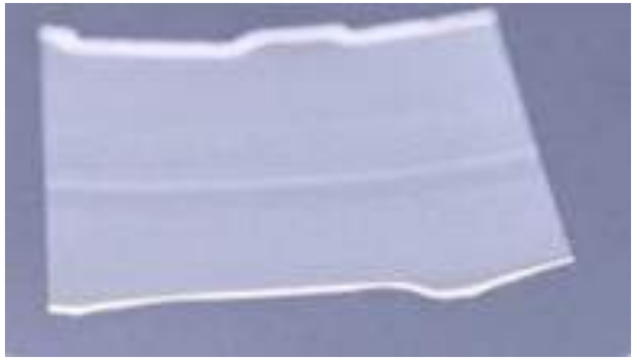
leading to improved claddings at the microscale





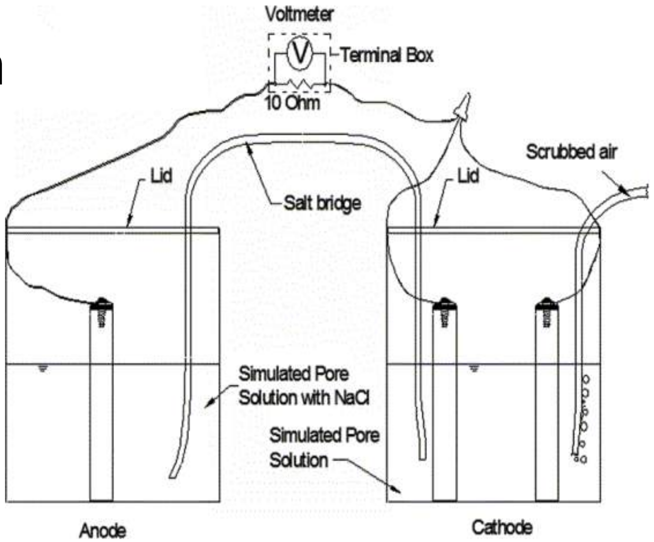
Production with Steel Mill Partners





Corrosion Testing

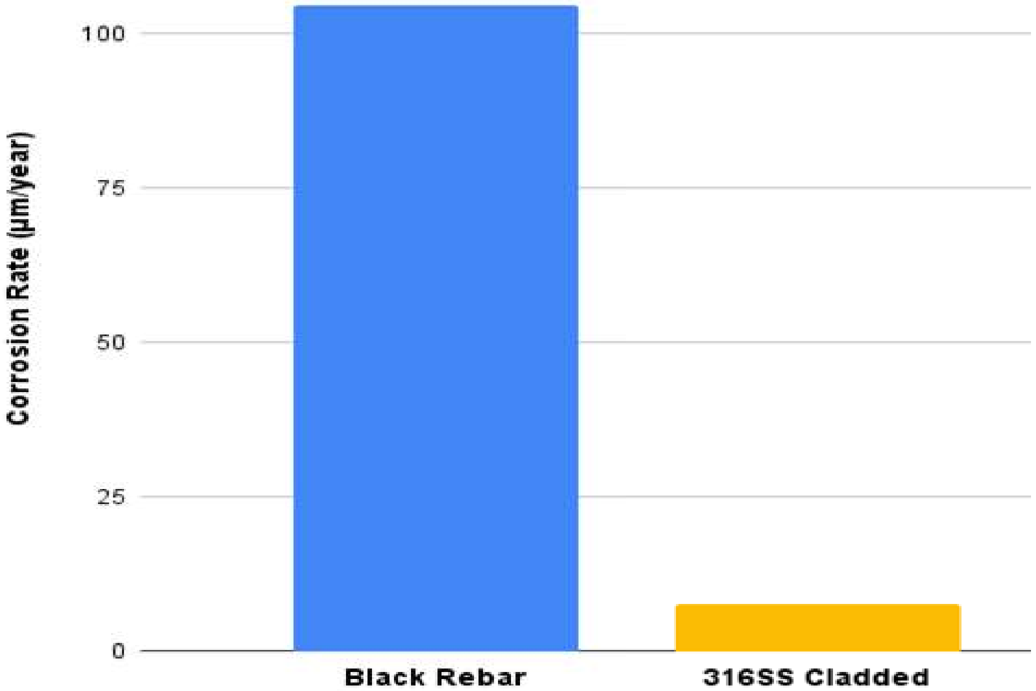
Macrocell corrosion
Experiment design
ASTM A955



Macrocell setup

Allium stainless-clad rebar shows 93% reduction in corrosion rate

Corrosion data



Stainless Clad Rebar History

AASHTO spec established

Standard Specification for

Stainless Clad Deformed and Plain Round Steel Bars for Concrete Reinforcement

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

- **AASHTO spec for stainless clad rebar exists but there is no domestic source/supplier**
- **There was 1 UK-based supplier (Stelax/Nuovinox and Cladinox) but no apparent commercial production for 10+ years**

Sustainability Impact

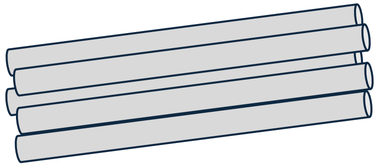
In a one bridge, you could avoid:

300 Tons CO2e
By decarbonizing steel (230 tons)

1400 Tons CO_2
By decarbonizing concrete
(5700 tons used)

4500 Tons CO_2
By extending lifetime from 30-100 years

Producing 50 million tons of clad rebar

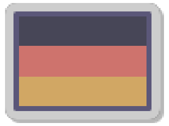


12% global
yearly production

Would avoid 1 billion tons of CO_2
2.7% yearly global emission

Greater than all aviation (1.7%)

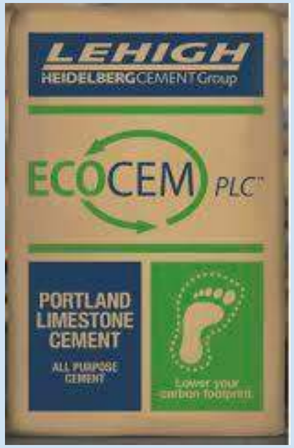
Greater than all of Germany (2.2%)



Without major changes to the industry
- No carbon tax, caps, or credits needed
- Using existing manufacturing facilities
- With existing engineering designs and codes

Stainless-Clad Rebar Enables Green Concrete

Clinker Replacement



Lower Carbon Footprint of Concrete by 10-15%

Carbon Capture Technology

CARBON CURE™

carbon clean

Use Concrete to Capture and Store CO2 from Atmosphere

Lower pH within concrete (more acidic chemistry) → corrosion

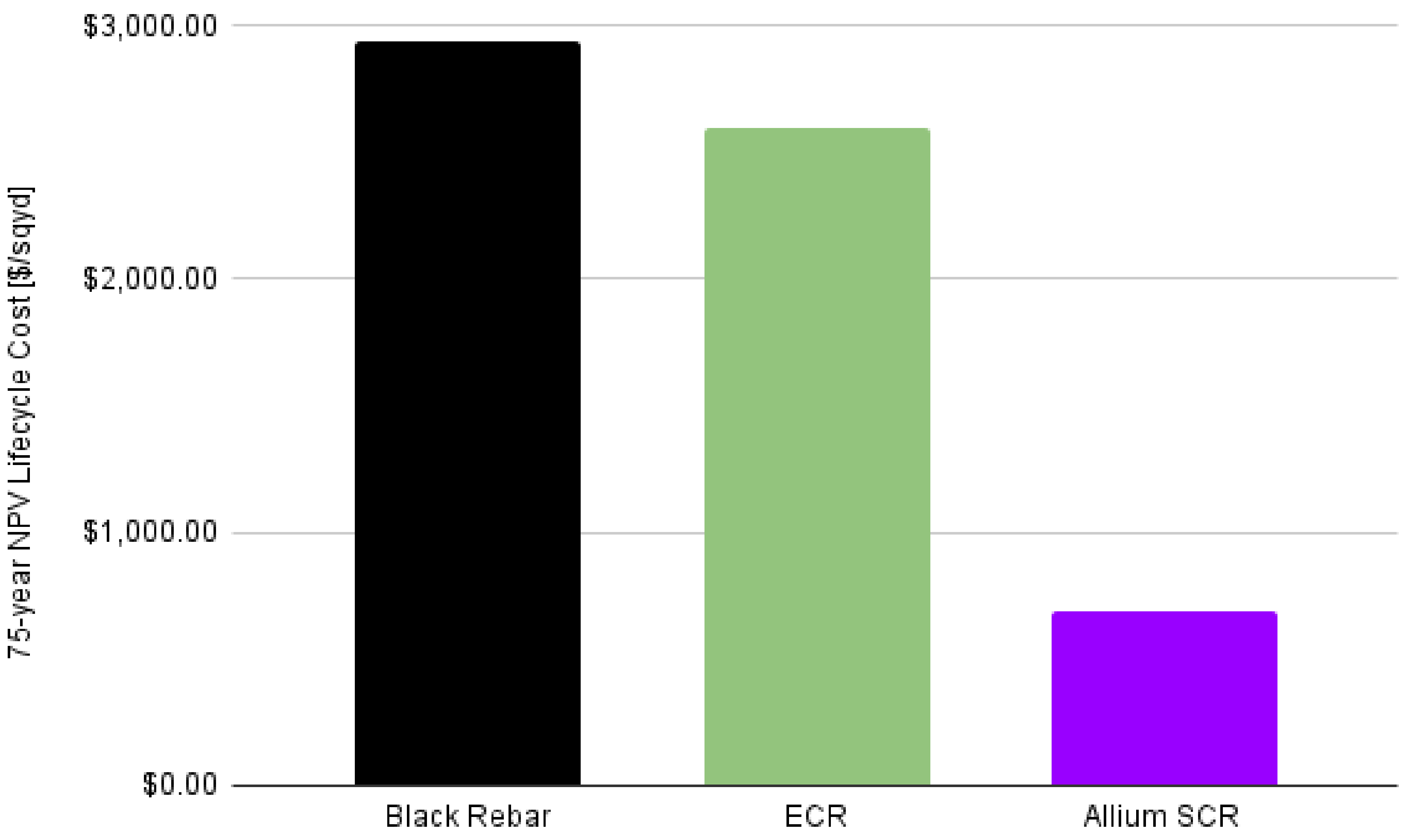
Our technology eliminates trade off and drives further CO2 reduction

Lifecycle Cost Analysis

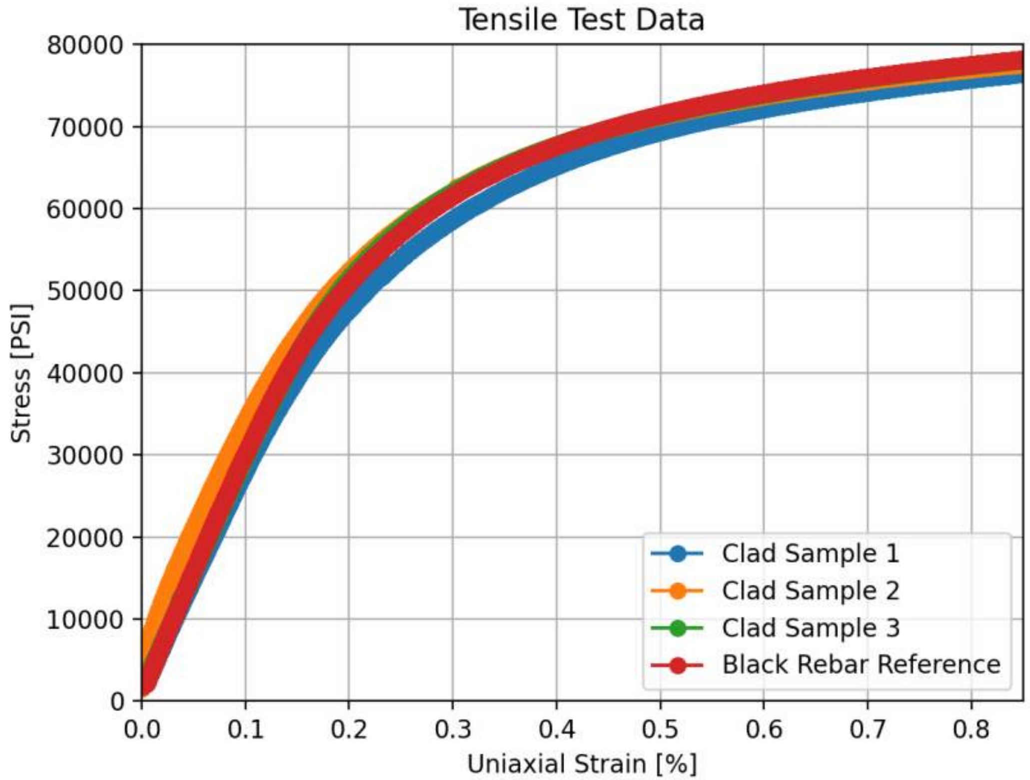
76% reduction in 75-year Lifecycle Net-Present-Value Cost of Ownership for California bridge use case

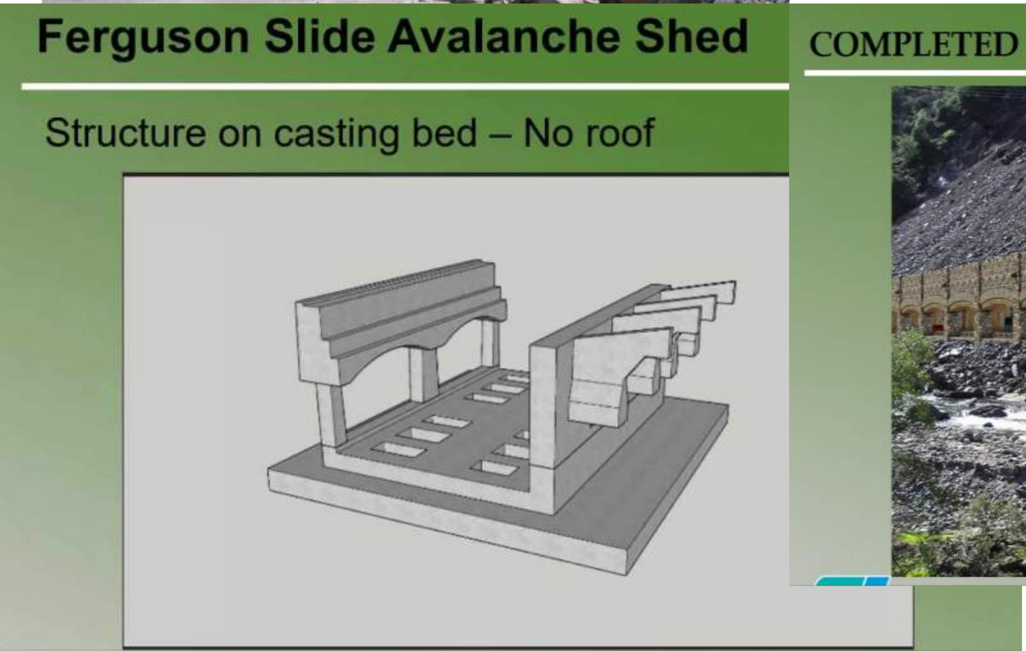
Analysis for bridge deck based on Caltrans + FHWA costs

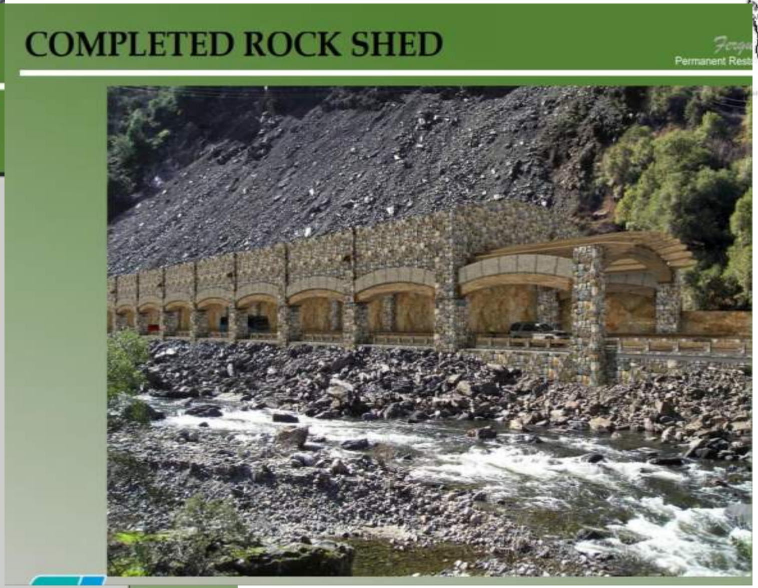
Potential to lower upfront costs **if you reduce concrete cover**

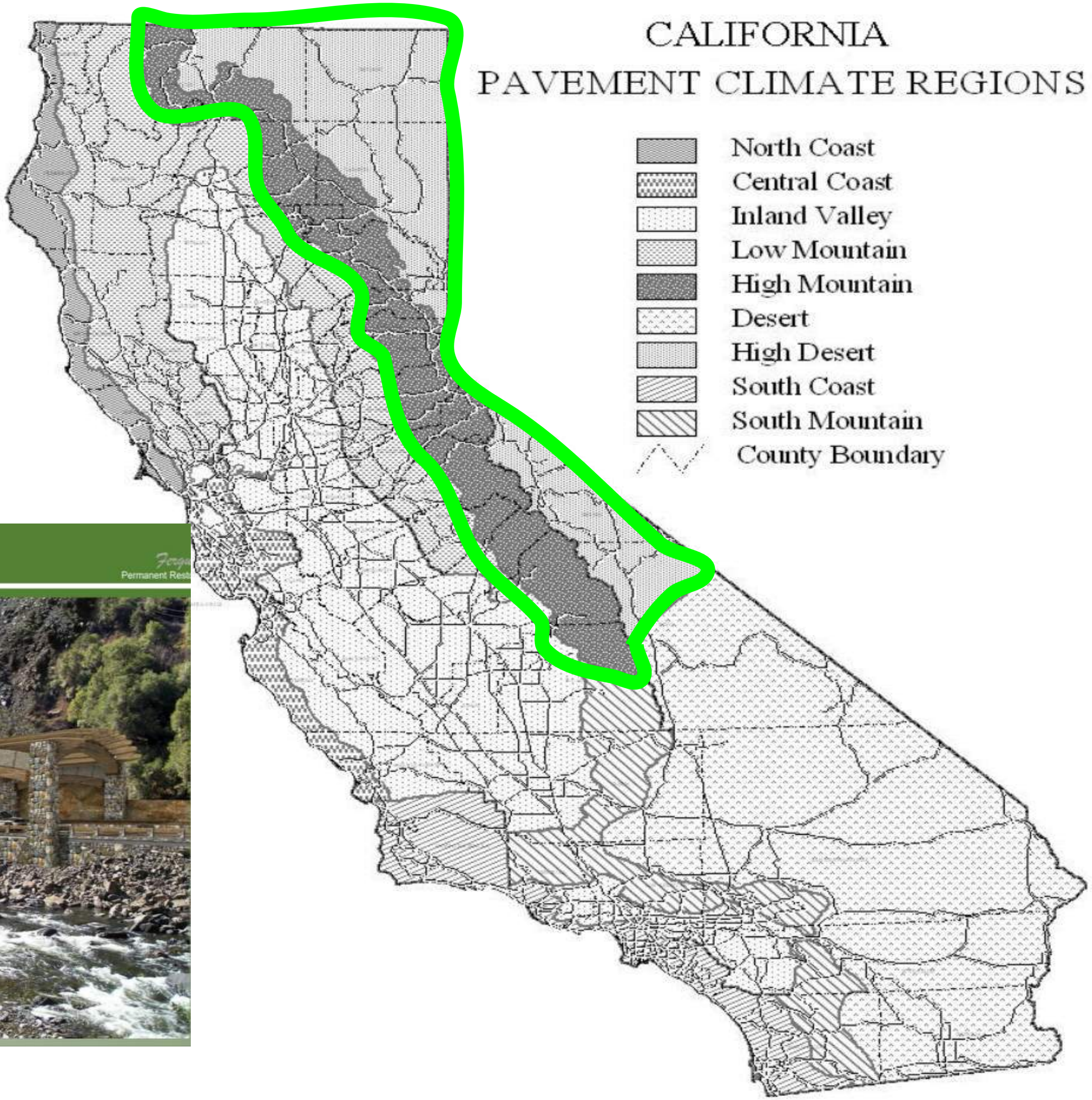


Sample	Ultimate Tensile Strength [PSI]	Yield Strength [PSI]	Total Elongation [%]
SS Clad 1	94,761	68,204	13.71
SS Clad 2	93,843	69,327	12.15
SS Clad 3	96,263	69,659	13.69
A615 Bar	95,457	69,722	13.49



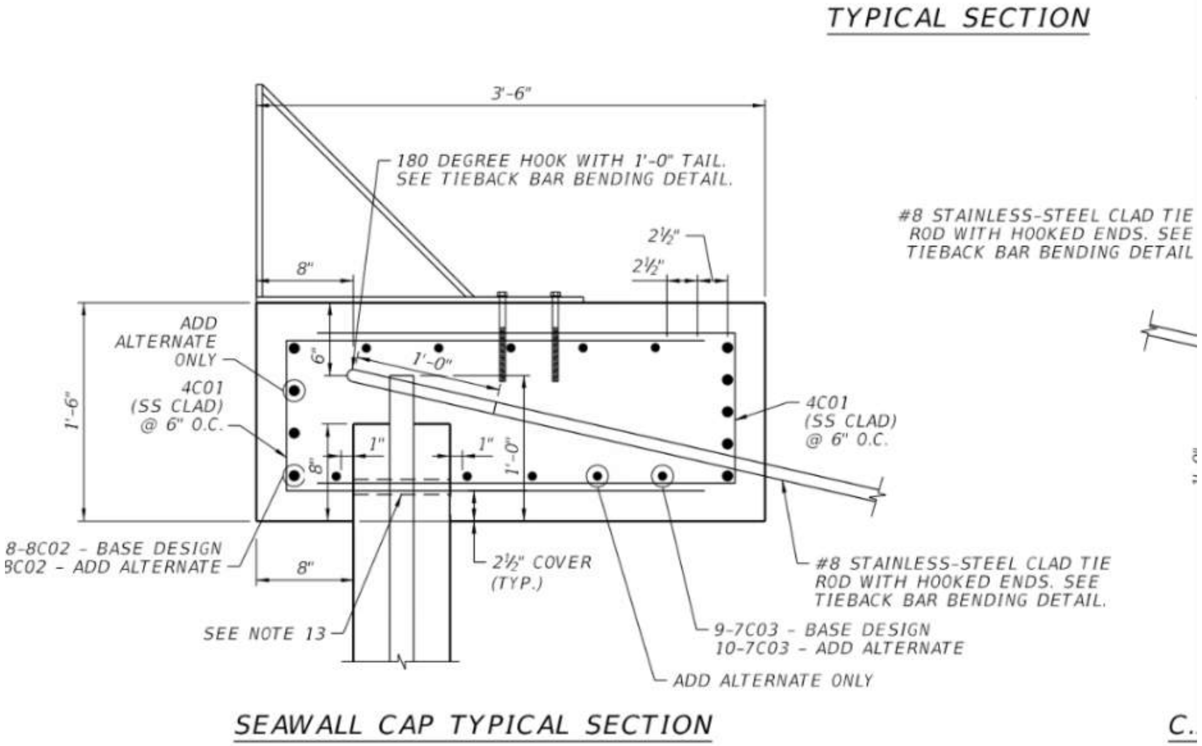

Ferguson Slide Avalanche Shed
Structure on casting bed – No roof


COMPLETED ROCK SHED


CALIFORNIA
PAVEMENT CLIMATE REGIONS
North Coast
Central Coast
Inland Valley
Low Mountain
High Mountain
Desert
High Desert
South Coast
South Mountain
County Boundary

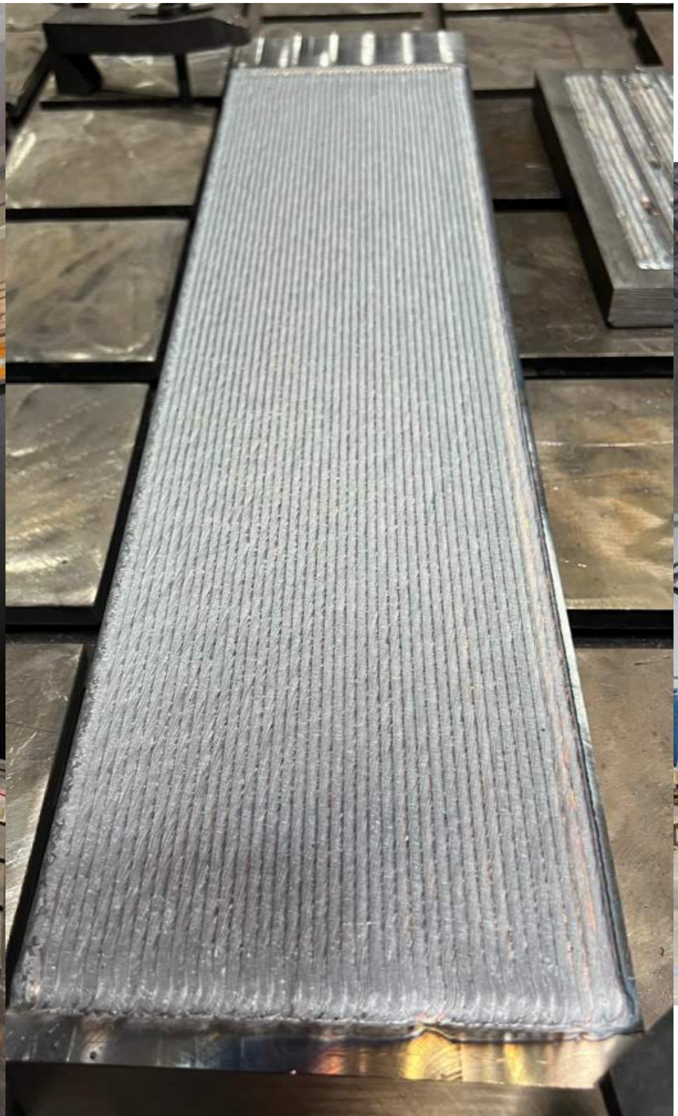
Case Study: SeaWall and Bulkhead Cap

Location: Key West, FL
Designer: HighSpans Engineering
EOR: Tom Waits
Status: specified into project design



HighSpans
ENGINEERING, INC.

Production Facility Startup In-Progress



Thank You!

Questions?

Innovative Composite Solutions for Sustainable Concrete Structures

Dextra

Presenter: Pierre HOFMANN

Dextra Group

Dextra

Innovative Composite Solutions for Sustainable Concrete Structures

Abstract:

Adoption of GFRP rebars as reinforcement in concrete structures is a well-know solution, yet several recent innovations allow advantageous design & construction methods:

- GFRP reinforcement in tunnels, allowing huge reduction in concrete consumption.
- GFRP carpets, used to cover large areas of slab-on-grade in a minimum amount of time.
- Splicing couplers, offering an alternative to the lap-splices, in concrete roads repair projects.

This presentation will showcase the remarkable benefits of GFRP solutions through case studies. We will explore comparative analyses of material usage, cost-effectiveness, and productivity enhancements.

More importantly, the reduction in embodied carbon will be quantified through CO2 emissions metrics and backed by recently published Environmental Product Declarations (EPD).

Speaker Bio

Mr. Pierre HOFMANN
Dextra Group - General Manager – Geotechnical Products

Pierre holds a Master of Engineering from ‘Ecole Centrale de Lille’ and a Master of Science in Project Management from ‘SKEMA Business School’. He joined Dextra in 2007 with a mission to develop innovative solutions using composite material, in power & transportation market segments. Since 2016, Pierre oversees the Geotechnical Product Line, promoting Fiber Reinforced Polymer (FRP) systems to be used in concrete & underground structures.

Pierre is associate member of the new ACI Committee 243 on the Use of Seawater-Mixed Concrete

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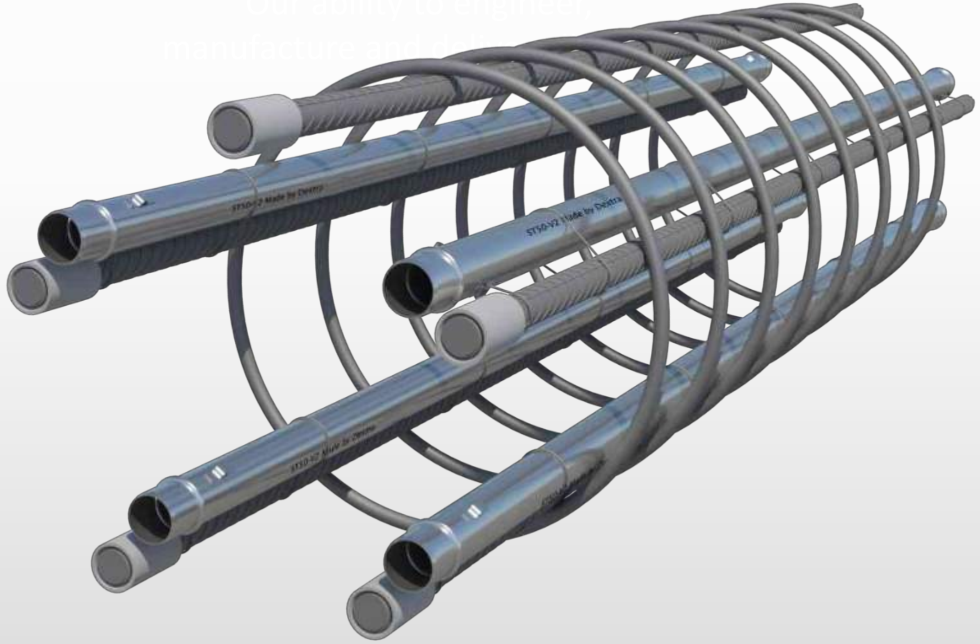
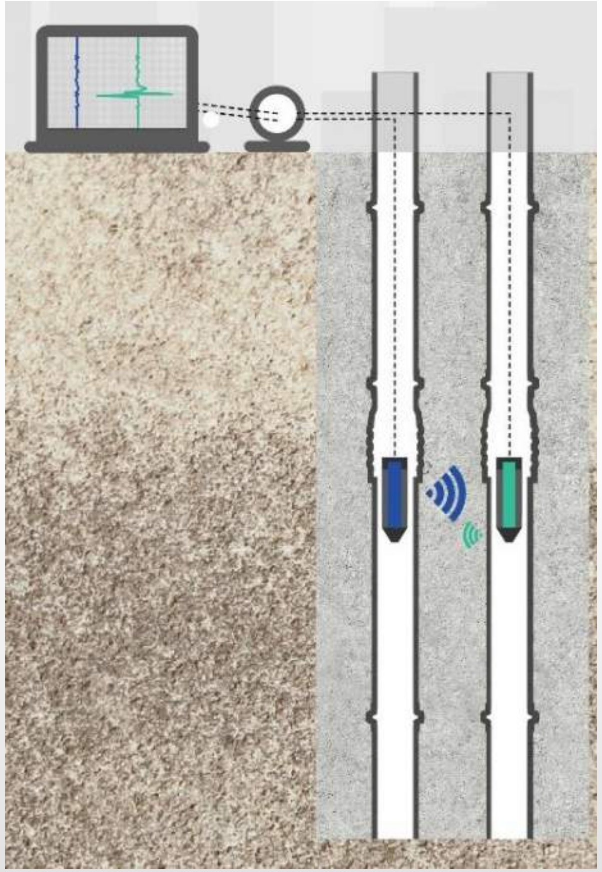
CROSSHOLE SONIC LOGGING (CSL) TUBE

SONITEC

The CSL Tube™

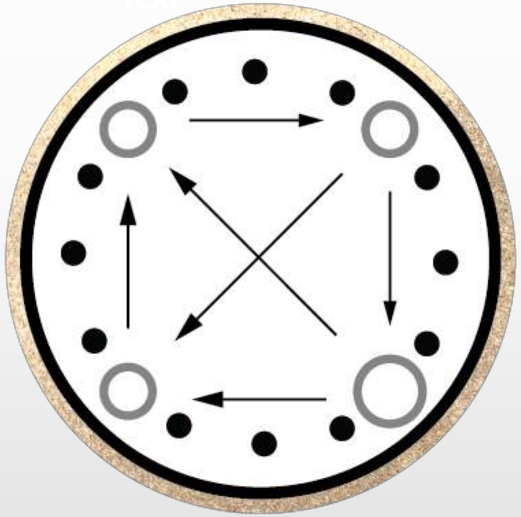




MADE RIGHT

RIGHT HERE

Foundation Technologies, Inc.®



ZERO need for threading

1/3 the weight to lift*

1/3 the man-hours to install*

1/3 Embodied Carbon

Dextra

APPLICATIONS OF COMPOSITE SOLUTIONS

Durabar	ASTEC	GEOTEC
FRP rebars for non-structural (flat work)	FRP rebars for structural and corrosive applications	Bolt & anchors for tunnels & stations
		

Dextra Durabar Rollout Carpet / Curtain

- Durabar™ Rollout Carpet is the latest patented product made from Durabar™ GFRP rebar.
- This revolutionary product is designed for ultimate versatility in construction projects.

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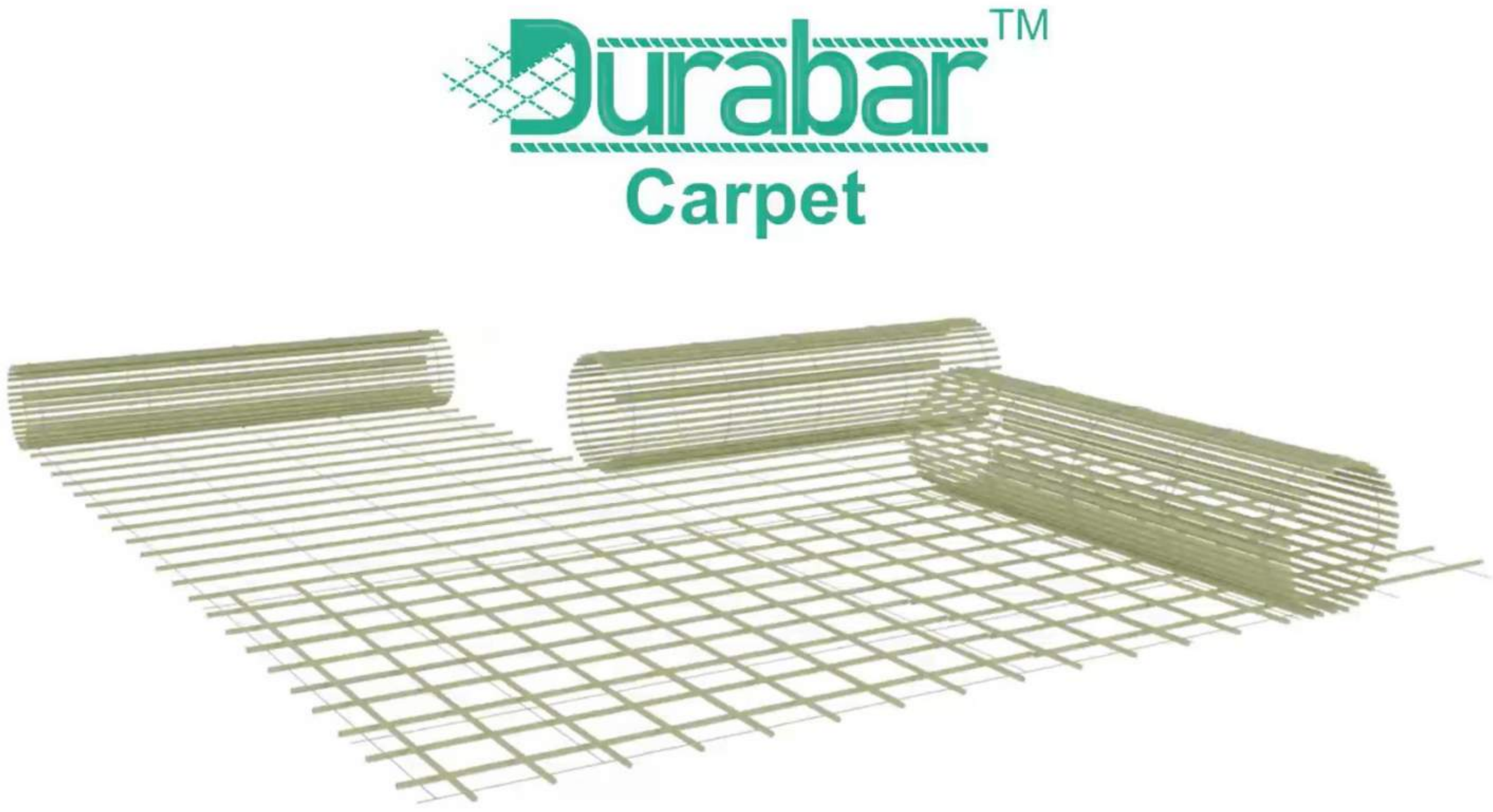
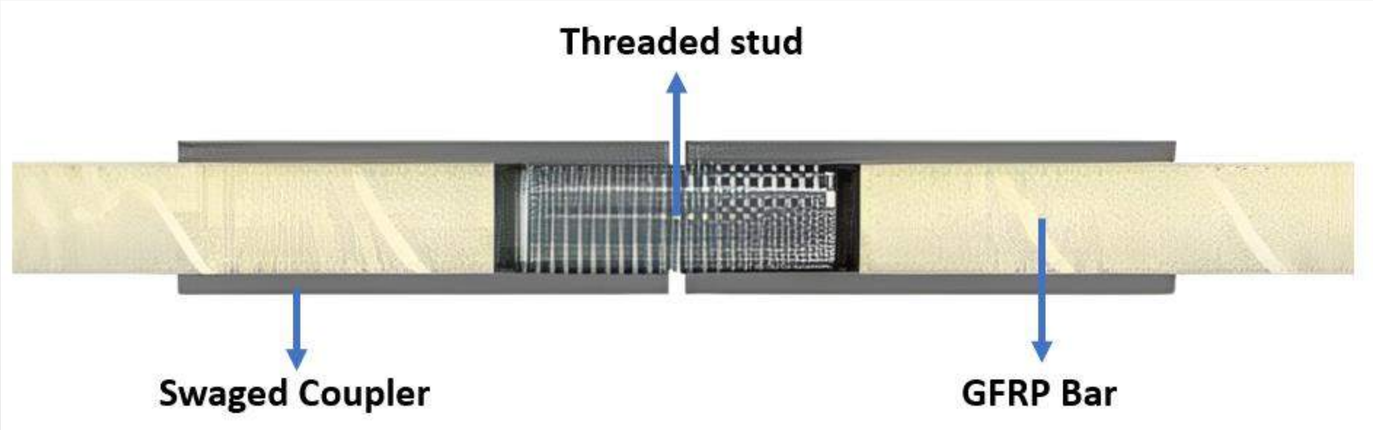
Dextra Durabar Rollout Carpet / Curtain



GFRP Bar Splicing System

- The GFRP bar splicing system is a designed solution for the connection of 2 high performance GFRP bars.
- The Dextra couplers are extrusion-swaged onto the GFRP rebar in the factory. The coupler-rebar systems are then installed on-site by threading them together.



GFRP Bar Splicing System

This splicing system can be adapted to all FRP bars geometry: sand coated, machined threaded, helical wrap…

Coupler and GFRP rebar before swaging

Coupler and GFRP rebar after swaging

GFRP Bar Splicing System

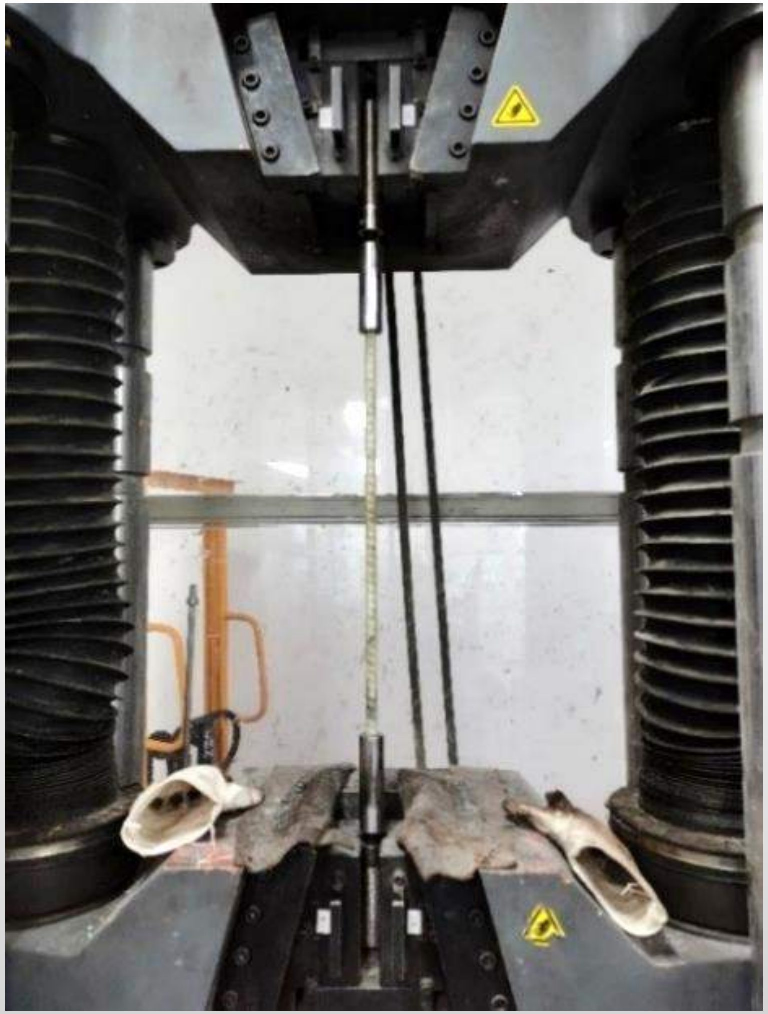
Coupler & GFRP rebar swaged by the automatic swaging machine.

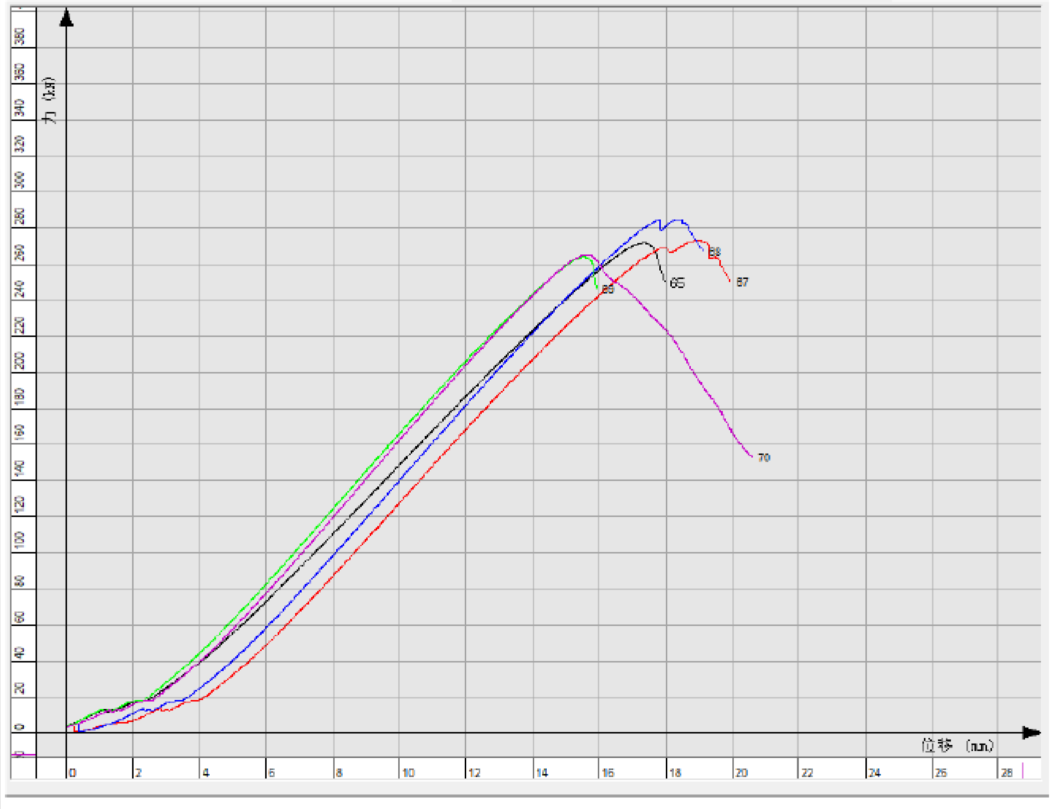
GFRP Bar Splicing System

Various combinations of couplers & GFRP bars.

GFRP Bar Splicing System

Tensile Tests for the Splicing system as per ASTM D7205M-21.





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GFRP Bar Splicing System

Datasheet (guaranteed values)

Dia (mm)	Nominal Dia. (mm)	Ultimate Tensile Strength				
		A - GFRP Bar min. (kN)	**A - GFRP Bar min. (kip)**	B - Coupler min. (kN)	**B - Coupler min. (kip)**	**B/A - Retention min. (%)**
#4 (13mm)	12.7	135	**30**	125	**28**	**≥90**
#5 (16mm)	15.9	186	**42**	149	**33**	**≥80**
#6 (19mm)	19.1	300	**67**	250	**56**	**≥80**
#8 (25mm)	25.4	428	**96**	343	**77**	**≥80**

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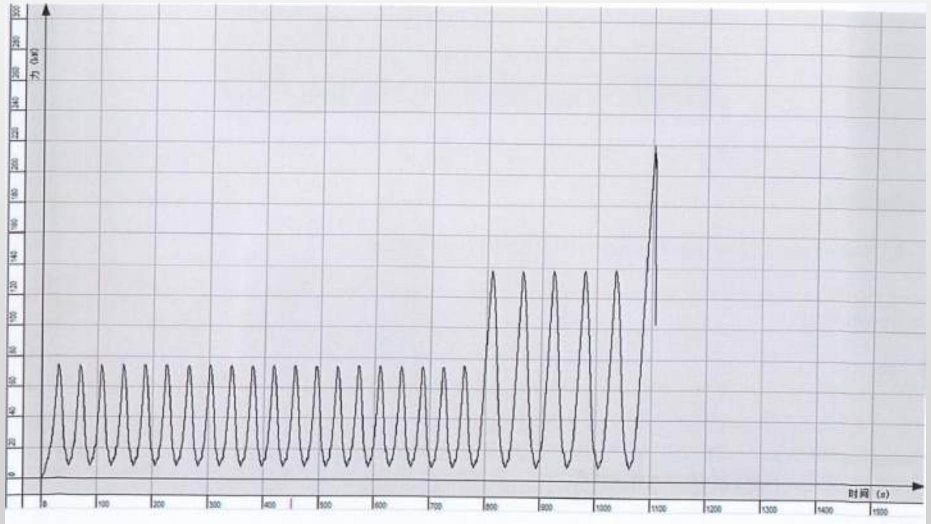
GFRP Bar Splicing System

Cycle Tensile Test

Cycle tensile test for the splicing system, $0.4f_{fu}$ for 20 cycles, $0.8f_{fu}$ for 5 cycles.

Stage	Upper Tension	Lower Tension	Cycles
1	$0.40\ f_{fu}$	$0.05\ f_{fu}$	20
2	$0.80\ f_{fu}$	$0.05\ f_{fu}$	5
3	Load in tension to failure Record the failure load and location		



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GFRP Bar Splicing System

Cycle Tensile Test result for the Splicing system

Cycle tensile test for the splicing system, $0.4f_{fu}$ for 20 cycles, $0.8f_{fu}$ for 5 cycles then load in tension to failure.

Dia (mm)	$0.40\ f_{fu}$ 20 cycles	$0.80\ f_{fu}$ 20 cycles	Failure load (kN)	Failure mode
#4 (13mm) Sand Coated	Passed	Passed	144.8	Bar Break
#5 (16mm) Machine thread	Passed	Passed	143.7	Bar Slip
#6 (19mm) Sand Coated	Passed	Passed	301.2	Bar Break

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GFRP Bar Splicing System

Precast prestressed girders ?

Possibility to delivery in coil up to OD=13mm (1/2”), to replace steel or CFRP tendons

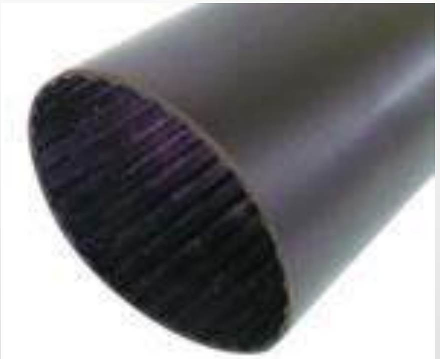
GFRP Bar Splicing System

Corrosion Mitigation



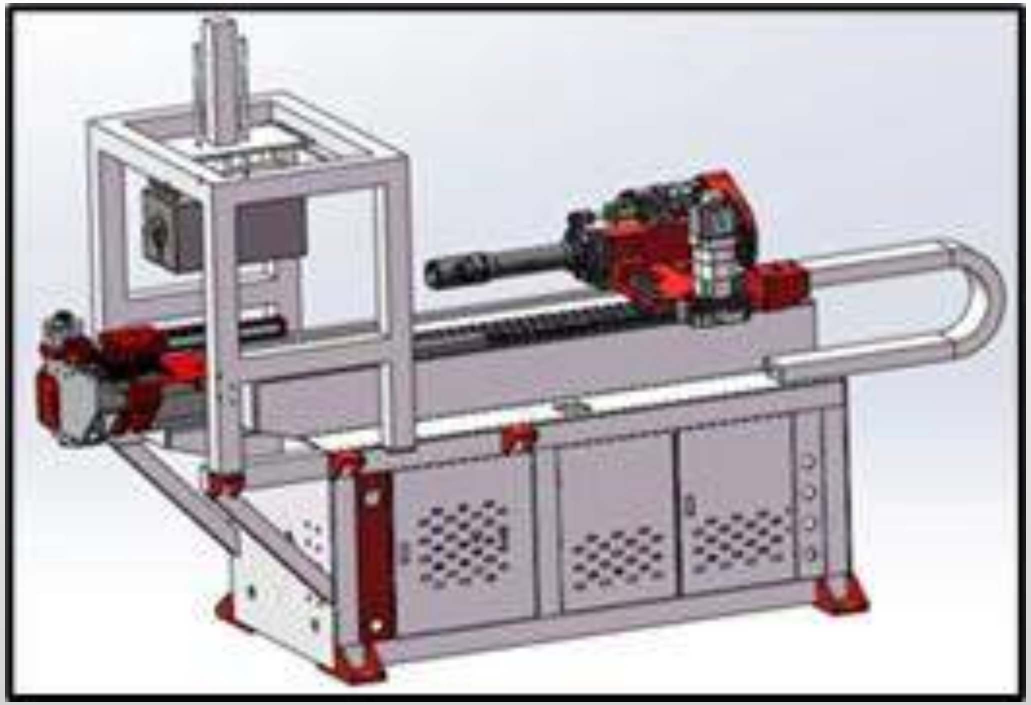
Options considered:

- Carbon steel sleeves + Stainless steel stud
- Stainless steel sleeves & stud
- Cold-spray galvanization
- Heat shrink sleeve



Thermoplastic Bendable GFRP Rebar

- FRP rebars with thermoplastic resin by ARKEMA ELIUM®
- This new generation of resin allows straight rebars to be bent at-site
- Resin can be made up to ***92% of recycled material***



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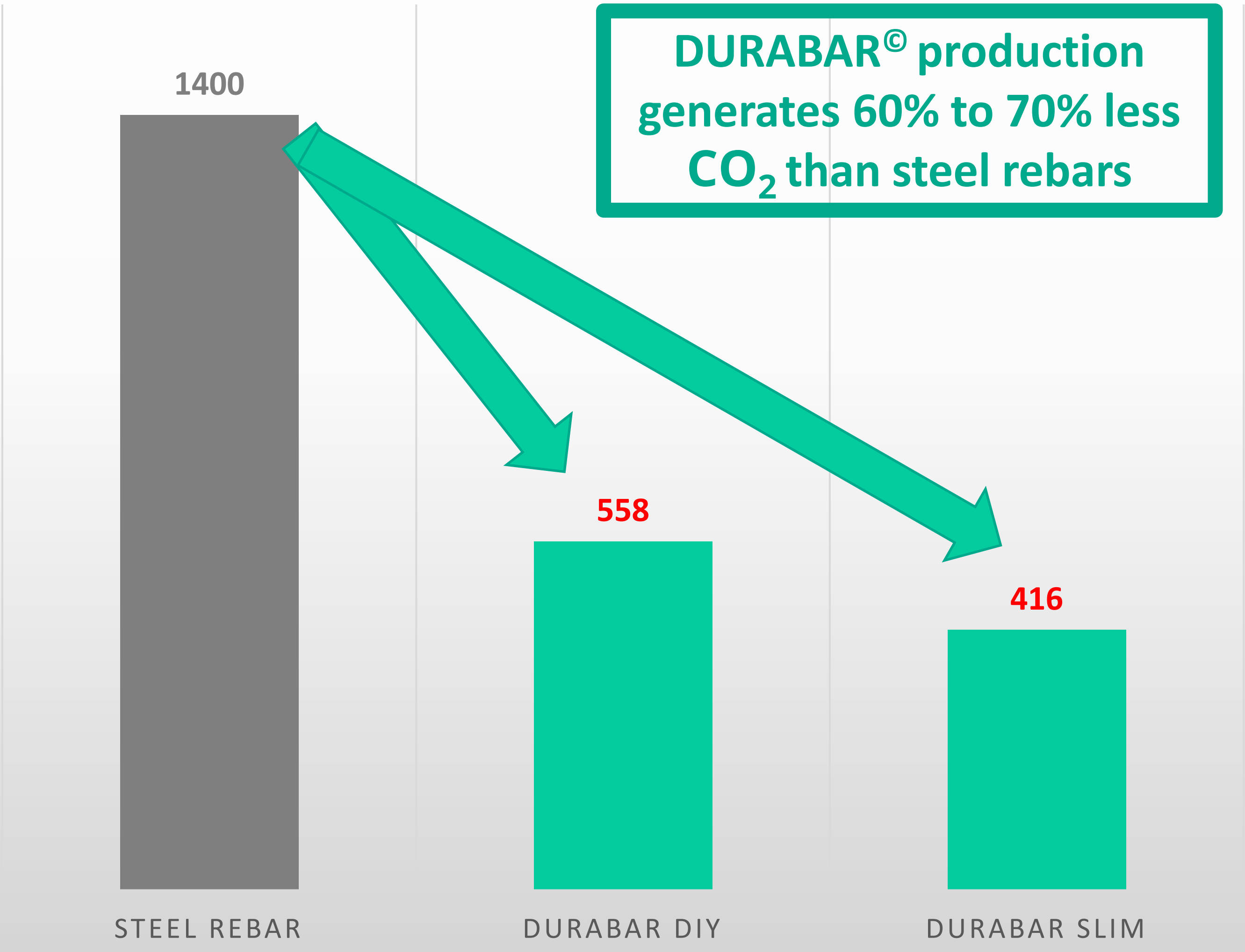
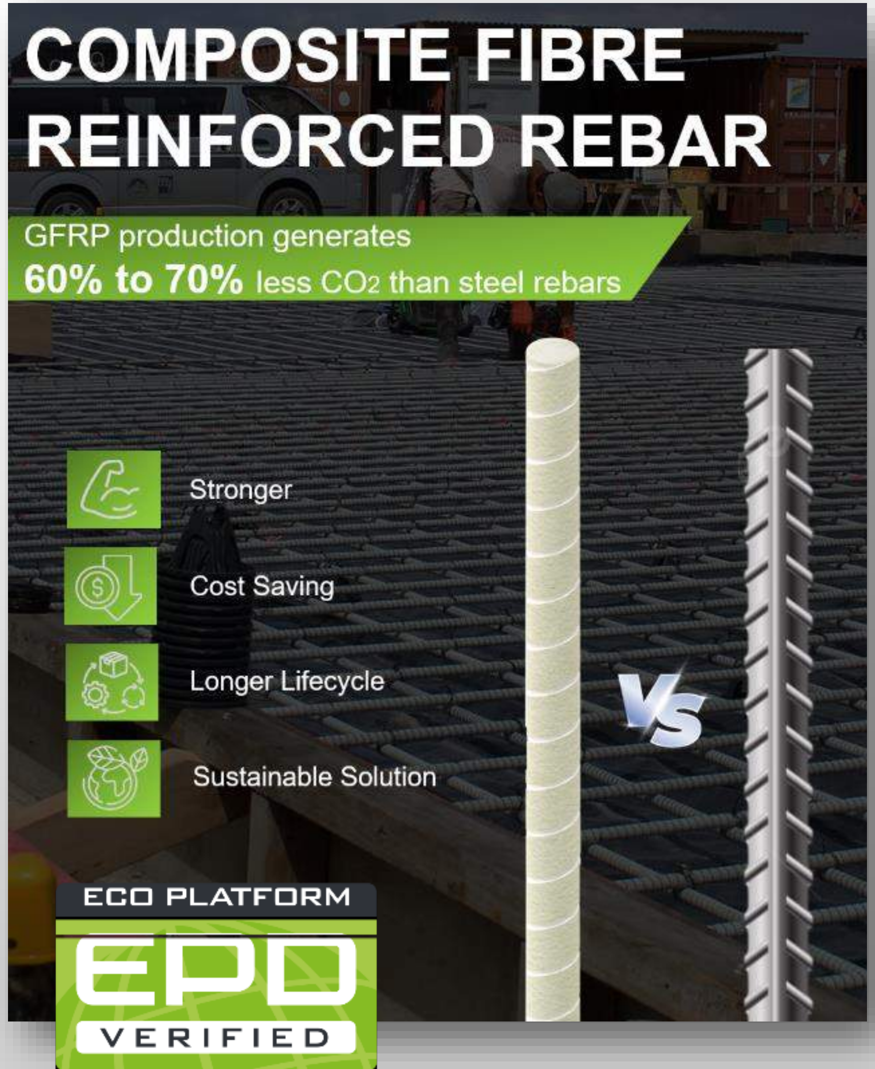
Life Cycle-Assesment (LCA) – GFRP vs Steel

CO_2 Emissions ($KgCO_2$/t) for GFRP equivalent to steel rebars





EMBODIED CARBON CALCULATOR = EXAMPLE

CONCRETE SLAB 792 m2

GFRP REINFROCEMENT CONCRETE

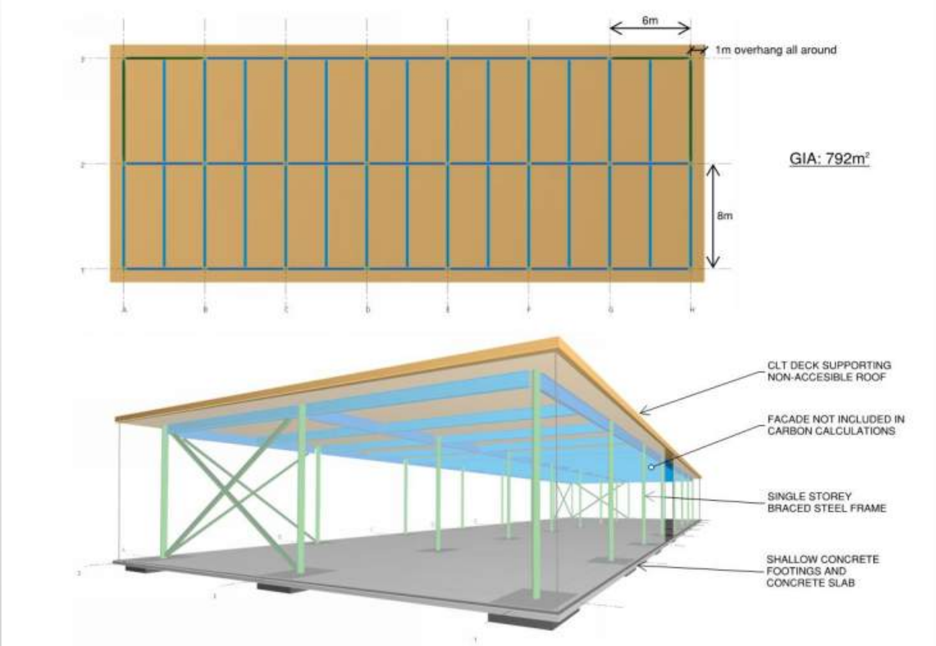
Material	Material Type	Material Specification	Structural Element	Description
Concrete	Precast_concrete	Reinforced - 150mm hollow core slab	1.1 Lowest floor/slab	Slabs
Custom_EPD	Other_EPD	GFRP Rebars	1.1 Lowest floor/slab	RC slabs

Up to 120 years

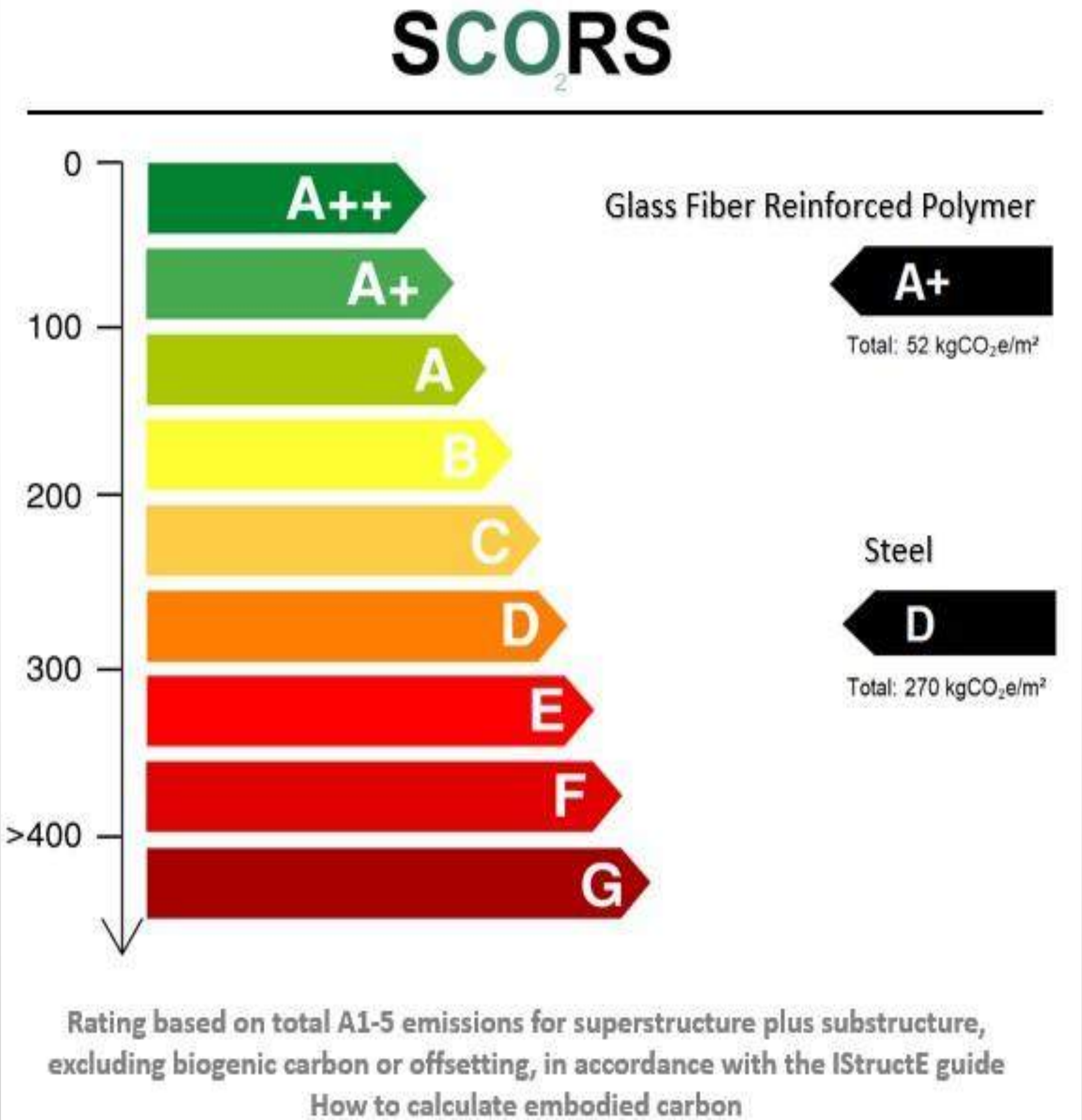
Component Lifespan [years]	Temporary Works	% of Temp Works Wasted	Volume [m³] or Mass [kg]?	Material Quantity [m³, kg]	Reinforcement [kg/m³]	Element Embodied Carbon [tCO_2e]	A1-A3	A4	A5w	B4	C2-C4	D	Biogenic Carbon
60	No		Volume [m3]	68	N/A (0)	30	22	4	0		3		
60	No		Mass [kg]	1,900	N/A	7	4	2	0		0		

Custom EPD Table

				Product Stage	Transport emissions	Waste Rate	Transport
Material	Description	Density (kg/m³)	Biogenic Carbon (Sequestration) [$kgCO_2e/kg$]	A1-A3 [$kgCO_2e/kg$]	A4 [$kgCO_2e/kg$]	WR [%]	C2 [$kgCO_2e/kg$]
Other_EPD	GFRP Rebars	2100		2.11	1.24	5.0%	0.0095



Credits: The Structural Engineer in July 2020



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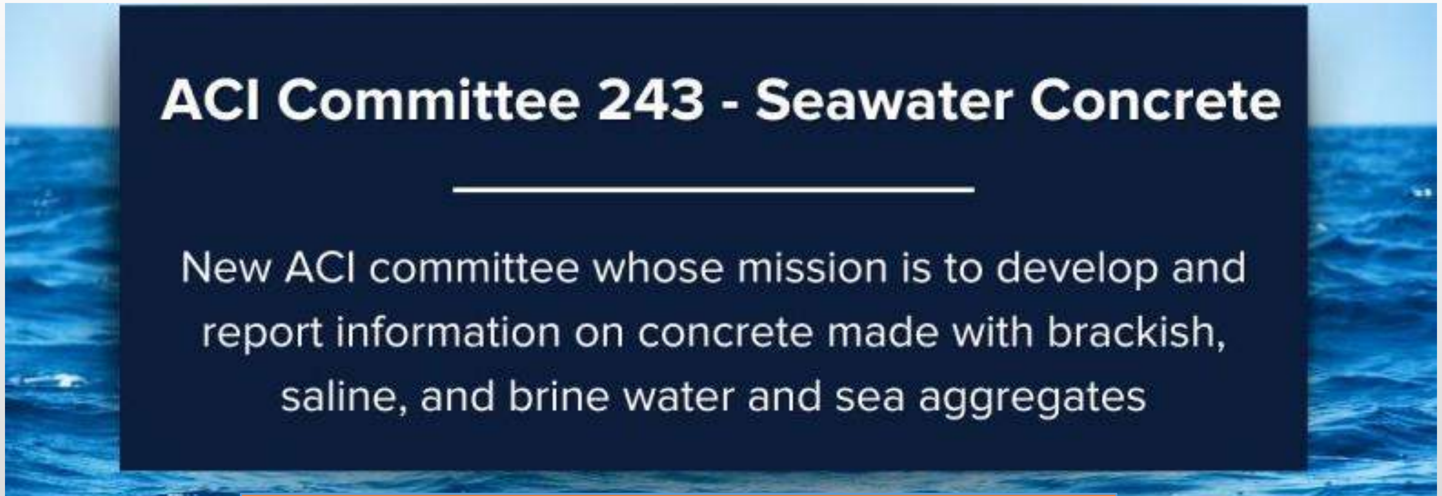
SEA-SAND SEAWATER CONCRETE (SSC)

SUSTAINABILITY

Beyond direct reductions of 60% to 70% of embodied carbon (CO_2)

Biggest impact is the reduction of CO_2 from concrete itself: reduce the quantity - up to 30% - and change its composition with recycled materials

GFRP Rebars	Sea-sand Seawater	Recycled Concrete Aggregate (RCA)
		



As of June 2024 - Dextra is associated member of this new committee

Questions

Contact Info

Name = Pierre HOFMANN

Affiliation = Dextra Group

Ph. = +66 (0)65 527 4965

Email = phofmann@dextragroup.com

GFRP BARS FOR MORE RESILIENT AND SUSTAINABLE BRIDGES

Do it Right, Do it Once!

Presenter(s): **Borna Hajimiragha**
Affiliation: *MST Rebar Inc.*

BIO:

Borna Hajimiragha,

Master's Degree in Composite Material, PEng,

CEO of MST Rebar Inc.

Email: borna.h@mstbar.com

Member:

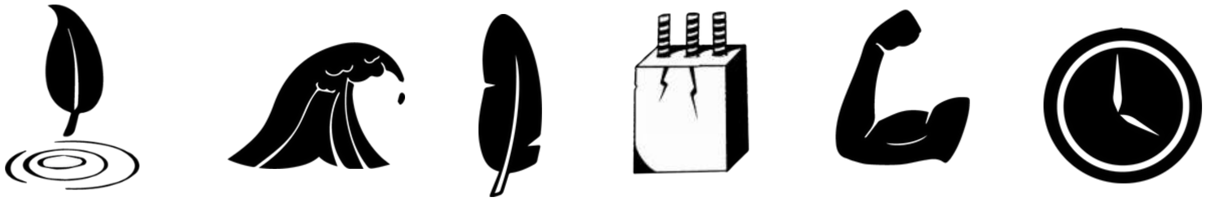
- ACI 440 Committee
- ASTM D30.10
- CAN/CSA S807
- CAN/CSA S806

Agenda

- Brief introduction and past projects
- Third-party Tastings on Mechanical Properties
- UV Exposure
- GPR Scan of GFRP Reinforced Concrete
- Environmental Product Declaration (EPD)
- Bond Strength
- TL-5 GFRP-REINFORCED CONCRETE BRIDGE BARRIER-DECK
- MST-BAR Traceability
- Qualifications and Certificates

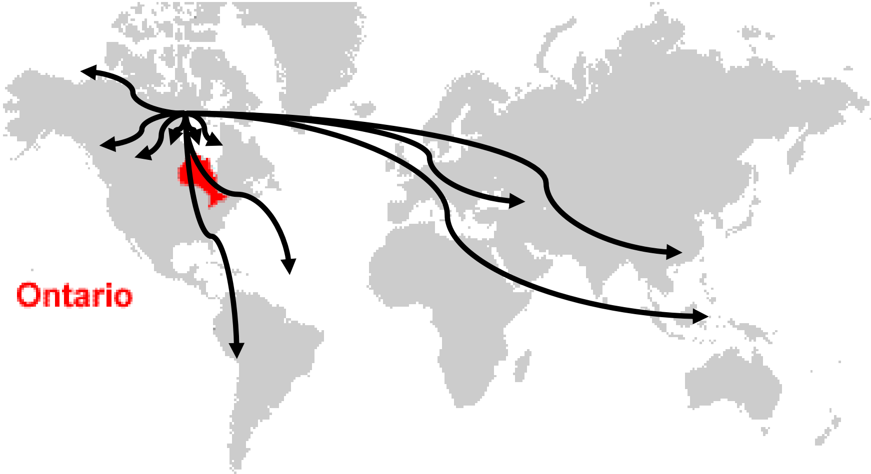
Benefits of MST-BAR

- **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**
- **Sustainable – 75% Less Energy to produce compare to Steel**



MST Rebar Inc.

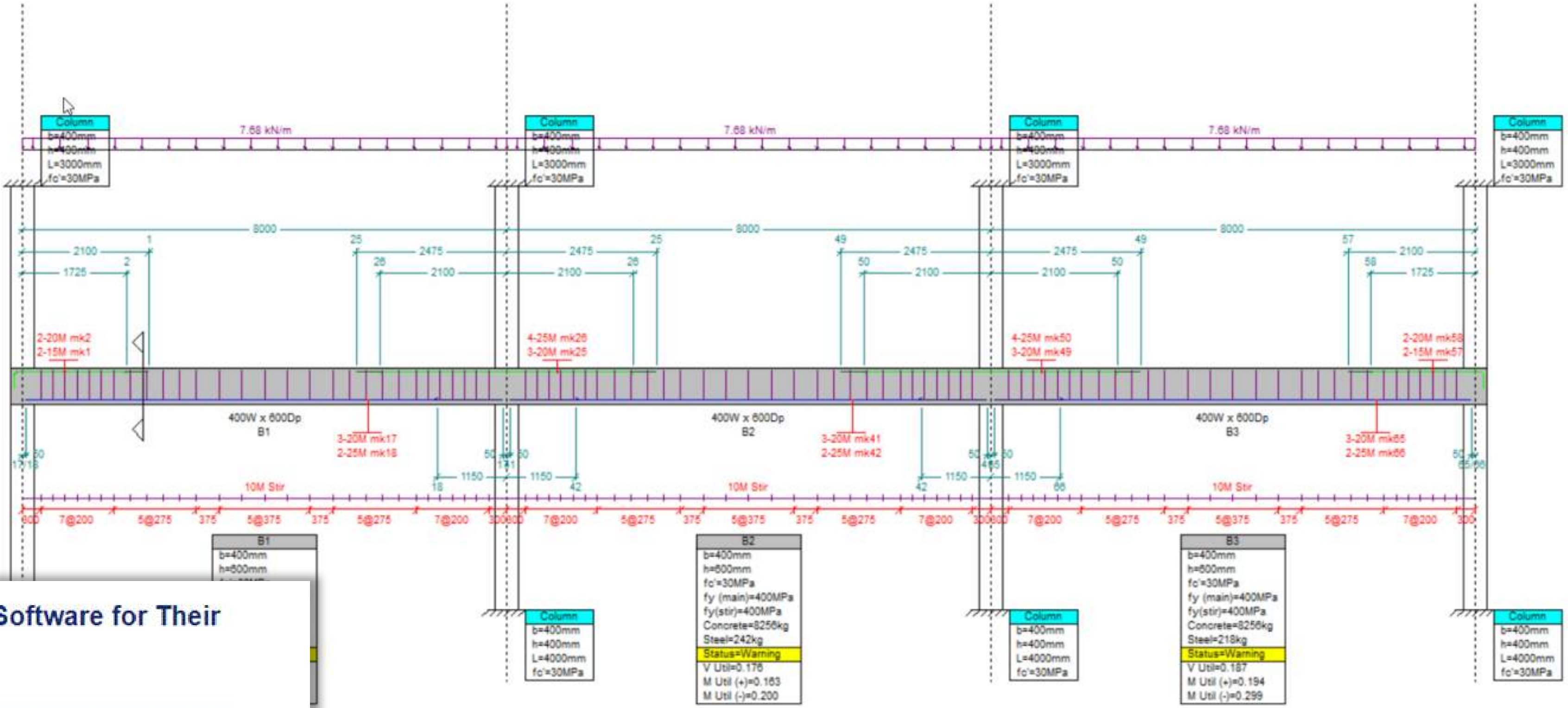
- 200,000 SQFT plant in Woodbridge
- Developed & Manufactured in North America
- Growing exponentially with $10s of millions in exports
- Largest Pultruder in the world
- Sold over 850,000,000 ft of rebar to date with over 15,000 completed projects
- Current capacity of 42,000 km (Equivalent of 60,000,000 kg of steel)
- 2024 capacity to exceed 127,000 km
- We only manufacture Grade III- High Modulus GFRP Straight, Bent and Headed bar as required by MTO



Altair S-CONCRETE, including S-LINE

S-LINE

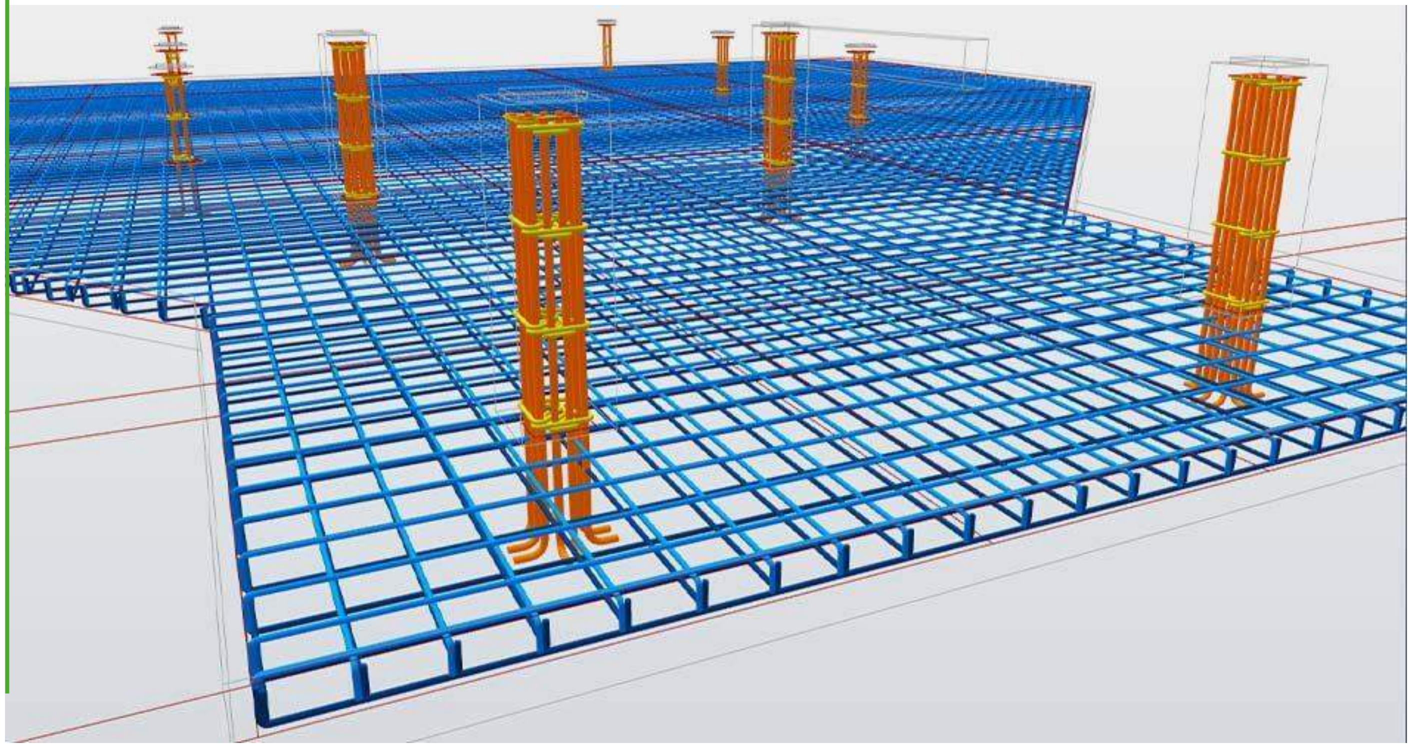
Continuous beam design with GFRP, CSA S806 and ACI440.11-22



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

Altair S-FOUNDATION

S-FOUNDATION



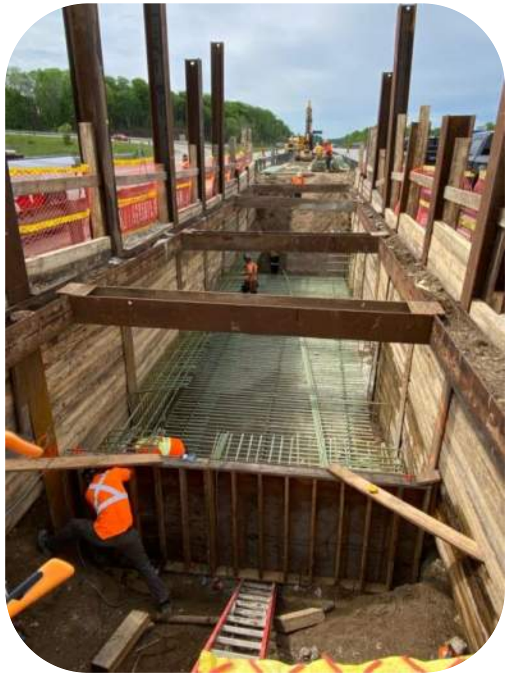
S-FOUNDATION to Include Design of GFRP

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

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

All MST-BAR bridges

MTO is using MST-BAR on 100's 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**

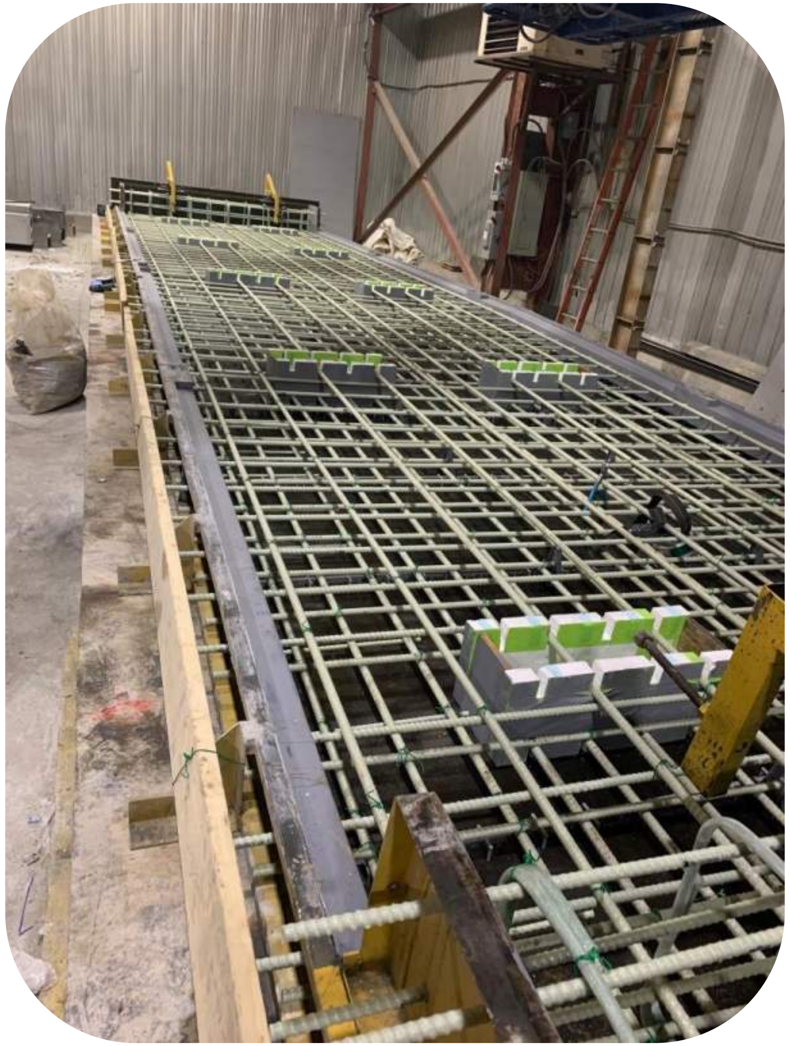
All MST-BAR bridges

Video: Lightweight & Flexibility

Foundations

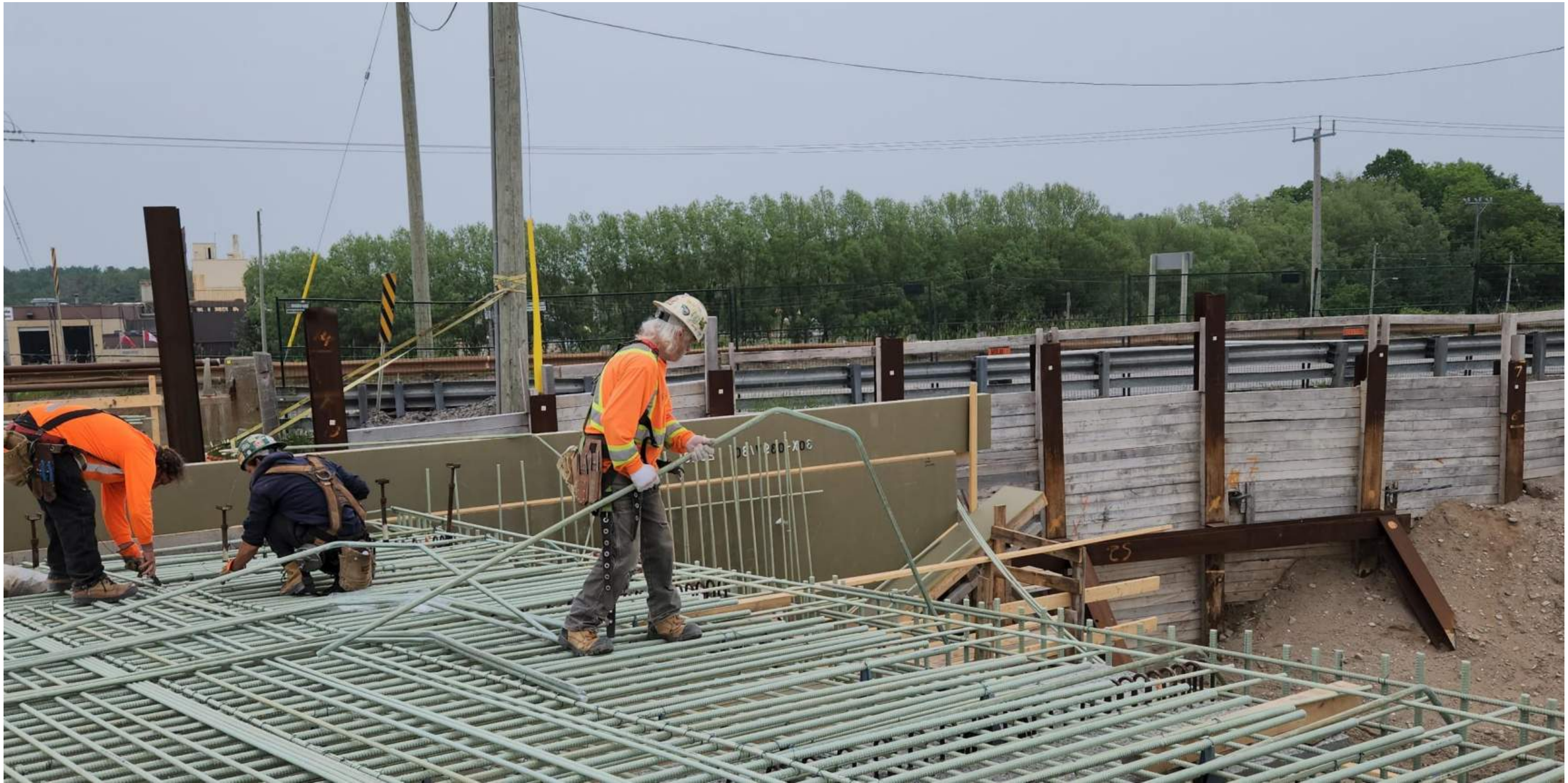
Precast Deck Panels and Connection

Bridge Deck and Precast Construction



Bridge Construction

Bridge Decks



Video: Construction of Bridge Deck

Bridge Decks and Abutments

Bridge Construction

Foundations and Pile Cages

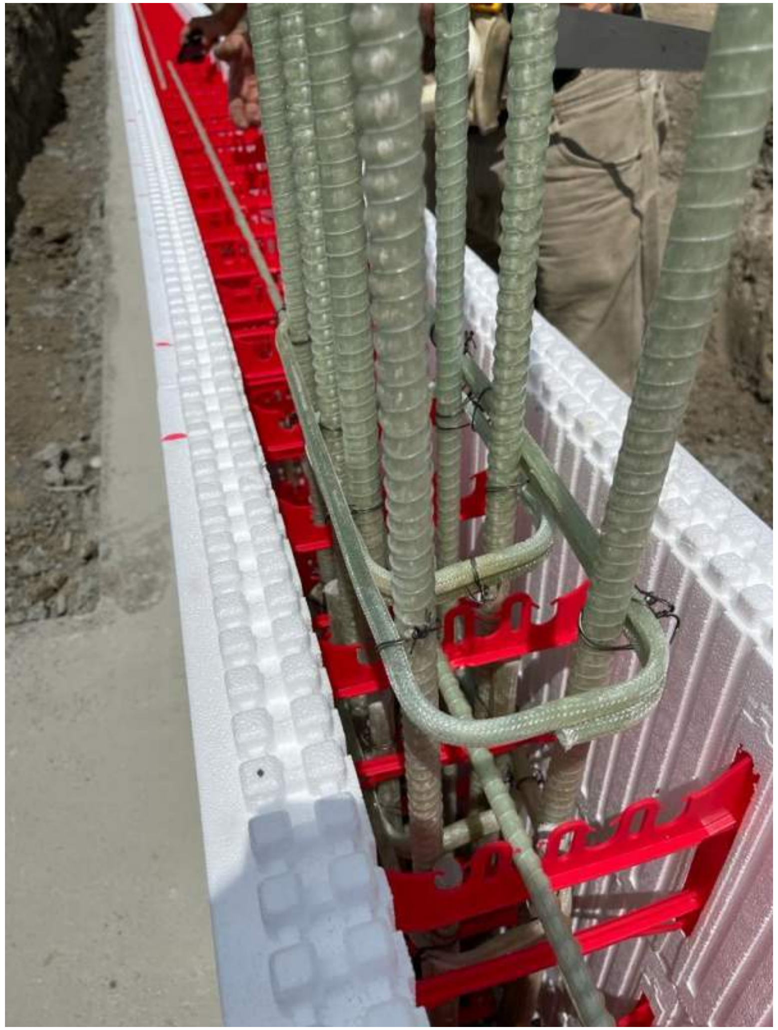
Commercial Building Construction

Residential Mid-rise Construction

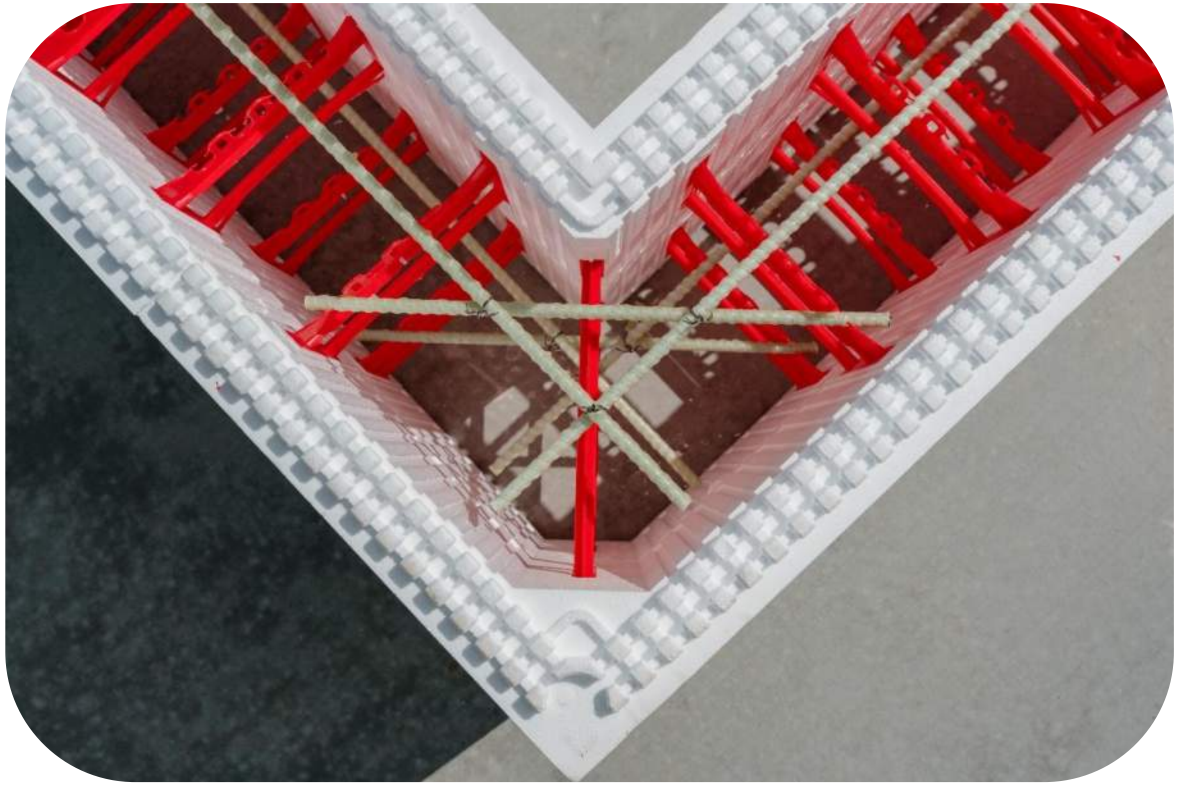
Residential Construction

Residential Footings

Residential Footing & Walls



Residential – Insulated Wall Panels



Residential Construction

Agenda

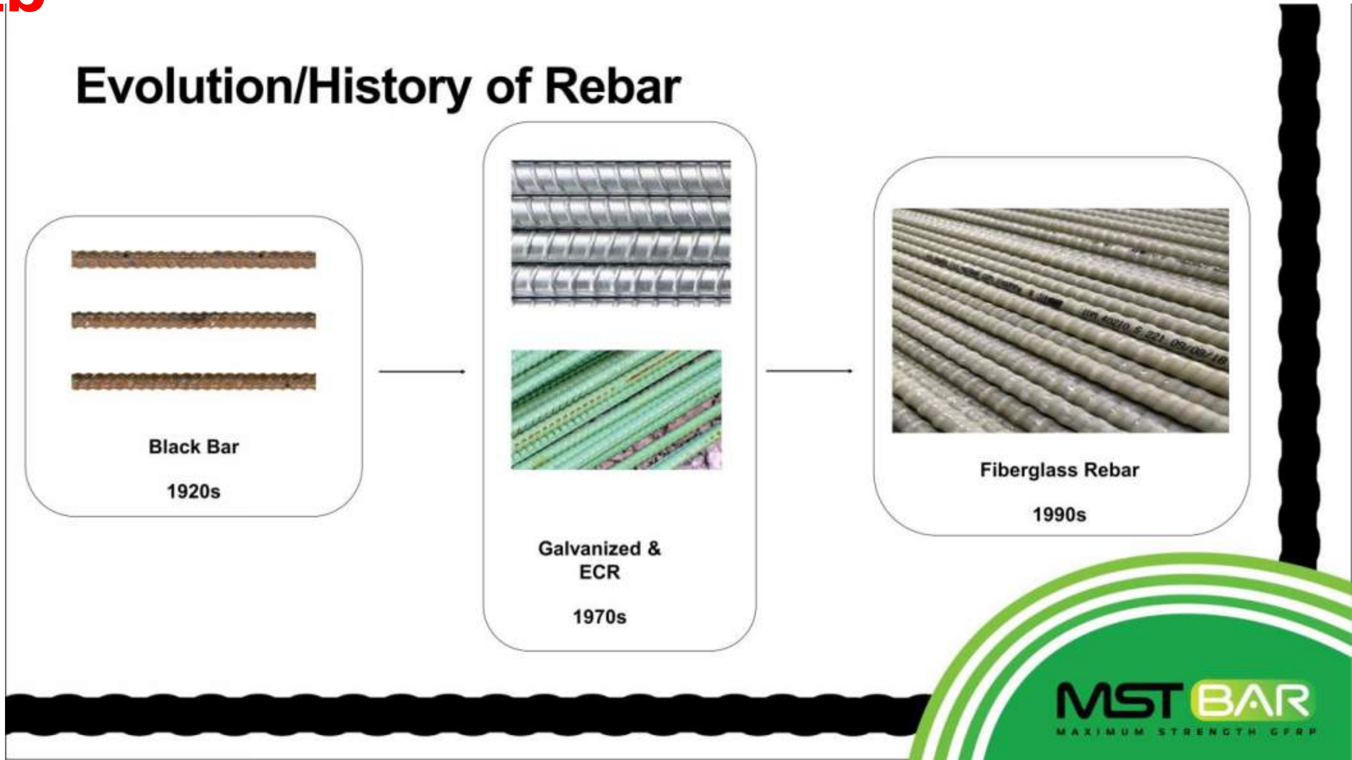
- Brief introduction and past projects
- Third-party Tastings on Mechanical Properties
- UV Exposure
- GPR Scan of GFRP Reinforced Concrete
- Environmental Product Declaration (EPD)
- Bond Strength
- TL-5 GFRP-REINFORCED CONCRETE BRIDGE BARRIER-DECK
- MST-BAR Traceability
- Qualifications and Certificates

Important facts

Premium Reinforcement: GFRP and Stainless Steel

GFRP: Premium reinforcement at NO PREMIUM PRICE any more.

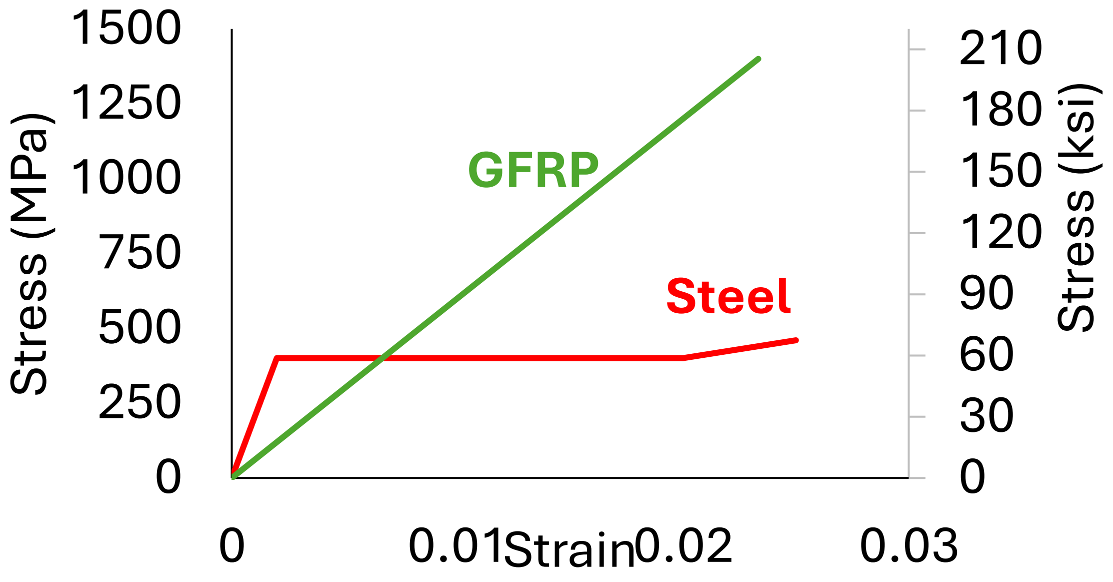
Approximate cost per lb: $0.45/lb



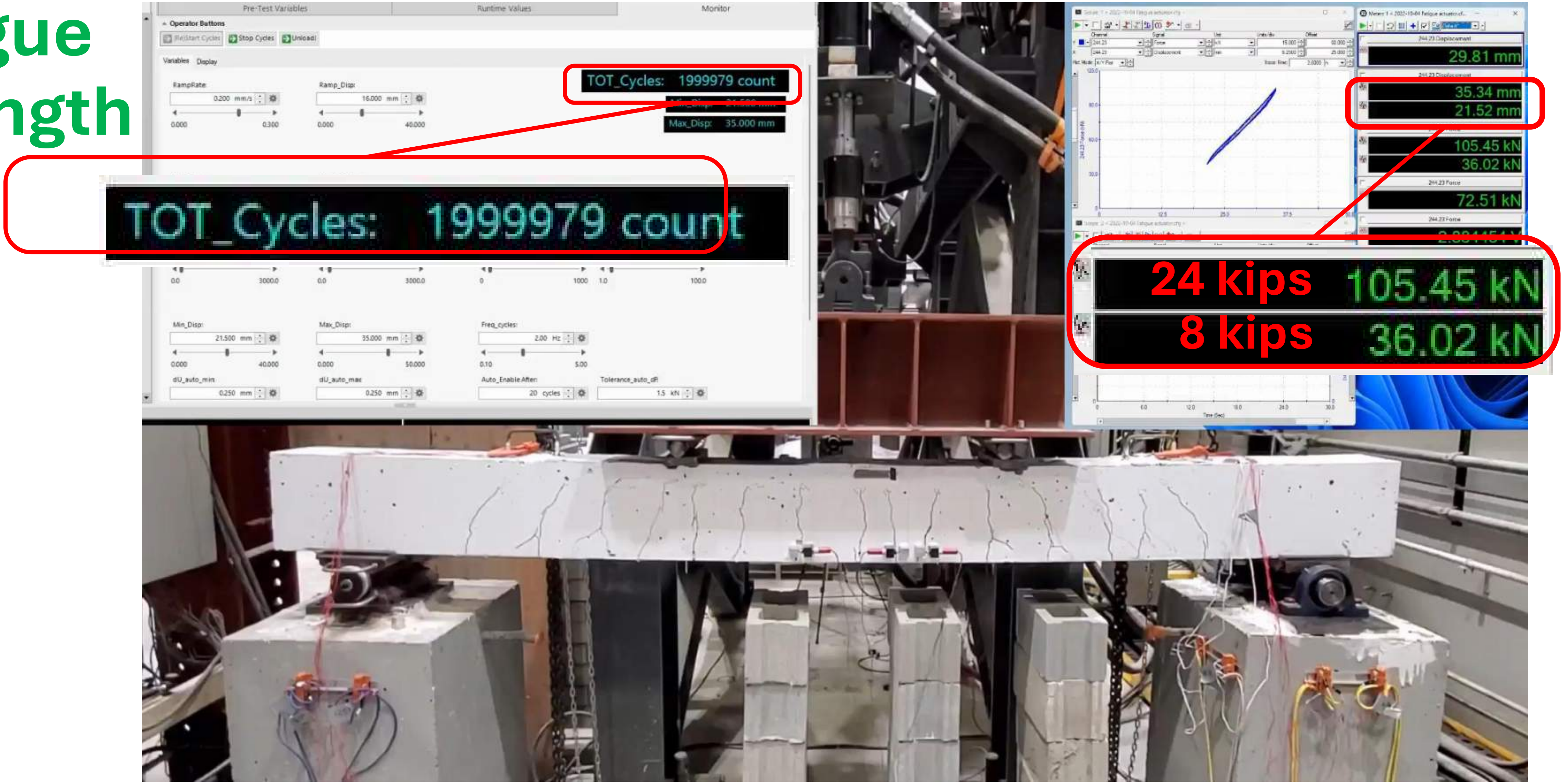
Important facts

Let's not conceal:

1. Elastic Modules of GFRP is lower than steel
   - You may need a maximum of 20-30% more rebar to achieve the same deflection
2. Material is linear elastic to failure (Brittle Material)
   - Sign of failure is by deformability and not ductility
3. FDOT, ODOT, Maine DOT, MDOT, TxDOT, NCDOT, SCDOT, MTO have used material....



Fatigue Strength



Fatigue test performed at Concordia University, CA under the supervision of Prof. Khaled Galal

Alkali Resistance in High pH Solution with and without Load

UNIVERSITÉ DE SHERBROOKE

NSERC Research Chair in Innovative FRP Reinforcement for Concrete Infrastructure

Certification of MSTBAR Glass Fibre-Reinforced Polymer (GFRP) Rebars of Size 15 mm (Production Lots No 1, No 2, and No 3): Alkali Resistance in High pH Solution with Load

Technical Report No 35

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Alkali Resistance in High pH solution without Load of MST GFRP Bars of Size No. 4 (13 mm Diameter): (Three Production Lots)

Technical Report

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Alkali Resistance of MST-BAR Glass Fibre-Reinforced Polymer (GFRP) Bars of Size No.3 in High pH Solution without Load: (Three Production Lots)

Technical Report

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Alkali Resistance in High pH Solution with and without Load

- Tensile strain of 3000 micro-strain.
- Tested part is inside PVC containers filled with an **alkaline solution** with a **pH of 13**
- Conditioned in an environmental chamber at a **temperature of 60°C (140°F)** for a period of **three months.**

Alkali Resistance in High pH Solution with and without Load

Lot #	Specimens	Average Tensile Capacity (MPa)	Tensile Capacity Retention R_{et}	Average Elastic Modulus (GPa)	Elastic Modulus Retention R_{et}
#1	Reference specimens	1077	89%	69.0	101%
	Conditioned specimens	960		69.5	
#2	Reference specimens	1084	91%	69.5	100%
	Conditioned specimens	982		69.4	
#3	Reference specimens	1067	92%	69.2	101%
	Conditioned specimens	981		69.6	

#5 with Load

- The average strength retention of 91%.
- The average modulus retention of 100%.

CSA S807 limit = 75%

Creep Rupture Strength

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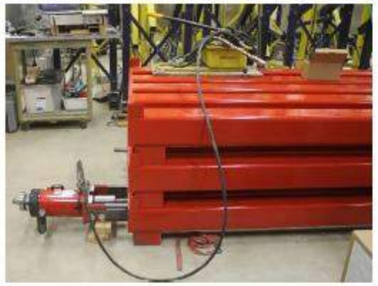
Creep Rupture Strength of MST-BAR (GFRP) Bars Size No. 3 (10 mm) (24 Tests from 3 Production Lots)

Final Report



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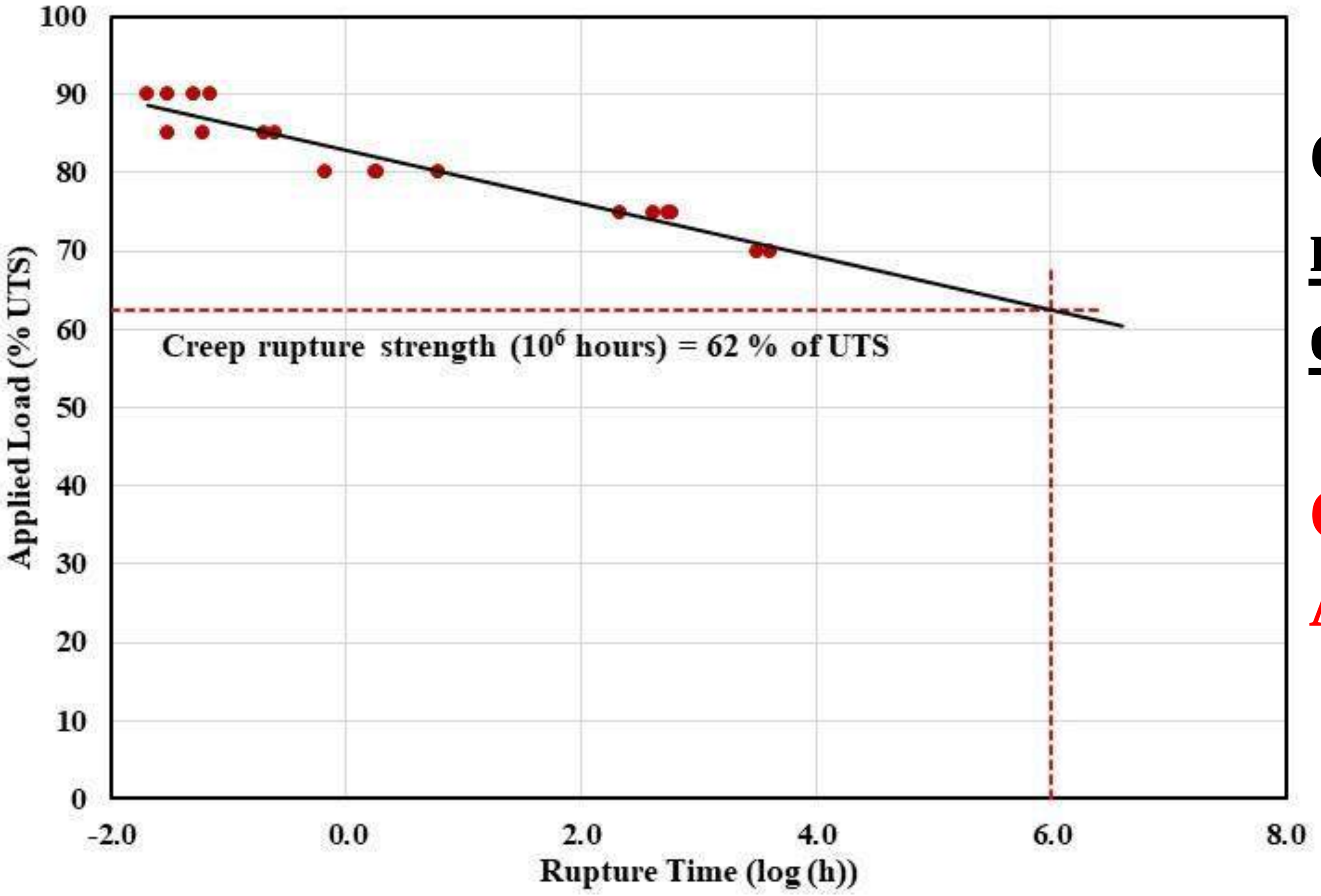
April 2022, REVISED September 2022

Creep Rupture Strength



Creep rupture strength, at <u>1 million hours (114 years)</u>, of <u>62% of Ultimate Tensile Strength</u>.

CSA S807:19 Limit = 35%
ACI 440.11-22 Code Limit = 30%

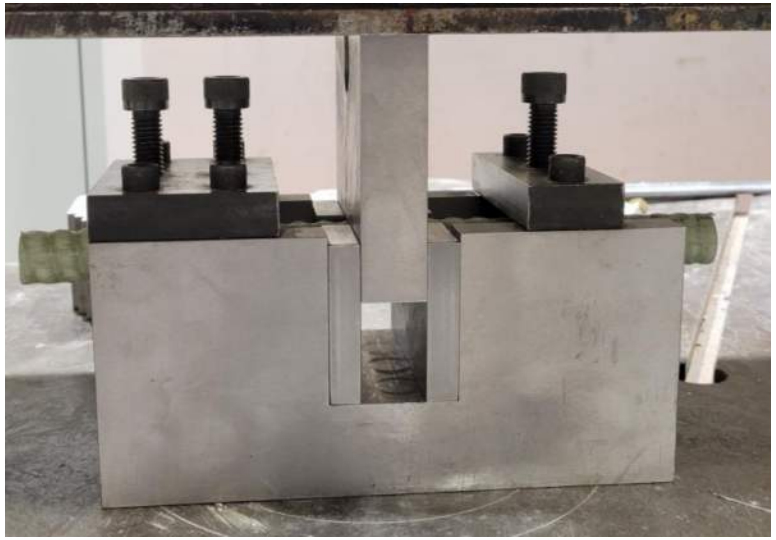
Transverse Shear Strength

Table 1: Transverse shear strength of MSTBAR GFRP bars of size 15 mm (Cross-sectional area = 199 mm²), (Production lots No 1, No 2, and No 3)

Specimen	Lot #	Shear Failure Load (kN)	Transverse Shear Strength (MPa)
1	#1	82	205
2		93	232
3		89	224
4		95	240
5		97	243
6		91	229
7		108	272
8		93	233
Average		**94**	**235**
SD		**7.5**	**18.9**
COV (%)		**8.0**	**8.0**
1	#2	96	242
2		100	252
3		94	235
4		91	228
5		90	226
6		102	257
7		94	235
8		103	260
Average		**96**	**242**
SD		**5.1**	**12.9**
COV (%)		**5.3**	**5.3**
1	#3	103	258
2		112	282
3		102	257
4		98	248
5		89	224
6		93	234
7		107	270
8		86	216
Average		**98.9**	**249**
SD		**8.9**	**22.5**
COV (%)		**9.0**	**9.0**

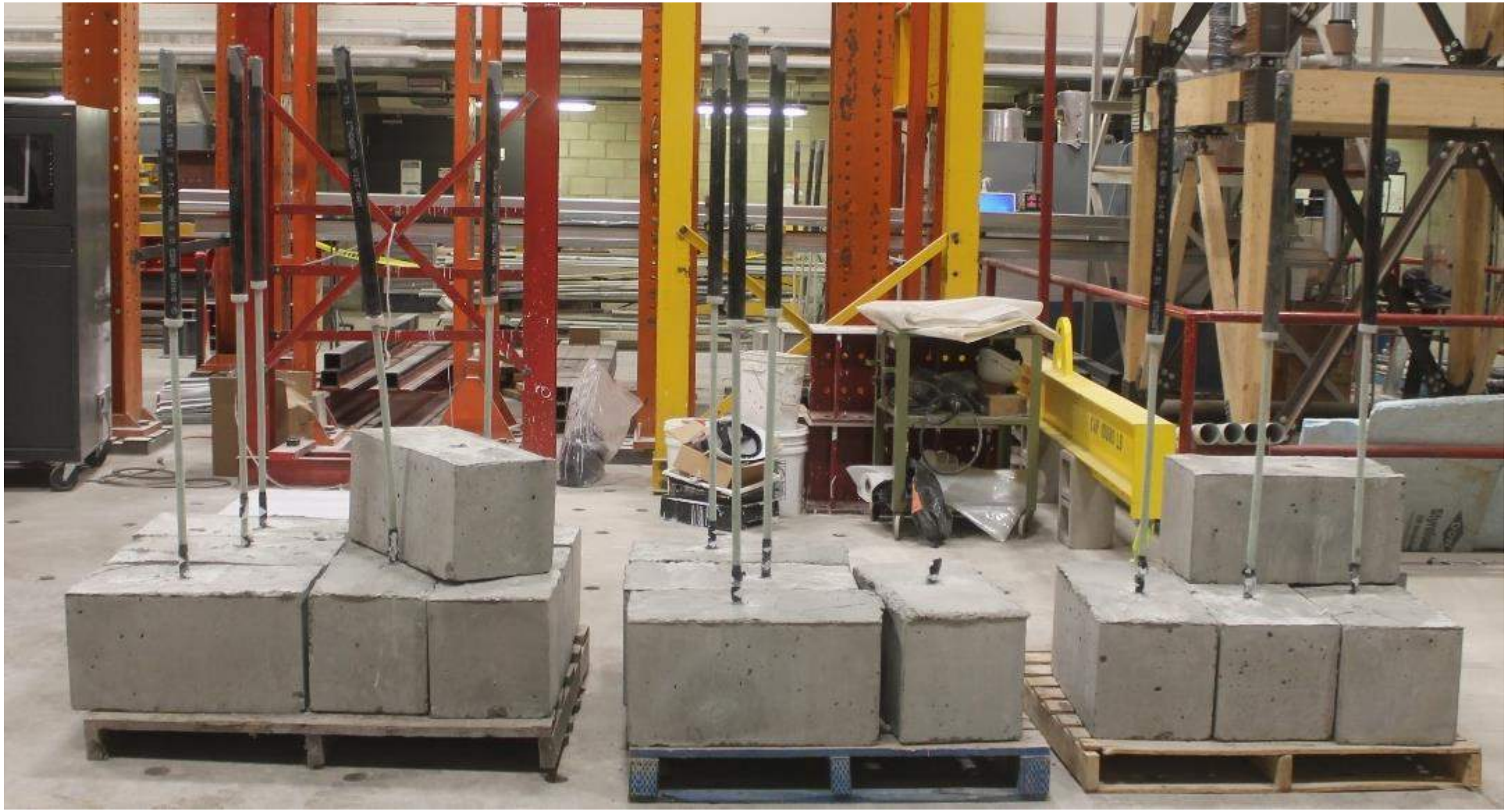
Average shear strength of 240 MPa (35 ksi)

CSA S807:19 Limit = 180 MPa



MSTBAR MAXIMUM STRENGTH GFRP

Strength of Bent Portion



Strength of Bent Portion

Table 2 - Tensile Strength of Bent Portions of MST GFRP Bent Bars #6
(Nominal Area 284 mm^2)

Specimen	Lot #	Maximum load (kN)	Ultimate tensile strength (MPa)
1	1	254	894
2		262	923
3		278	979
4		258	908
5		251	884
6		243	856
7		267	940
8		251	884
Average		258	908
SD		10.9	38.5
COV %		4.2	4.2
1	2	263	926
2		241	849
3		250	880
4		233	820
5		229	806
6		231	813
7		248	873
8		242	852
Average		242	853
SD		11.4	40.2
COV %		4.7	4.7

132 ksi

124 ksi

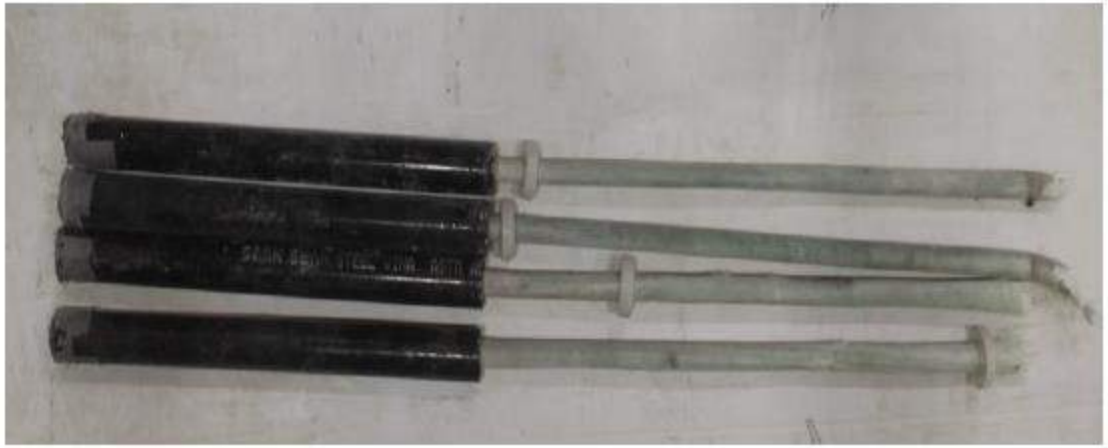


Figure 2 – Typical failure of bent portions the tested MST GFRP bent bars of #6

Agenda

- Brief introduction and past projects
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- **UV Exposure**
- GPR Scan of GFRP Reinforced Concrete
- Environmental Product Declaration (EPD)
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UV EXPOSURE

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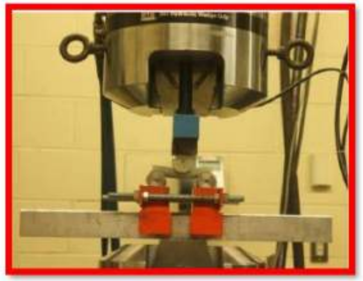
Summary of Test Results of #3 MSTBAR GFRP Bars Exposed to UV Waves

Technical Report (DRAFT)



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February 8, 2024

UV EXPOSURE

Reference (UV Protection)

Reference (Non-UV Protection)

1500 hrs (UV Protection)

1500 hrs (Non-UV Protection)

3000 hrs (UV Protection)

3000 hrs (Non-UV Protection)

UV EXPOSURE

Scanning Electron Microscopy (SEM)

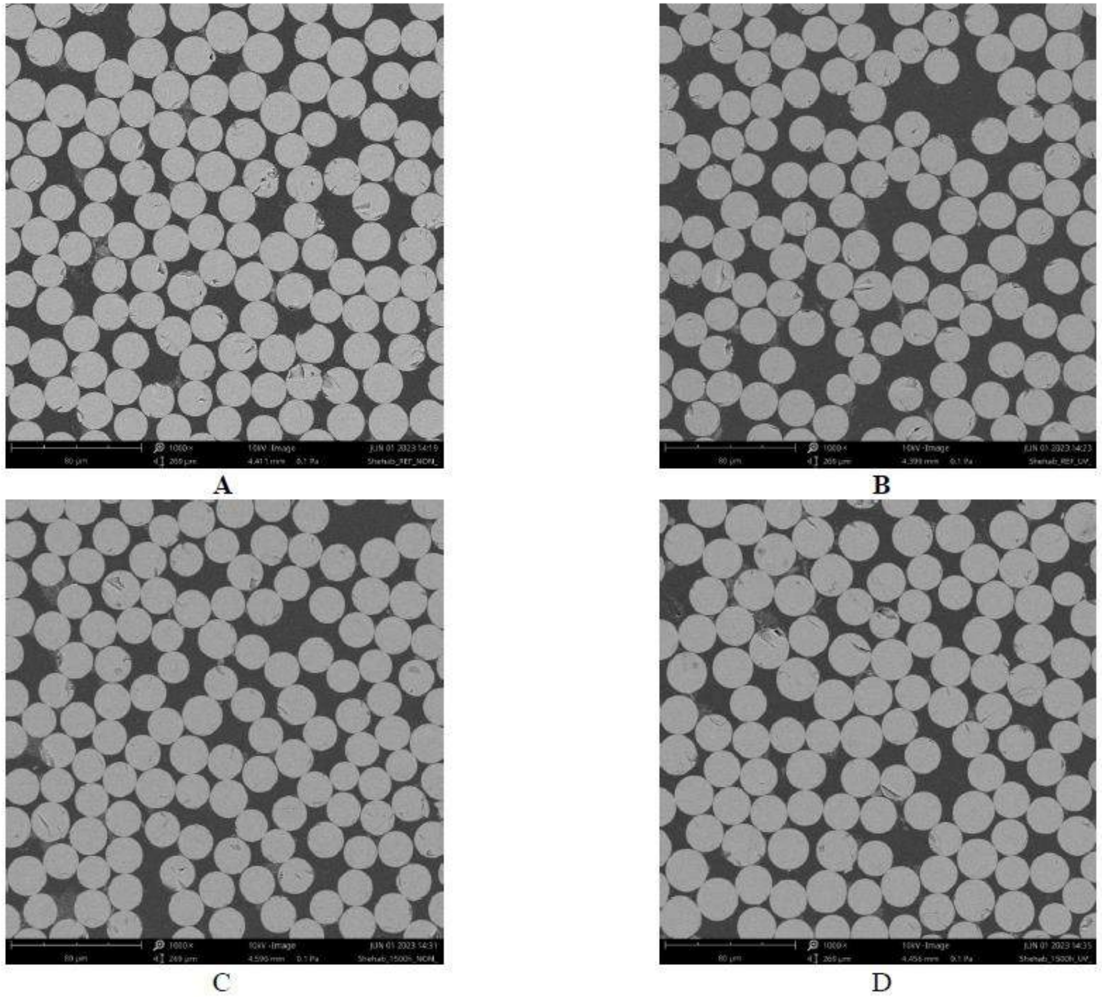


Fig. 3. SEM of bar #3: A: Ref (Non-UV Protection); B: Ref (UV Protection); C: 1500 hrs conditioning (Non-UV Protection); D: 1500 hrs conditioning (UV Protection).

Fourier Transform Infrared Spectroscopy (FTIR)

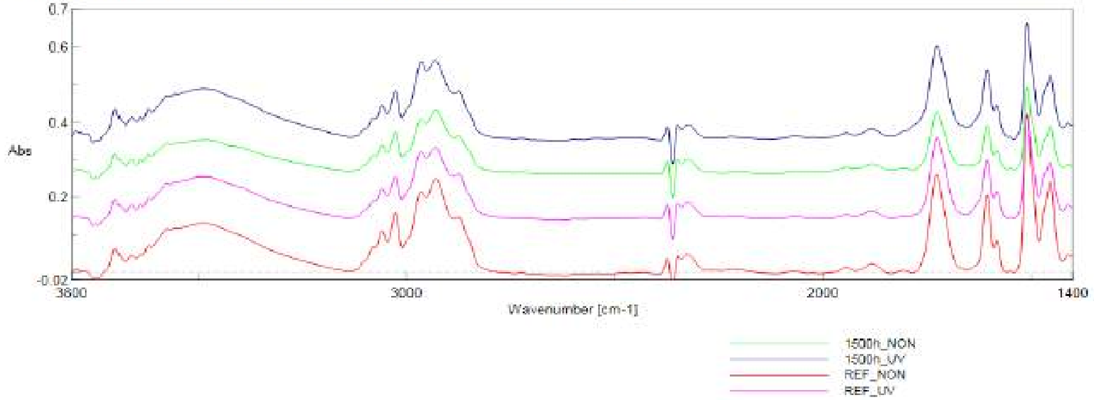


Fig. 2. FTIR spectra of the GFRP specimens.

UV EXPOSURE

Test results of #3 MSTBAR GFRP bars (Reference bars)

Specimen	Condition	Maximum load (kN)	Bar Diameter	Inter-laminar shear strength (MPa)
1	Ref (UV Protection)	6.9	9.5	65.0
2		6.0	9.5	56.3
3		6.6	9.5	62.0
4		6.2	9.5	58.7
5		6.9	9.5	65.0
Average		**6.5**		**61.4**
SD		**0.4**		**3.9**
COV (%)		**6.3**		**6.3**
1	Ref (Non-UV Protection)	6.0	9.5	56.4
2		6.1	9.5	57.3
3		5.8	9.5	54.9
4		5.0	9.5	47.0
5		6.1	9.5	57.1
Average		**5.8**		**54.6**
SD		**0.5**		**4.3**
COV (%)		**7.9**		**7.9**

Test results of #3 MSTBAR GFRP bars exposed to UV waves for 1500 hrs

Specimen	Condition	Maximum load (kN)	Bar Diameter	Inter-laminar shear strength (MPa)
1	1500 hr (UV Protection)	7.3	9.5	68.3
2		7.4	9.5	69.4
3		7.1	9.5	66.4
4		7.3	9.5	68.9
5		6.7	9.5	63.1
Average		**7.1**		**67.2**
SD		**0.3**		**2.6**
COV (%)		**3.8**		**3.8**
1	1500 hr (Non-UV Protection)	6.2	9.5	57.9
2		6.3	9.5	59.0
3		6.2	9.5	57.9
4		6.6	9.5	61.7
5		6.1	9.5	57.6
Average		**6.3**		**58.8**
SD		**0.2**		**1.7**
COV (%)		**2.9**		**2.9**

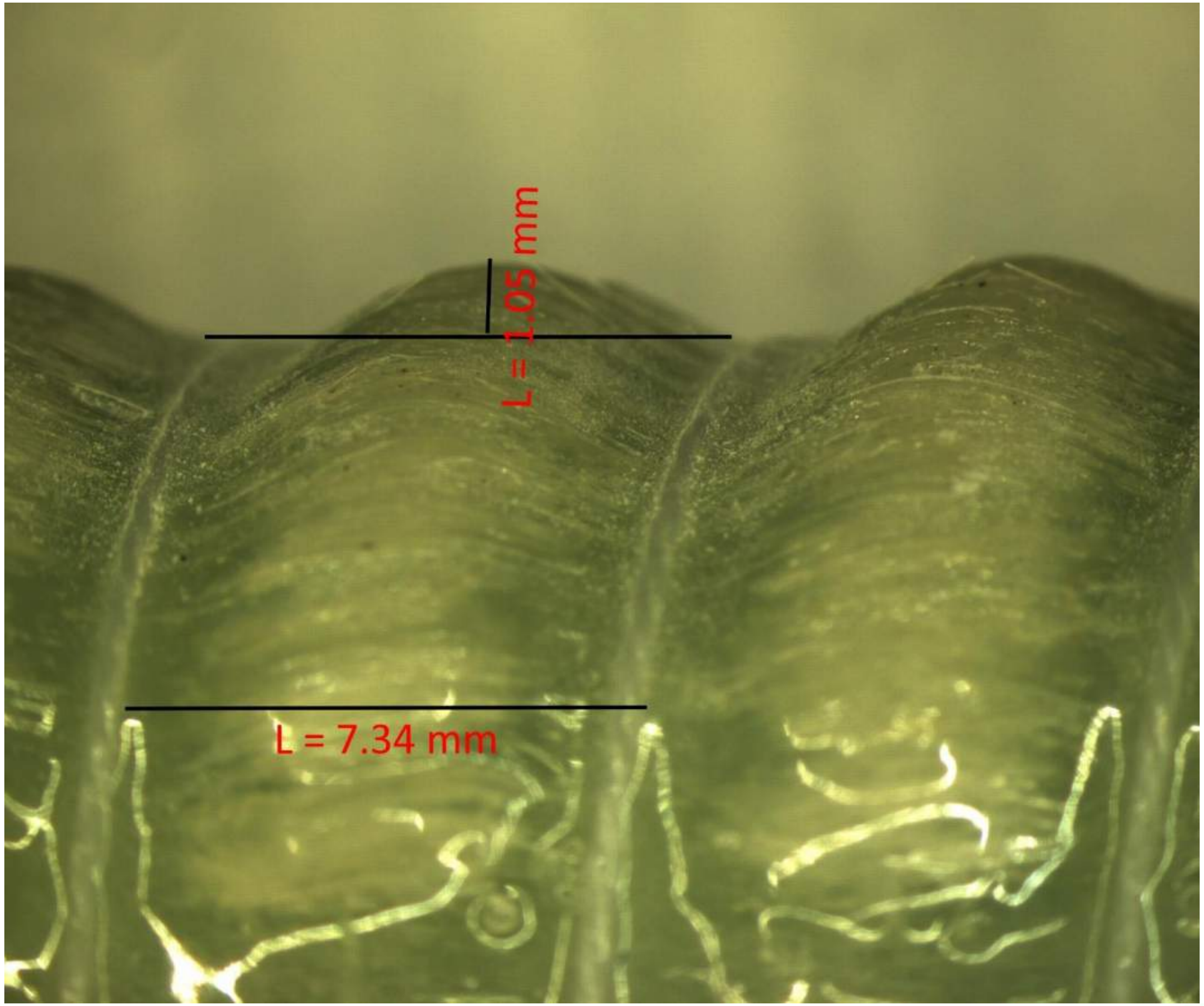
Test results of #3 MSTBAR GFRP bars exposed to UV waves for 3000 hrs

Specimen	Condition	Maximum load (kN)	Bar Diameter	Inter-laminar shear strength (MPa)
1	3000 hr (UV Protection)	7.3	9.5	68.7
2		7.9	9.5	74.3
3		7.6	9.5	71.5
4		7.3	9.5	68.7
5		7.2	9.5	67.7
Average		**7.5**		**70.2**
SD		**0.3**		**2.7**
COV (%)		**3.9**		**3.9**
1	3000 hr (Non-UV Protection)	5.9	9.5	55.5
2		6.1	9.5	57.4
3		6.2	9.5	57.9
4		6.3	9.5	59.3
5		6.6	9.5	62.1
Average		**6.2**		**58.4**
SD		**0.3**		**2.5**
COV (%)		**4.2**		**4.2**

Interlaminar Shear Strength (MPa)					
With UV Protection			W/O UV Protection		
Ref	1500 hrs	3000 hrs	Ref	1500 hrs	3000 hrs
61.4	67.2	70.2	54.6	58.8	58.4

Approximately 10% increase in interlaminar shear strength

UV EXPOSURE



UV EXPOSURE

Conclusions

According to the test results, UV conditioning of the #3 MSTBAR GFRP bar samples has no influence/effect on the horizontal shear strengths- results.

Moisture absorption tests showed good behavior of the tested GFRP bars when immersed in water for 24 hrs. The water absorption values were well below the limits provided by CSA S807-19 and ASTM spec.

The mean glass transition temperature was above 100°C for both unconditioned and UV-conditioned GFRP bars, meeting the 100°C limit of CSA S807-19 and ASTM spec.

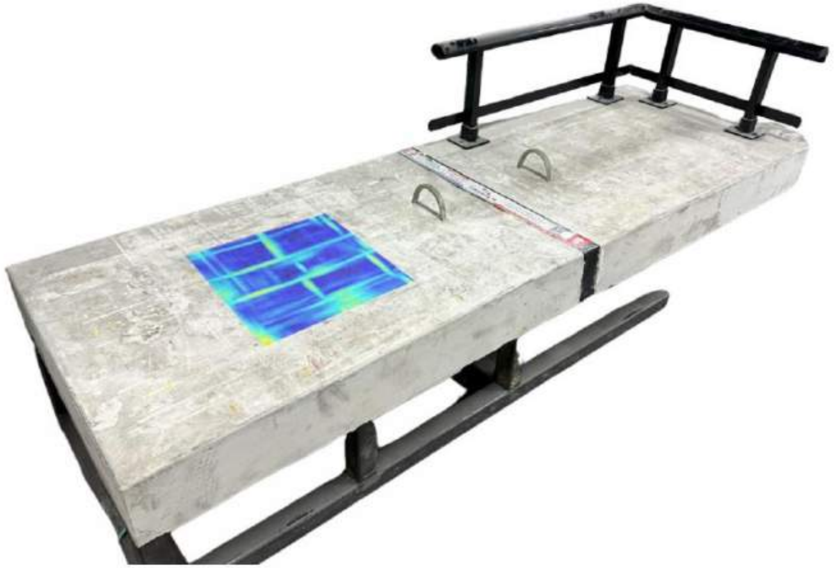
FTIR analysis confirmed that the GFRP bars had not been chemically degraded by UV conditioning.

The Scanning Electron Microscopy (SEM) analysis of unconditioned and conditioned GFRP bars exposed to UV showed that no defects in polymer matrix, fibers, or interfaces were observed.

Agenda

- Brief introduction and past projects
- Third-party Tastings on Mechanical Properties
- UV Exposure
- **GPR Scan of GFRP Reinforced Concrete**
- Environmental Product Declaration (EPD)
- Bond Strength
- TL-5 GFRP-REINFORCED CONCRETE BRIDGE BARRIER-DECK
- MST-BAR Traceability
- Qualifications and Certificates

GPR Scan of GFRP Reinforced Concrete



GPR Scan of GFRP Reinforced Concrete

MST Bar - 260 Hanlan Road, Woodbridge, ON

Feasibility Study

FPrimeC Project Number: 202311-04

FPrimeC SOLUTIONS

MST BAR MAXIMUM STRENGTH GFRP

GPR Scan of GFRP Reinforced Concrete

Figure 3 - GPR Scanning using Conquest 100 System.

GPR Scan of GFRP Reinforced Concrete

Figure 4 - GPR Scanning using GS8800 system.

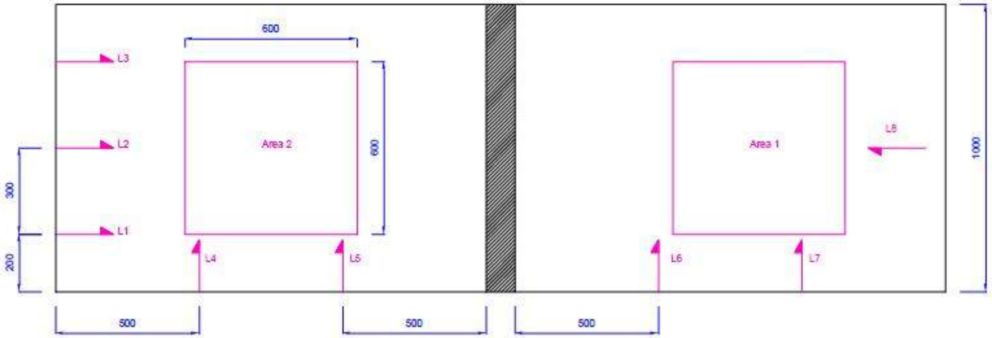


Figure 5 - Approximate location of GPR line and Area Scans.

GPR Scan of GFRP Reinforced Concrete

Table 1 - Key observations from the GPR scans.

	Conquest 100 by Sensors and Software		GP8800 by Proceq	
	Depth (mm)	Spacing (mm)	Depth (mm)	Spacing (mm)
Top Transverse Rebars	90	250	50	250
Top Longitudinal Rebars	60	150	50	150
Bottom Transverse Rebars	150	250	150	250
Bottom Longitudinal Rebars	150	250	150	150

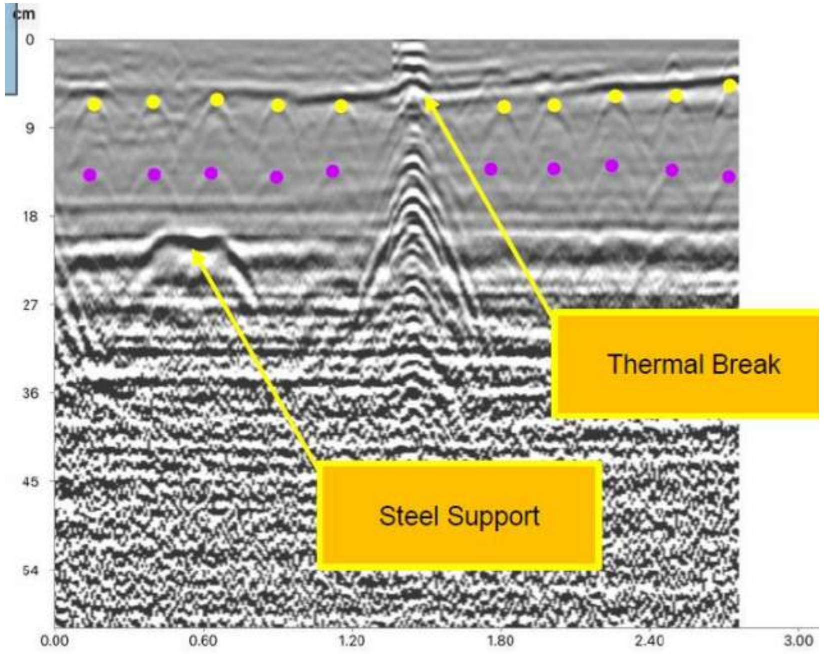


Figure B 1 – Line Scan 1.

GPR Scan of GFRP Reinforced Concrete

The GPR scans obtained from both GPR equipment show sign of sub-surface targets (in this project, GFRP bars). Upon review, the following key remarks can be made:

- Both GPR devices were able to locate the top layer of rebar using line scans.
- Both GPR devices were able to show the back-end reflection from bottom of slab.
- The imaging was clearer on the GP8800 scanner in comparison to the images produced by the Conquest 100 GPR scanner. This was most likely because the antenna frequency of the Conquest 100 has a fixed rate of 1000 MHz, while the GP8800 antenna frequency automatically sweeps across a wider frequency range (from the low 400 MHz to 6,000 MHz) creating a superior scan when compared to Conquest 100 GPR scanner.
- Some of the GFRP bars in the top layer were not detected in the Conquest 100 scans, making it difficult to determine rebars spacing and placement, effectively. Furthermore, the conquest 100 system did not generate scans with consistent quality and clarity.
- The bottom rebars could not be detected (with proper clarity) using the Conquest 100.
- The GP8800 produced clear picture of the GFRP bars (both top and bottom layers). However, the targets generally lack the clarity of scans when it is compared to steel reinforced concrete scanned with the same GPR scanner. The backend reflection, was more distinct using the GP8800 GPR scanner.
- The GP8800 GPR scanner by Proceq would appear to be a viable option to scan concrete containing GFRP bars for the purpose of drilling.

Agenda

- Brief introduction and past projects
- Third-party Tastings on Mechanical Properties
- UV Exposure
- GPR Scan of GFRP Reinforced Concrete
- **Environmental Product Declaration (EPD)**
- Bond Strength
- TL-5 GFRP-REINFORCED CONCRETE BRIDGE BARRIER-DECK
- MST-BAR Traceability
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Environmental Product Declaration (EPD)

Global warming potential (fossil)	GWP - Fossil	kg CO_2 equivalents (GWP100)	Baseline model of 100 years of the IPCC based on IPCC 2013

AUSTRALASIA EPD®
ENVIRONMENTAL PRODUCT DECLARATION

ECO PLATFORM EPD VERIFIED

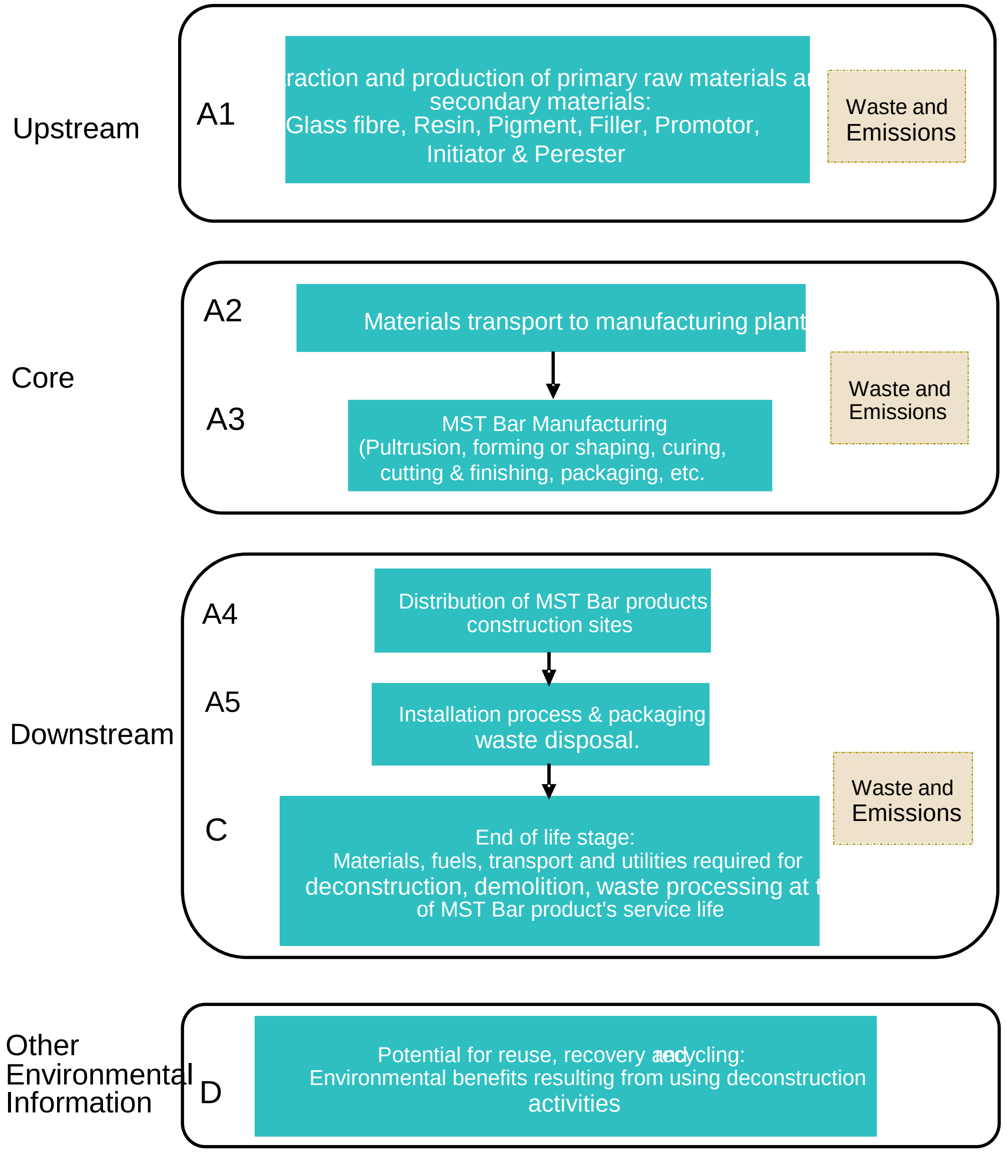
End-of-life: Disposal/Reuse/Recycling (C1 – C4)

Table 7 - Life cycle inventory for end-of-life

Module	Item	Value	Comment
Deconstruction (C1)	Excavator	0.16 L/m^3	
Waste transport (C2)	Distance to landfill/ recycling plant	100 km	Conservative estimate
Waste reprocessing (C3)	Recycling of installed MST Bar products at the end of life in accordance with respective material's recycling rate in Australia.	Initial mass of components x recycling rate	Recycling rate for plastics is 12.6% (conservative consideration) The recycling of fiberglass rebar is assumed to be similar to the common process used for recycling thermoset polymers (Beauson et al., 2016, Gonçalves et al., 2022)
Land disposal (C4)	Land disposal of installed products that are not recycled at the end of life	Initial mass of components that is not recycled	

MST BAR
MAXIMUM STRENGTH GFRP

Environmental Product Declaration (EPD)



A1 to A3: 2.8 kg CO2 eq.
2.8/4

A4: 0.159 kg CO2 eq.

A5: 0.15 kg CO2 eq.

Indicator	ABR	Unit	A5	C1	C2	C3	C4	D
Global warming potential - fossil	GWP - Fossil	kg CO_2 eq.	0.151	5.57E-05	1.09E-02	8.40E-01	1.16E-01	-5.74E-01

MST BAR
MAXIMUM STRENGTH GFRP

Environmental Product Declaration (EPD)

MST BAR
MAXIMUM STRENGTH GFRP

MST-BAR GRADE III GFRP

Global warming Potential (GWP) – Greenhouse Gas (GHG) of a 6-meter-long MST-BAR

Bar Size	#3	#4	#5	#6	#7	#8	#9	#10	#11
GWP-GHG (kg CO_2 eq.)*	3.95	6.28	8.97	12.56	16.15	21.89	25.12	30.86	38.57

* Calculated based on the Environmental Product Declaration (EPD) of Glass Fiber Reinforced Rebars

Agenda

- Brief introduction and past projects
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- TL-5 GFRP-REINFORCED CONCRETE BRIDGE BARRIER-DECK
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Bond Strength

Embedment length of 80 mm (~ 3in.).

Specimen	Failure Load *kN*	Bond Strength *MPa*	Failure Mode
1	113	29	Concrete Splitting
2	103	26	Concrete Splitting
3	105	26	Concrete Splitting
4	106	27	Test Stopped
5	105	26	Test Stopped
Average	**106.5**	**27**	
Standard Deviation	3.93	1.0	
Coefficient of Variation (%)	3.7	3.7	

CSA S807:19 Limit = 10 MPa (1450 PSI)
ASTM D7957 Limit= 9MPa (1300 PSI)

Failure Load #5 MST: 23.8 Kips (Concrete Splitting)

Yield strength of Steel #5 Grade 60: 60 KSI x 0.31in2 = 18.6 Kips

Bond Strength of Post-installed MST-BAR

In-Situ testing of post-installed MST-BAR

Bond Strength of Post-installed MST-BAR

In-Situ testing of post-installed MST-BAR HILTI HIT-RE 500 V3

Hole that is approximately 1.5d_{bar}

The embedment length was 125 mm.

Table 5 Summary of confined tests results of MST-BAR with the HILTI HIT-RE 500 V3 adhesive in fibre-reinforced concrete (FRC)

Sample	Failure Load kN	Failure Stress MPa	Failure Mode*
Sample 1	167.5	842	GFRP-adhesive pullout and concrete cone failure
Sample 2	173.3	871	Shear Failure
Sample 3	190.6	958	Test Stopped due to H&S Concerns
Sample 4	150.2	755	GFRP-adhesive pullout and concrete cone failure
Sample 5	150.2	755	GFRP-Adhesive Pullout
Average	166.4	836	121 ksi
Standard Deviation	17.0	86	
Coefficient of Variation (%)	10	10	

Table 6 Summary of unconfined tests results of MST-BAR with the HILTI HIT-RE 500 V3 adhesive in normal concrete

Sample	Failure Load kN	Failure Stress MPa	Failure Mode*
Sample 1	173.3	871	GFRP-Adhesive Pullout and Cone Failure
Sample 2	141.6	711	Shear Failure
Sample 3	153.1	769	Concrete Cone Failure
Sample 4	153.1	769	GFRP-Adhesive Pullout
Sample 5	196.4	987	Test Stopped due to H&S Concerns
Average	163.5	822	119 ksi
Standard Deviation	21.6	109	
Coefficient of Variation (%)	13	13	

MST BAR
MAXIMUM STRENGTH GFRP

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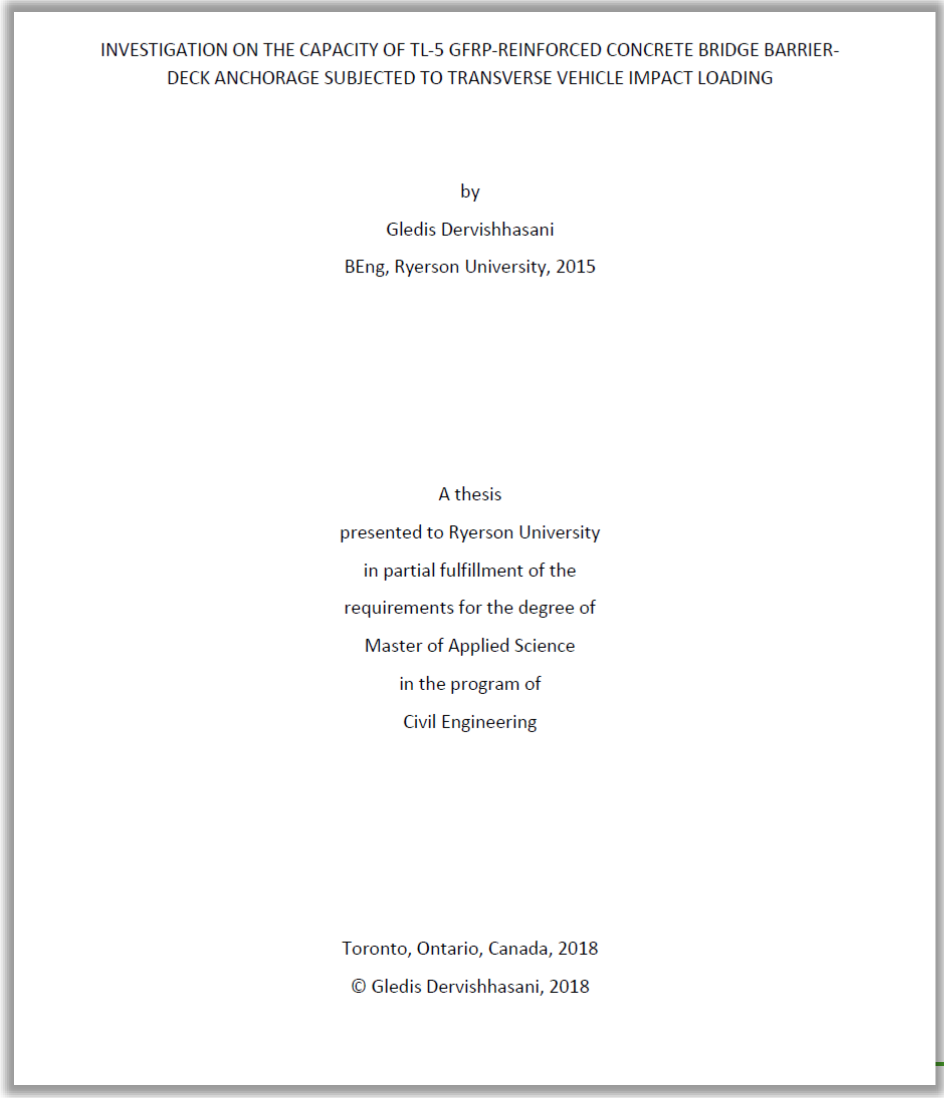
TL-5 GFRP-REINFORCED CONCRETE BRIDGE BARRIER-DECK



INVESTIGATION ON THE CAPACITY OF TL-5 GFRP-REINFORCED CONCRETE BRIDGE BARRIER-DECK ANCHORAGE SUBJECTED TO TRANSVERSE VEHICLE IMPACT LOADING

by

Gledis Dervishhasani

BEng, Ryerson University, 2015

A thesis

presented to Ryerson University

in partial fulfillment of the

requirements for the degree of

Master of Applied Science

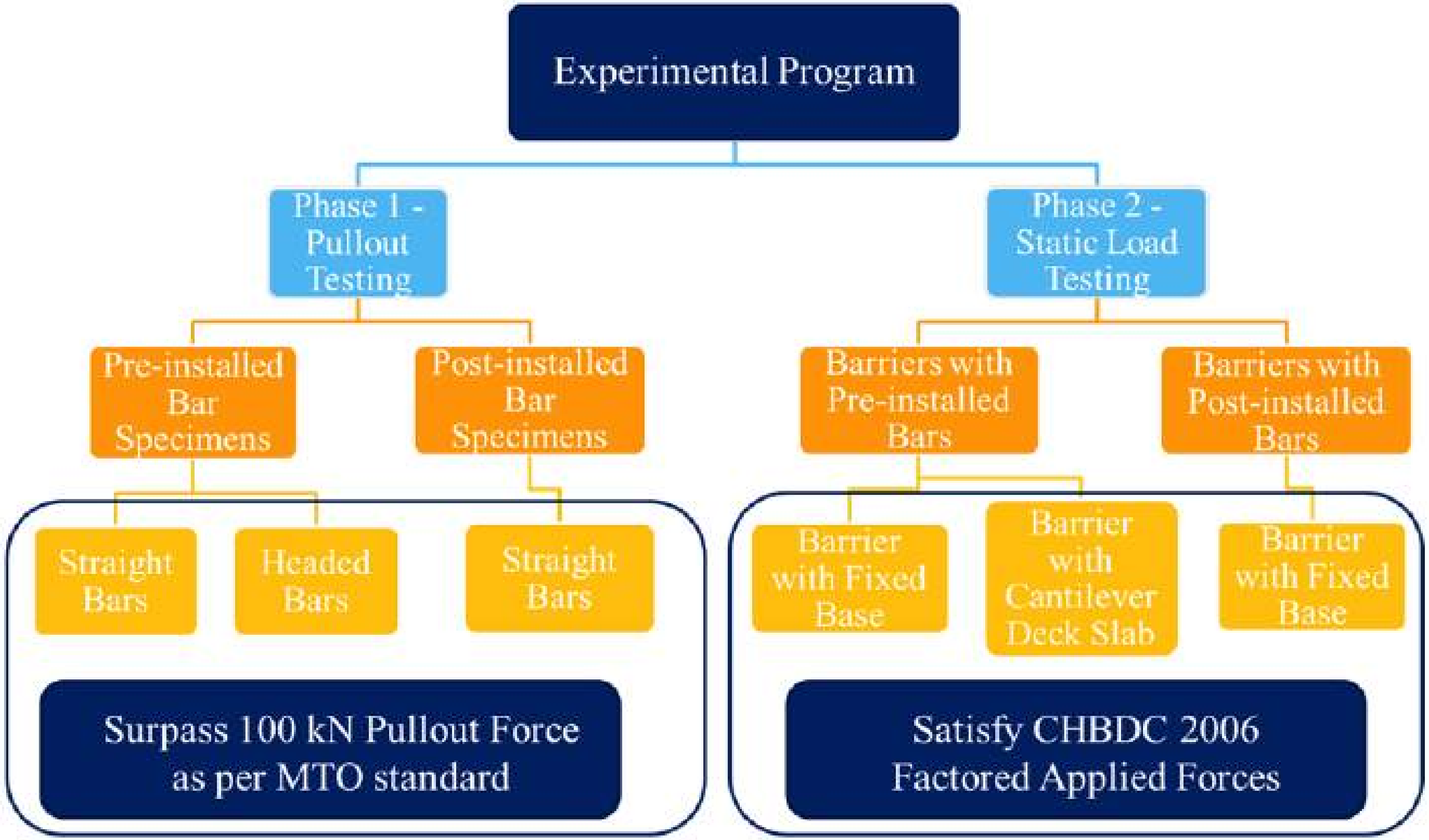
in the program of

Civil Engineering

Toronto, Ontario, Canada, 2018

© Gledis Dervishhasani, 2018

TL-5 GFRP-REINFORCED CONCRETE BRIDGE BARRIER-DECK



TL-5 GFRP-REINFORCED CONCRETE BRIDGE BARRIER-DECK

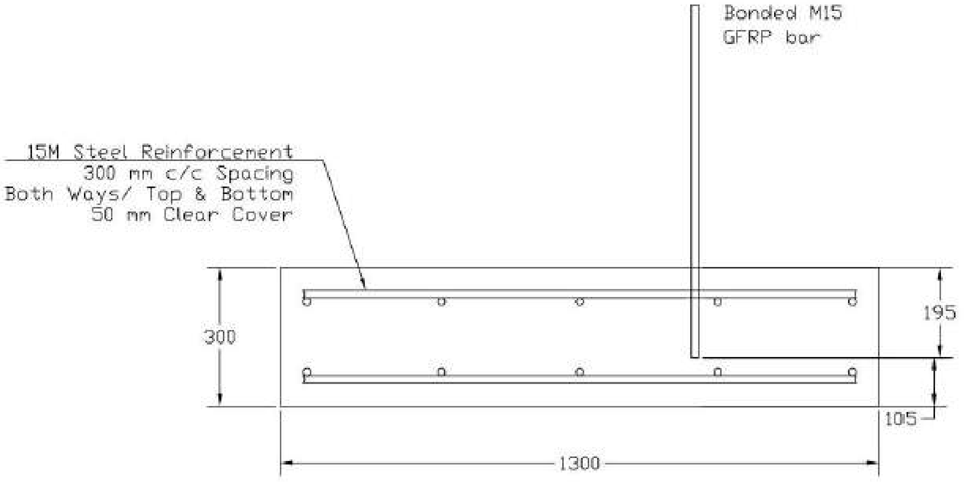


Figure 3.6: Group 1 - Straight fully-bonded GFRP bar in concrete

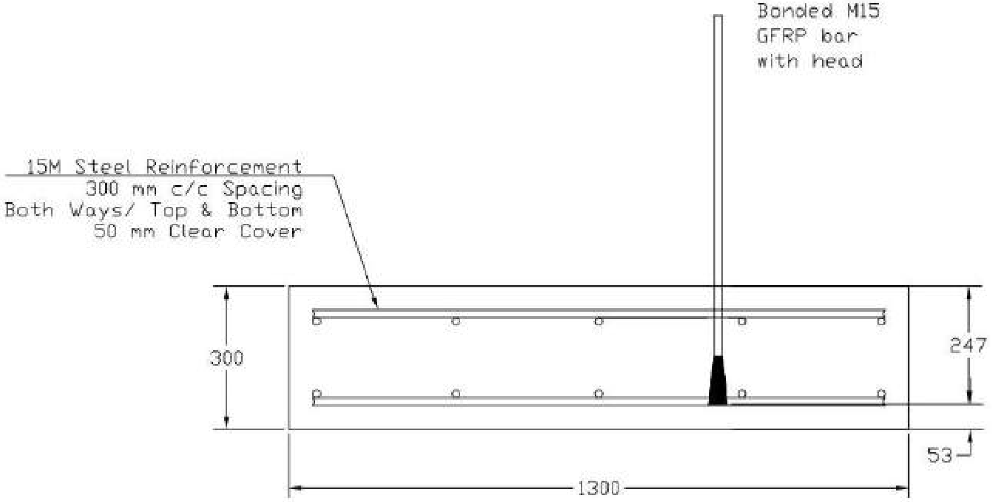


Figure 3.7: Group 2 – Headed-end GFRP bar with fully-bonded straight length in concrete

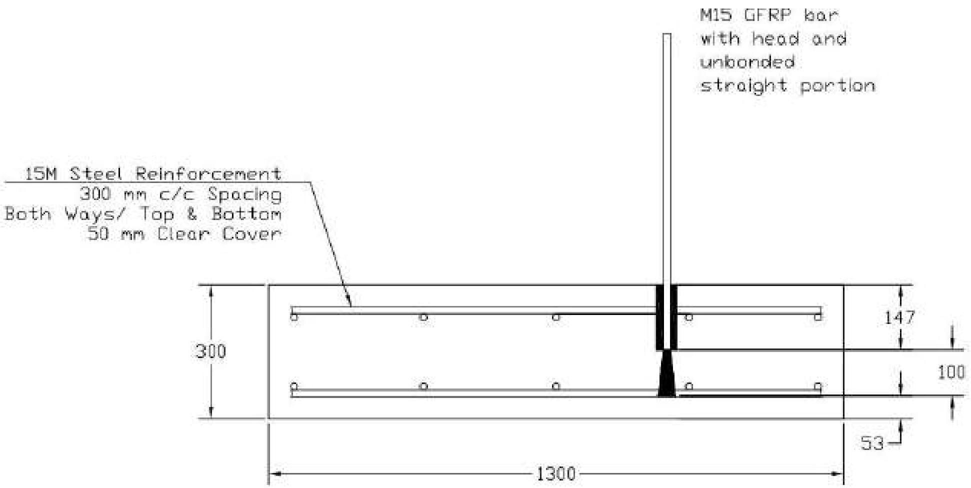
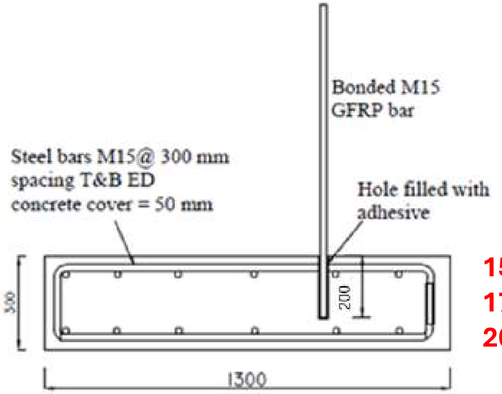


Figure 3.8: Group 3 – Headed-end GFRP bars with unbonded straight portion in concrete



150 mm
175 mm
200 mm

Figure 3.12: Post-installed GFRP bar in concrete slab

MST BAR
MAXIMUM STRENGTH GFRP

TL-5 GFRP-REINFORCED CONCRETE BRIDGE BARRIER-DECK

TL-5 GFRP-REINFORCED CONCRETE BRIDGE BARRIER-DECK

Type of construction	Group	Sample	Failure load (kN)	Type of failure	Group average failure load (kN)
Pre-Installed bars	1	A	150.88	Bar crushing at grip	145.48
		B	146.02	Bar crushing at grip	
		C	140.35	Bar crushing at grip	
		D	144.67	Bar crushing at grip	
		E	145.48	Bar crushing at grip	
	2	A	157.89	Bar crushing at grip	148.34
		B	127.67	Bar crushing at grip	
		C	161.94	Bar crushing at grip	
		D	151.69	Bar crushing at grip	
		E	142.51	Bar crushing at grip	
	3	A	137.38	Bar slip from head	131.04
		B	122.00	Bar slip from head	
		C	137.38	Bar slip from head	
		D	127.40	Bar slip from head	
Post-Installed bars	1	A	158.70	Bar crushing at grip	152.49
		B	194.87	Bar slip	
		C	146.83	Bar crushing at grip	
		D	158.97	Bar slip	
		E	103.10	Bar slip	
	2	A	134.68	Bar slip	112.82
		B	96.09	Bar slip	
		C	120.38	Bar slip	
		D	89.61	Bar slip	
		E	123.35	Bar slip	
	3	A	163.56	Bar slip, concrete cone	144.83
		B	116.60	Bar slip	
		C	153.58	Bar crushing at grip	
		D	156.01	Bar crushing at grip	
		E	134.41	Bar slip	

TL-5 GFRP-REINFORCED CONCRETE BRIDGE BARRIER-DECK

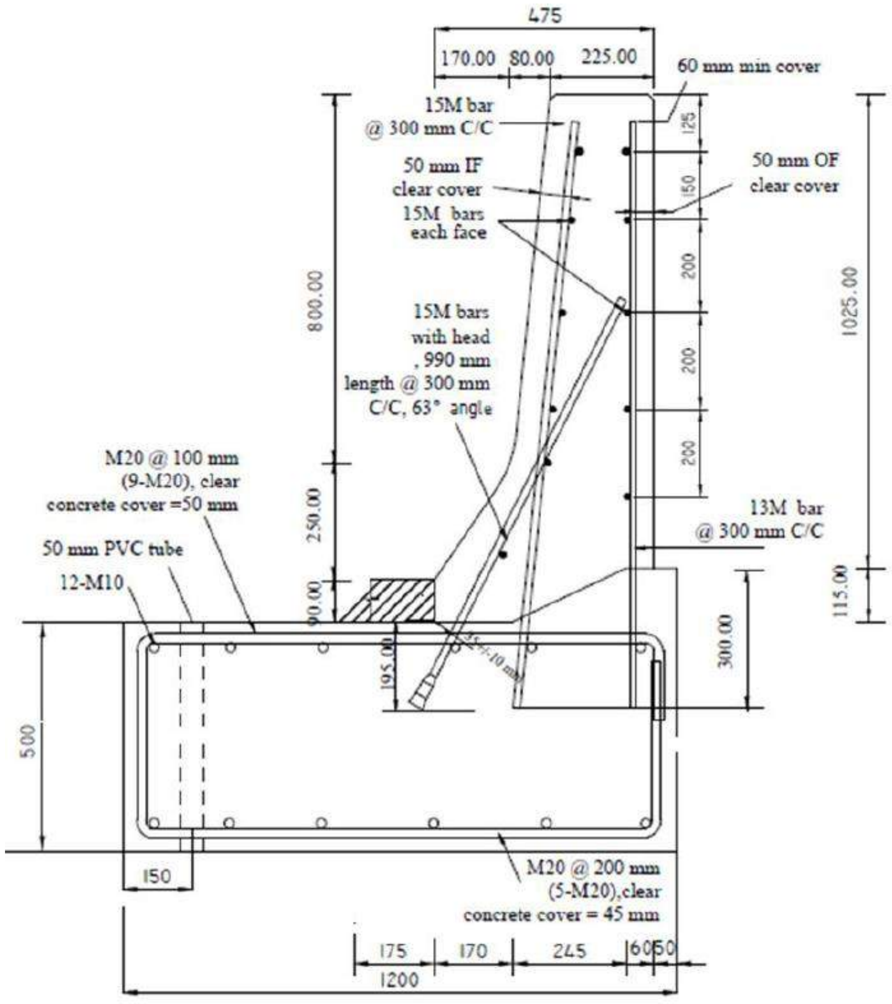


Figure 4.1: Barrier specimen B-1 details (Interior Location - No Cantilever)

B-1

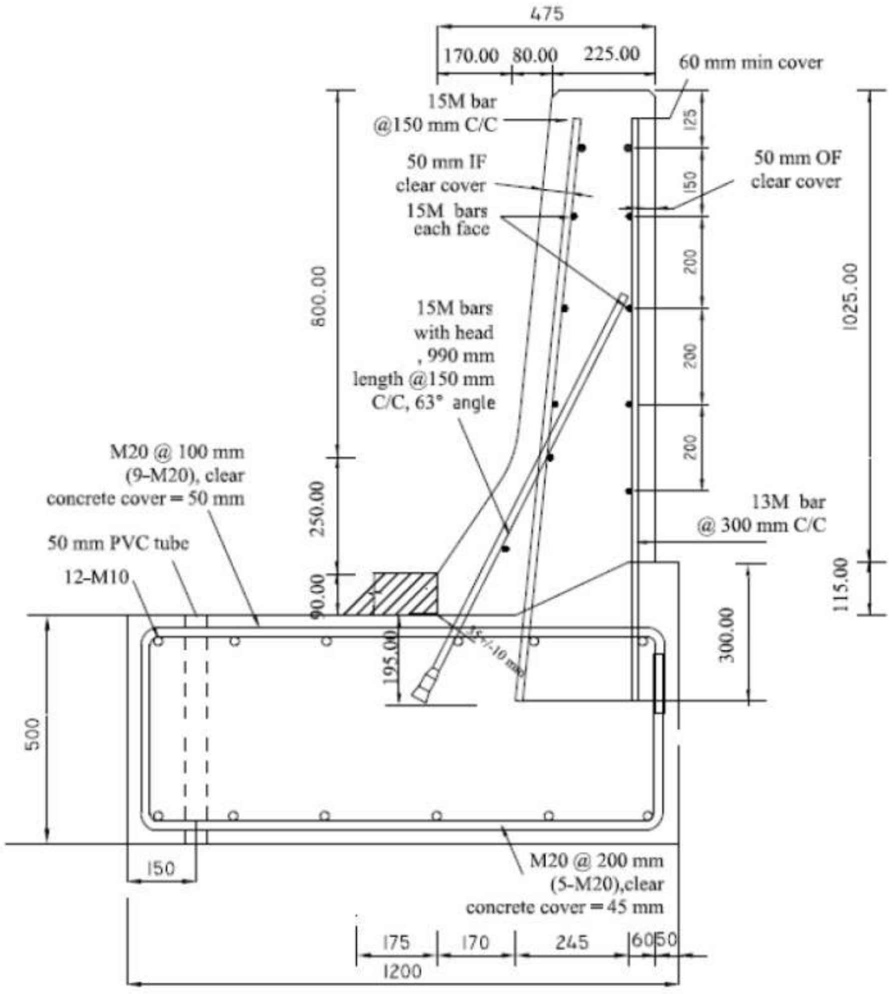


Figure 4.2: Barrier specimen B-2 details (Exterior Location - No Cantilever)

B-2

TL-5 GFRP-REINFORCED CONCRETE BRIDGE BARRIER-DECK

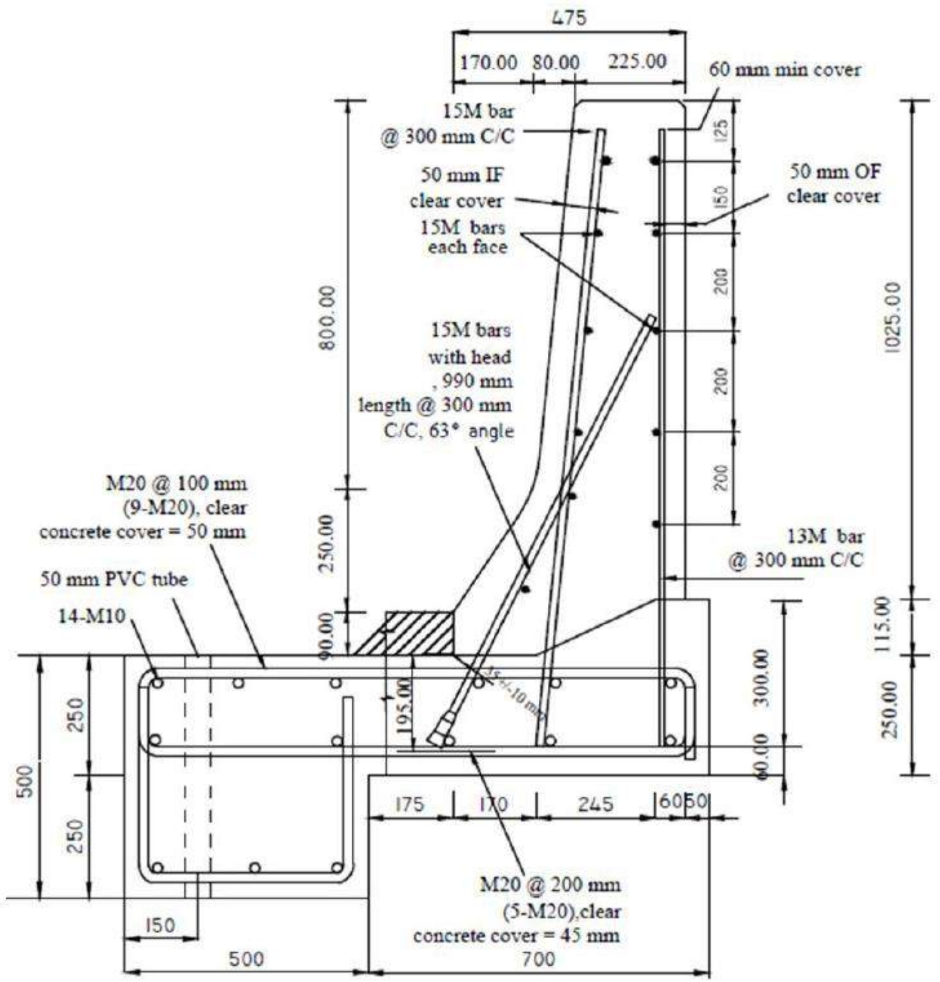


Figure 4.3: Barrier specimen B-3 details (Interior Location - With Cantilever)

B-3

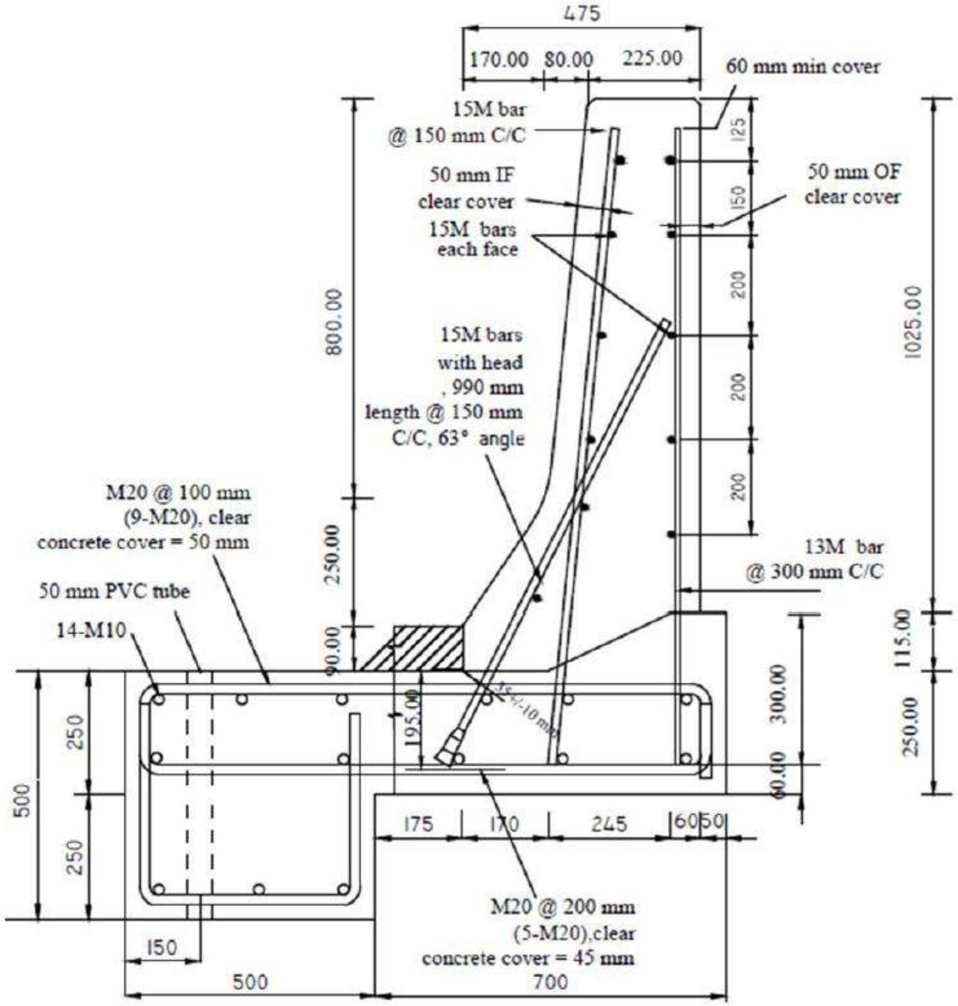


Figure 4.4: Barrier specimen B-4 details (Exterior Location - With Cantilever)

B-4

TL-5 GFRP-REINFORCED CONCRETE BRIDGE BARRIER-DECK

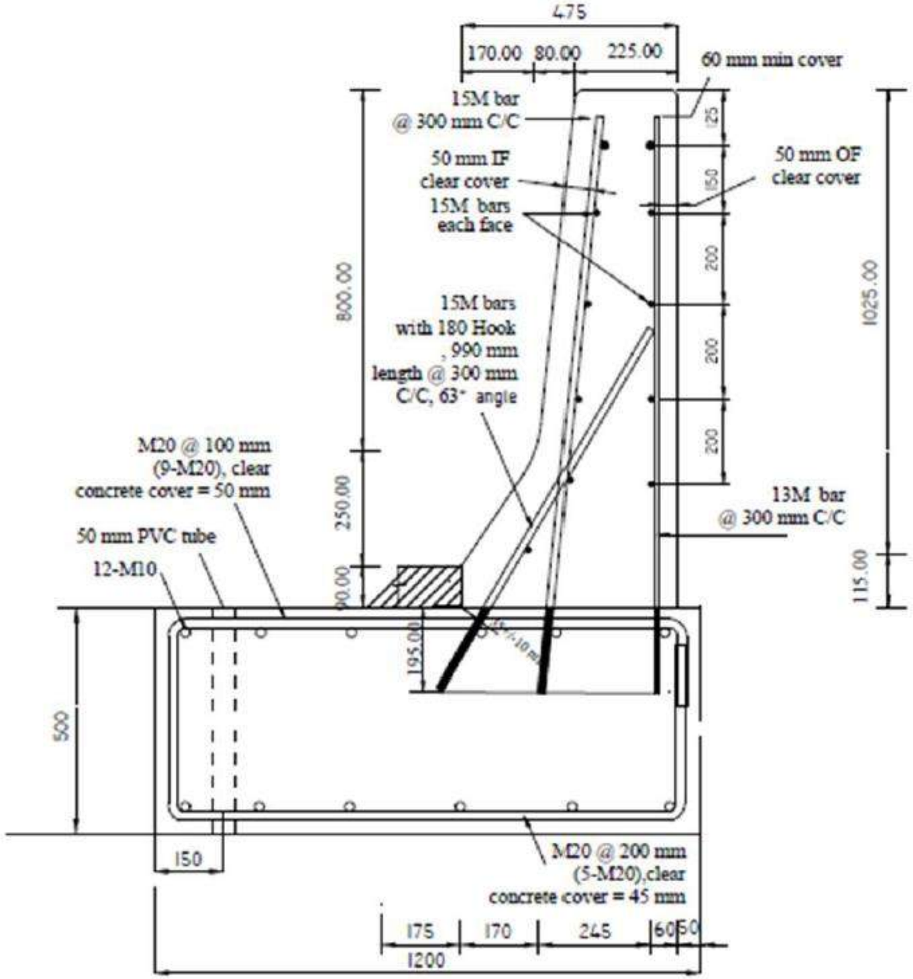


Figure 4.5: Barrier specimen B-5 details (Interior Location - No Cantilever - Post-Installed)

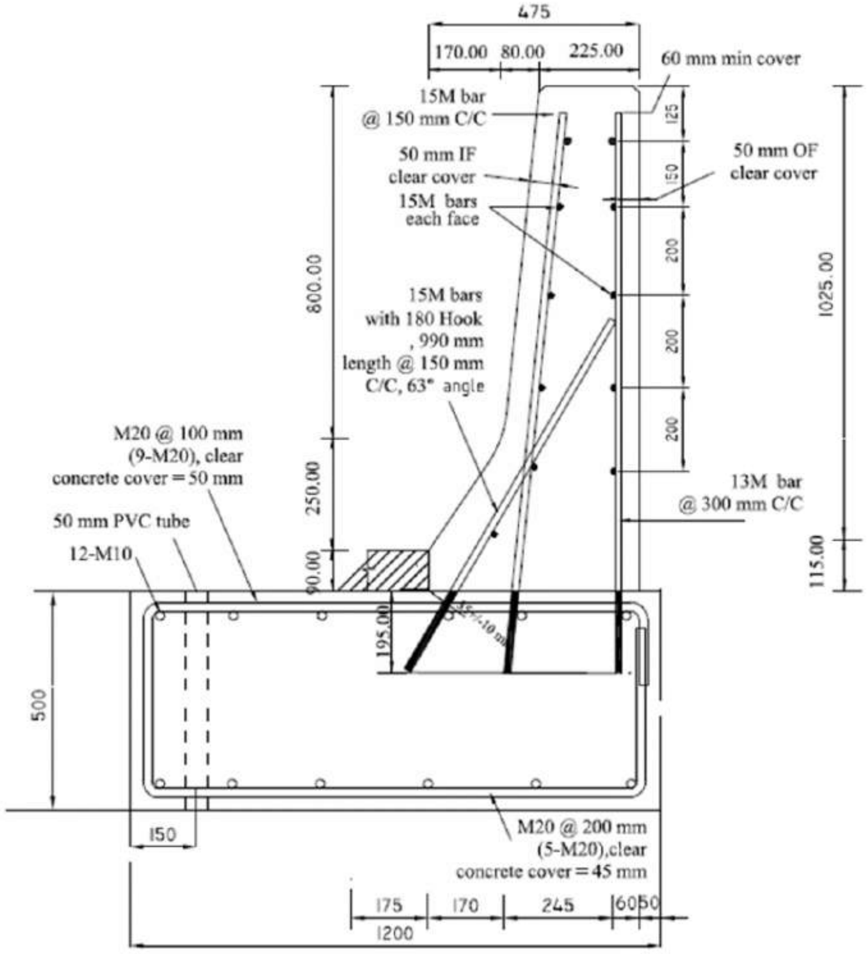


Figure 4.6: Barrier specimen B-6 details (Exterior Location - No Cantilever - Post-Installed)

B-5 **B-6**

MST BAR MAXIMUM STRENGTH GFRP

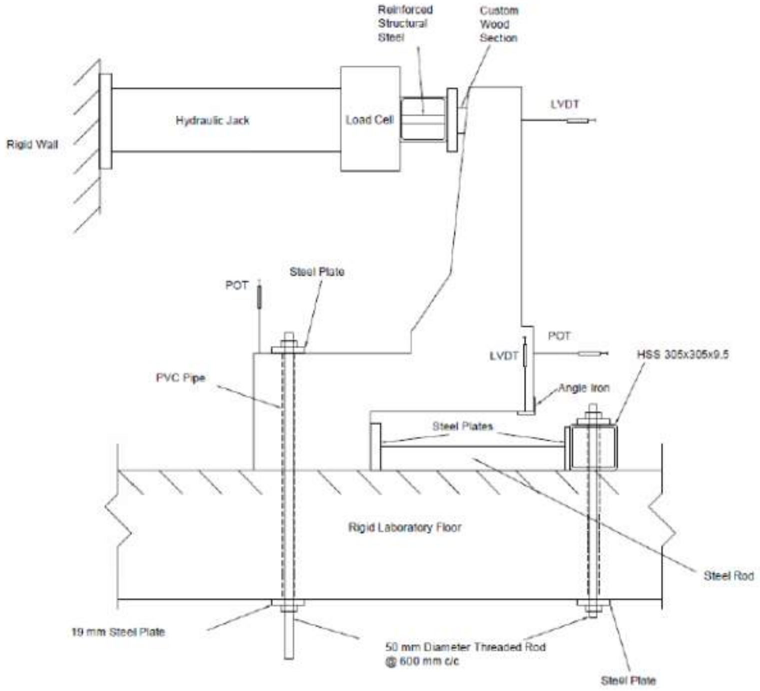
TL-5 GFRP-REINFORCED CONCRETE BRIDGE BARRIER-DECK

Figure 4.14: Typical GFRP wall mesh at exterior location

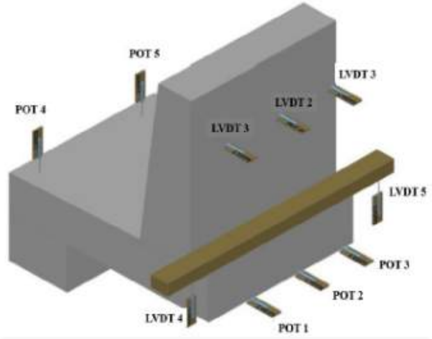
e) Barrier with rigid base f) Barrier with deck cantilever g) Barrier handling

Figure 4.15: Views of typical barriers after removal of formwork and while transporting it to the test rig

TL-5 GFRP-REINFORCED CONCRETE BRIDGE BARRIER-DECK



(a) Test setup showing the tie-down system to stabilize the deck slab during testing



(b) Locations of potentiometers (POTs) to measure displacements

Table 4.6: Barrier Labeling Legend

Name	Description
B-1	No cantilever; Interior location (300 mm spacing of front bars)
B-2	No cantilever; Exterior location (150 mm spacing of front bars)
B-3	Cantilever; Interior location (300 mm spacing of front bars)
B-4	Cantilever; Exterior location (150 mm spacing of front bars)
B-5	Post-Installed; No cantilever; Interior location (~~300~~ 150 mm spacing of front bars)
B-6	Post-Installed; No cantilever; Exterior location (300 mm spacing of front bars)

MST BAR
MAXIMUM STRENGTH GFRP

TL-5 GFRP-REINFORCED CONCRETE BRIDGE BARRIER-DECK

Table 4.14: Experimental results benchmarked against CHBDC requirements and safety factors

Criteria	Specimen					
	Fixed base - interior	Fixed base - exterior	Cantilever - interior	Cantilever - exterior	Post-installed -interior	Post-installed - exterior
	B-1	B-2	B-3	B-4	B-5	B-6
Experimental failure load (kN)	168.63	182.63	129.64	163.41	159.74	186.74
Experimental failure load (kN/m)	187.37	202.92	144.04	181.57	177.49	207.49
Experimental resisting moment (kN.m/m)	185.49	200.89	142.60	179.75	175.71	205.41
2006 CHBDC design moment (kN.m/m)	83.00	102.00	83.00	102.00	83.00	102.00
Factor of safety (experimental failure moment/ CHBDC design moment)	2.23	1.97	1.72	1.76	2.12	2.01
Factor of safety (experimental failure moment/ CHBDC design moment) with 0.75 durability factor	1.68	1.48	1.29	1.32	1.59	1.51
Top front displacement (mm)	26.32	23.74	44.75	66.76	8.92	11.28
Bottom back displacement (mm)	3.81	4.27	8.43	13.42	0.73	3.46
Overhang (mm)	-	-	17.57	27.88	-	-
Front uplift (mm)	0.39	1.62	3.66	5.30	0.97	0.96
GFRP micro strain	6503.93	3914.80	7198.86	5494.50	16268.69	7225.97
Concrete micro strain	-818.33	-868.00	-784.67	-1735.00	-893.33	-701.33
Observed failure mechanism	GFRP-concrete anchorage	Diagonal shear in the wall	GFRP-concrete anchorage	GFRP-concrete anchorage	Concrete breakout	Diagonal shear in the wall

Agenda

- Brief introduction and past projects
- Third-party Tastings on Mechanical Properties
- UV Exposure
- GPR Scan of GFRP Reinforced Concrete
- Environmental Product Declaration (EPD)
- Bond Strength
- TL-5 GFRP-REINFORCED CONCRETE BRIDGE BARRIER-DECK
- **MST-BAR Traceability**
- Qualifications and Certificates

MST-BAR Traceability

#5 –15M GRADE III VER1025.S.338.2023

Size

CSA S807 Grade

Resin Lot #

Straight or Bend

Julian Date

Year

Plus: ASTM-D7957 16

1000MPa – 60GPa

www.mstbar.com

L16 : Machine/Line

Agenda

- Brief introduction and past projects
- Third-party Tastings on Mechanical Properties
- UV Exposure
- GPR Scan of GFRP Reinforced Concrete
- Environmental Product Declaration (EPD)
- Bond Strength
- TL-5 GFRP-REINFORCED CONCRETE BRIDGE BARRIER-DECK
- MST-BAR Traceability
- Qualifications and Certificates

Qualifications and Certificates


**For an updated manufacturer compliance status throughout the audit cycle, SCAN the code with your mobile device.

PRODUCT EVALUATION & AUDIT
DATAMINE
COMPLIANT

COMPLIANCE AUTHENTICATION

AASHTO

This authenticates:

MST Rebar Inc., Woodbridge, ON

successfully complies with the AASHTO Product Evaluation & Audit Solutions

Composite Concrete Reinforcements (CCR)

Work Plan

January 2024
Date of Administration

December 31, 2024
Date of Expiration

Jim Tymon
AASHTO Executive Director

MST BAR
MAXIMUM STRENGTH GFRP

Qualifications and Certificates

CERTIFICATE OF COMPLETION

This certificate is awarded to

MST-BAR

For successful completion of the

FRP Institute for Civil Infrastructure

FRP Manufacturer Quality Audit

Performed on July 8, 2022

This Quality Audit is applicable to the facility located at:

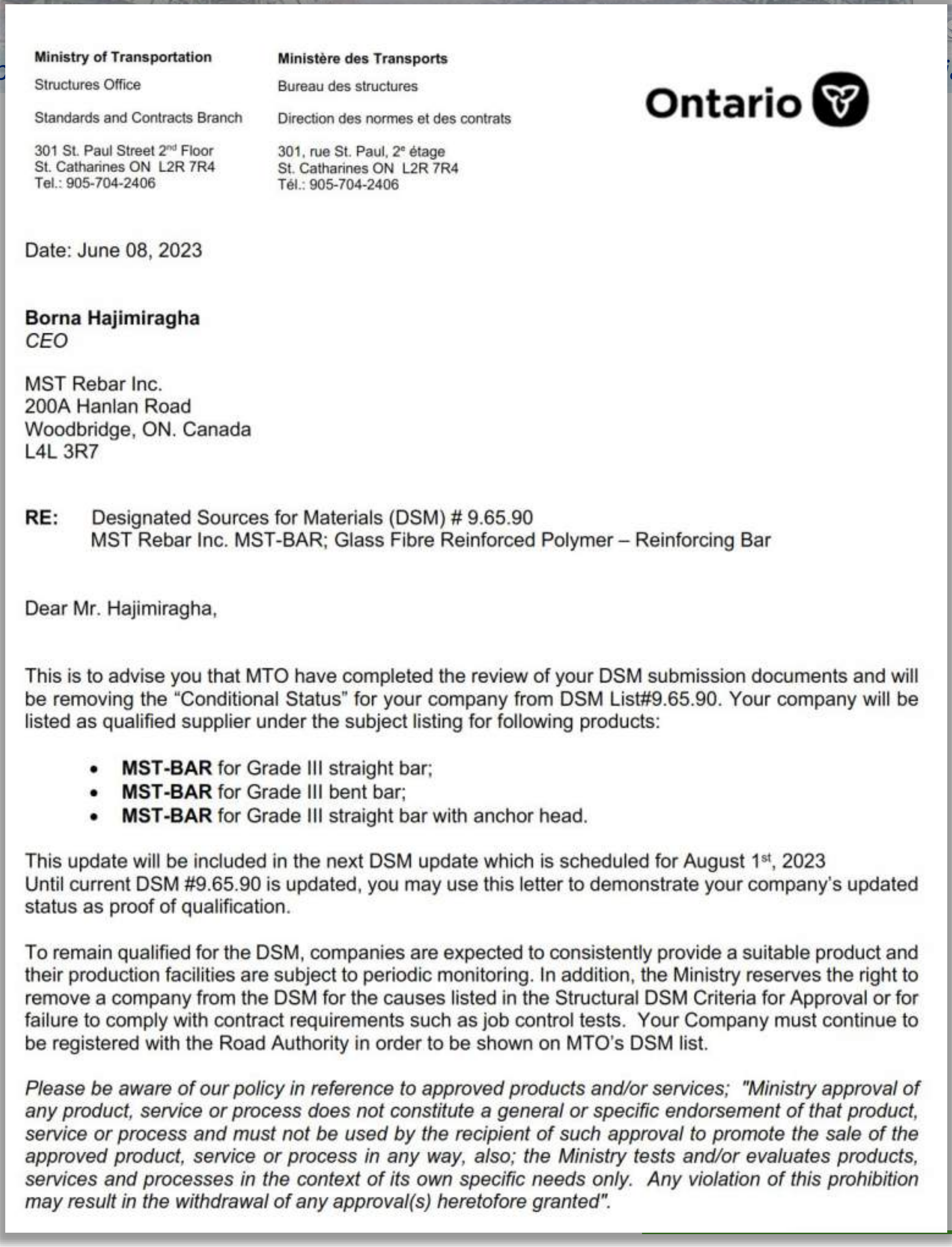
200A Hanlan Road, Ontario, Canada

FRP INSTITUTE for CIVIL INFRASTRUCTURE FRP 2022

Auditor	Date	President	Date
	8/8/2022		8/8/2022

MST BAR
MAXIMUM STRENGTH GFRP

Qualifications and Certificates



Ministry of Transportation
Structures Office
Standards and Contracts Branch
301 St. Paul Street 2nd Floor
St. Catharines ON L2R 7R4
Tel.: 905-704-2406

Ministère des Transports
Bureau des structures
Direction des normes et des contrats
301, rue St. Paul, 2e étage
St. Catharines ON L2R 7R4
Tél.: 905-704-2406

Ontario

Date: June 08, 2023

Borna Hajimiragha
CEO

MST Rebar Inc.
200A Hanlan Road
Woodbridge, ON. Canada
L4L 3R7

RE: Designated Sources for Materials (DSM) # 9.65.90
MST Rebar Inc. MST-BAR; Glass Fibre Reinforced Polymer – Reinforcing Bar

Dear Mr. Hajimiragha,

This is to advise you that MTO have completed the review of your DSM submission documents and will be removing the "Conditional Status" for your company from DSM List#9.65.90. Your company will be listed as qualified supplier under the subject listing for following products:

- **MST-BAR** for Grade III straight bar;
- **MST-BAR** for Grade III bent bar;
- **MST-BAR** for Grade III straight bar with anchor head.

This update will be included in the next DSM update which is scheduled for August 1st, 2023
Until current DSM #9.65.90 is updated, you may use this letter to demonstrate your company's updated status as proof of qualification.

To remain qualified for the DSM, companies are expected to consistently provide a suitable product and their production facilities are subject to periodic monitoring. In addition, the Ministry reserves the right to remove a company from the DSM for the causes listed in the Structural DSM Criteria for Approval or for failure to comply with contract requirements such as job control tests. Your Company must continue to be registered with the Road Authority in order to be shown on MTO's DSM list.

Please be aware of our policy in reference to approved products and/or services; "Ministry approval of any product, service or process does not constitute a general or specific endorsement of that product, service or process and must not be used by the recipient of such approval to promote the sale of the approved product, service or process in any way, also; the Ministry tests and/or evaluates products, services and processes in the context of its own specific needs only. Any violation of this prohibition may result in the withdrawal of any approval(s) heretofore granted".

MST BAR
MAXIMUM STRENGTH GFRP

Qualifications and Certificates

FDOT

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
QUALITY CONTROL PROGRAM INSPECTION REPORT

Facility ID: FRP-25
Description: MST Rebar Inc.
Company Profile Name: MST Rebar Inc.
Facility Address: 200A Hanlan Road , Woodbridge, Ontario, CANADA L4L3R7

QC Manager: James Wang
Email Address: james.w@mstbar.com
Telephone No.: (416) 875-8250

MAC Evaluation ID: 0000099380
Inspection District: SMO
Date(s) of Inspection: 1/9/2024
Report Status: Satisfactory

Evaluation Type: Quality Control Program Inspection
Category: Fiber Reinforced Polymer
Inspection Type:

Checklist: Fiber Reinforced Polymer - SMO Fiber Reinforced Polymer Annual Audit - Version I [QCP] PASSED

Comments:

Alexander Lewis
Signature of QCP Inspector

January 09, 2024
Date Approved

Recipients:		
	Profile Manager	BORNA HAJIMIRAGHA
	QC Manager	James Wang
	Contact Person	Bari Haji
	Other	Cliff
	Other	Rodrigo

MST BAR
MAXIMUM STRENGTH GFRP

Qualifications and Certificates

ICC EVALUATION SERVICE®

ICC Evaluation Service, LLC
Western Regional Office 3060 Saturn Street, Suite 100 Brea, CA 92821
t: 1.800.423.6587, ext. 1 f: 562.695.4694 www.icc-es.org

APPROVED

Form Q-24

Date of Inspection*	07-19-2023
ICC-ES Evaluation Report Number * *Please fill out a separate Q-24 for each master/follower report number as applicable.	ESR-4664
Reissue Date of Evaluation Report * *This date can be found on the upper right-hand corner of the first page of the evaluation report published on the ICC-ES website.	03/2022
Revision or Correction Date of Evaluation Report * *This date can be found on the upper right-hand corner or at the bottom of the first page of the evaluation report published on the ICC-ES website.	01/2023
Name of Report Holder*	Tuf-N-Lite, LLC
Name of Manufacturing Facility*	MST Rebar Inc
Manufacturer's Representative Name*	Bari Haji
Manufacturer's Representative Title	Standard and Procedures Coordinator
Manufacturer's Representative E-Mail Address*	bari.h@mstbar.com
Manufacturer's Representative Phone Number	(416) 999-6284
Address of Inspected Facility *	Street*: 260 Hanlan Rd. City*: Woodbridge State*: Ontario
Country and Province, if outside of the United States*	Canada
Names of Products Inspected* *Be sure to identify products using names provided in the evaluation report.	4EQ Structural Bar
Name of Agency Conducting Inspection*	ICC NTA, LLC
Name of Inspector*	Kyle Lacefield
Inspector's E-Mail Address*	klacefield@icc-nta.org
Inspector's Phone Number	(574) 213-4994

Thank You!

'The measure of intelligence is the ability to change'
-Albert Einstein.

Questions

Contact Info

Borna Hajimirgha

MST Rebar Inc.

1855-740-0377 Ext 101

Borna.h@mstbar.co[redacted]

Evaluating Prestressed Concrete Beams with Cracks using Machine Learning

Pinar Okumus

Associate Professor

Department of Civil, Structural and Environmental Engineering

University at Buffalo

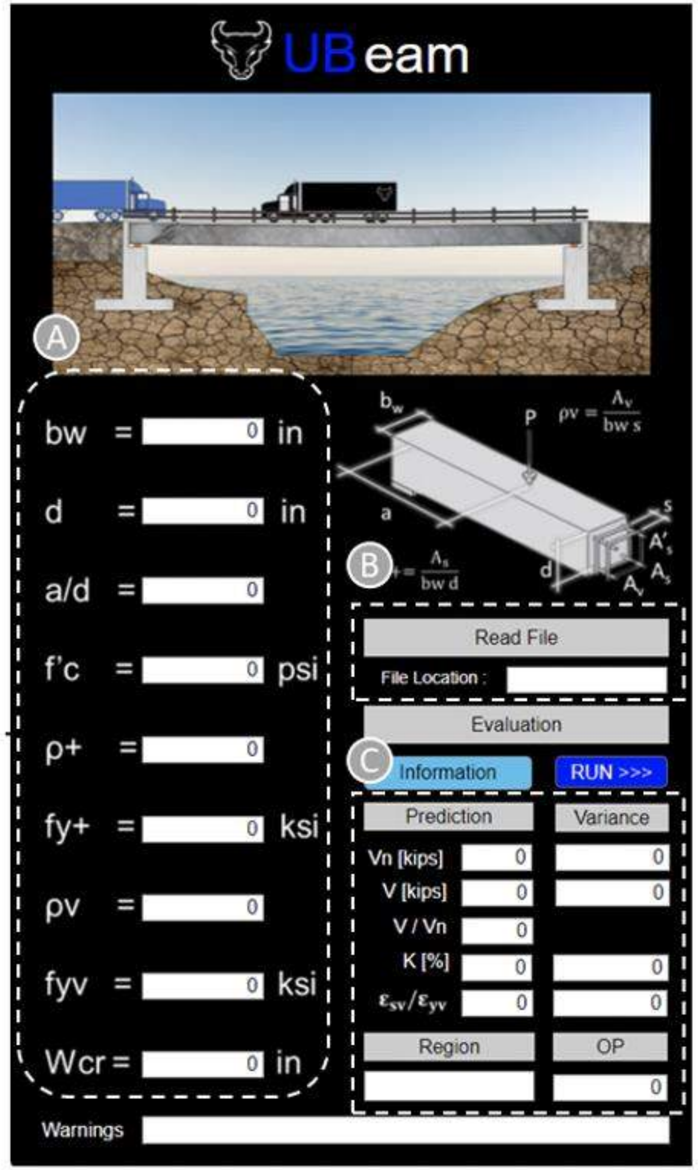
Collaborators: Dr. Elhami Khorasani

Ph.D. Student: Mr. Mohamed Hassan Lasheen

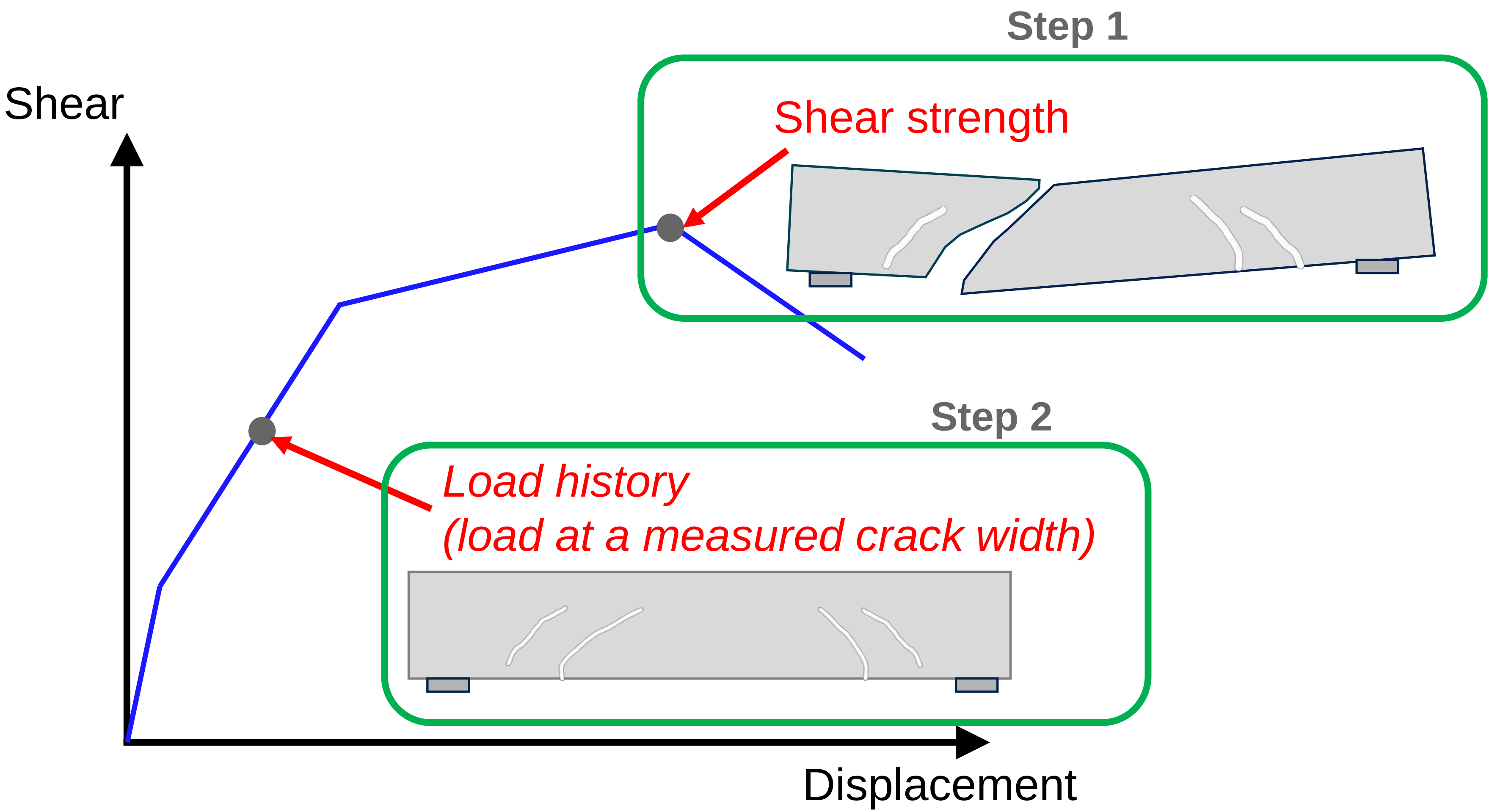
Motivation

Problem: Concrete members that have shear cracks need to be evaluated for safety.

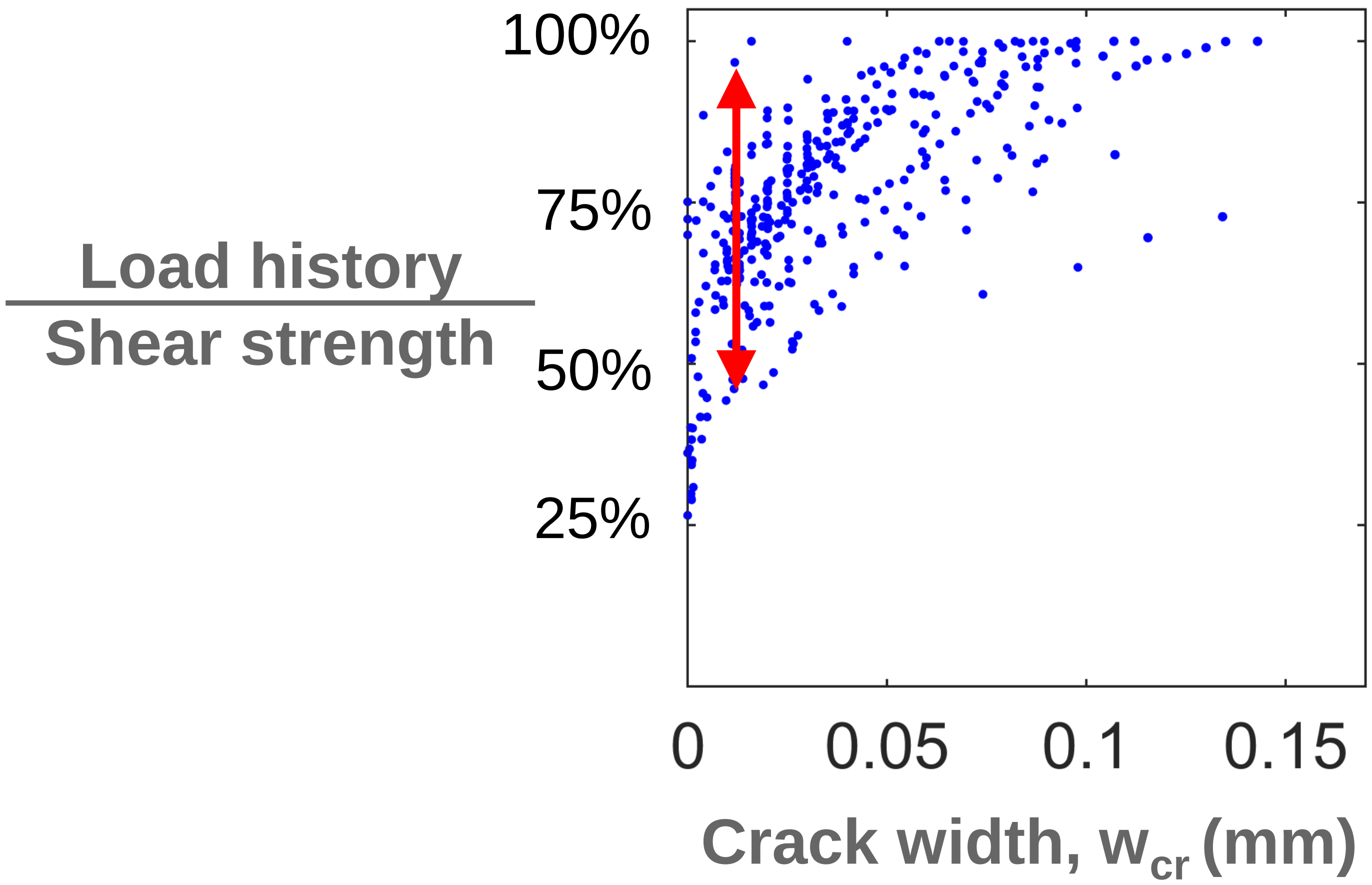
Proposed solution: Develop a machine learning (ML) tool that can relate crack width to load history.



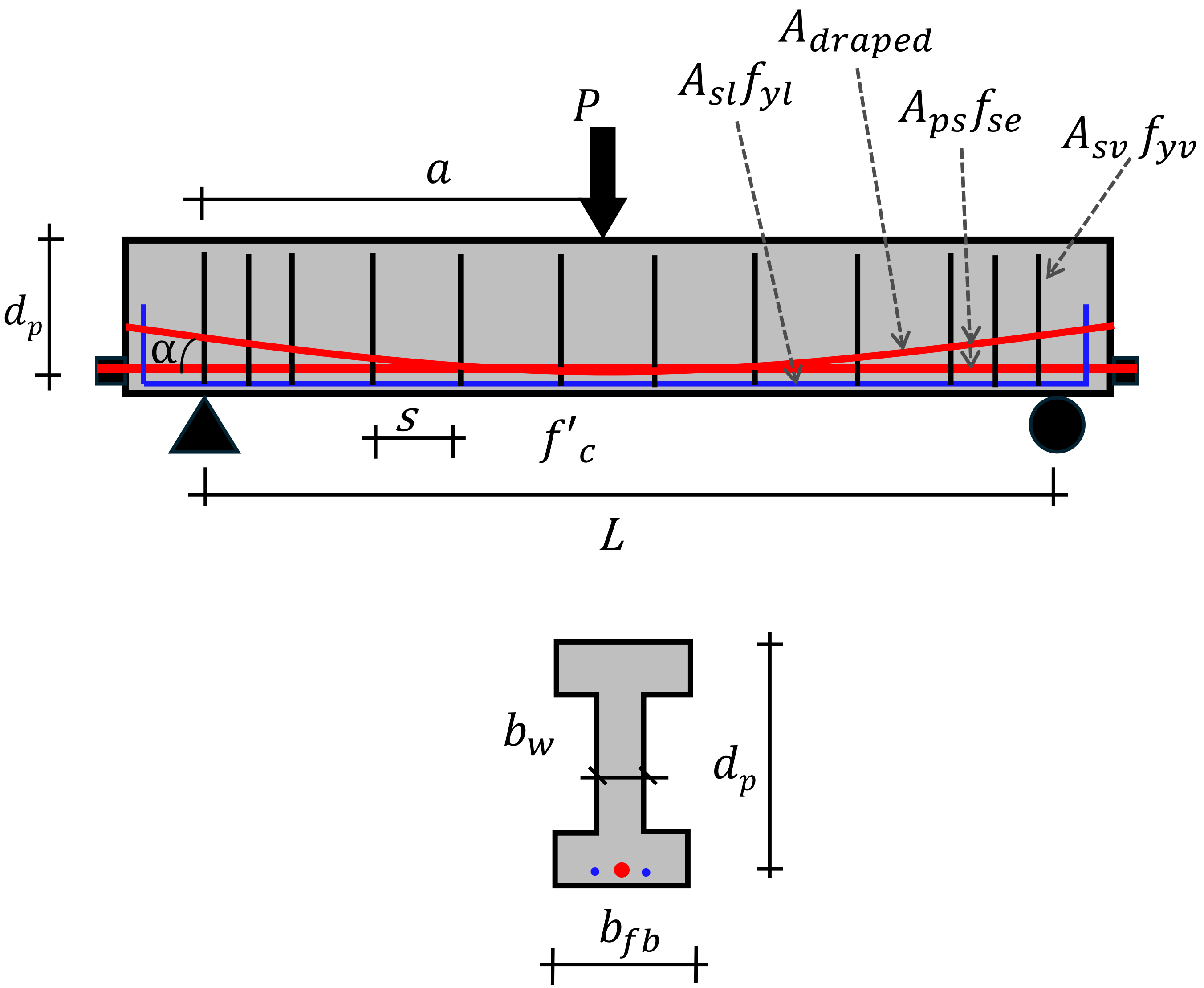
Load history and shear strength



Data visualization



Definition of predictive features

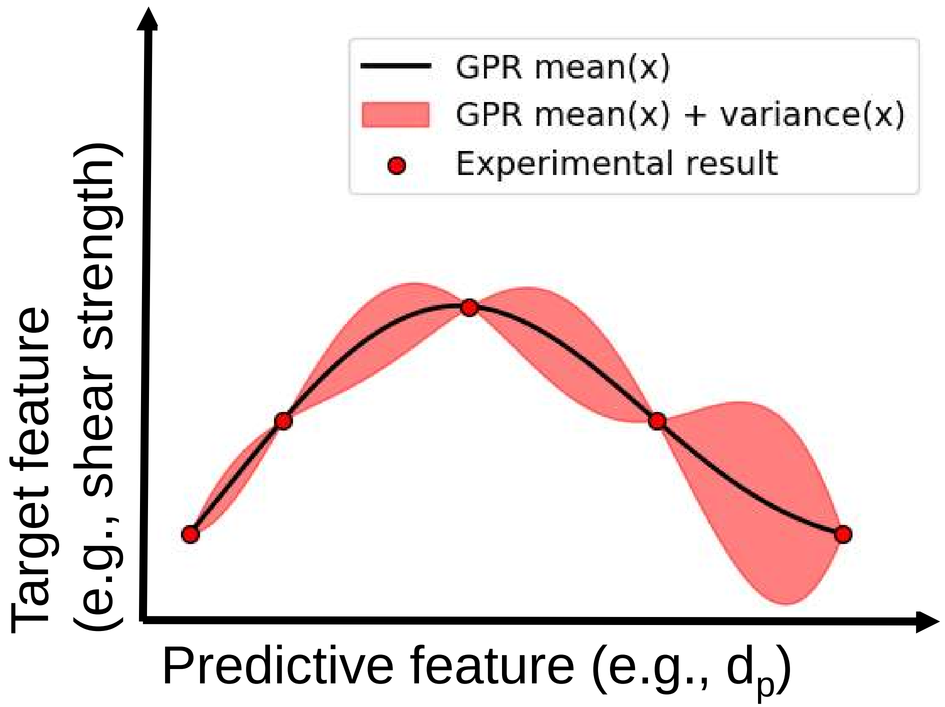


Features	
A_{ps}	Prestressing steel area
A_{sl}	Longitudinal reinforcement area
A_{sv}	Transverse reinforcement area
A_{girder}	Beam cross-sectional area
a	Shear span
b_w	Beam web width
b_{fb}	Beam bottom flange width
f_{se}	Effective prestress
f_{yv}	Yield strength of shear reinforcement
f_{yl}	Yield strength of longitudinal reinforcement
f'_c	Concrete compressive strength
s	Shear reinforcement spacing
d_p	Distance from extreme compression fiber to strands
α	Angle of draping
w_{cr}	**Crack width**

Machine learning algorithms

Gaussian process regression (GPR)

- A nonlinear complex model.
- The prediction functions are distributions with a mean and variance.



Data collection and filtering

Shear strength predictions:

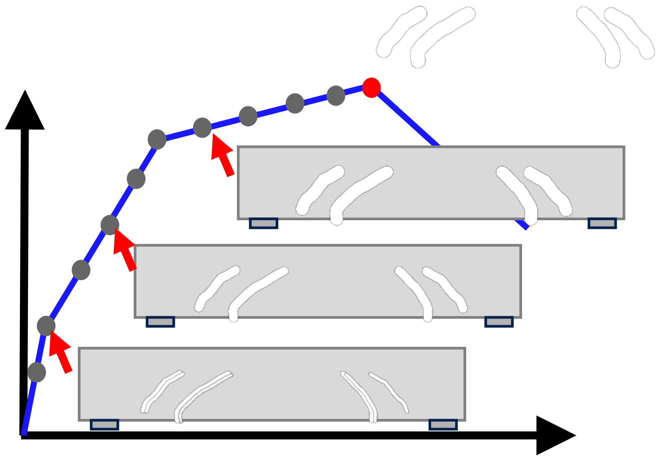
Nakamura et al. (2013) data

1146 tests → **Additional filtering to exclude**

- deep beams (a/d<2)
- continuous beams
- external prestressing
- unbonded prestressing
- lightweight concrete

→ Filtered data: 887 tests → 2013-2024 data: 10 tests → Final data: 897 tests

Load history predictions:

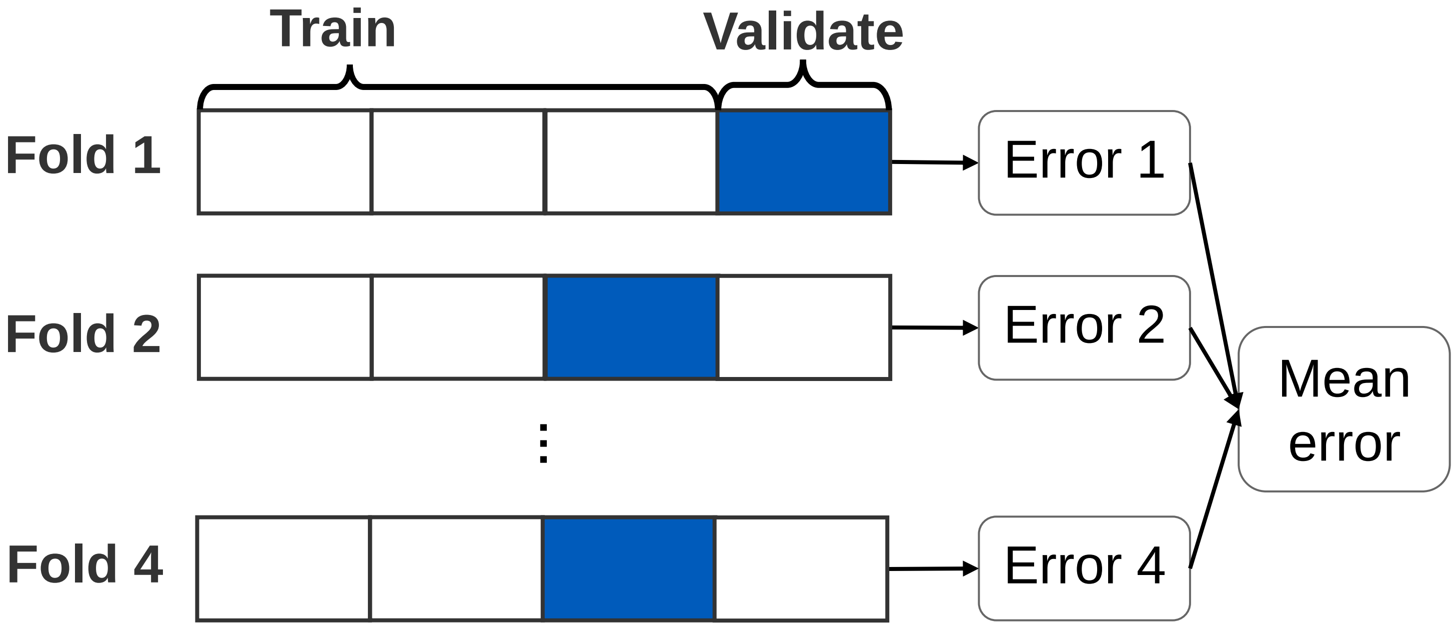


→ **Additional filtering to exclude**

- beams without crack width records

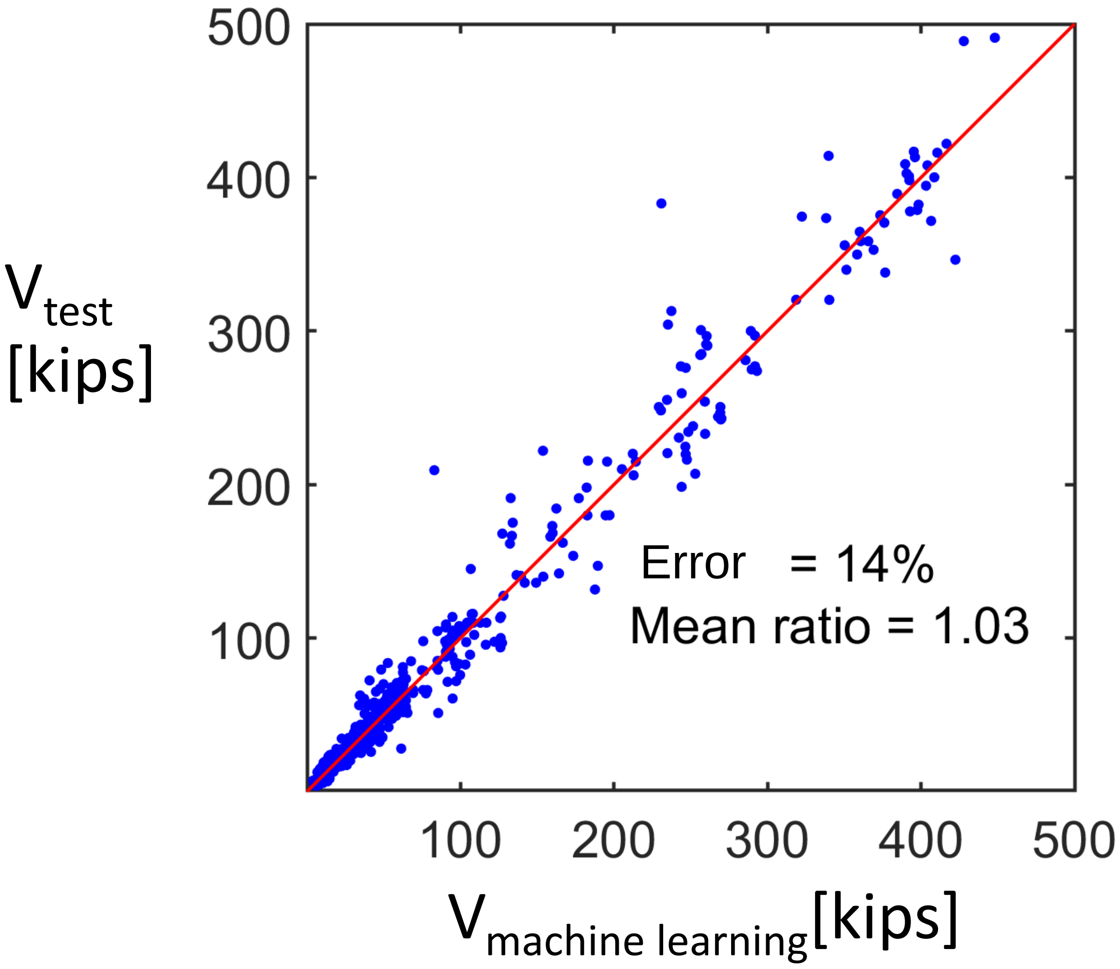
→ 79 tests → Final data: 391 crack width measurements

k-fold cross-validation

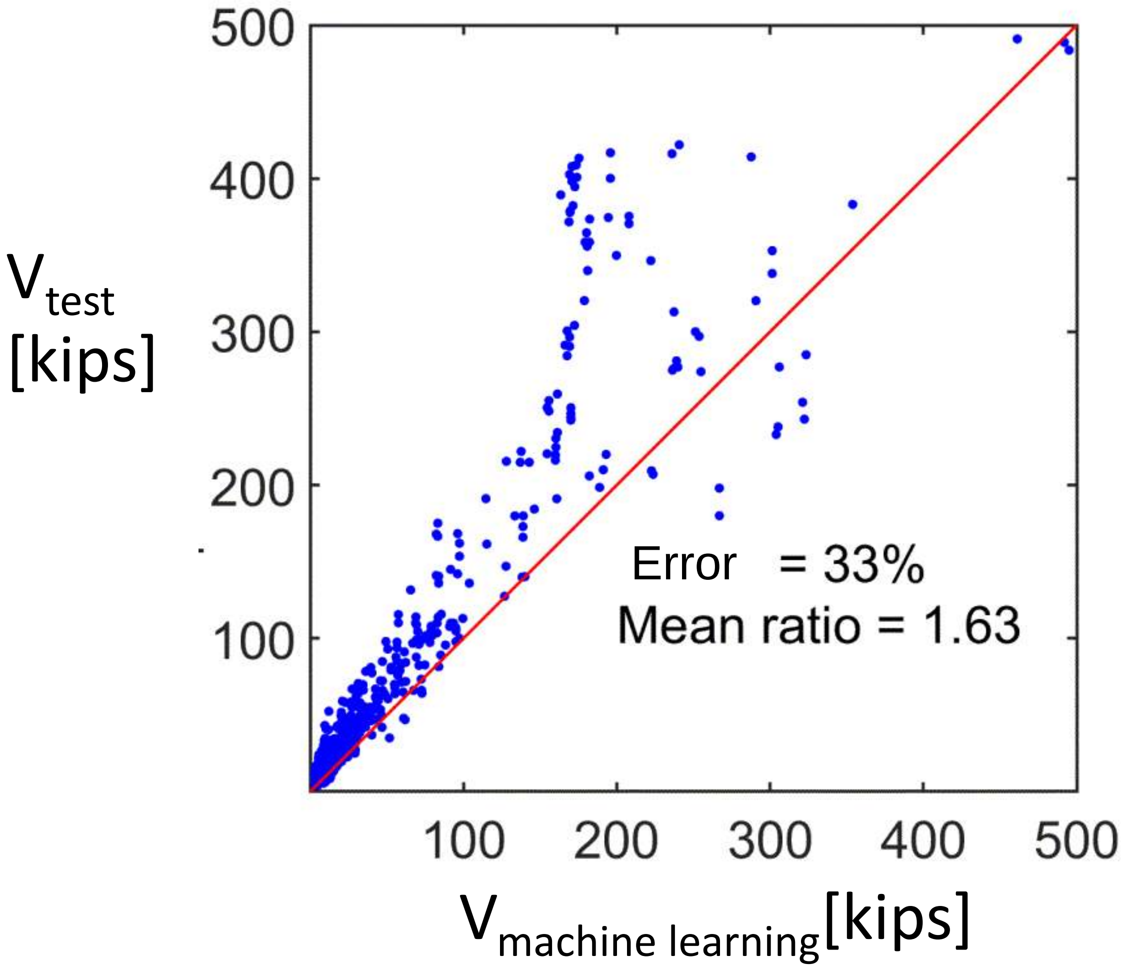


Shear strength predictions of machine learning vs AASHTO

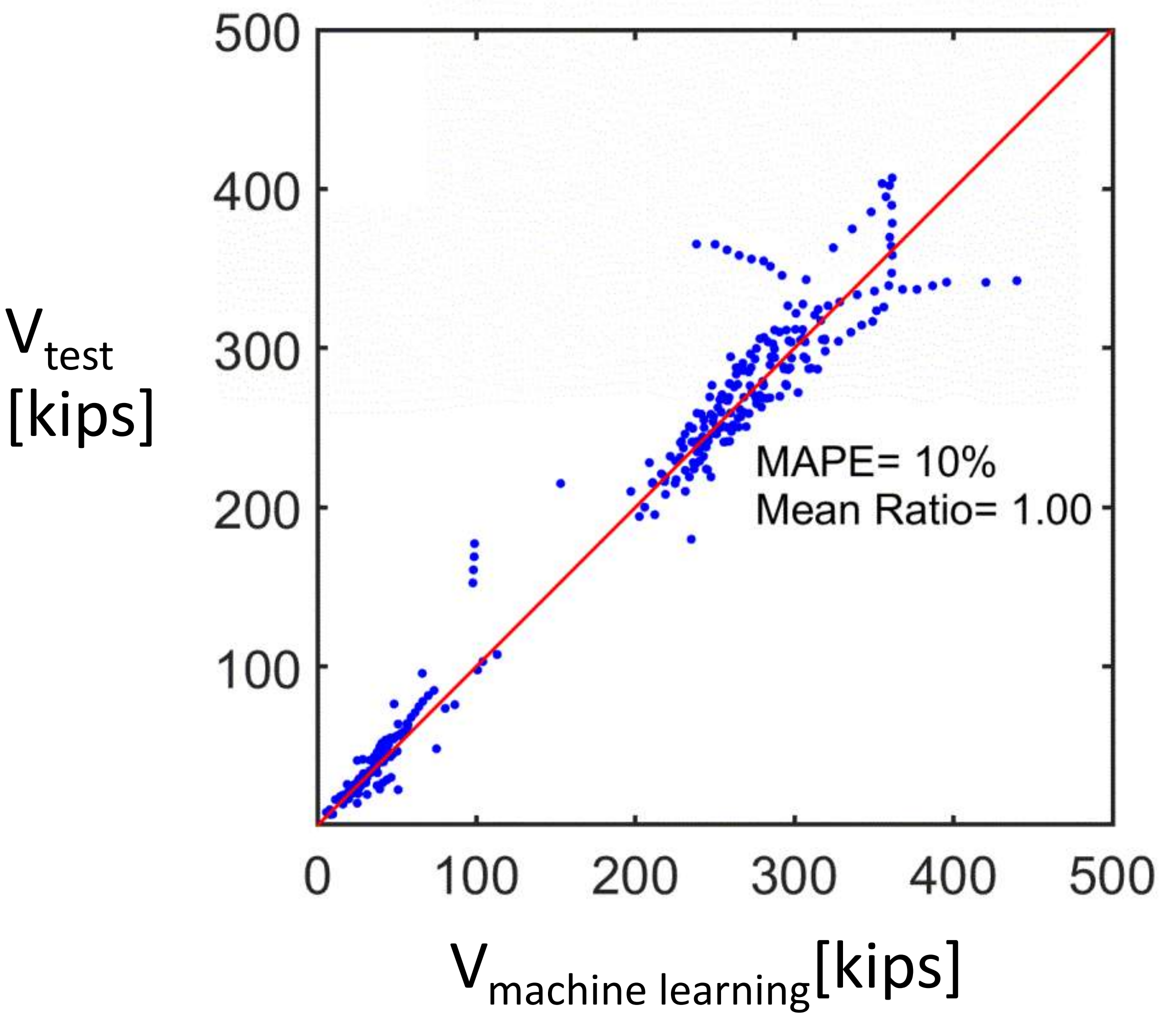
Machine Learning



AASHTO LRFD Bridge Design Specifications

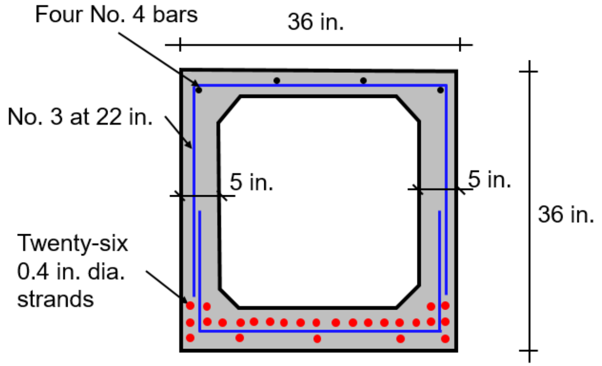


Load history predictions of machine learning



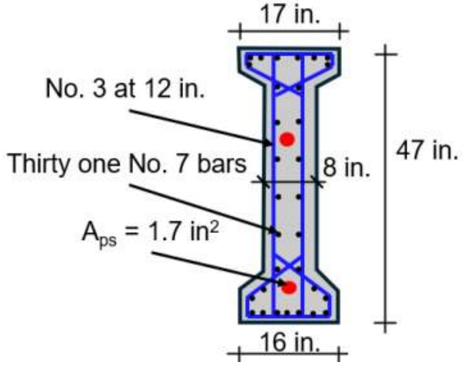
Demonstration with unseen test data

	$A_{sv} < A_{sv,min}$	$A_{sv} \geq A_{sv,min}$
Poorly represented	Beam G3-1 (Hanson & Hulsbos, 1971) **Error = 35%**	Beam C80P2S-10 (Lee et al., 2010) **Error = 16%**
Well represented	Beam PS1-0 (Lee et al., 2010) **Error = 15%**	Beam PS-4-M2 (Lee et al., 2010) **Error = 3%**



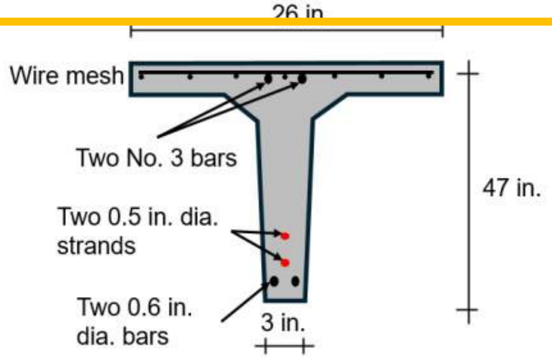
Beam G3-1 (Hanson & Hulsbos, 1971)

Error = 35%



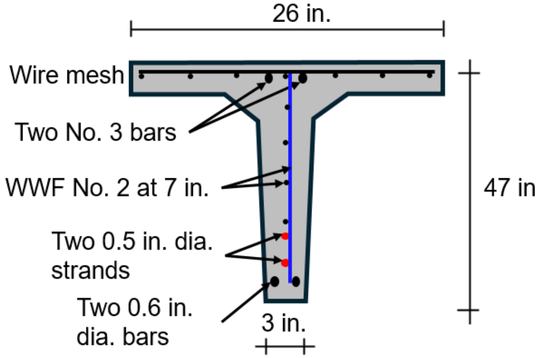
Beam C80P2S-10 (Lee et al., 2010)

Error = 16%



Beam PS1-0 (Lee et al., 2010)

Error = 15%



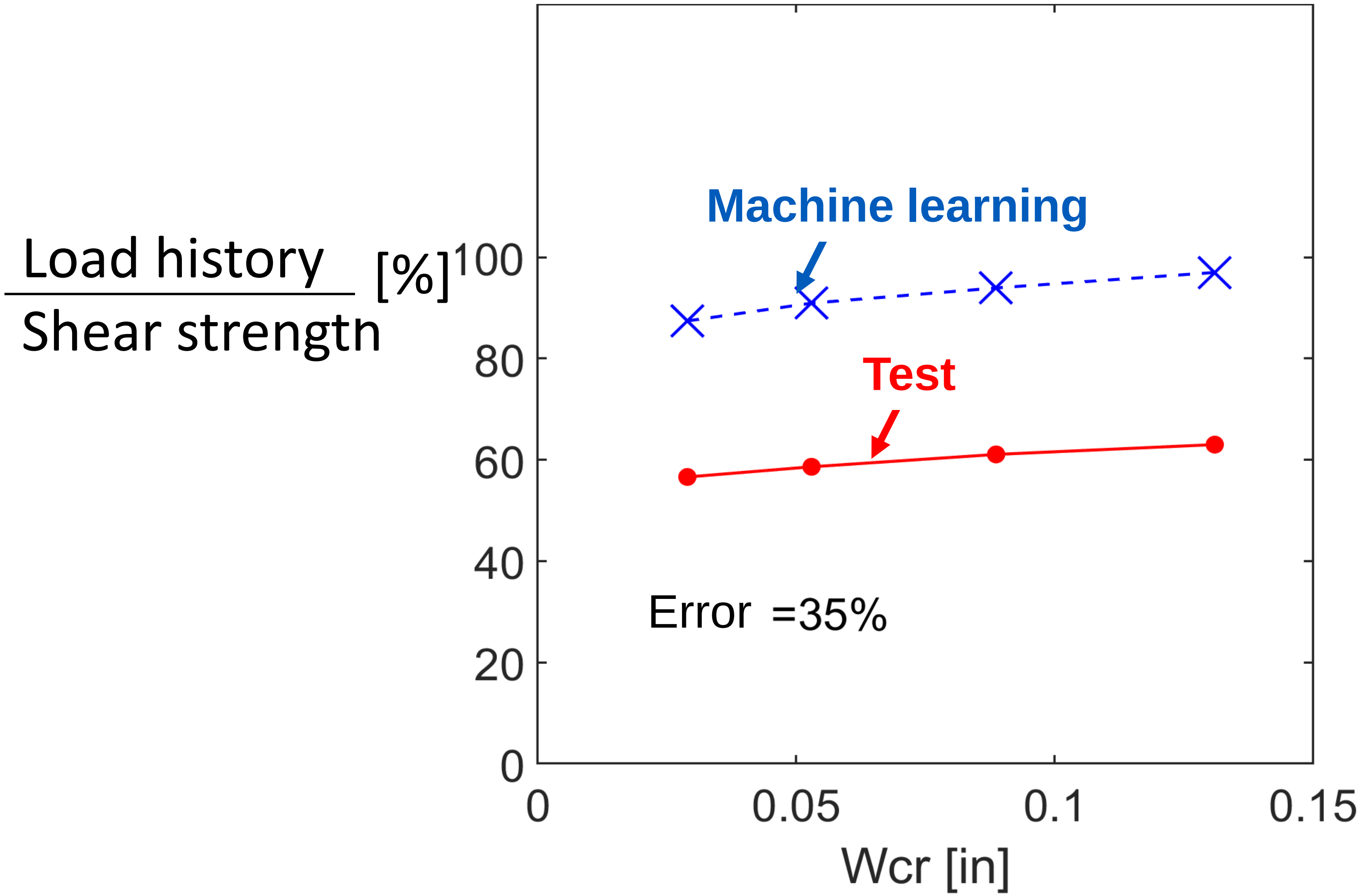
Beam PS-4-M2 (Lee et al., 2010)

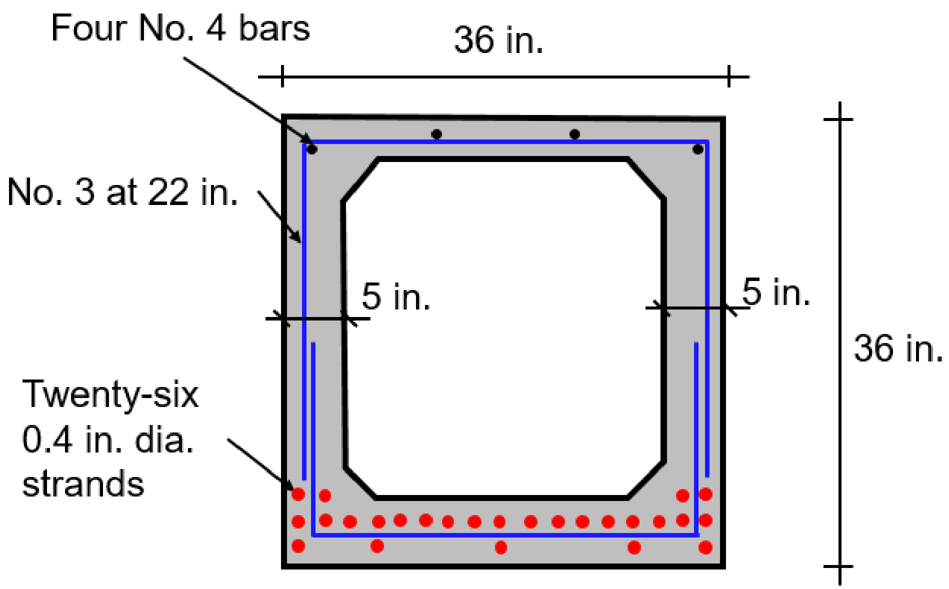
Error = 3%

Prestressing steel ● Shear reinf. —— Mild reinf. ●

Demonstration with unseen test data

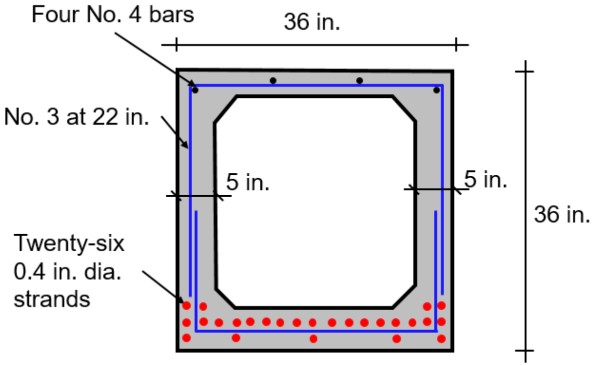
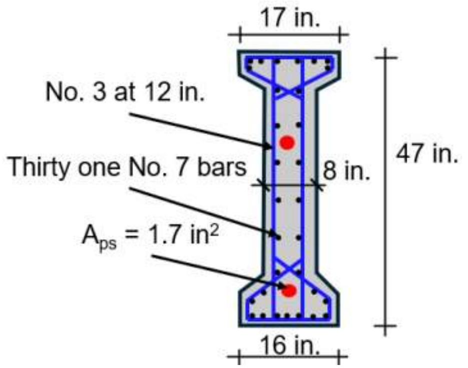
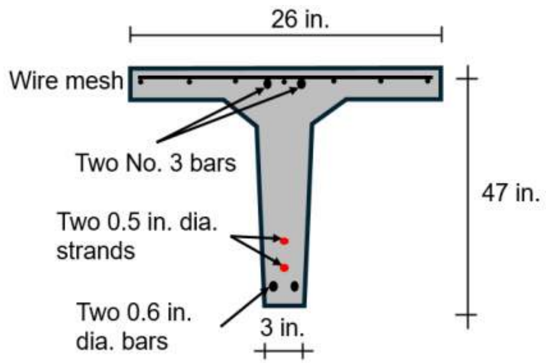
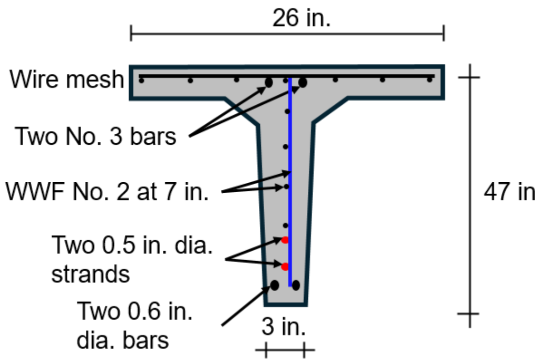
Beam features poorly represented by test data and $A_{sv} < A_{sv,min}$





Beam G3-1 (Hanson & Hulsbos, 1971)

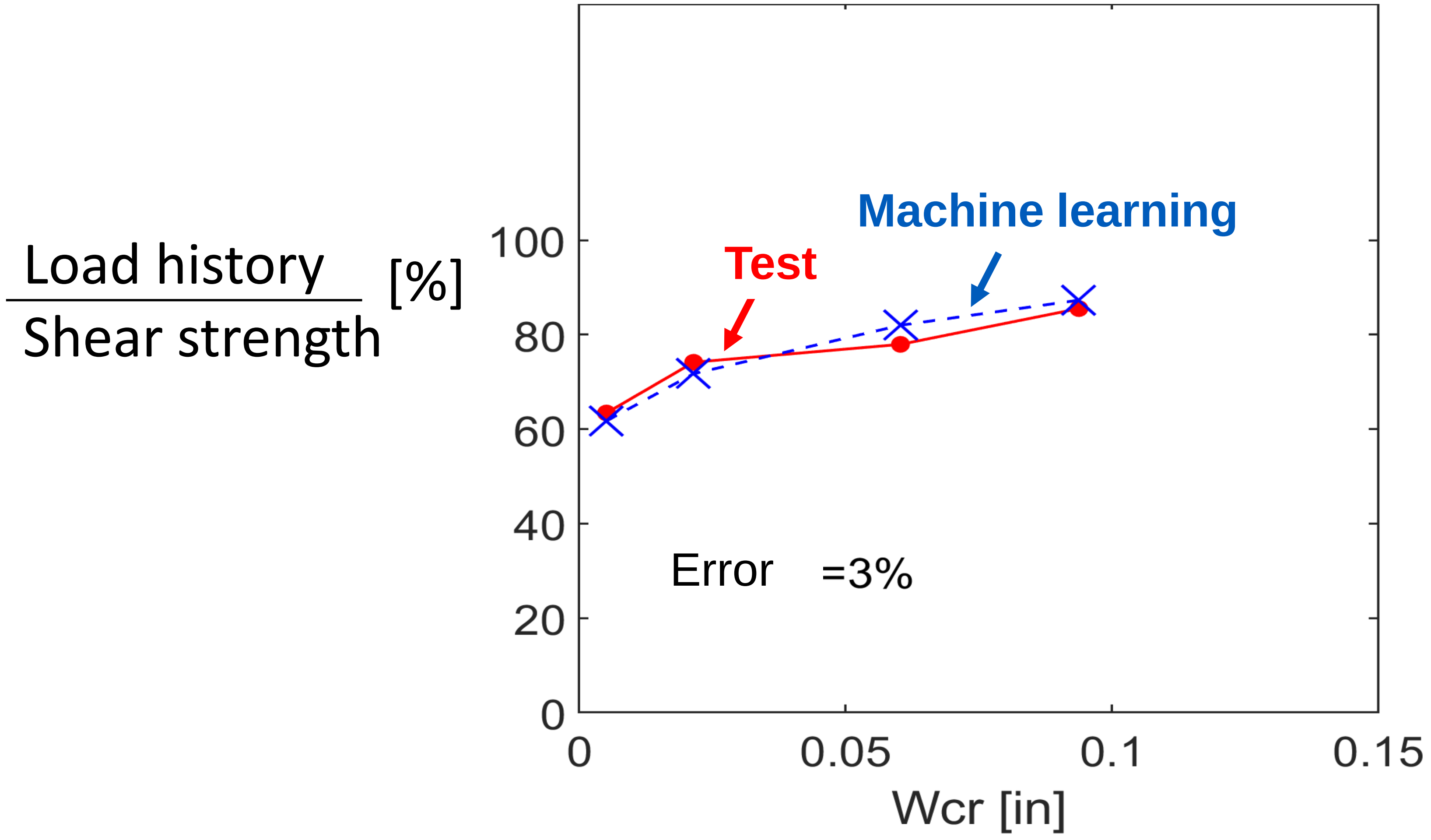
Demonstration with unseen test data

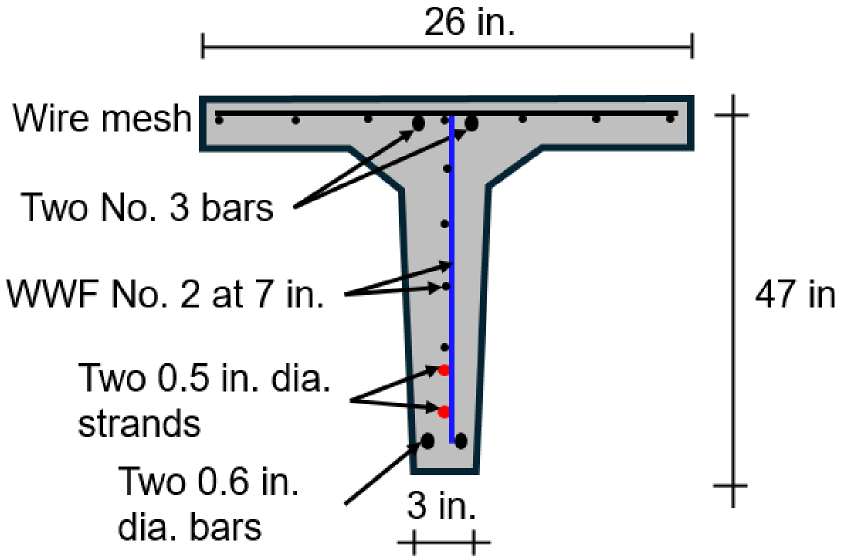
	$A_{sv} < A_{sv,min}$	$A_{sv} \geq A_{sv,min}$
Poorly represented	 Beam G3-1 (Hanson & Hulsbos, 1971) **Error = 35%**	 Beam C80P2S-10 (Lee et al., 2010) **Error = 16%**
Well represented	 Beam PS1-0 (Lee et al., 2010) **Error = 15%**	 Beam PS-4-M2 (Lee et al., 2010) **Error = 3%**

Prestressing steel ● Shear reinf. —— Mild reinf. ●

Demonstration with unseen test data

Beam features well represented by test data and $A_{sv} > A_{sv,min}$





Beam PS-4-M2 (Lee et al., 2010)

Conclusions

- Machine learning predicted shear capacity with 14% error.
- Machine learning predicted shear load history with 10% error.
- Machine learning has acceptable predictions for the unseen beams when $A_{sv} \geq A_{s,min}$ and when beam features are well represented by training test data.

Acknowledgments

Financial support:

TRANS-IPIC TRANSPORTATION INFRASTRUCTURE PRECAST INNOVATION CENTER

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Thank you

Questions

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References

- Pérez, R. N. C. (2023). Assessment of the shear capacity and condition of cracked reinforced concrete beams using machine learning. PhD Dissertation, University at Buffalo, State University of New York.
- Hanson, J. M., & Hulsbos, C. (1971). Ultimate Shear Tests of Large Prestressed Concrete Bridge Beams. *Special Publication*, *26*, 523-551.
- Lee, S.-C., Cho, J.-Y., & Oh, B.-H. (2010). Shear Behavior of Large-Scale Post-Tensioned Girders with Small Shear Span-Depth Ratio. *ACI Structural Journal*, *107*(2).
- Maruyama, K., & Rizkalla, S. H. (1988). Shear design consideration for pretensioned prestressed beams. *Structural Journal*, *85*(5), 492-498.

Post-Fire Assessment and Resilience Design of Reinforced Concrete Bridges

Negar Elhami-Khorasani

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Department of Civil, Structural and Environmental Engineering
University at Buffalo

Collaborators: Dr. Ravi Ranade and Dr. Anthony Tessari

Ph.D. Student: Mr. Nima Tajik Hesaramir

2007: I-80/880 Highway bridge in Oakland, CA (MacArthur Maze)

2023: I-95 at the Pennsylvania Route 73, PA

2021: Dry Canyon Bridge, Lava Wildfire, CA

2017: I-85 bridge in Atlanta, GA

2024: Near downtown Los Angeles, CA

2001: The Howard Street Tunnel Fire, Baltimore, MD

Motivation

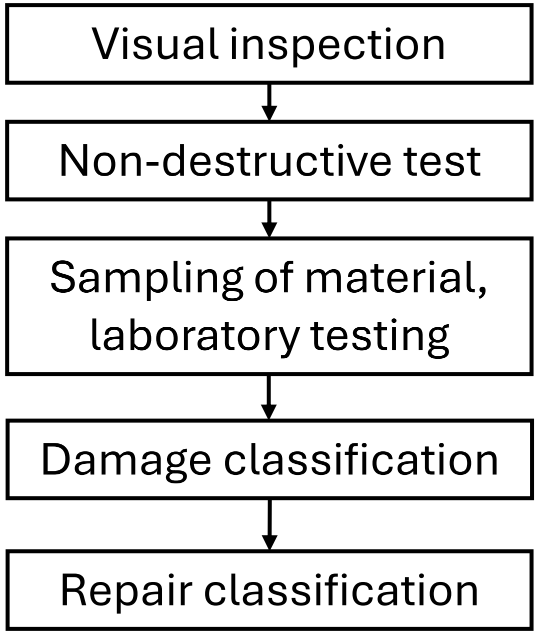
Post-fire damage assessment

- Limited available guidelines for assessing damage to concrete structures after a fire
- Deciding whether a structure should be demolished or repaired

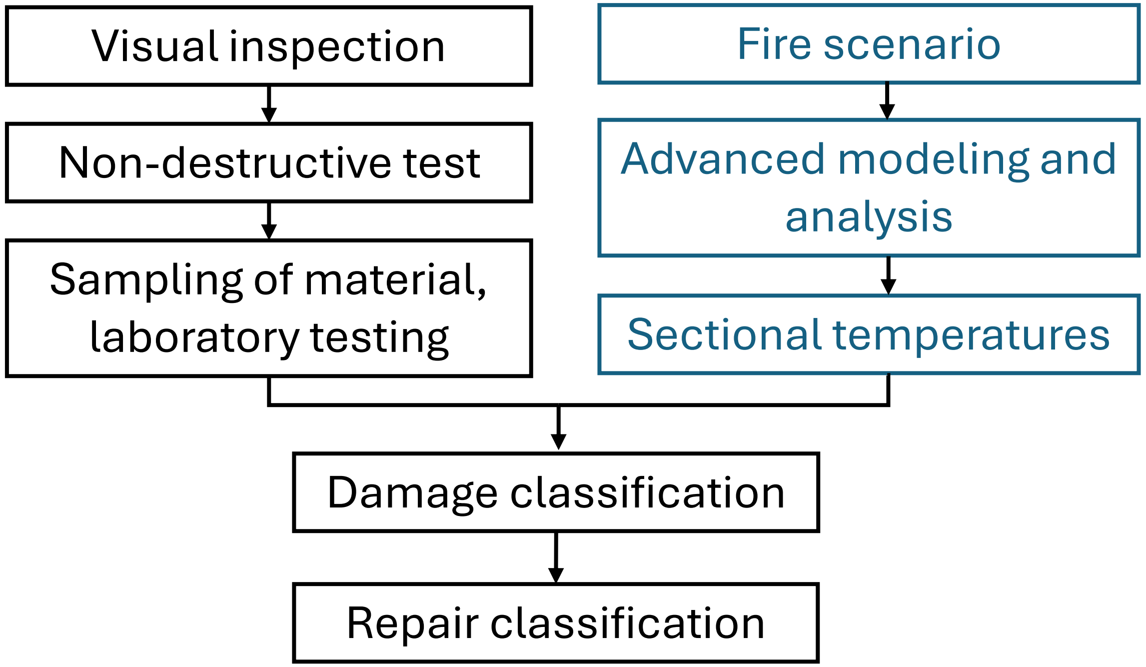
Performance-based design

- Predicting the level of damage, associated downtime, and costs for pre-defined fire scenarios during the design phase
- Adjusting the design to meet the resilience goals set by the project stakeholders

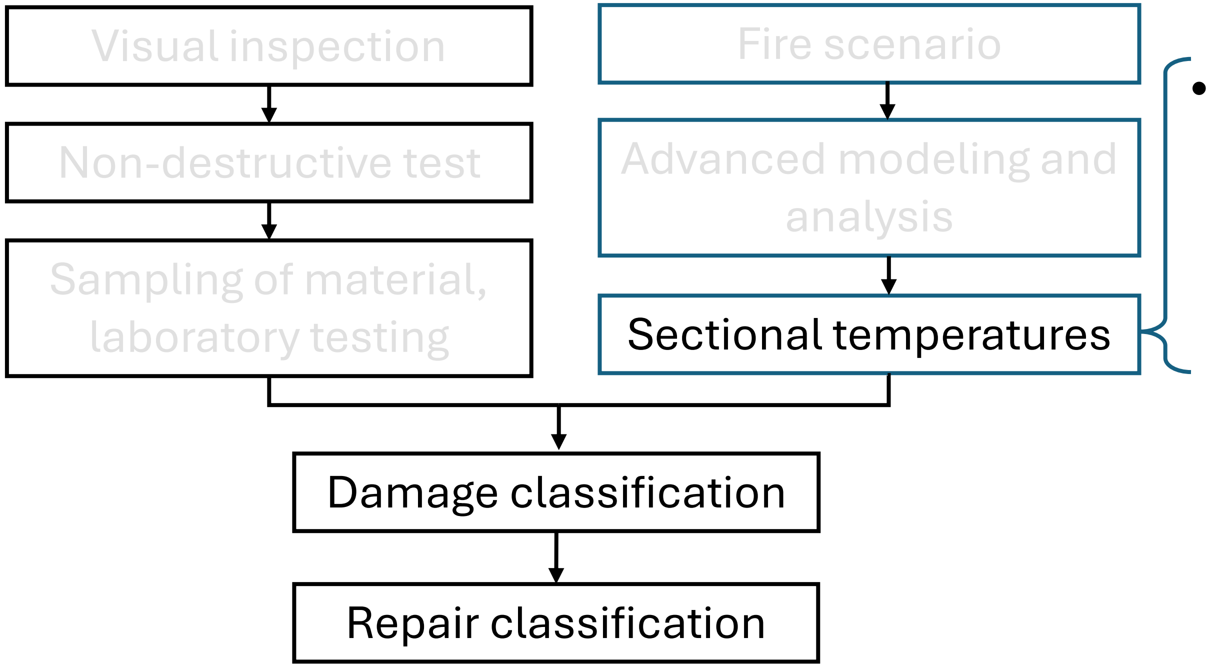
Background: Damage assessment procedure



Advanced analysis

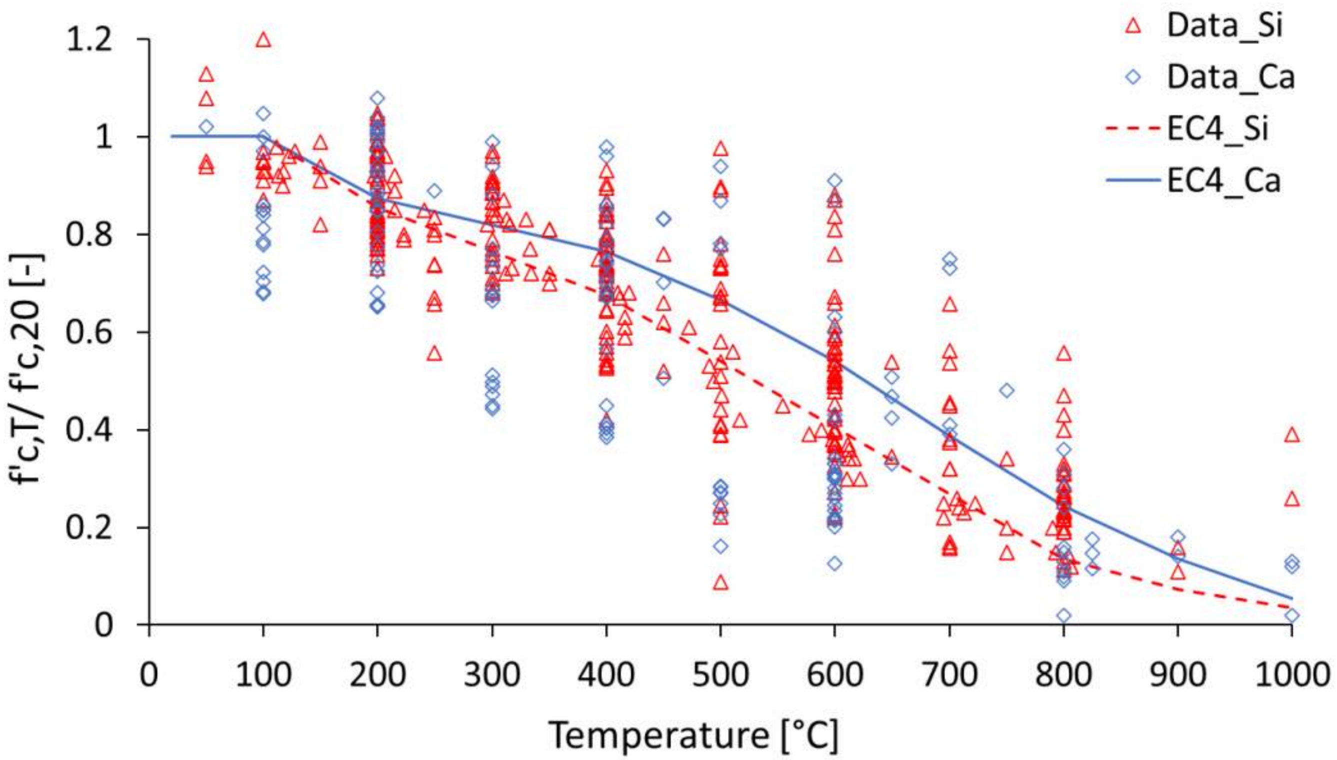


Advanced analysis



- Temperature thresholds for damage states
  - Reduction in post-fire strength of concrete and steel rebar
  - Reduction in bond strength

Residual material properties



Residual concrete strength

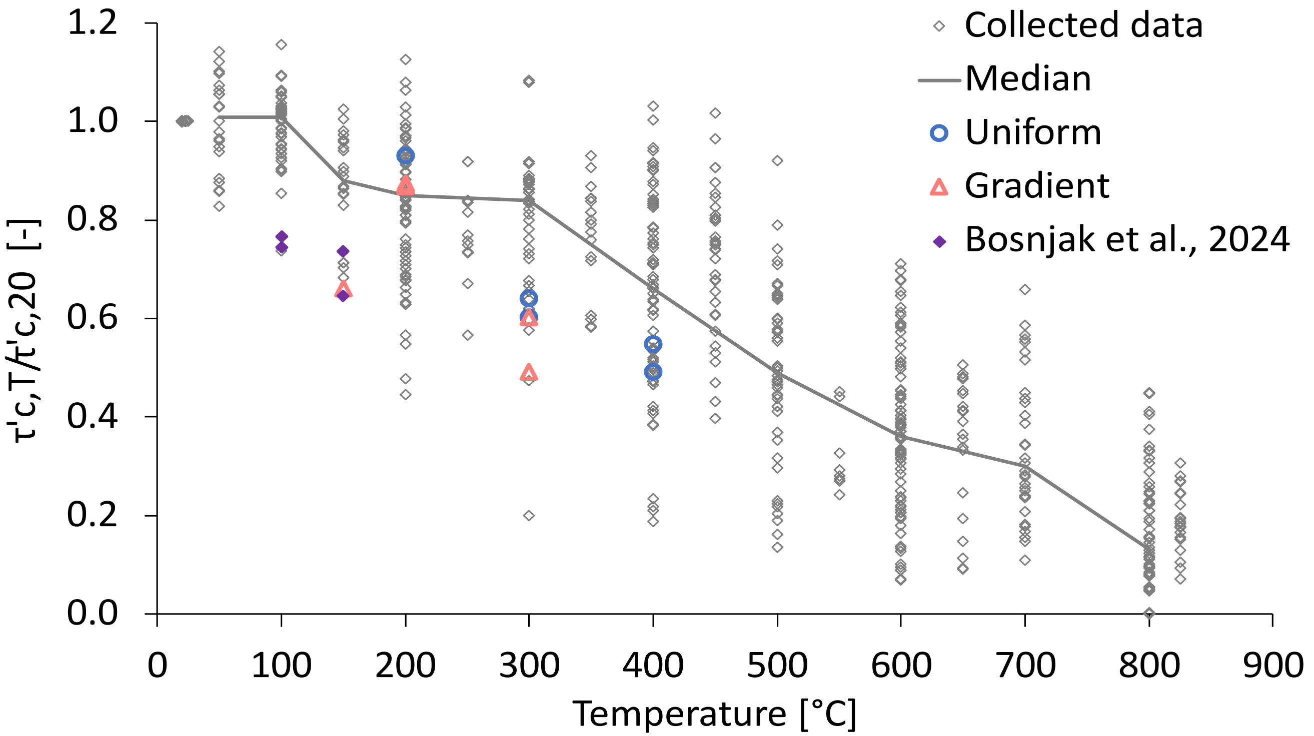
- Normal-strength concrete
- 340 points for concrete with siliceous aggregate, 150 points for concrete with calcareous aggregate
- Eurocode 4 (EC4) recommendation close to the median of the collected data

Residual steel strength

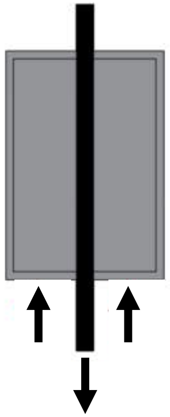
- A linear decrease in steel yield strength after 1000°F (537°C) according to ACI Code 562

Shahraki, M., Hua, N., Elhami-Khorasani, N., Tessari, A., Garlock, M. (2022). "Residual compressive strength of concrete after exposure to high temperature: A review and probabilistic models," *Fire Safety Journal*, 103698

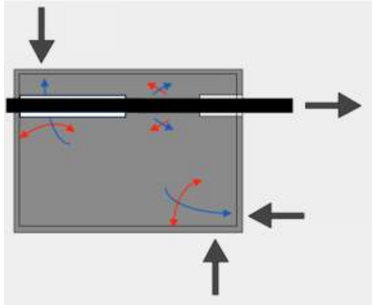
Residual bond properties



Simple pull-out



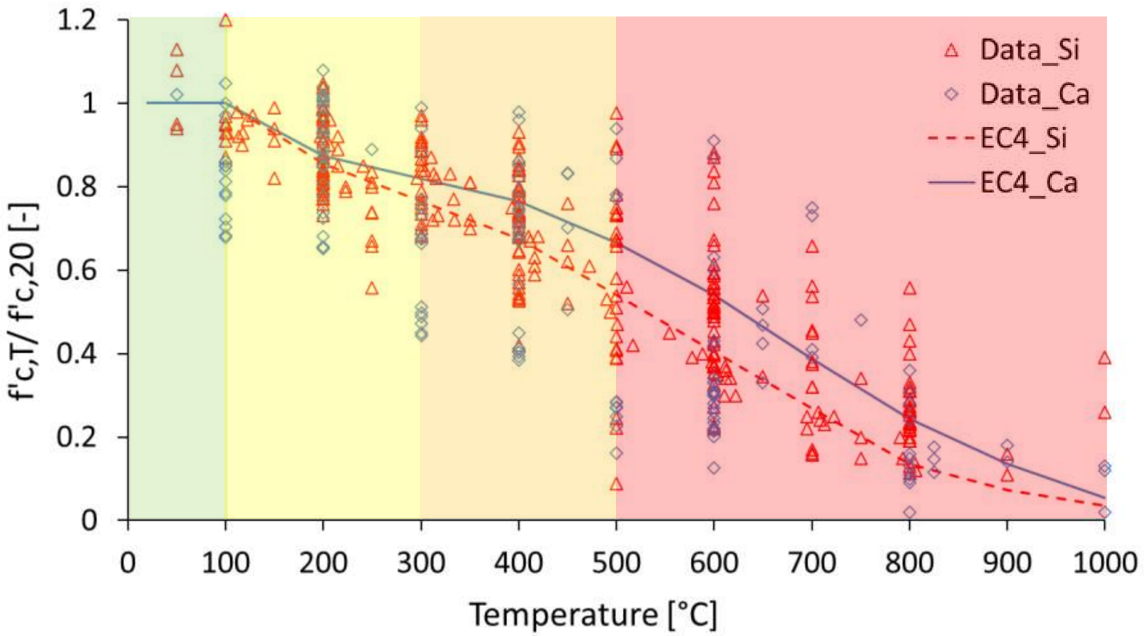
Beam-end pull-out

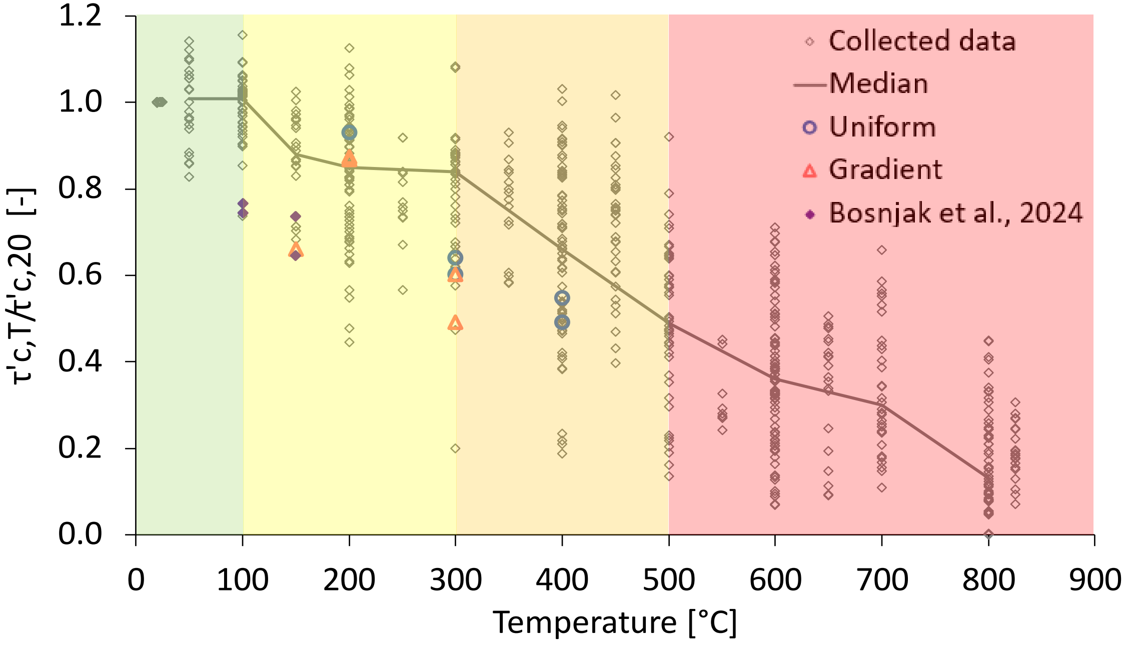


Residual bond strength

- More than 700 data points from studies published after 2004
- Most tests based on pull-out tests with cylinders or cubes and uniform heating

Damage classification





Green	No damage
Yellow	Slight damage
Light orange	Moderate damage
Red	Extensive damage

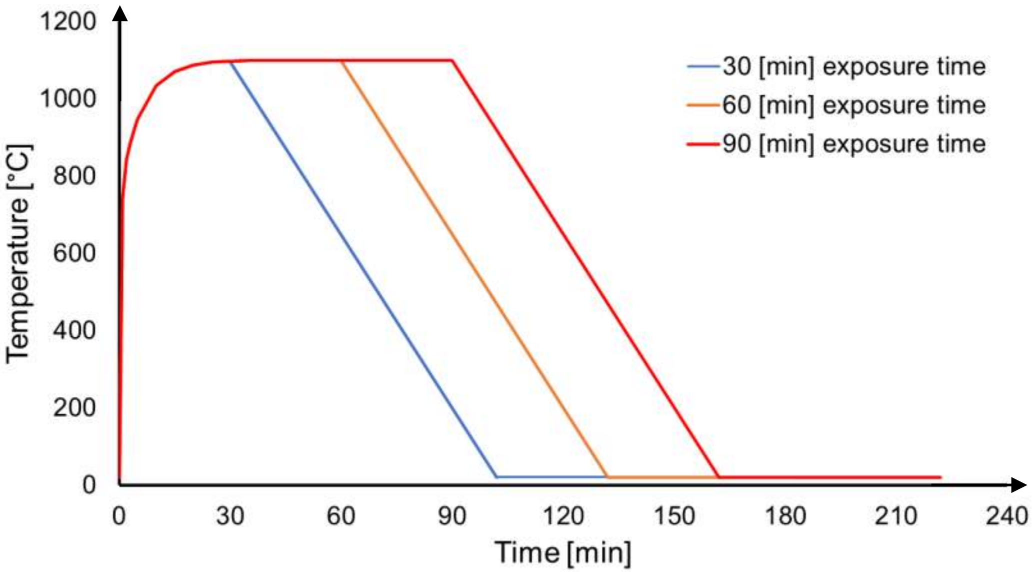
Damage classification

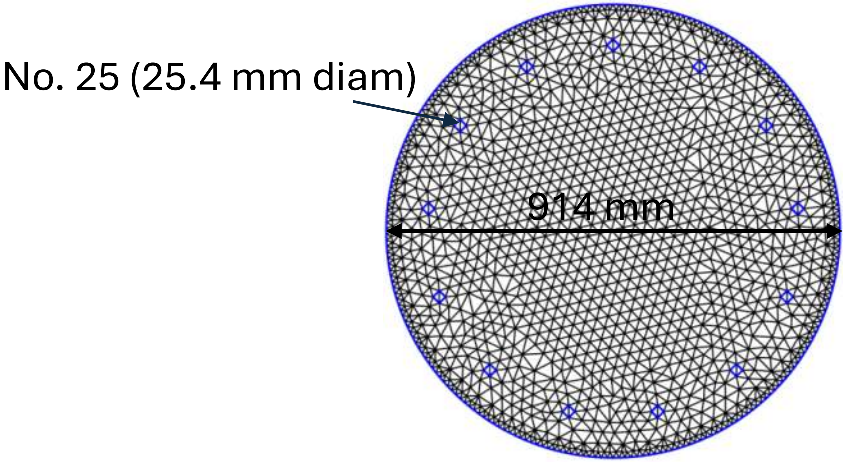
Damage state	Average depth of concrete with temperature > 300 °C	Temperature of reinforcement	Note
1	$d <$ half cover depth	$T <$ 100°C ($T <$ 212°F)	Reductions in concrete and bond strength at the rebar level have minimal impact
2	half cover depth $\leq d <$ cover depth	100°C $\leq T <$ 300°C (212°F $\leq T <$ 572°F)	Concrete beyond rebar remains below 300°C (572°F)
3	cover depth $\leq d <$ half section depth	300°C $\leq T <$ 500°C (572°F $\leq T <$ 932°F)	Reductions in concrete and bond strength at the rebar level are within ~50%, steel strength starts to degrade
4	$d \geq$ half section depth	$T \geq$ 500°C ($T \geq$ 932°F)	Large reductions in material and bond properties

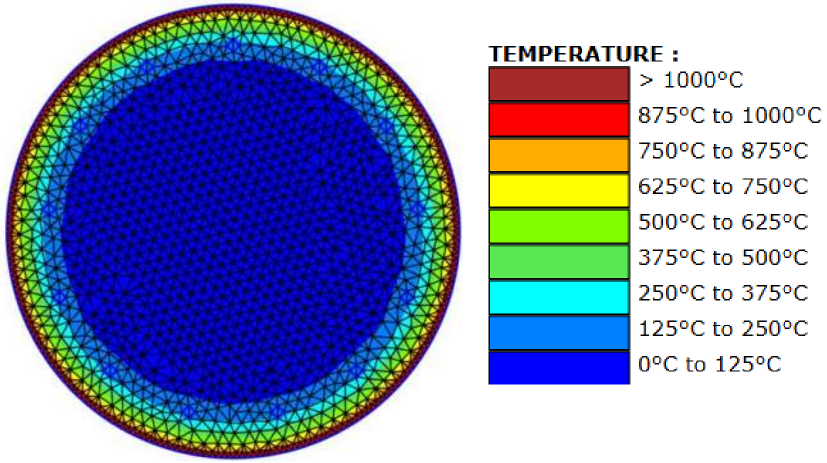
Thermal analysis: sample column

Bridge design (Wang, 2022)

- Bridge location: Washington State
- Year built: 1959
- Height of the column: 9 m
- Cover thickness: 57 mm





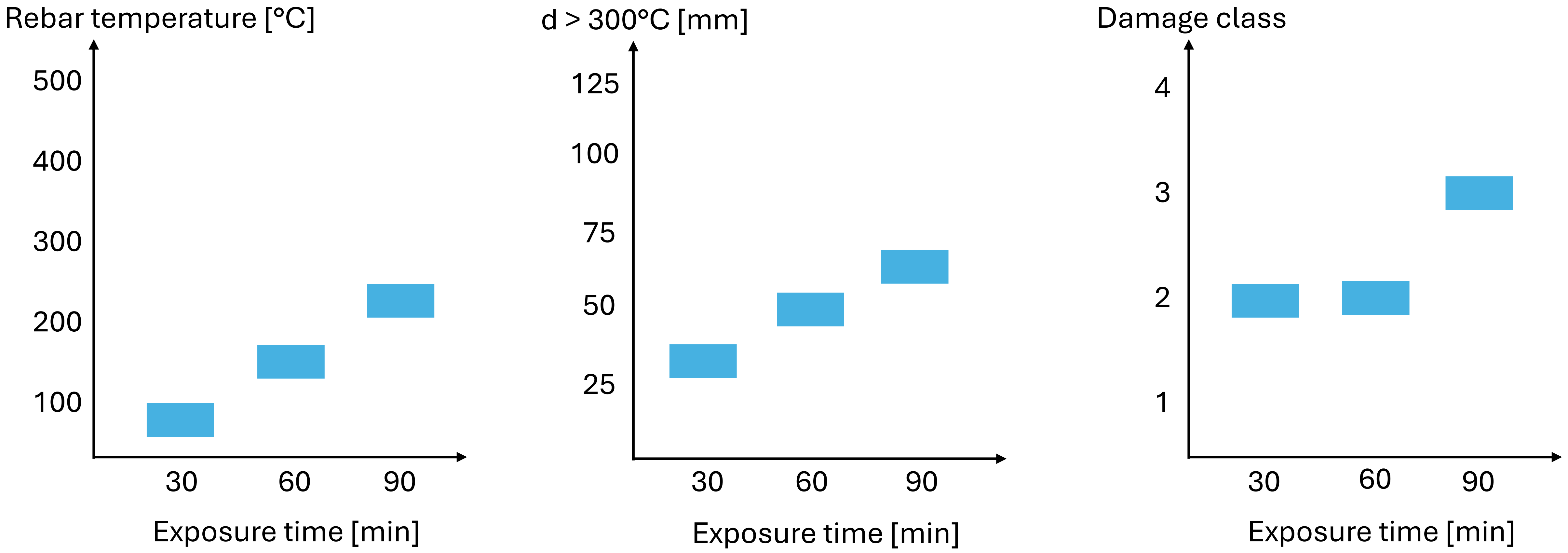


Time: 90 min

Wang, H. (2022). *Corrosion and seismic analyses of reinforced concrete bridges*. Doctoral dissertation, State University of New York at Buffalo, Buffalo, NY, USA.

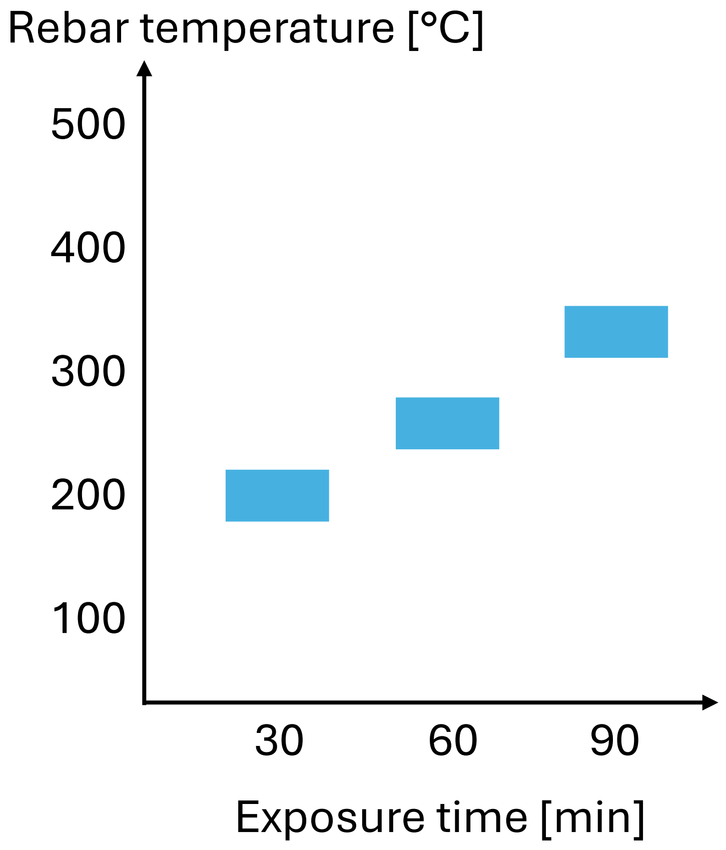
Damage classification of the sample column

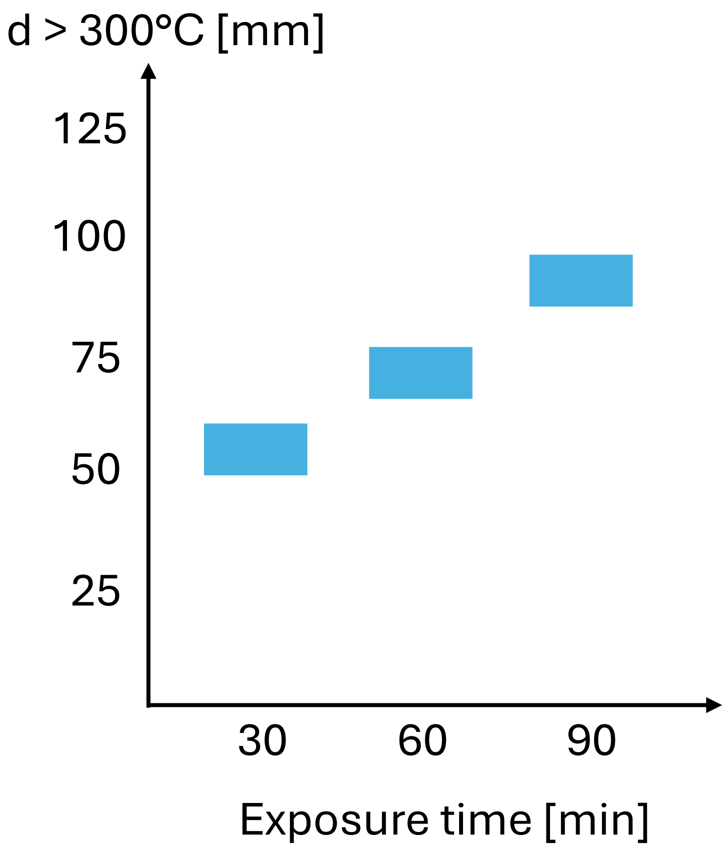
Hydrocarbon Fire Curve

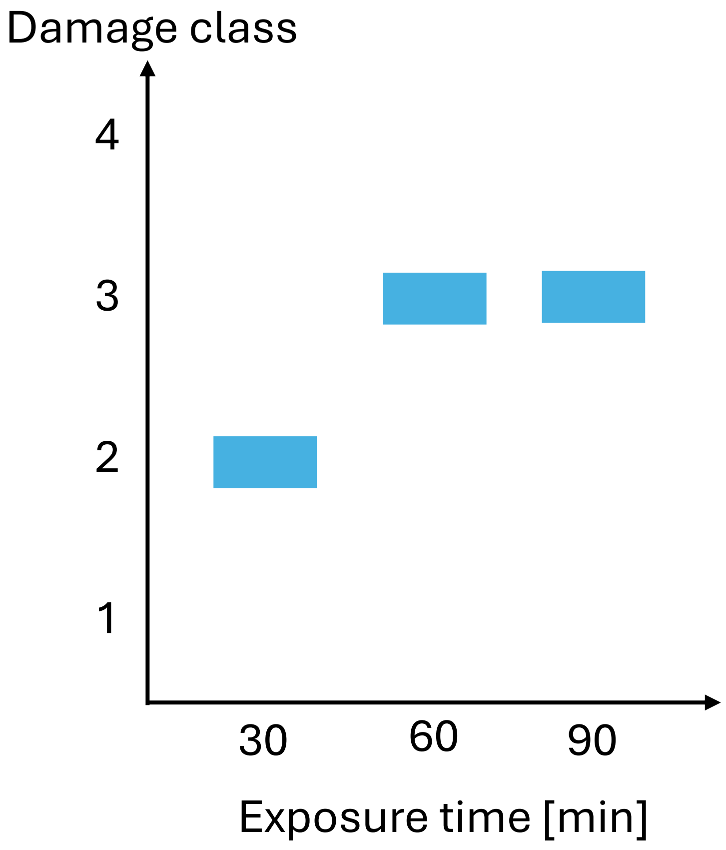


Damage classification of the sample column

Hydrocarbon Fire Curve + Cooling Phase







Conclusions

Main conclusions

- The average reduction in bond strength is similar to or larger than the reduction in residual concrete strength
- Thermal analysis is a quick and efficient method that can supplement existing techniques for assessing post-fire damage
- Considering the cooling phase of the fire is crucial for accurately evaluating the structure

Next step

- The proposed damage classification is being evaluated based on the residual capacity of sample structural elements obtained from finite element modeling

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Thank you!

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THE RESPONSE OF FIBER REINFORCED POLYMER COMPOSITE MATERIAL UNDER FIRE AND ITS MITIGATION METHODS

Ray Liang, Siddhant Sitoula, Chao Zhang,

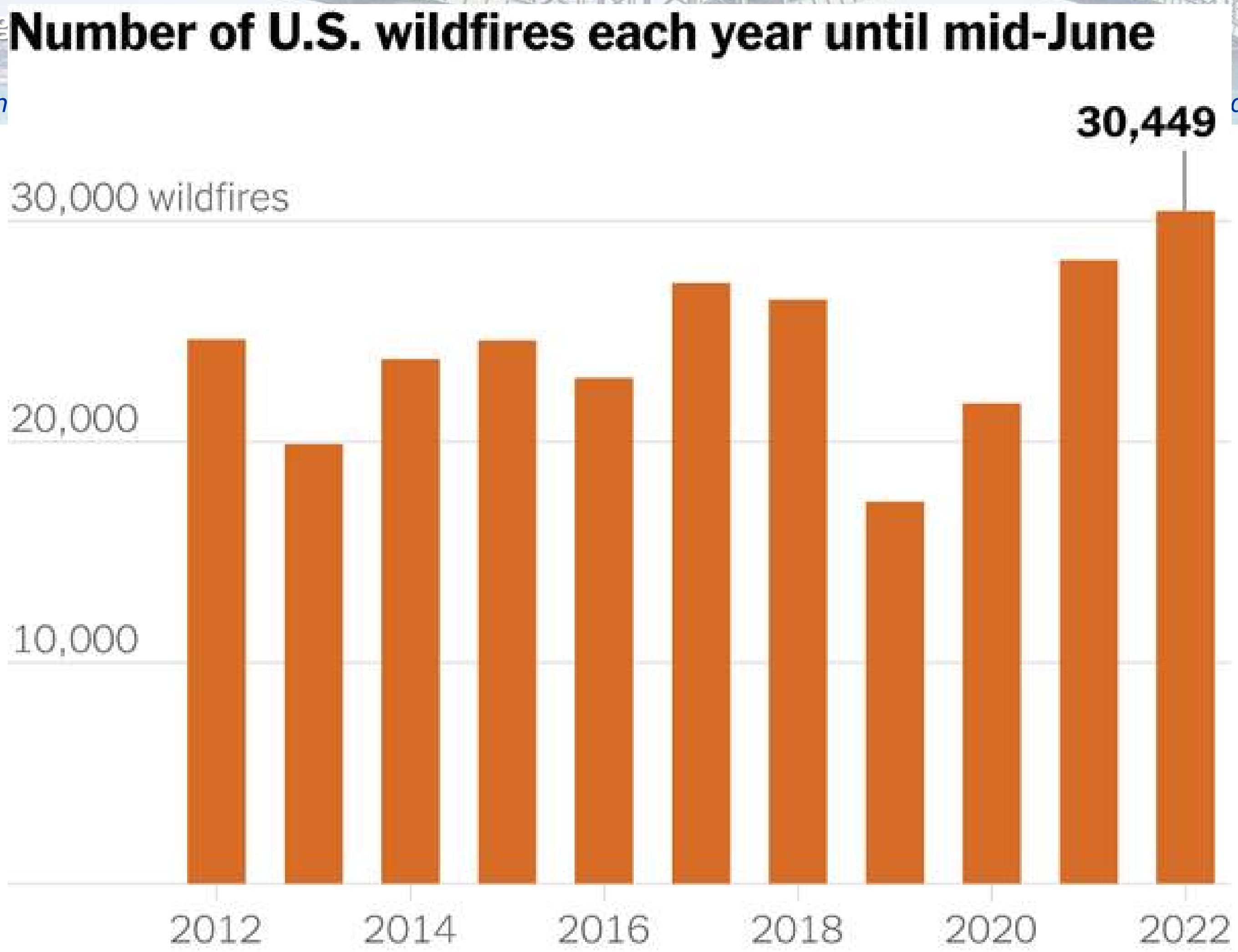
Hota Gangarao, Rakesh Gupta

Center for Integration of Composites into Infrastructure

West Virginia University
Where Greatness is Learned

Need and Industrial Relevance

- FRP poles have been receiving keen attention from utility companies due to their inherent advantages over wood, steel and concrete poles, especially for mountainous terrain.
- However, frequent wildfires pose a threat to these FRP composite poles without fire protection mechanisms.
- Fire performance of FRP composites is regarded as one of the top listed weaknesses.
- A better understanding of how FRP composite utility poles respond to wildfires is needed.
- Sponsored by Electric Power Research Institute (EPRI)



85% wildfires are caused by human activities!

Data until June 17 of each year. | Source: National Interagency Fire Center
Courtesy of Ashley Wu & Matthew Cullen, New York Times, June 20, 2022

Composite Poles and Crossarms under Fire Stress

Courtesy of RS Technologies

FRP Poles Survive under Wildfires

How can that be possible ?

Courtesy of RS Technologies

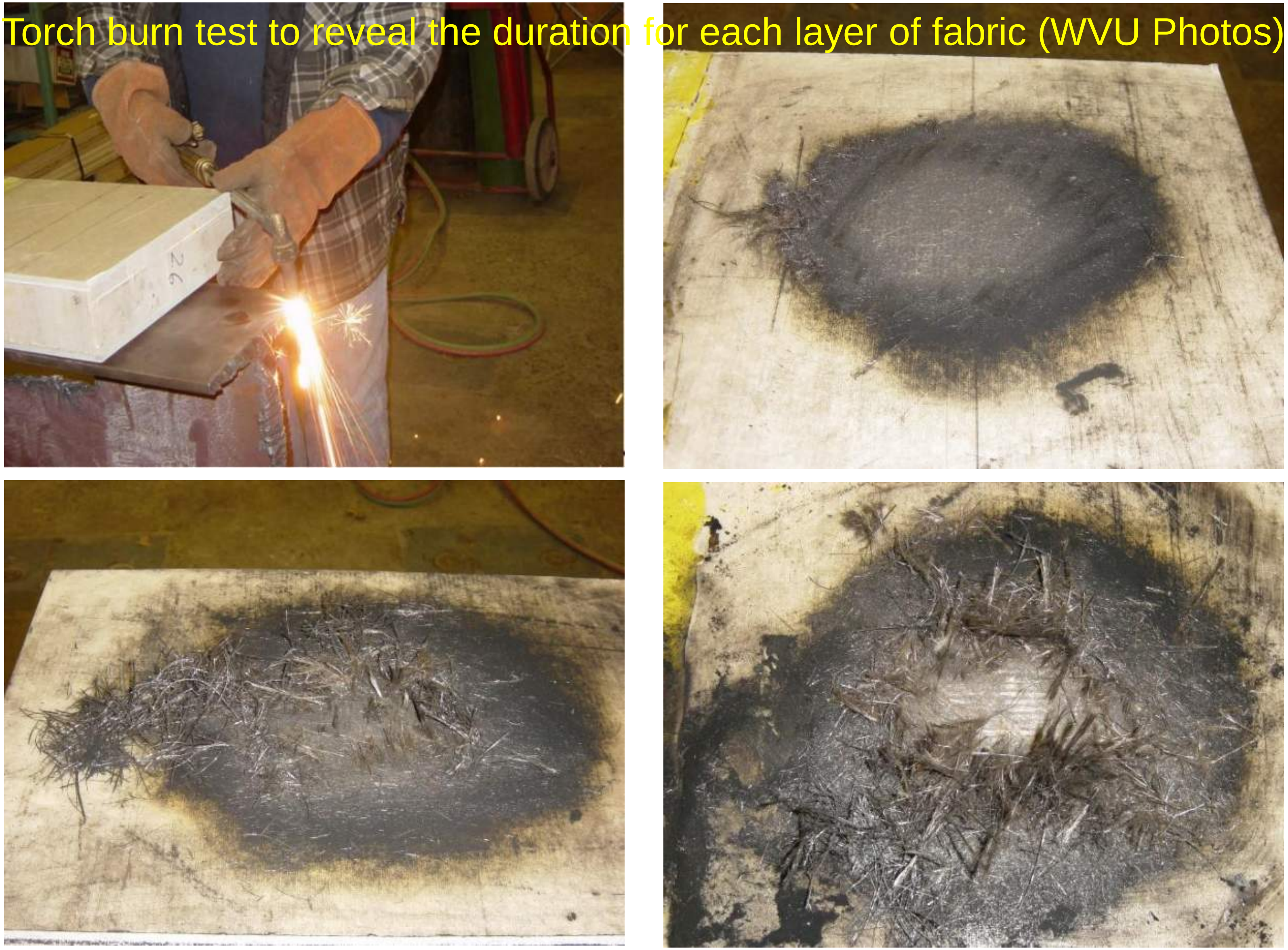
Research Objectives

To better understand the performance of GFRP composite under fire and its implication to FRP composite utility structures when exposed to wildfire related thermal stresses

- Review on fire performance of FRP composites
- Strength reduction under fire exposure for poles and crossarms
- Strategies to enhance the fire performance of FRP poles
- Evaluation of wildfire protection methods
- FRP wraps to restore the capacity of post-fire FRP poles and crossarms

Understanding delayed ignition and a phased burning due to protection of fiber layers of construction

Torch burn test to reveal the duration for each layer of fabric (WVU Photos)



Torch burn test to reveal the duration for each layer of fabric

Second torch burn test to monitor the temperature on back panel surface while torch burning on the front panel surface, showing no temperature change before and after burn test for a reasonable duration. (WVU Photos)

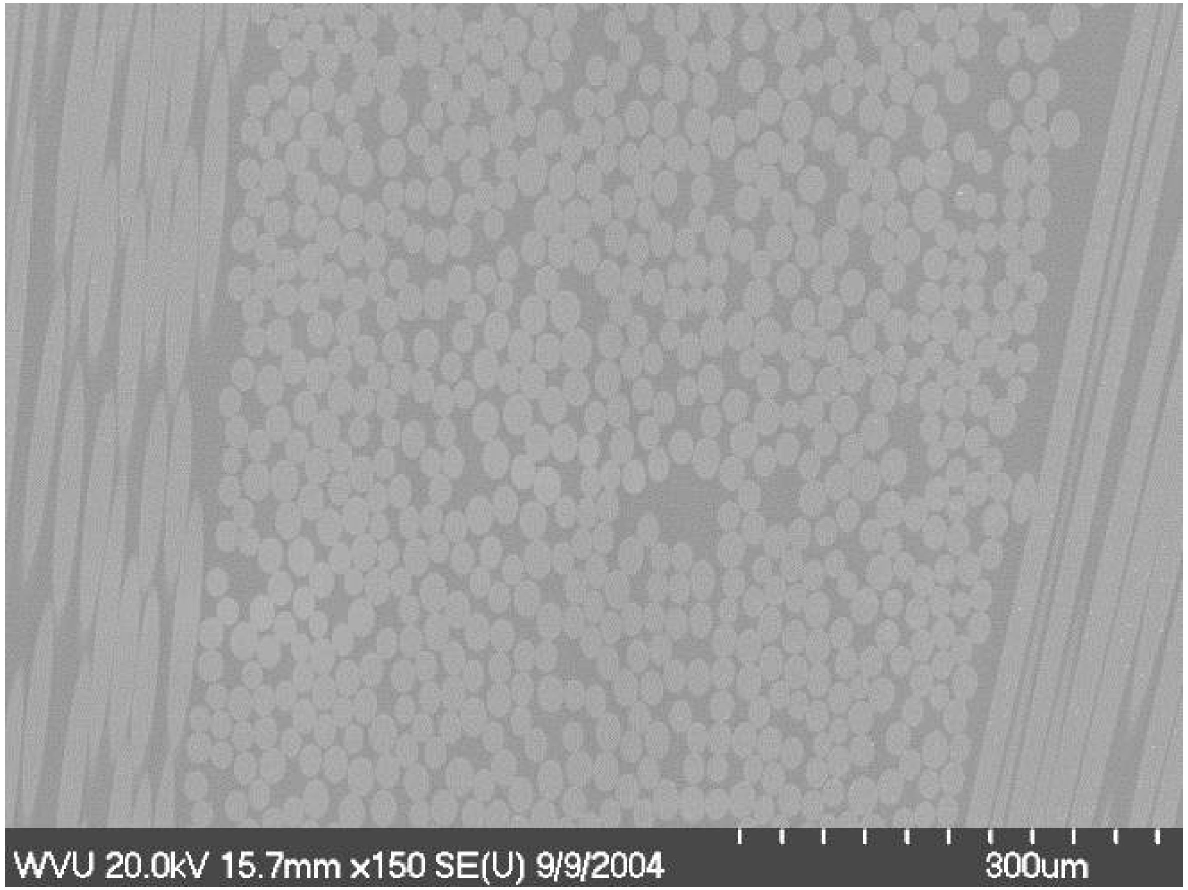
A Multi-stage Burning Process of GFRP Composite

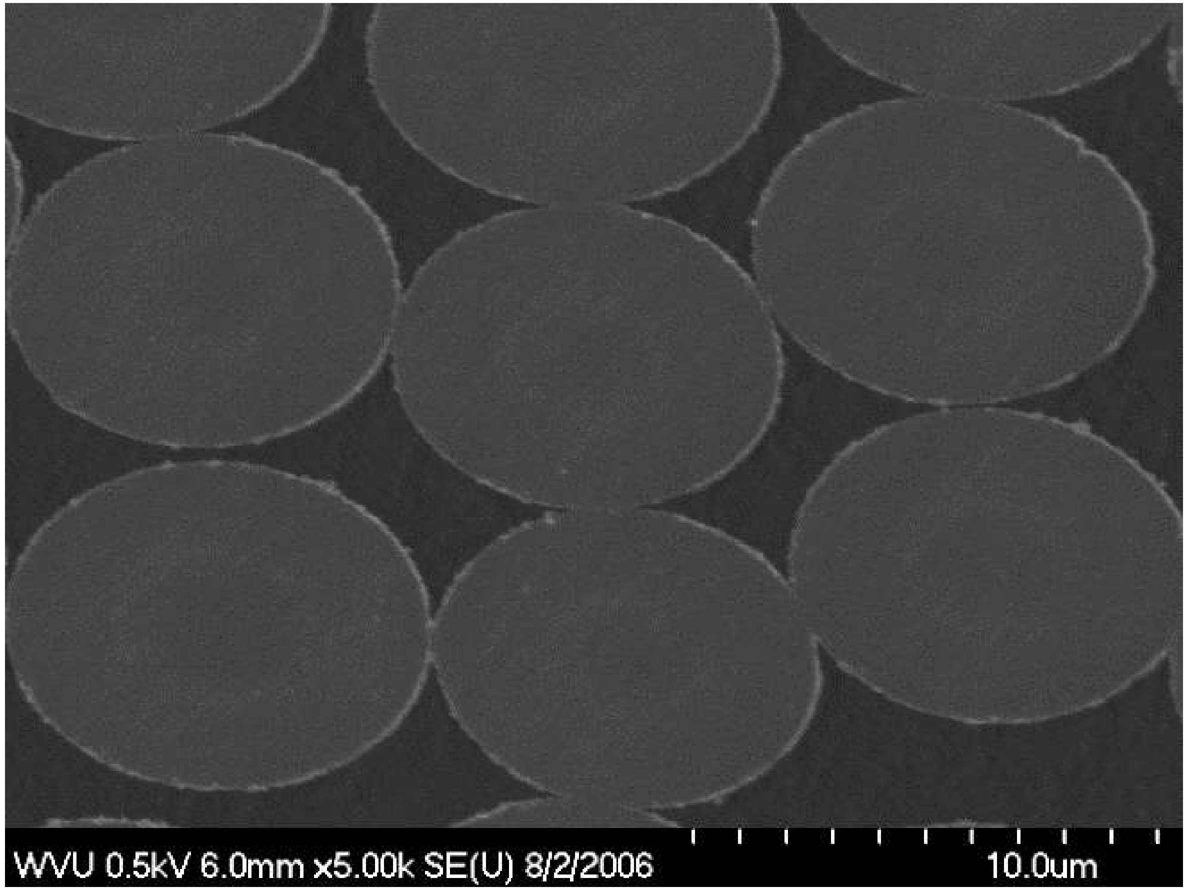
A phased burning feature of a GFRP laminae as reflected by the recurring of "loss and return" pattern of visibility in the test room

1 min 23 sec into test of four-inch thick composite deck panel as per Test Standard ISO 9705-1993

7 min after start of test of a multifunctional non-load-bearing wall panel with intumescent coating as per ASTM E119

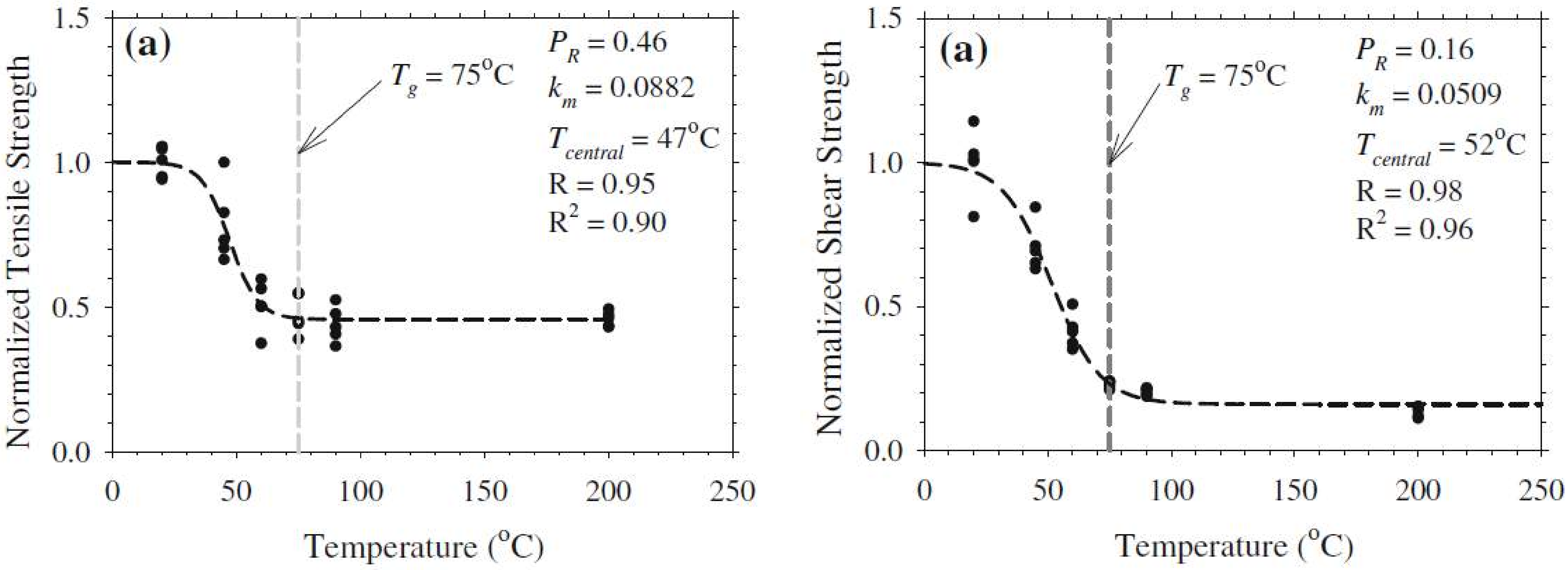
Layered Fiber Architecture of Composite and Its Implications to Fire Performance





SEM viewing of cross-sections of FRP composite (WVU Photos)

Properties of Composite Materials at Elevated Temperatures



Normalized tensile and shear strength as a function of temp. of epoxy based GFRP
[Adapted from Chowdhury et al., 2011].

Samples

- Poles from 4 manufacturers A, B, C, D.
  - ✓ Coded as A-P, B-P, C-P, D-P
- Crossarms from 6 manufacturers A, B, C, E, F, G.
  - ✓ Coded as A-C, B-C, C-C, E-C, F-C, G-C



Simulated Wildfire Exposure

- Develop flame exposure test
- Subject samples to fire for 1,2,3 minutes
- Measure mechanical properties under bending and short beam shear
- Analysis of the data for reduction models
- Apply various protection methods to samples
- Evaluate the effectiveness of each method

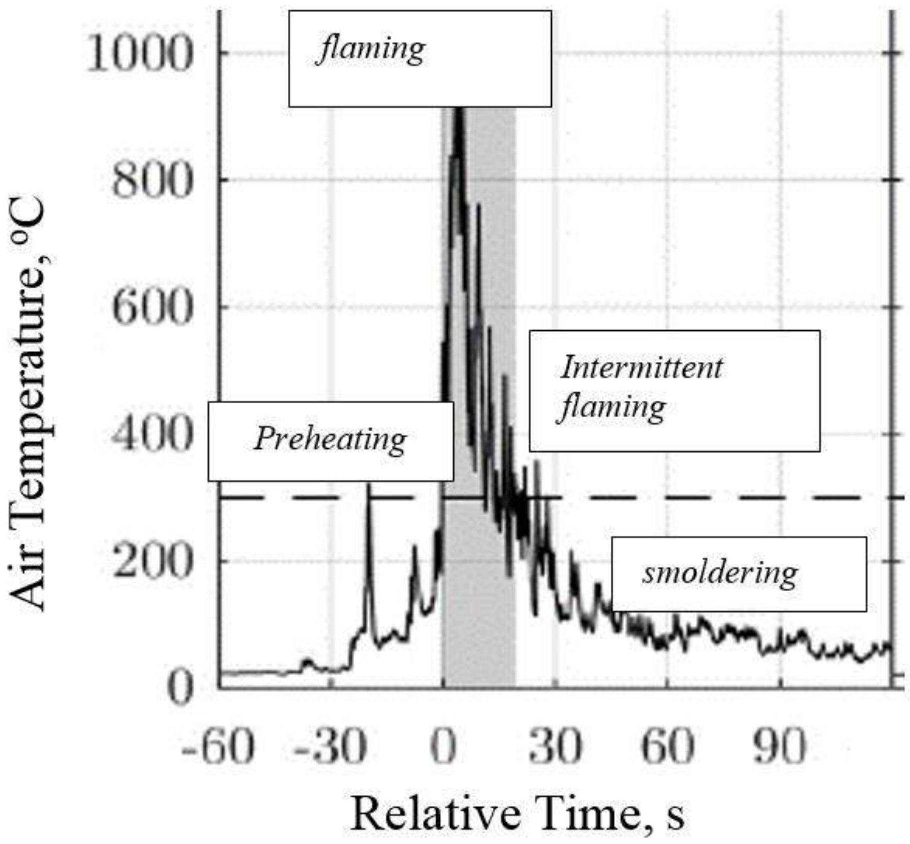
Simulating Wildfires

Wildfires are uncontrolled burning of vegetation in uninhabited and wildland-urban interface areas ignited due to many natural and human causes (85%).

- Temperature range, heat flux, exposure time
- Ground fires, surface fires and crown fires
- Wildfire behavior is complex

Air temperature as the fire front approaches and various stages of burning [Mueller et al., 2018]

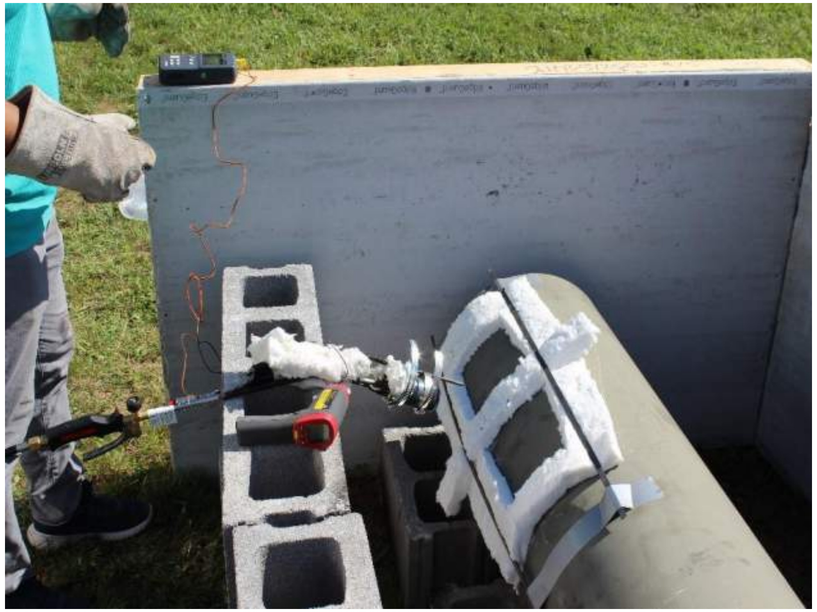
- Typical fire duration is 45-60 sec
- Typical fire temp peak below 1000 C
- Moderate: 30 to < 90 sec
- Severe: 90-120 sec
- Extreme 121 to 180 sec

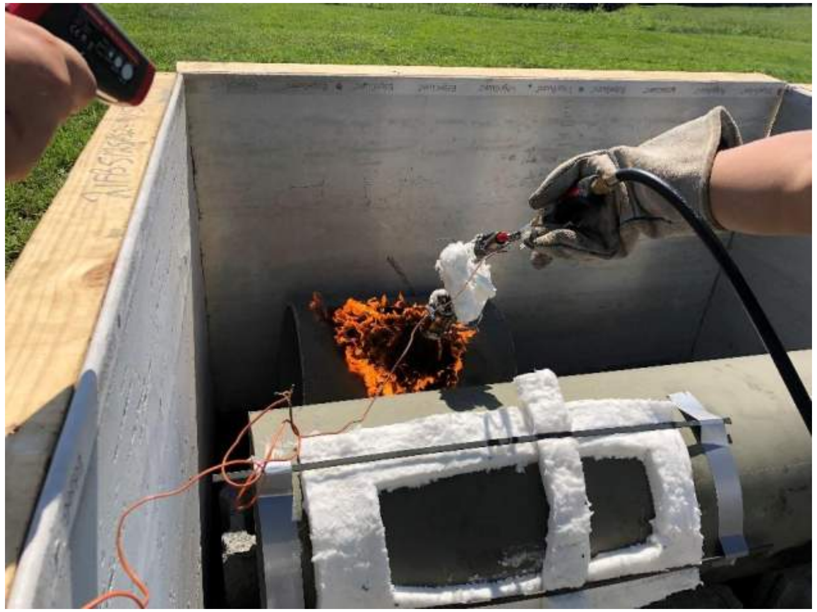


Layers of A Fire

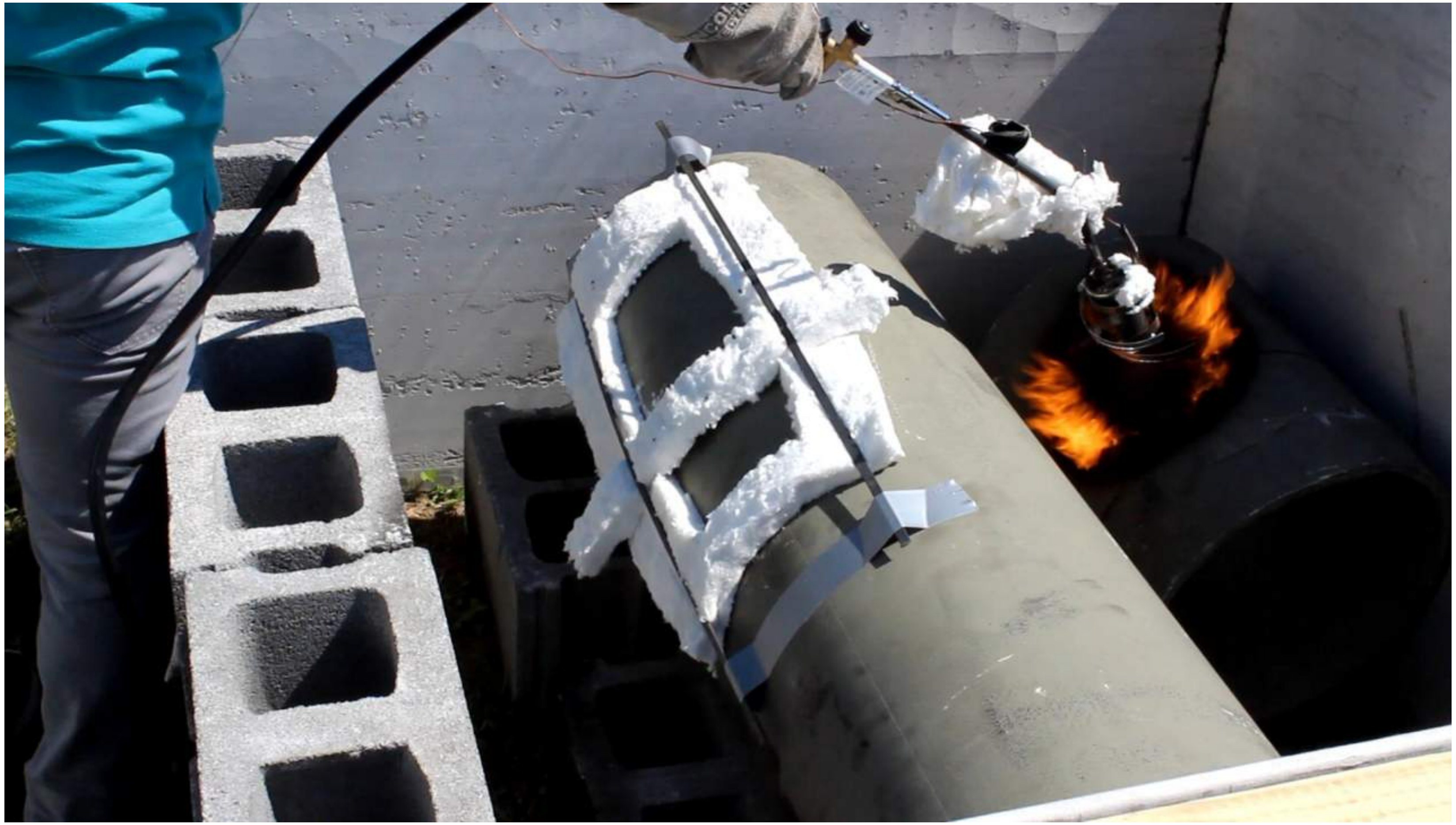
Fire Exposure 1000C, 1-2-3 minutes

"A regional collaboration promoting holistic resilient and sustainable infrastructure solutions with a focus on efficient highway and pedestrian bridges and structures"

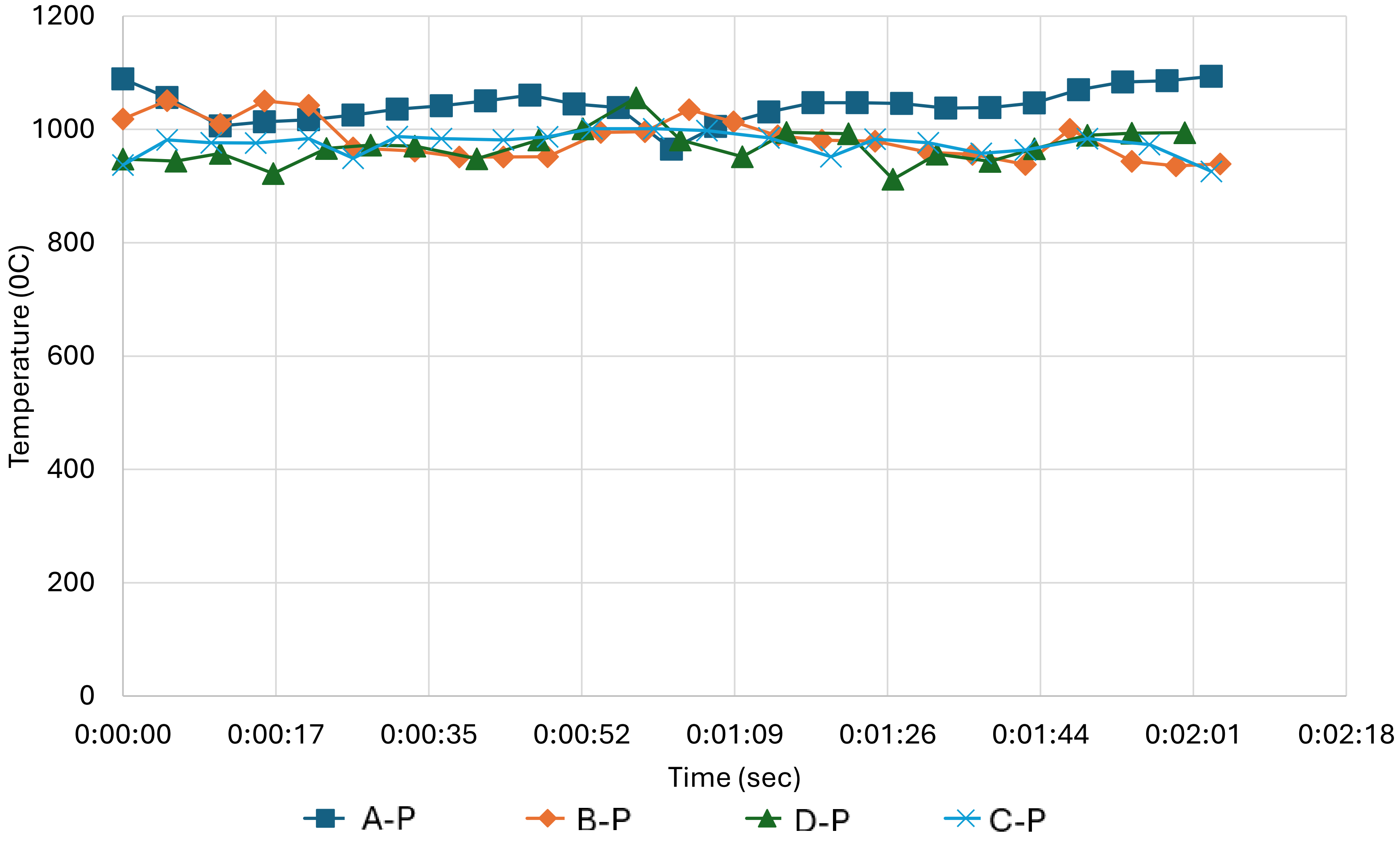




Flame Exposure Test 1000C, 1-2-3 minutes

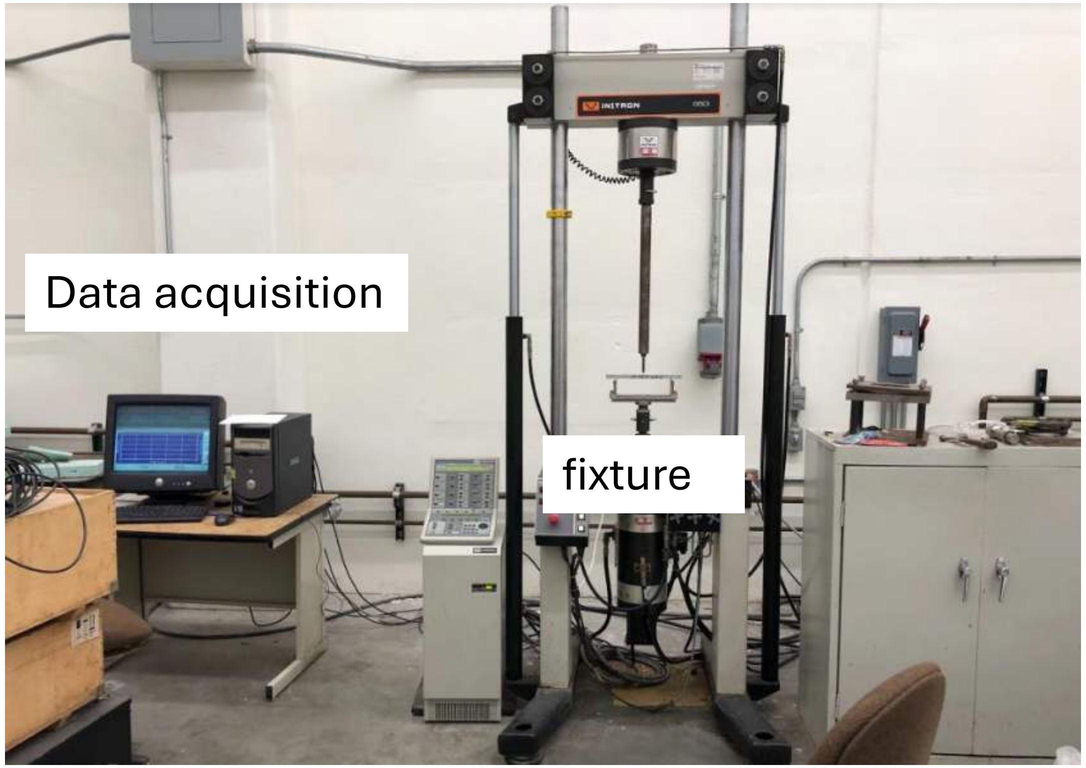


Sample temperature profile of the flame impacting the surface of the pole samples for 2 min duration



Mechanical Test-setup

- ASTM D790-17 for the bending test
- ASTM D2334-16 for the short beam shear test



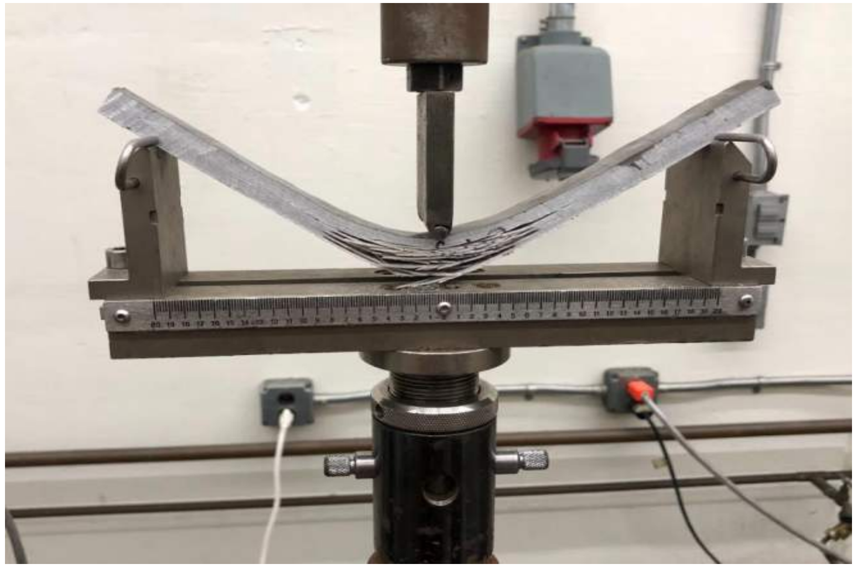
$\frac{L}{d}$=16 for bending test

$\frac{L}{d}$=4 for short beam shear test

L= Span length of specimen
d= thickness of the sample

Number of bending Tests: 229
Number of shear Tests : 99
A total number of Mech Tests: 328

Mechanical Test-setup

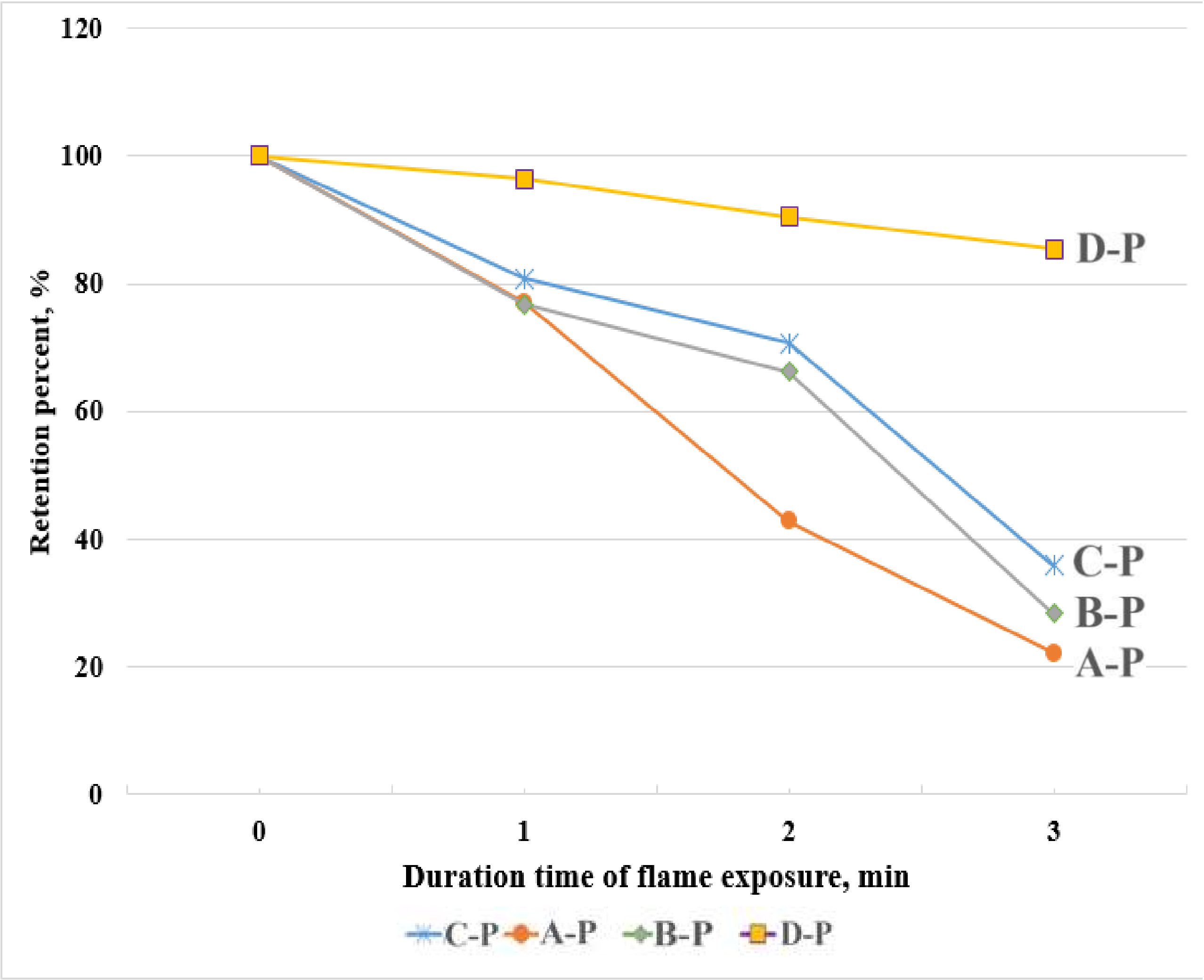


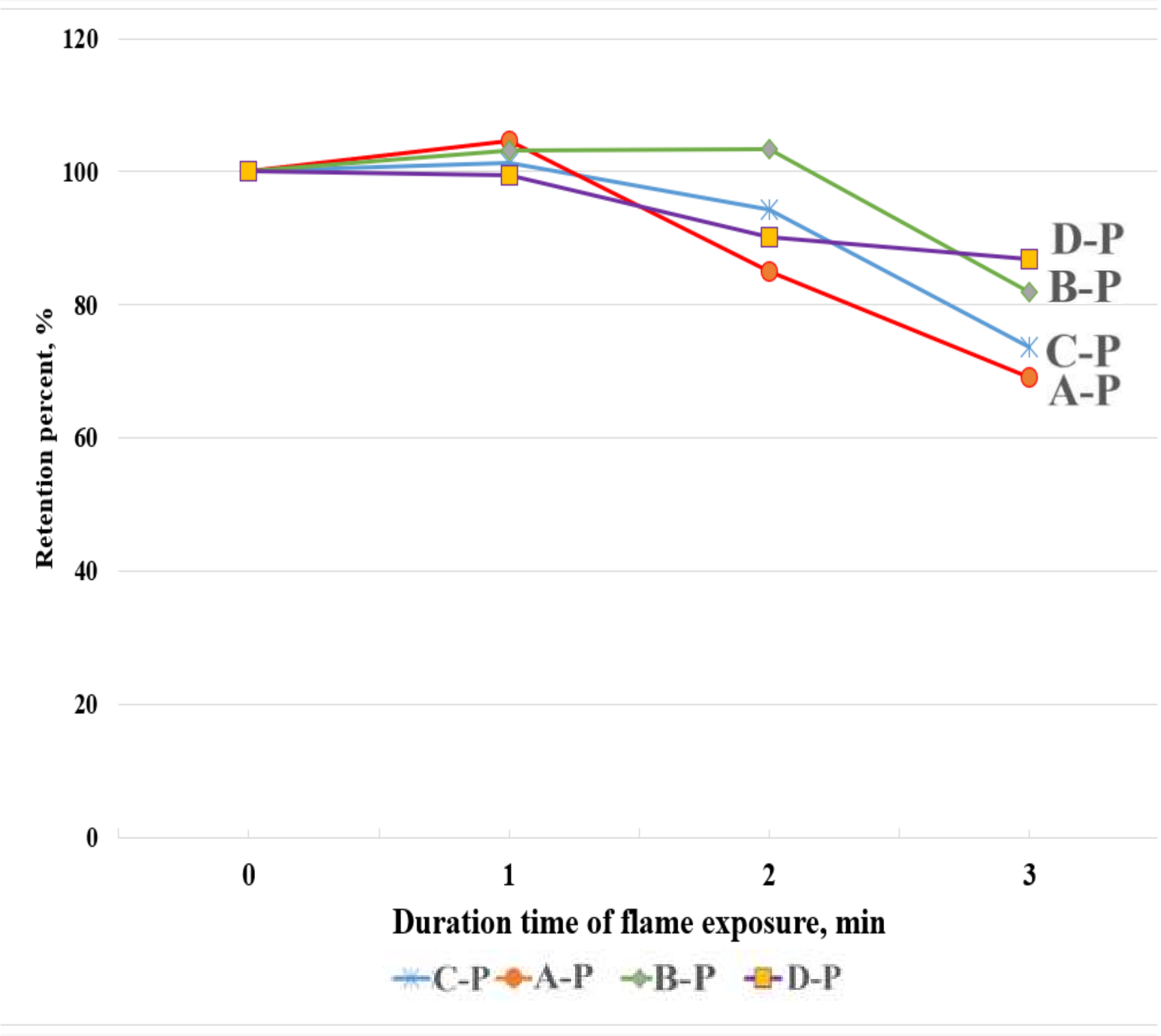
Three-point bending test on a sample

Short-beam shear test on a sample

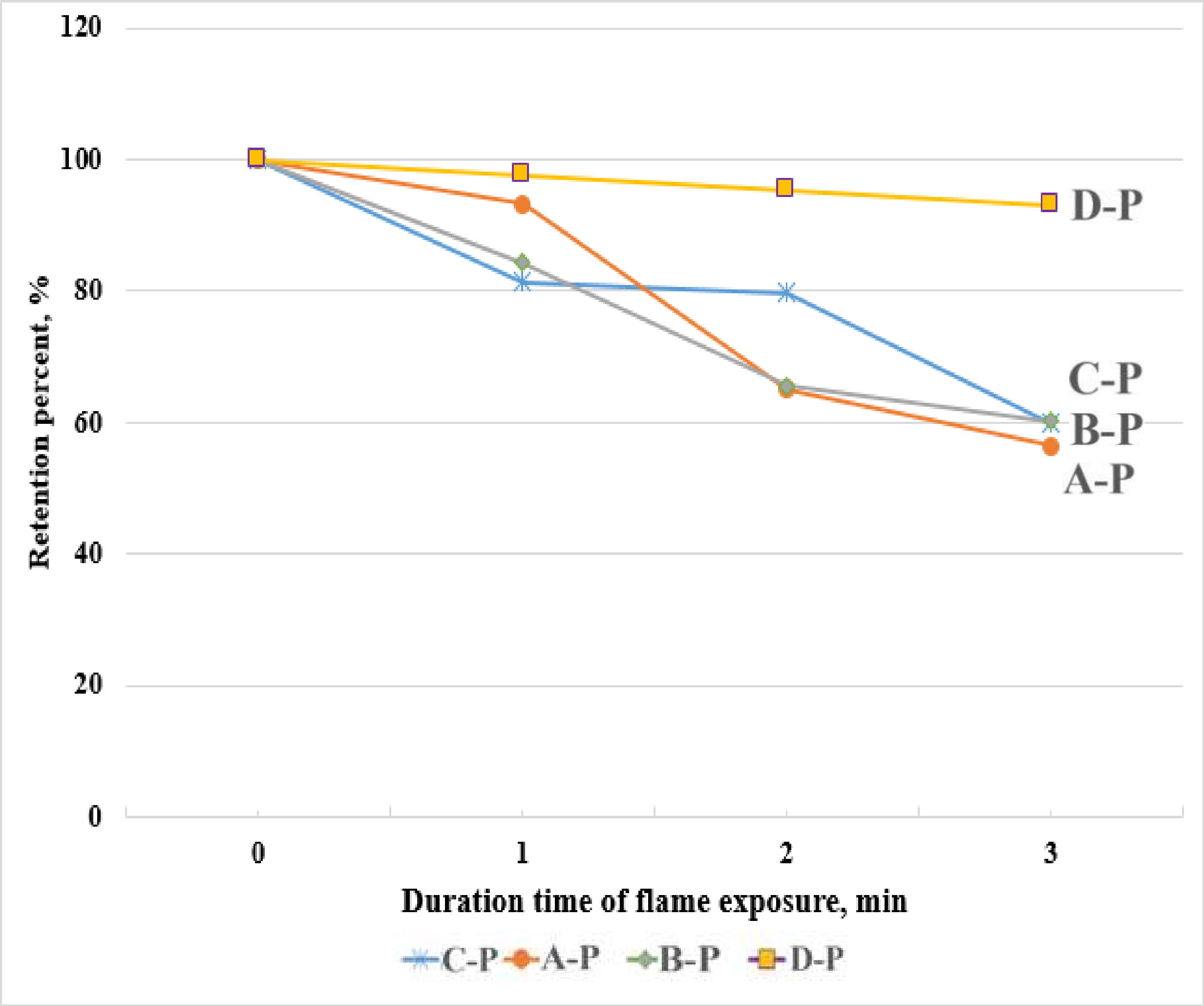
- Tests were conducted by applying load on both unburnt and burnt sections/surfaces of the specimens.
- Bending and short-beam shear tests were conducted for poles.
- Only bending tests were conducted for cross-arms.

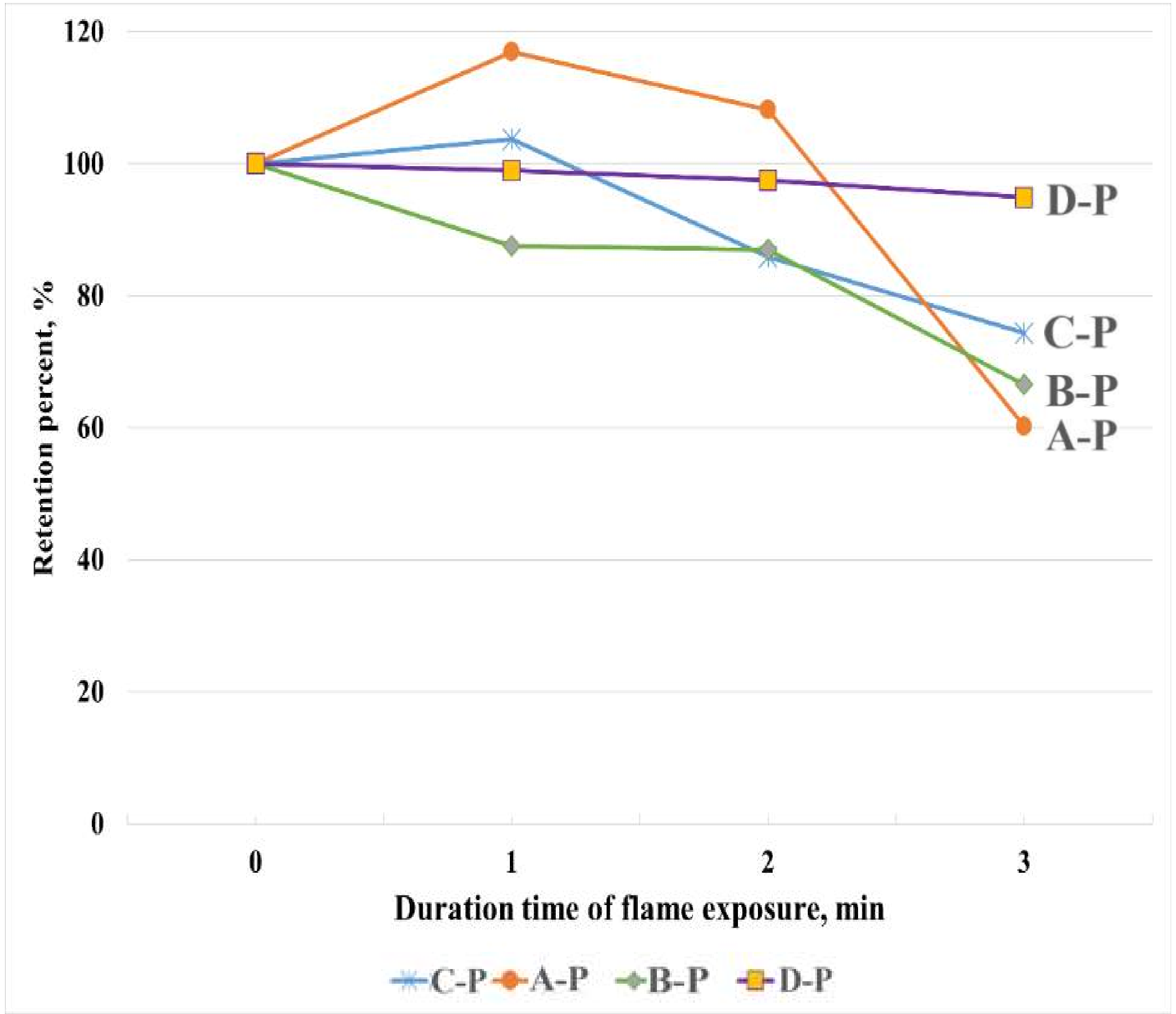
Bending Strength Retention Percentage for Uncoated (left) and Coated (right) Poles



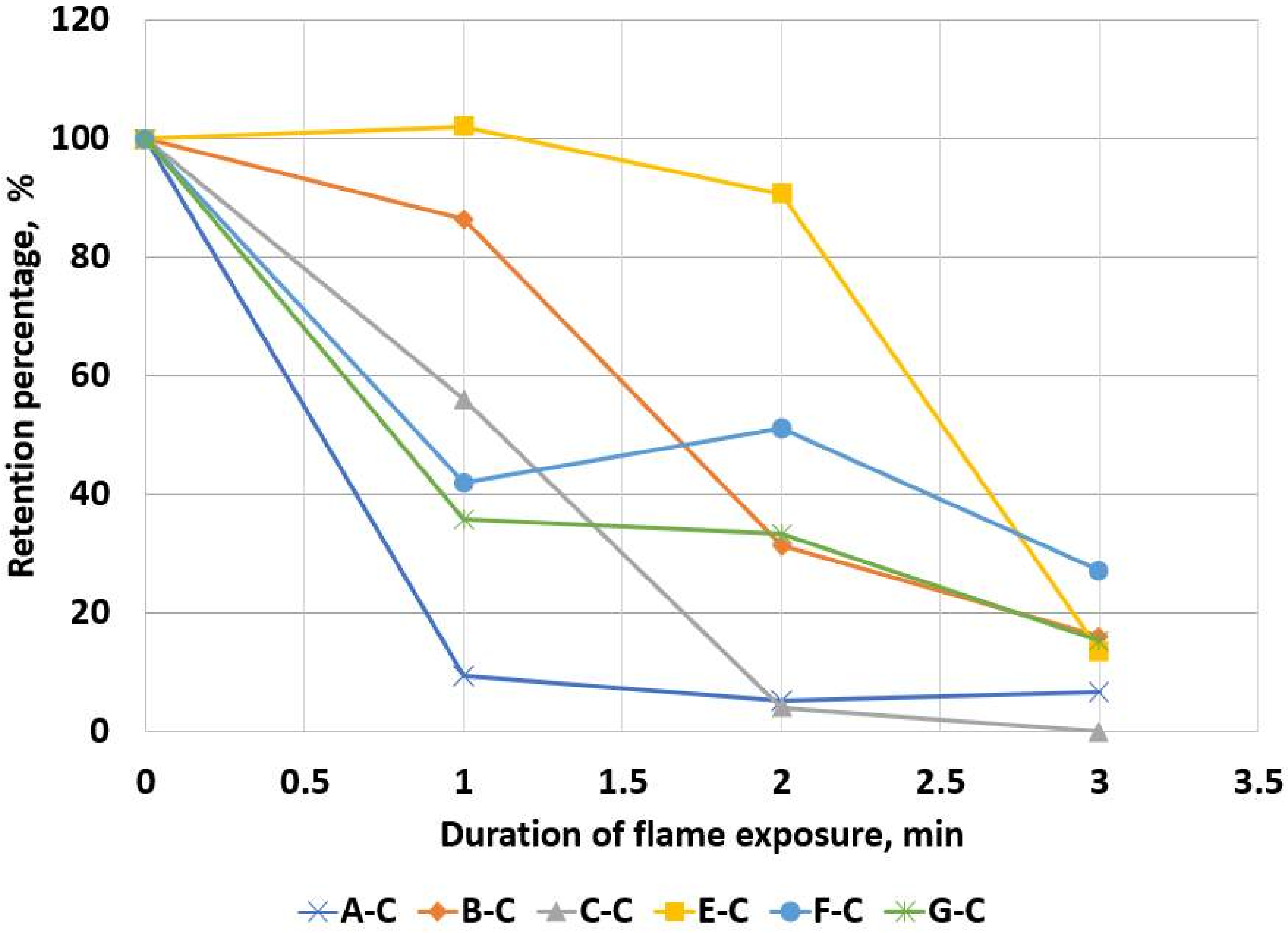


Shear Strength Retention Percentage for Uncoated (left) and Coated (right) Poles





Percentage of bending strength retention for different manufacturers' crossarm samples

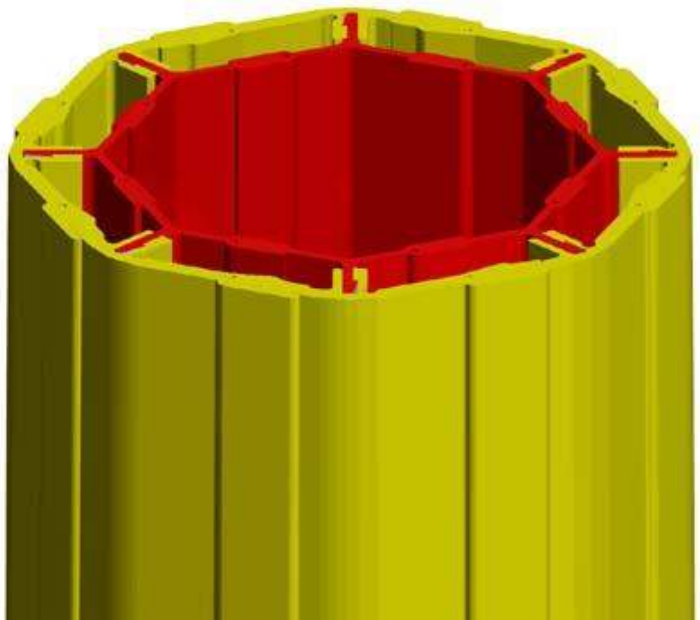


Remarks on Mechanical Property Data

- For uncoated poles, the strength is able to be retained at
  - 1 min fire exp: 85-98% under shear, 78-95% under bending
  - 2 min fire exp: 70-95% under shear, 70-91% under bending
  - 3 min fire exp: 55-90% under shear, 32-88% under bending
- For uncoated crossarms, the strength under bending is able to be retained at 60-95% for 1 min fire exp

Strategies to Minimize Fire Hazard

- Better resin formulation with higher filler content
- Innovations in fiber materials and architecture
- Use of intumescent coating
- Use of fire retardant core materials
- Use of fire resistant sheeting
- Smart design such as double wall system (Heil, 2001)

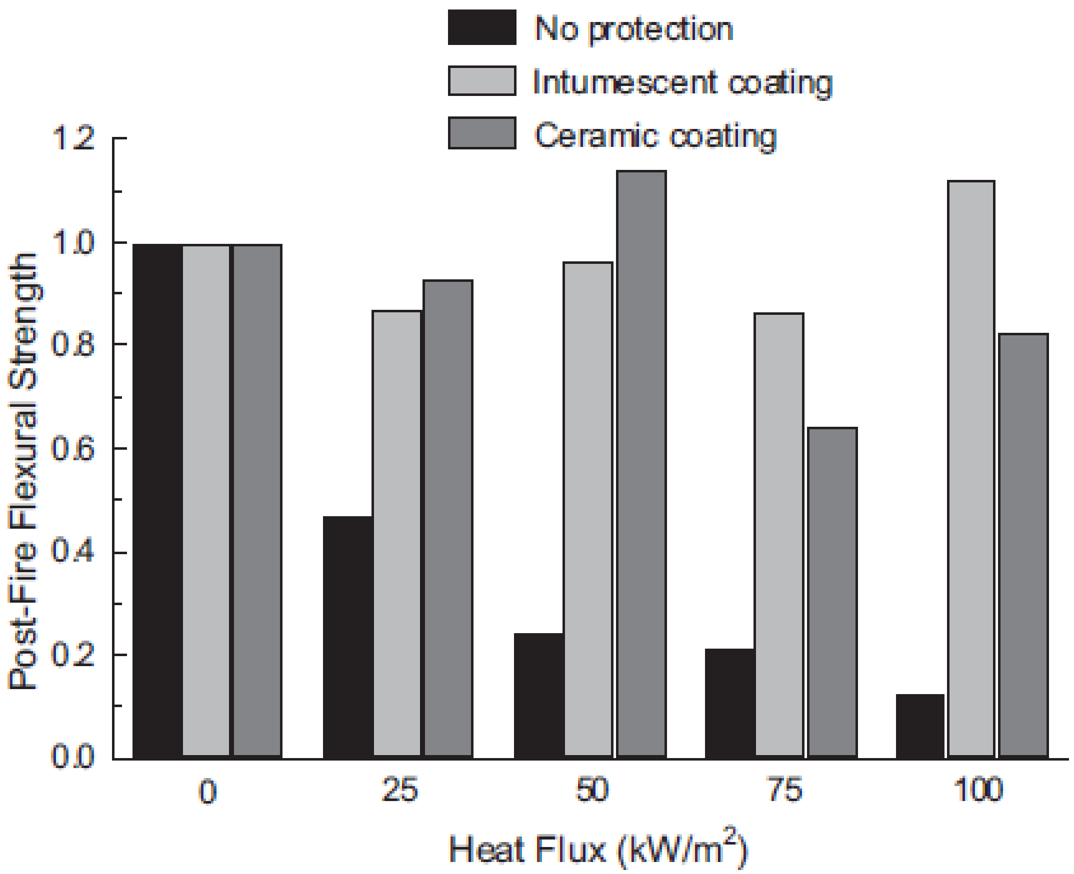


Improving Fire Resistance

Phenomenon of fire progression: thermal decomposition and formation of solid residue; violatile gases react with oxygen and gives off heat

Methods:

- Use flame retardants such as aluminum trihydroxides (ATH) as filler
- Halogen additives to prevent gases reacting with oxygen
- Use phosphorous as retardant to promote char
- Use intumescent coating



Effect of fire protection coatings on the residual flexural strength [Mouritz and Gibson, 2006].

Application of Intumescent Coating

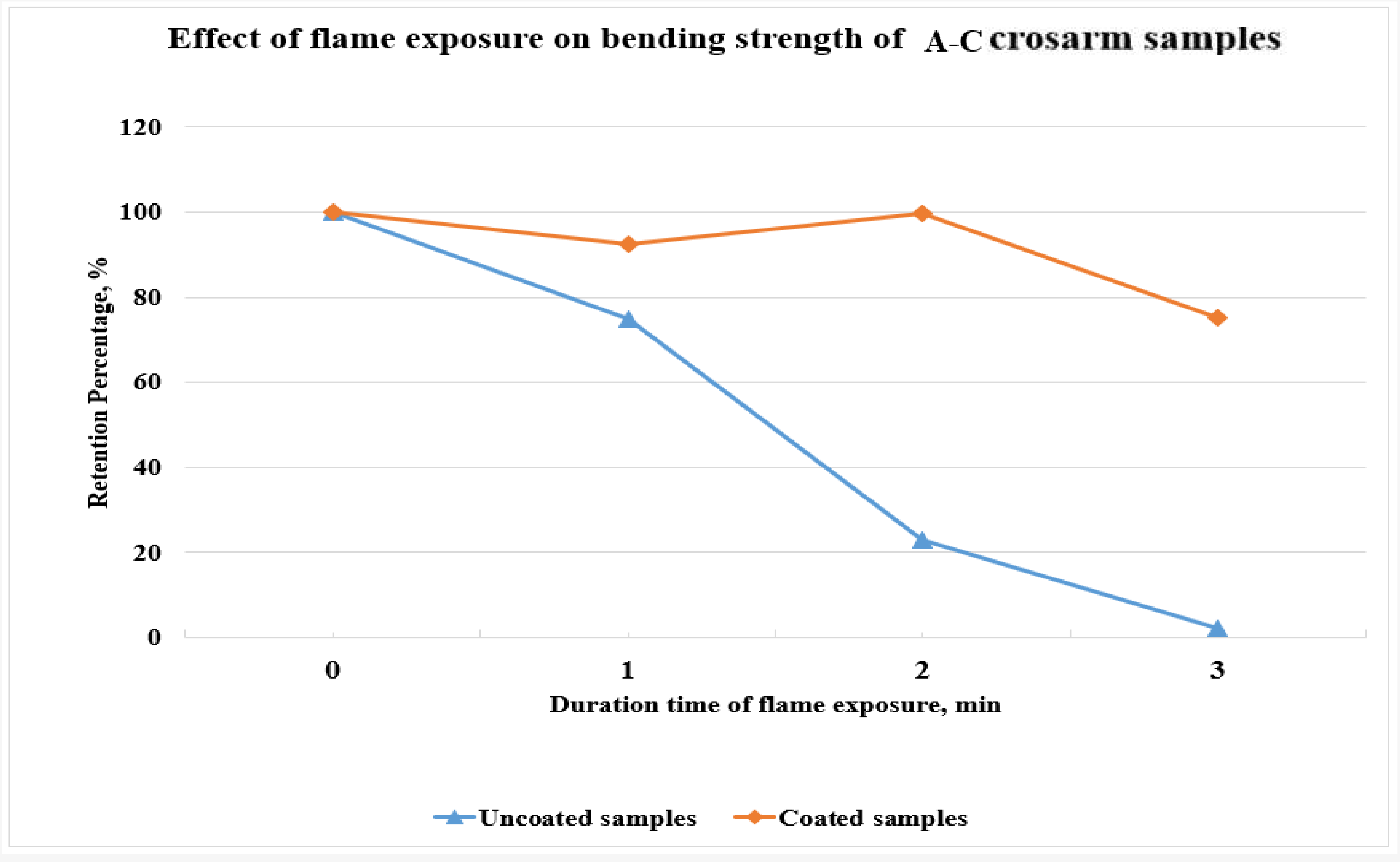
Poles with Protective Sleeve

Manufacturer A

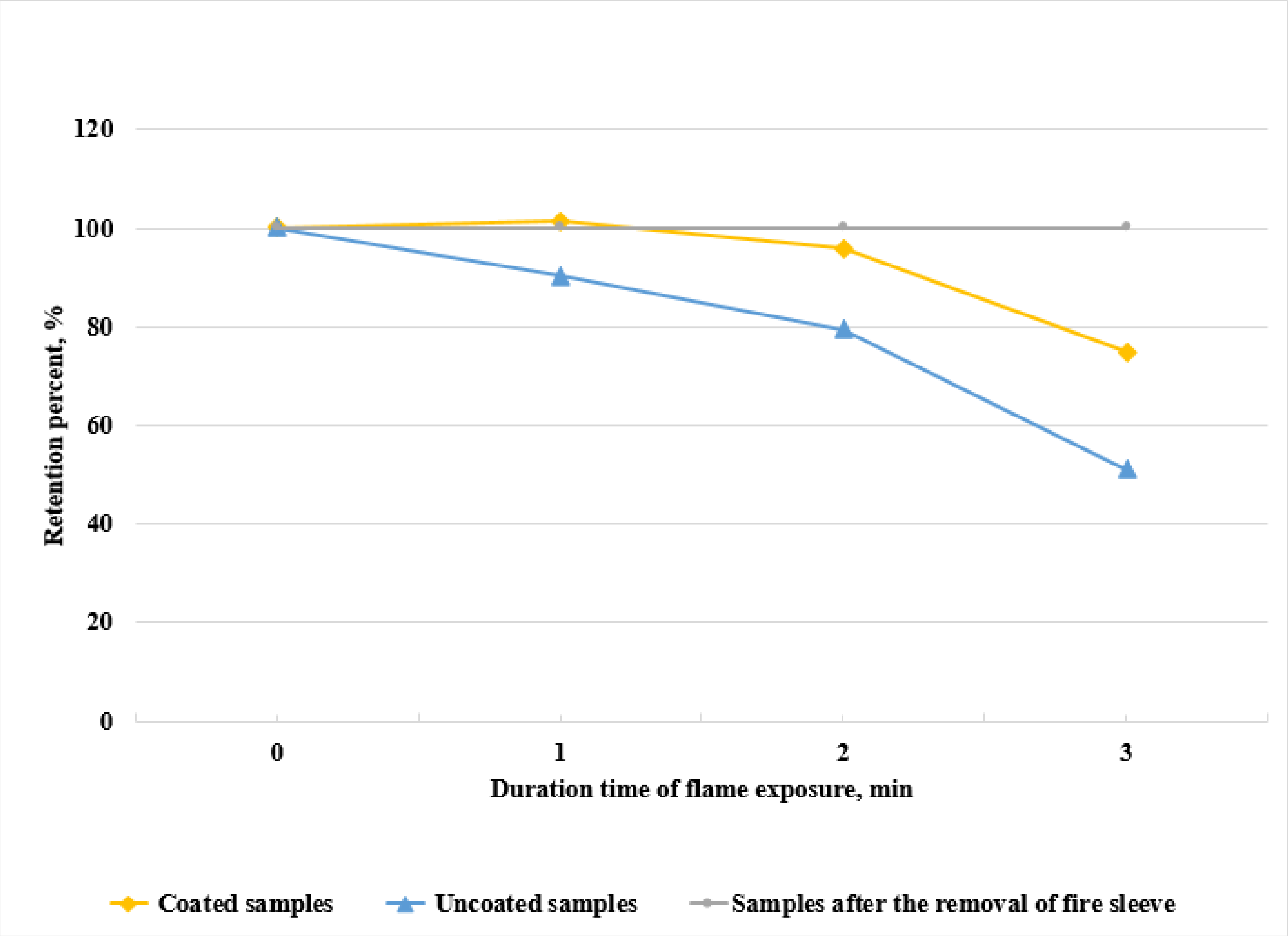
Manufacturer B

Bending Strength of Manufacturer A Crossarm Samples

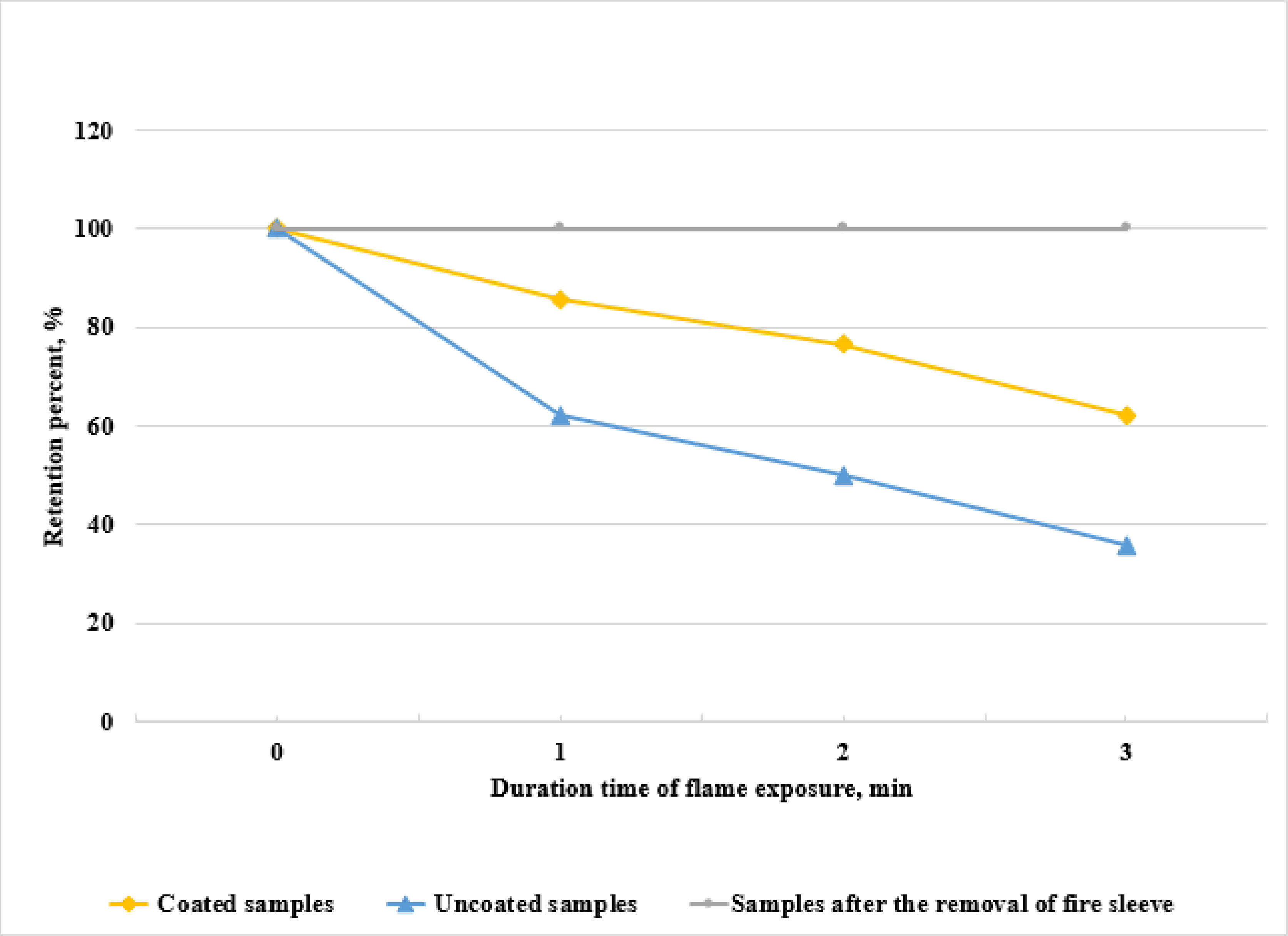
"A regional collaboration promoting holistic resilient and sustainable infrastructure solutions with a focus on efficient highway and pedestrian bridges and structures"



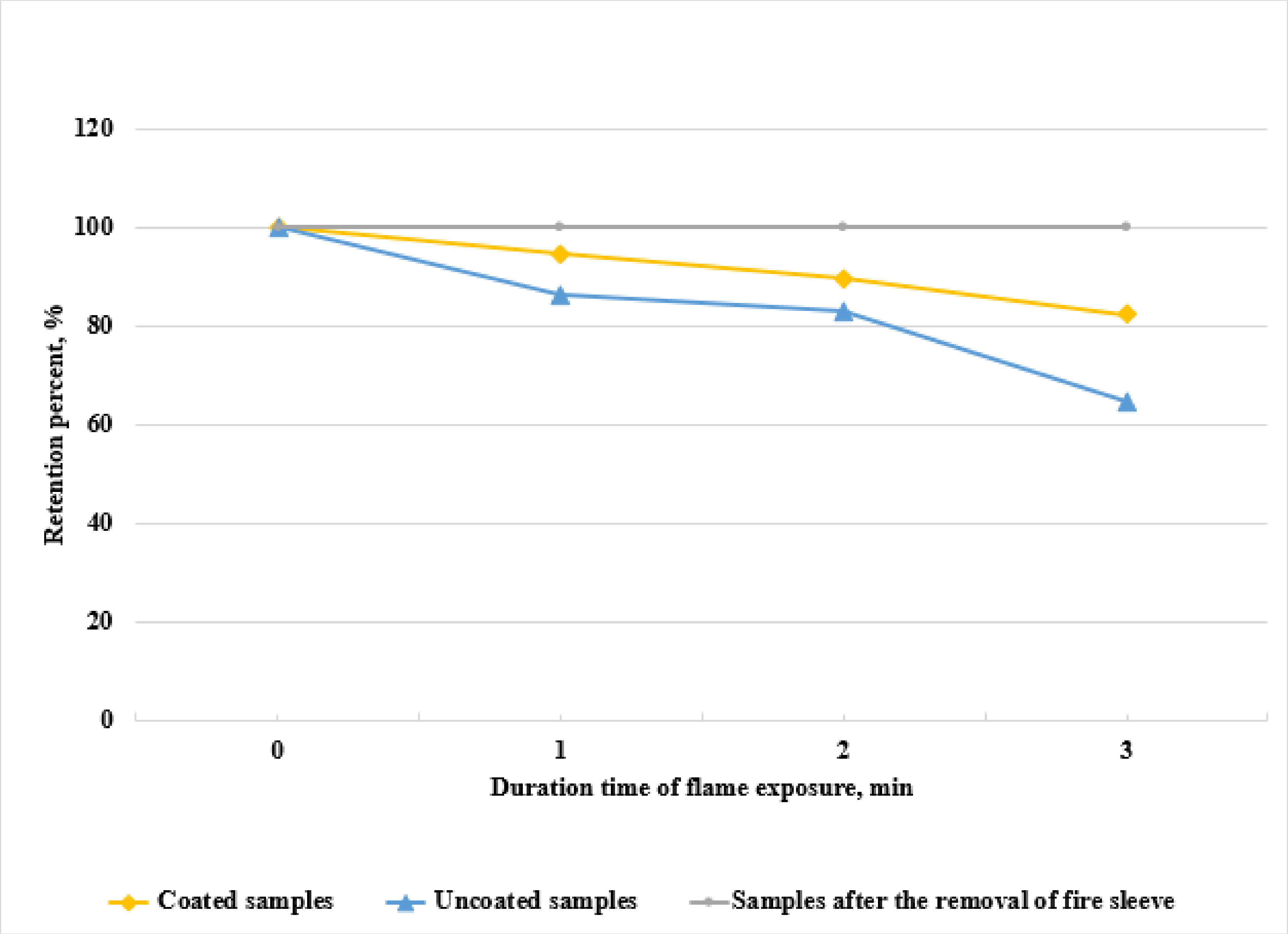
Bending Strength of Manufacturer A Composite Pole



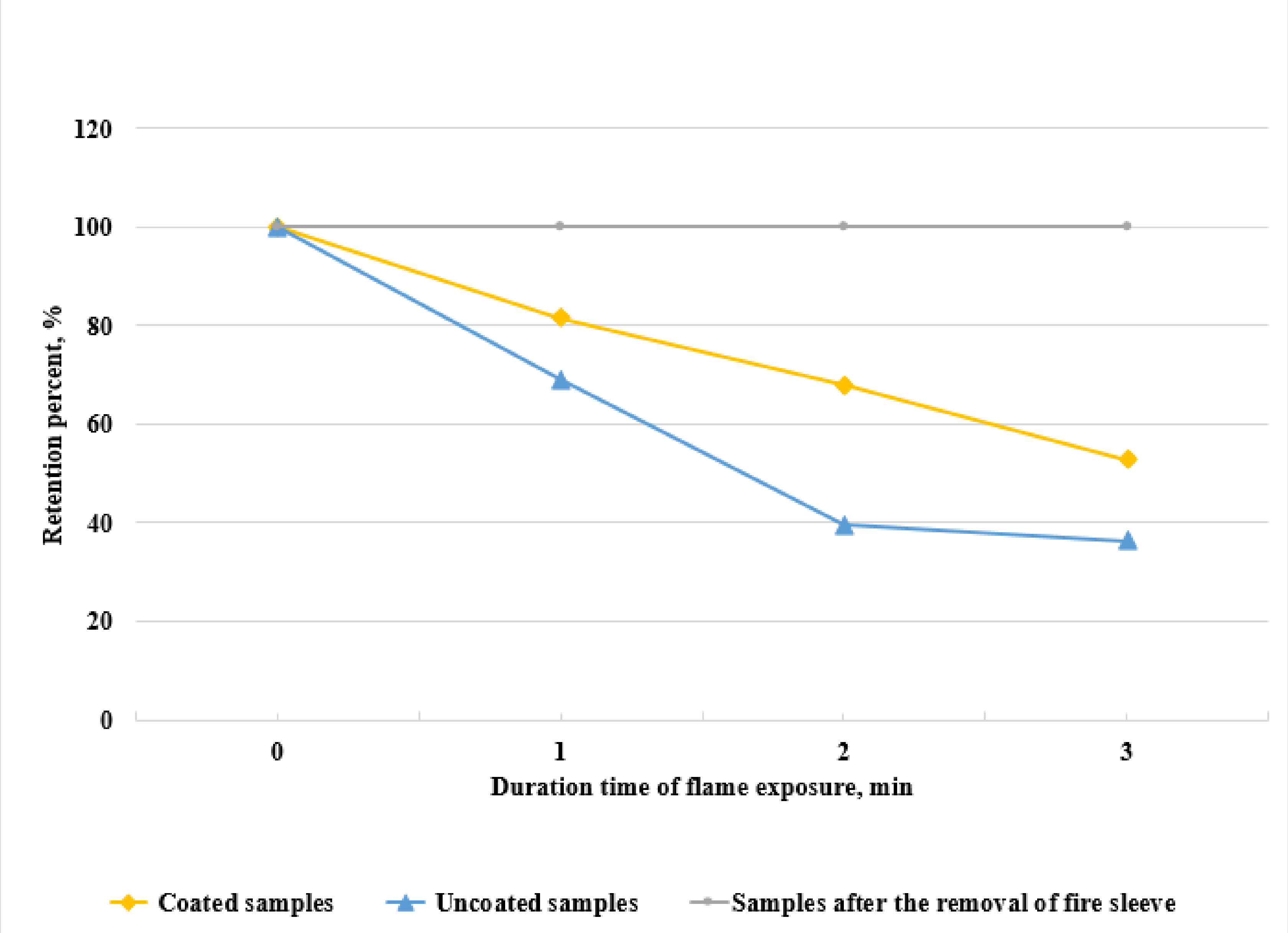
Bending Strength of Manufacturer B Composite Pole



Shear Strength of Manufacturer A Composite Pole



Shear Strength of Manufacturer B Composite Pole



Effectiveness of Fire Protection Methods

Protection Method	Protection Effectiveness	Material Cost	Labor Cost	Notes
Intumescent Coating	Moderate to high	$1/ft $50 for 50 feet pole	$150 (automation)	Labor cost will be higher if NOT automated, $300
Sleeve	Full	30% additional per pole $1500 for 50 feet pole	$500	Protection sleeve only applicable to 1 feet below ground and 20 feet above ground

Conclusions and Impact

- Self-extinguishing after wildfire exposure with damage to outer layers only
- Our study has identified FRP burning as a phased process due to layered fiber construction even without intumescent coating. This multi-stage burning process appears unique in the fire behavior of GFRP composites.
- FRP utility poles, especially with use of intumescent coatings, are able to survive from general wildfires. This conclusion will help utility industries to use FRP poles with confidence.
- FRP utility poles with protective sleeve offer the best protection again wildfire but at additional high cost.
- FRP wraps readily available can be used to retrofit the post-fire utility poles, if needed. This will further release potential concerns from utility industries.

Design of FRP Composite Structures with FRP Reinforcements

- **Instructor:**

  Hota GangaRao, PhD, PE,

  Wadsworth Distinguished Professor, CEE Department, Statler College, WVU

  Director, NSF IUCRC- CICI and WVU-CFC
- **Fall 2024-Course Number: CE 493B (WVU)**
- This course will provide a comprehensive understanding of the design and application of FRP composites in structural engineering.
- Detailed Course Outline is available.
- **POC:**

  Hota Gangarao Hota.Gangarao@mail.wvu.edu

  304 293 9986

Northeastern Peer Exchange for Resilient and Sustainable Bridges

August 7, 2024 – Buffalo, NY.

University at Buffalo

Institute of Bridge Engineering

Analyzing Shear Strength of the Lightweight Concrete Reinforced with Glass Fiber Reinforced Polymer (GFRP) Bars

Saeid Haji Ghasemali

State University of new York at Canton (SUNY Canton)

Analyzing Shear Strength of the Lightweight Concrete Reinforced with Glass Fiber Reinforced Polymer (GFRP) Bars

Short Biography of speaker(s)

✓ **Dr. Saeid Haji Ghasemali , Associate Professor, SUNY Canton**

Education: Ph.D. in Structural Engineering

✓ **Professional Roles:**

Associate Professor, SUNY Canton

Senior Structural Engineer, Reinforced Earth Company Ltd., Mississauga, Canada

Licensed P.Eng. in Ontario and Nova Scotia

Active in ACI and CSA-S6 technical committees

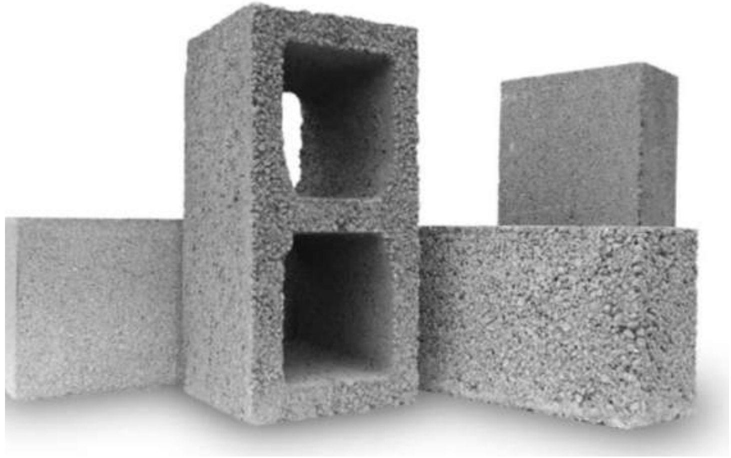
✓ **Research Focus:**

GFRP-reinforced concrete, Lightweight concrete

Analyzing Shear Strength of the Lightweight Concrete Reinforced with Glass Fiber Reinforced Polymer (GFRP) Bars

- **Introduction**
- **Lightweight concrete**

✓ Increased Transport Efficiency
✓ Reduced Dead Load
✓ Improved Thermal Insulation



Virginia Dare Bridge – Manteo, NC

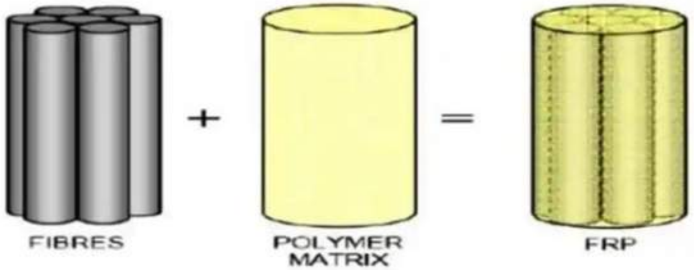
Raftsundet - Norway

Analyzing Shear Strength of the Lightweight Concrete Reinforced with Glass Fiber Reinforced Polymer (GFRP) Bars

• Introduction

- **GFRP (Glass Fiber Reinforced Polymer)**

✓ Corrosion Resistance
✓ High Tensile Strength
✓ Lightweight Profile
✓ Significant effect on Carbon Foot print



Analyzing Shear Strength of the Lightweight Concrete Reinforced with Glass Fiber Reinforced Polymer (GFRP) Bars

- **Introduction**

Wotton Bridge (Quebec, Canada):

Analyzing Shear Strength of the Lightweight Concrete Reinforced with Glass Fiber Reinforced Polymer (GFRP) Bars

- **Introduction**

Halls River Bridge (Florida, USA)

Analyzing Shear Strength of the Lightweight Concrete Reinforced with Glass Fiber Reinforced Polymer (GFRP) Bars

Investigating shear strength

- Ensuring structural integrity
- Refining design codes
- Optimizing GFRP use in lightweight concrete
- Enhancing construction efficiency
- Minimizing maintenance needs
- Promoting sustainability in construction

Analyzing Shear Strength of the Lightweight Concrete Reinforced with Glass Fiber Reinforced Polymer (GFRP) Bars

Environmental Impact of FRP vs. Steel Reinforcement

Sustainability of Alternative Reinforcement for Concrete Structures: Life Cycle Assessment of Basalt FRP Bars

Author: A. Pavlović, T. Donchev, D. Petkova, N. Staletović

Environmental Impact Comparison:

- **BFRP Bars:**
- ✓ Lowest environmental impact compared to all other materials (steel, stainless steel, galvanized steel, GFRP).
- ✓ Global Warming Potential (GWP) of 6 mm BFRP Bars:
- ✓ 74% lower than steel.
- ✓ 22% lower than steel with 100% recycled content.
- ✓ 49% lower than galvanized steel.
- ✓ 88% lower than stainless steel.
- ✓ 44% lower than GFRP.

Analyzing Shear Strength of the Lightweight Concrete Reinforced with Glass Fiber Reinforced Polymer (GFRP) Bars

Effect of concrete Density on the Strength of concrete

- **ACI 440.11-22**

✓ Exclude lightweight concrete

- **ACI-318-22**

✓ LWC Strength = λ x NWC Strength

w_c, lb/ft³	λ	
≤ 100	0.75	(a)
$100 < w_c \le 135$	$0.0075w_c \le 1.0$	(b)
> 135	1.0	(c)

Analyzing Shear Strength of the Lightweight Concrete Reinforced with Glass Fiber Reinforced Polymer (GFRP) Bars

Experimental Setup

- **Materials used:**

✓ Expanded shale lightweight aggregates

Table 1. Density of Lightweight aggregate

Type of Aggregate	Specific Density (lb/ft^3)
LW Expanded clay	98
NW Coarse Aggregate	168

✓ GFRP bars

Table 2. Material property of the GFRP bar

Bar Number	Area (in^2)	E_f (ksi)	F_{fu} (ksi)	ε_{fu} %
3	0.11	9427	164	1.91

Analyzing Shear Strength of the Lightweight Concrete Reinforced with Glass Fiber Reinforced Polymer (GFRP) Bars

Experimental Setup

- **Mix formulations:**

Table 3. LWC Beam mix formulation

Material	density lb/ft3 SSD	percentage (weight)	F'c PSI (Average)
Fine, Silica sand	165	34	
coarse agg ,shale 3/8	97.97	25	
coarse agg ,shale 3/4	97.97	12	
Portland	196.54	10	
slag	180.96	10	
Water	62.4	9	
Total	116.31	100	5206.34

Table 4. NWC Beam mix formulation

Material	density lb/ft3 SSD	percentage (weight)	F'c PSI (Average)
Fine, Silica sand	165	37.83	
coarse agg , 3/4	168.00	43.04	
Portland	196.54	13.85	
slag	180.96	0.00	
Water	62.4	5.28	
Total	150.11	100.00	5311.53

Analyzing Shear Strength of the Lightweight Concrete Reinforced with Glass Fiber Reinforced Polymer (GFRP) Bars

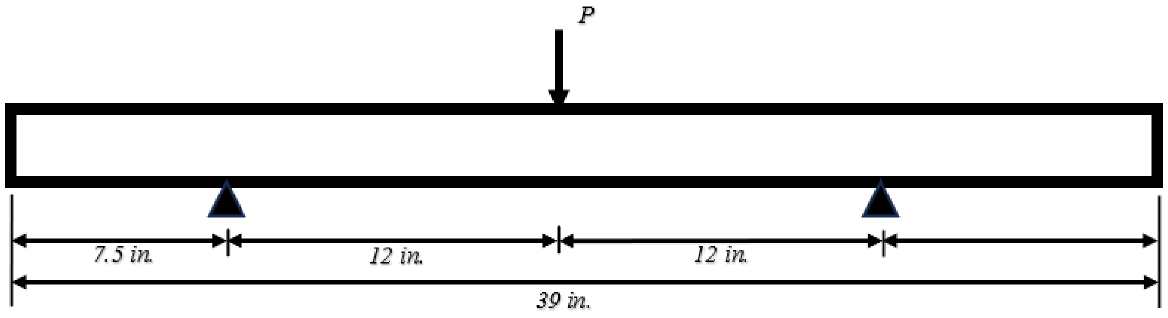
Experimental Setup

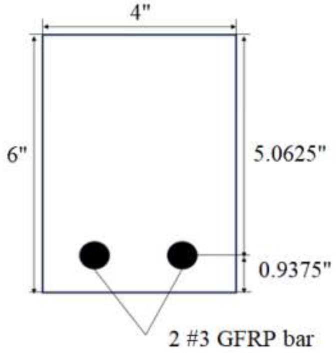
- **Dimensions of beams**

Table 5. Beam Detail

Beam	Number	Span Length (in)	Loading Span (in)	Beam height (in)	Beam Width (in)	Compressive Strength (ksi), 28 days	Bar
LWCG	2	24	12	6	4	5.2	2 # 3
LWCS	2	24	12	6	4	5.2	2 # 3
NWCG	2	24	12	6	4	5.3	2 # 3
NWCS	2	24	12	6	4	5.3	2 # 3

- **Loading conditions**





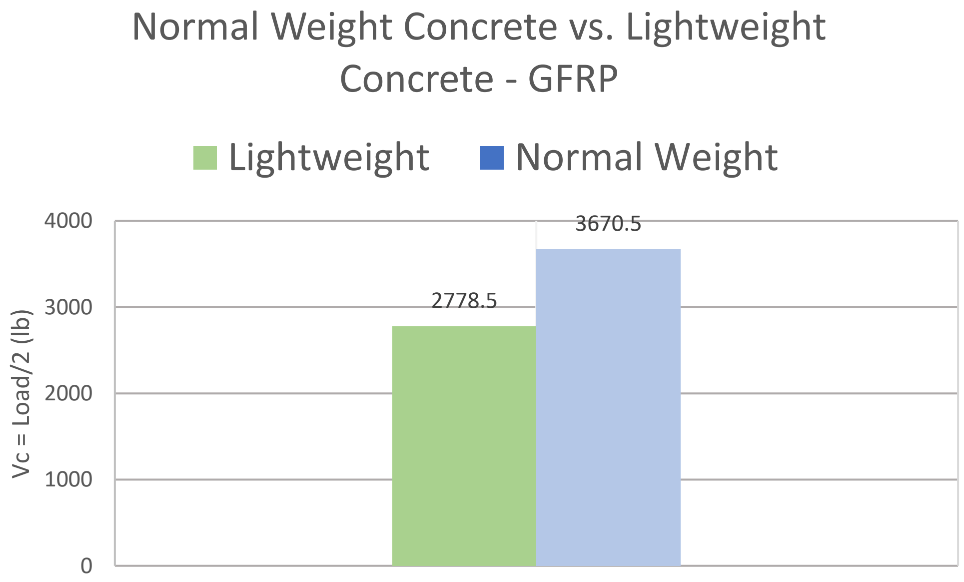
Analyzing Shear Strength of the Lightweight Concrete Reinforced with Glass Fiber Reinforced Polymer (GFRP) Bars

Experimental Result, Shear Strength

- **Typical shear failure shapes observed**

- **Experimental results**

✓ Suggestion of the proper Lambda value for the Shear Strength of LWC reinforced with GFRP λ =0.76 ACI-318-22: λ=0.0075 Wc =0.87



Analyzing Shear Strength of the Lightweight Concrete Reinforced with Glass Fiber Reinforced Polymer (GFRP) Bars

Conclusion

- **Shear failure modes observed due to lack of shear reinforcement.**
- **The ACI 318-22 equation for calculating the λ factor is not appropriate for lightweight concrete reinforced with GFRP.**
- **More research is needed to identify the effect of unit weight on the λ factor.**
- **Study limitations include absence of shear reinforcement and focus on specific beam types.**

Contact Info

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Northeastern Peer Exchange for Resilient and Sustainable Bridges

August 7, 2024 – Buffalo, NY.

University at Buffalo

Institute of Bridge Engineering

Life Cycle CO2 Emissions Assessment for GFRP and Steel Structural Components and Systems

Md Ala Uddin, Faysal Ahamed, Hota GangaRao, Yoojung Yoon

Center for Integration of Composites into Infrastructure

West Virginia University
Where Greatness is Learned

Speaker Bio

Md Ala Uddin

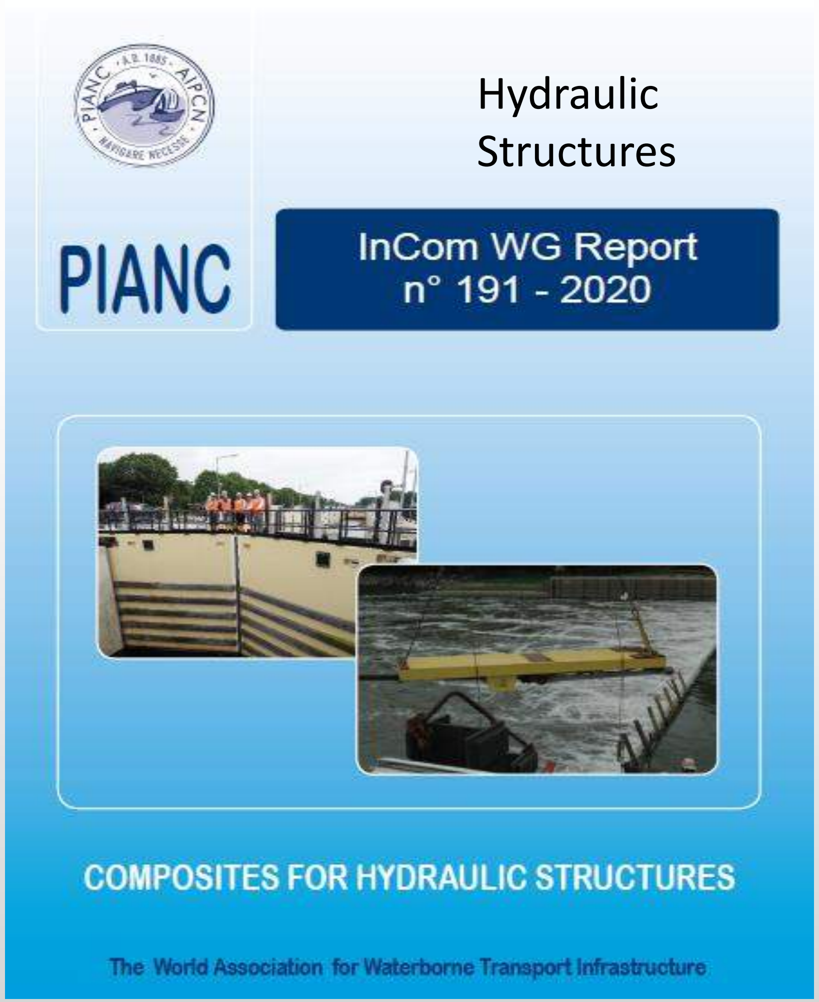
Md Ala Uddin is a Ph.D. student in Civil Engineering at West Virginia University. His research includes data-driven deterioration modeling of bridge structures, Life-Cycle Assessment (LCA), cost-effectiveness analysis, non-destructive testing, and defect analysis with Deep Learning. He holds an MS in Structural Engineering and a BS in Civil Engineering from Bangladesh University of Engineering and Technology (BUET). Mr. Uddin has over five years of professional experience in structural modeling (bridges and building), design, retrofitting, construction quality control, cost estimation, and bid package evaluation.

Faysal Ahamed

Faysal Ahamed is an MS student in Civil Engineering at West Virginia University. His research includes deterioration modeling and life-cycle sustainability evaluation of structural materials. He holds a BS in Civil Engineering from Bangladesh University of Engineering and Technology (BUET). Mr. Ahamed has over six years of professional experience in construction site supervision, quality control, and bid package evaluation at Bangladesh Navy.

GFRP Applications

Hydraulic Structures



Cooling Tower

GFRP Applications

Denzell Mills Bridge, WV

Turnpike Bridge, WV

Whiteday Bridge, Opekiska, WV

FRP Wraps for Retrofitting Bridges

GFRP Applications

WTC FRP Pedestrian Bridge over 9th Street in New York City

Research Background

- Life-cycle assessment (LCA) estimates CO_2 emissions of a product or process, including all stages of its life-cycle.
- Building and construction sector accounts for 37% of energy and process-related CO_2 emissions in 2021* (UNEP).
- Focus is on long-term structural and service life efficiencies with low-carbon emission from materials, and carbon sequestration to mitigate environmental impact.
- Synthetic fibers, such as glass and carbon coupled with polymeric binders, have emerged as alternative construction materials.
- Numerous studies demonstrated better thermo-mechanical performance of fiber-reinforced polymer (FRP) materials over conventional construction materials
- CO_2 emissions of GFRP in structural components and systems remain unexplored, especially with respect to service life.

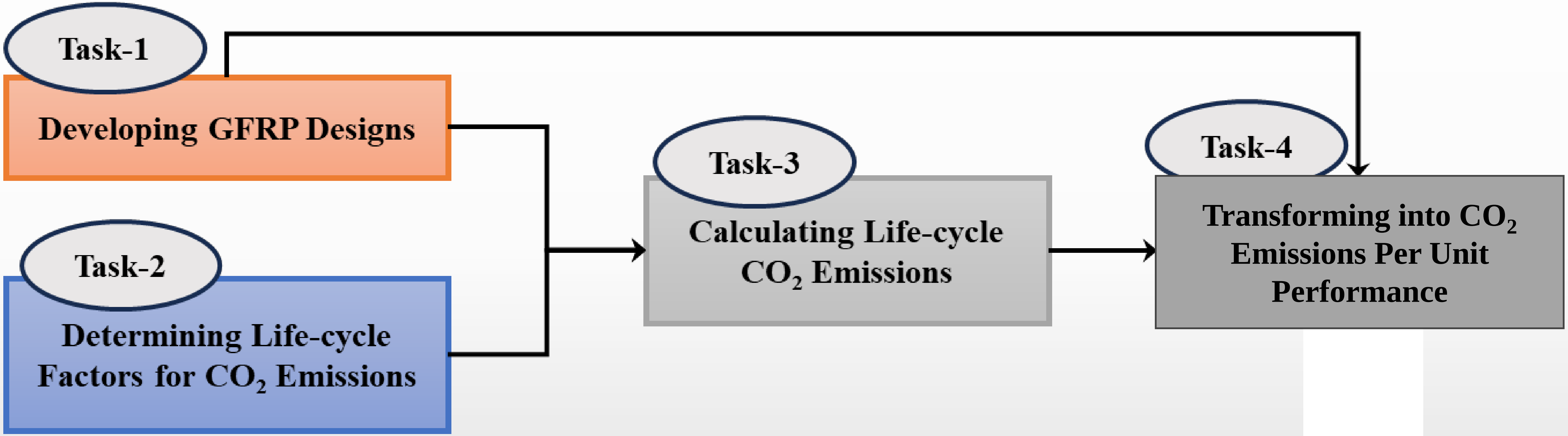
Objective and Scope

- **Objective:** Evaluate CO_2 emissions over the service life of GFRP materials in structural components and systems compared to traditional steel/concrete and calculate unit performance measures.

  - ✓ "**Unit performance**" refers to the efficiency of a component, or system to fulfill its function, measured by a combination of responses as, strength, durability, weight, environmental impact, and cost over a unit service time.
  - ✓ It often involves comparing CO_2 emissions per unit volume and service life to evaluate both the functional and environmental efficiencies, including recyclability.

- The focus of comparative (steel vs. GFRP) evaluation is on:
  - ✓ Structural shapes such as truss, signpost, frame etc. made of steel and GFRP materials.

Project Tasks



Task-1: Developing Designs

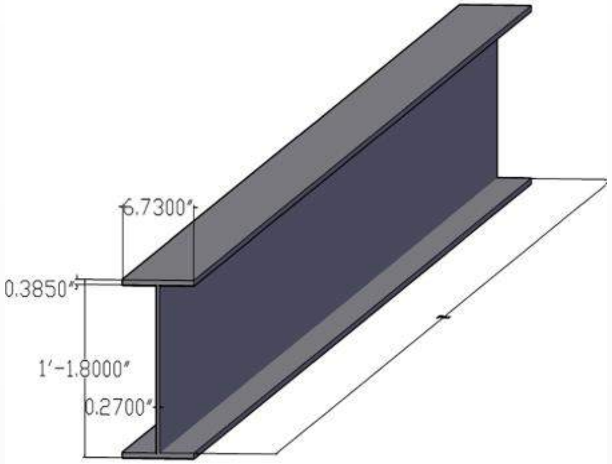
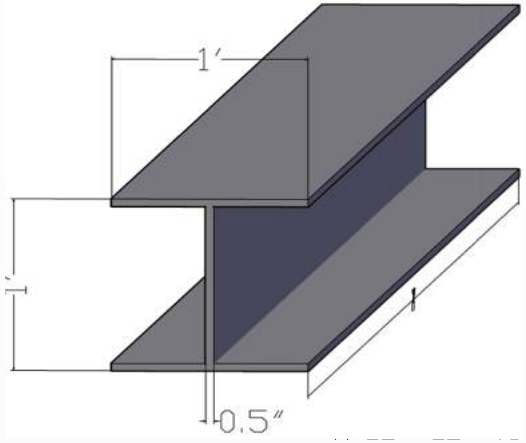
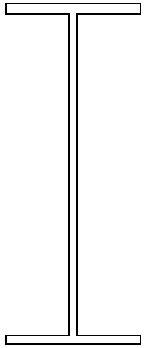
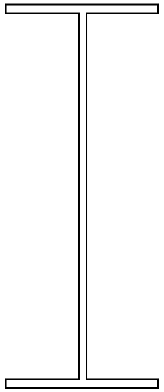
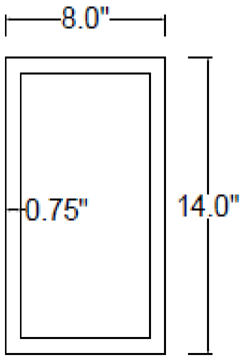
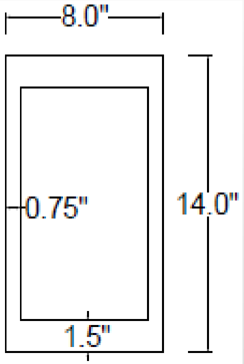
Design Type	Design Specification
Steel beam vs. GFRP beam	➢ Span length 24’ ➢ Dead load 600 lbs/ft ➢ Live load 860 lbs/ft
Building portal frame with steel. vs. GFRP	➢ Spacing of frames 15' ➢ Span length 30' ➢ Height of column 12' ➢ Supported concrete slab thickness 6", and ➢ Live load on slab 30 psf.
Bridge portal frame with steel vs. GFRP	➢ Rigid frame bridge with clear span 50' ➢ Road width 25', height 20' ➢ Hinged end condition

Note: All GFRP designs are based on readily available pultruded shapes with manufacturers and not structurally optimized shapes.

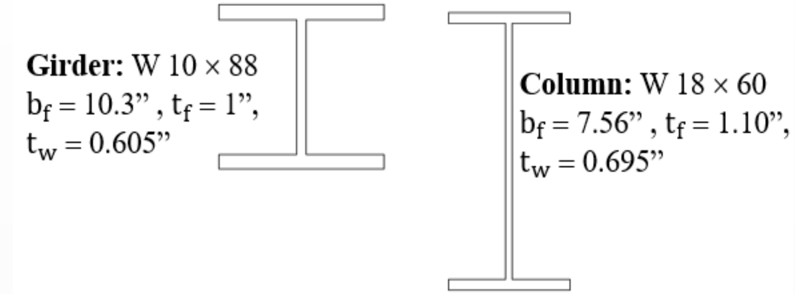
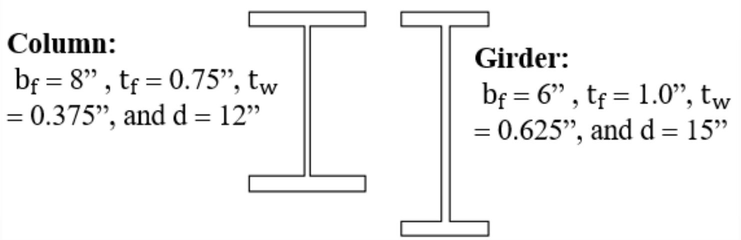
Task-1: Developing Designs (Cont.)

Design Type	Design Specification
Roof truss with steel vs. GFRP	➢ 60' span (6 bays @ 10' c/c) ➢ Length of vertical, horizontal, and diagonal members is 15',10' and 18'.
Highway truss with steel vs. GFRP	➢ Highway bridge with span length 120' (4 bays @ 30' each) ➢ Height of truss 10', and ➢ Live load HL-93.
Steel signpost vs. GFRP signpost	➢ Height of hollow circular post is 25.5’ ➢ Length of truss members are 4', 4', and 5.66', and ➢ Area of signboard is 8’ X 10'

Task 1: Designed Sections

Design Type	Steel Section	GFRP Section
Beam		
Building Portal Frame	 Steel Column Section: W 24 " x 76" $t_w = \frac{7}{16}$", $t_f = \frac{5}{8}$", b_f= 9"  Steel Beam Section: W 27 " x 94" $t_w = \frac{1}{2}$", $t_f = \frac{11}{16}$", b_f= 10"	 GFRP Column Section: 8 " x 14" with 0.75" thickness  GFRP Beam Section: 8 " x 14" t_f = 1.5", b_f = 0.75"

Designed Sections (Cont.)

<table>
<tr><th>Design Type</th><th>Steel Section</th><th>GFRP Section</th></tr>
<tr><td>Bridge Portal Frame</td><td>
</td><td>
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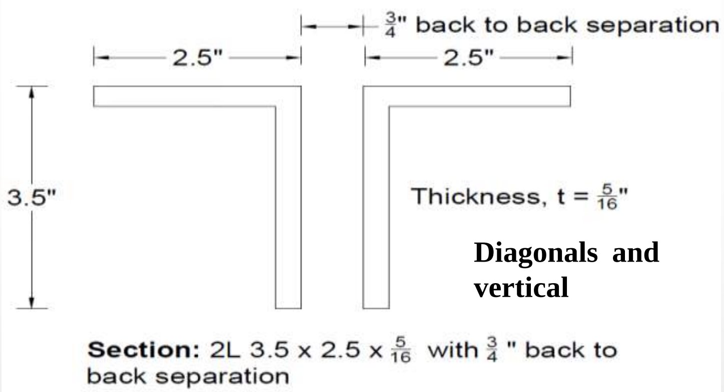
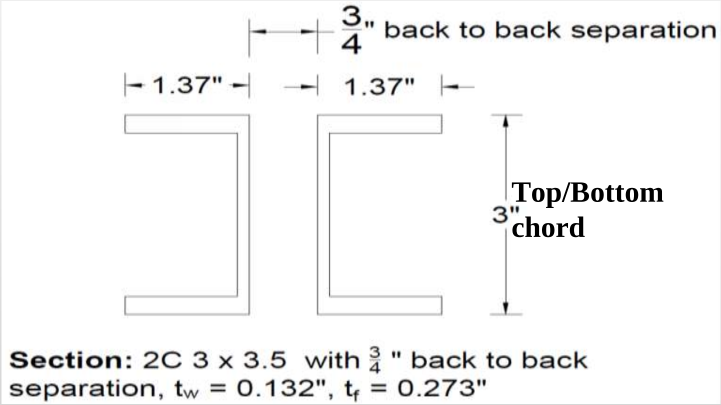
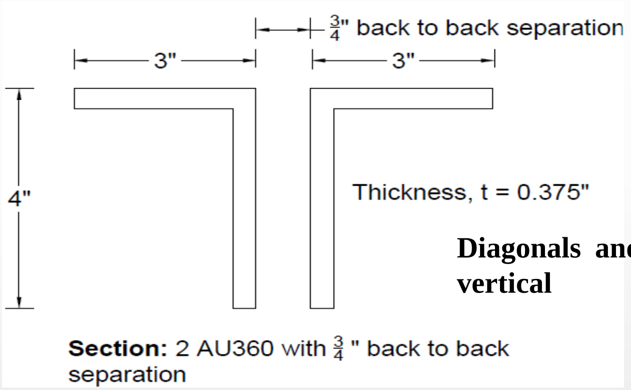
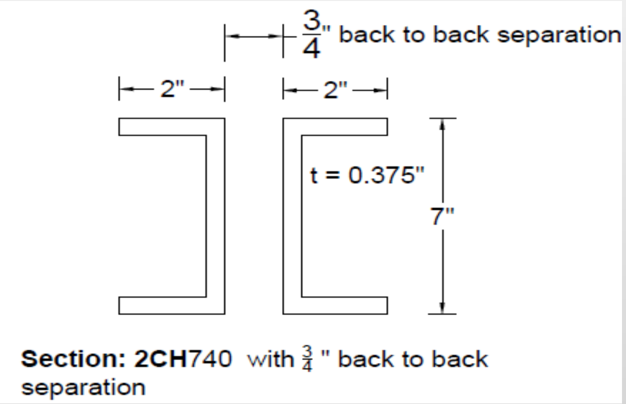
<tr><td>Roof Truss</td><td>


</td><td>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Task 1: Designed Sections (Cont.)

<table>
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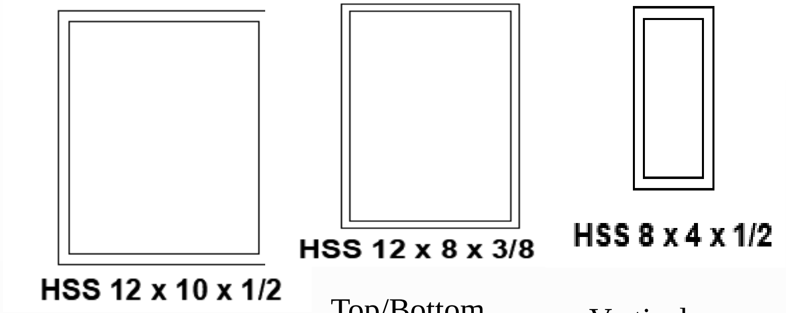
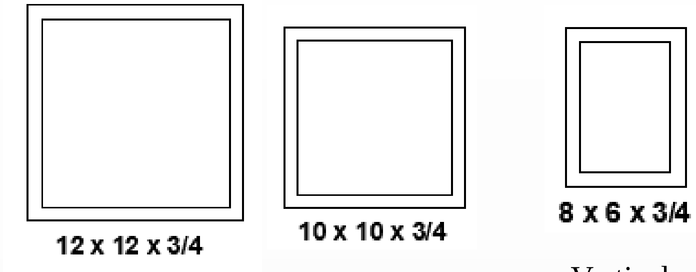
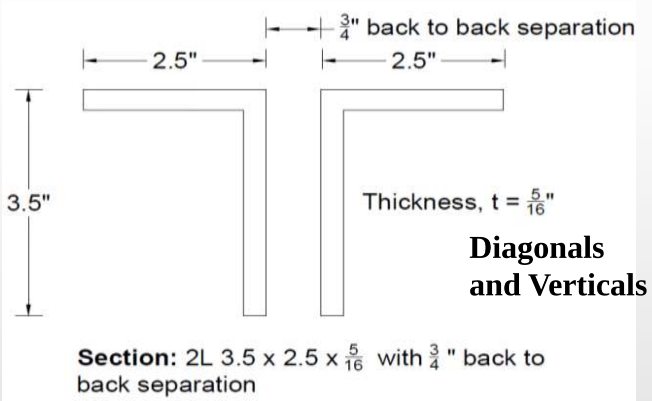
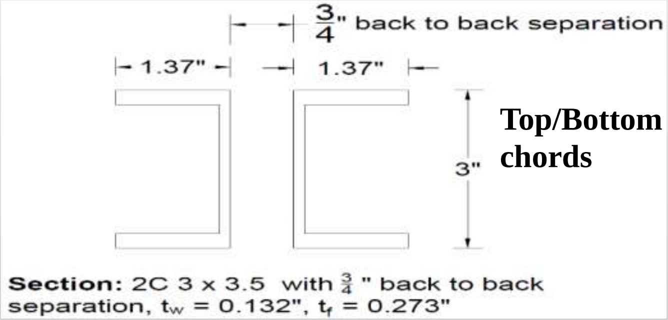
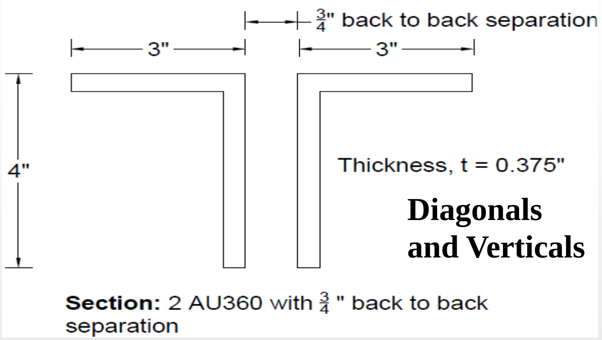
<tr><td>Highway Bridge Truss</td><td>

End Diagonal
Top/Bottom chords, other diagonals
Vertical Members</td><td>

End Diagonal
Top/Bottom chords, other diagonals
Vertical Members</td></tr>
<tr><td>Signpost</td><td>

Diagonals and Verticals


Top/Bottom chords</td><td>

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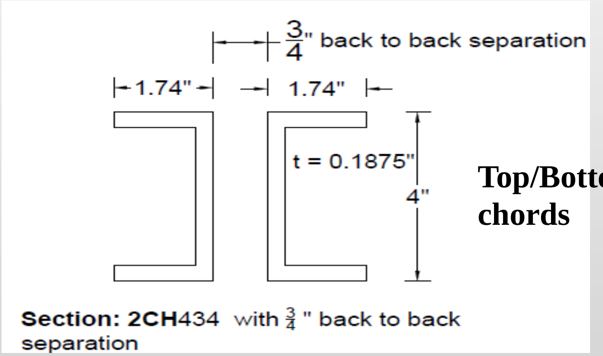

Top/Bottom chords</td></tr>
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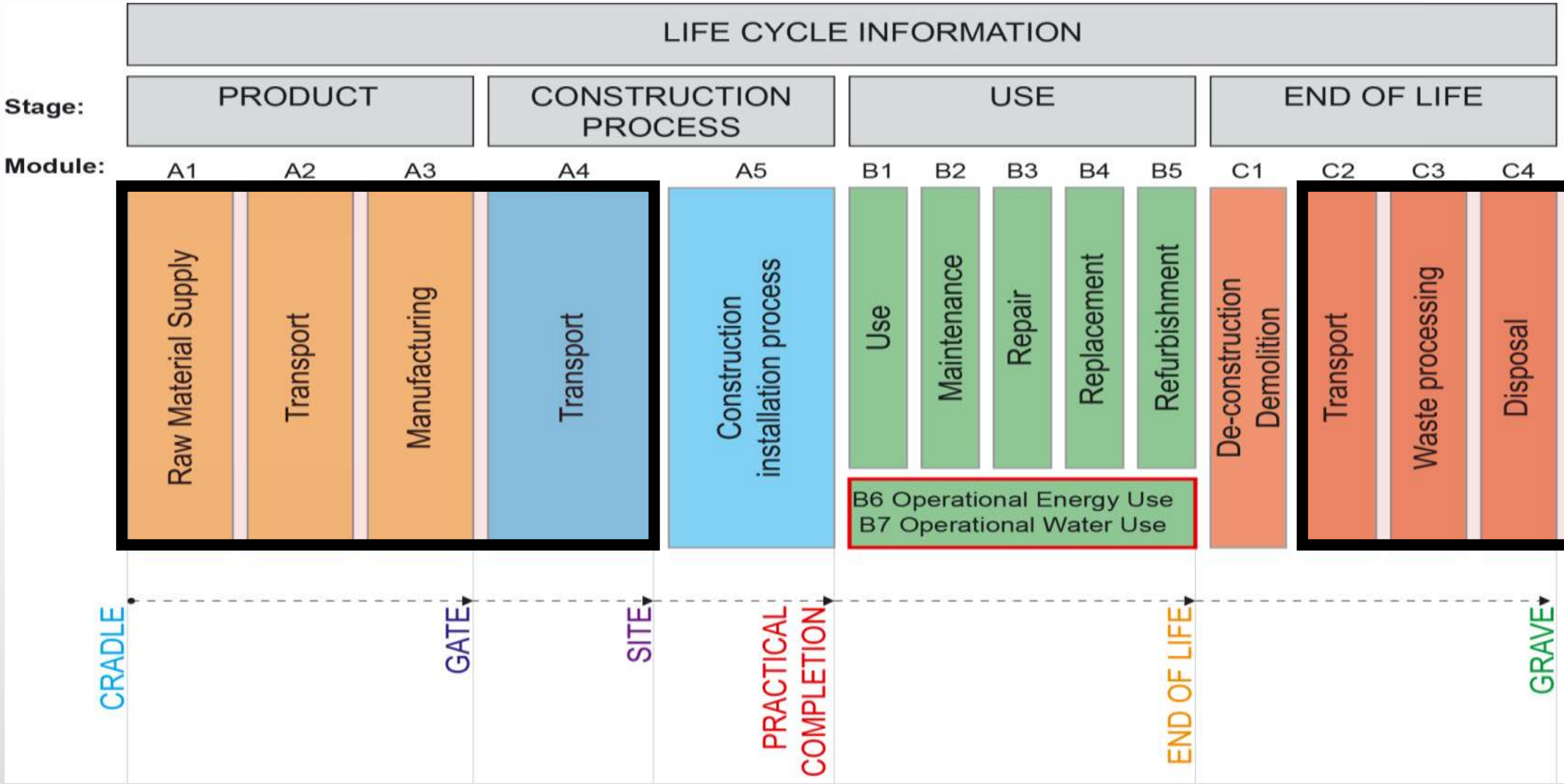
Task 2: Determining Life-cycle CO_2 Emission

Life-cycle stages/substages for CO_2 emissions



Highlighted stages/sub-stages were considered for CO_2 estimation

Note: Material wastage (A5w) = A13 + A4 + C2 + C34 is also included.

Task 2: Determining Life-cycle CO_2 Emission

- ECF Values Used for CO_2 Emission Calculations

Lifecycle Stage	Condition	ECF (Kg CO_2 e/Kg)	Source
Production (A1 to A3)	- **Mild Steel:** Structural steel - **GFRP: Pultrusion process,** E-Glass with Polyester	**1.55** **2.69**	Table 2 in Orr et al. (2020) ACMA (2012)
Transport (A4)	- Average 200 miles road travel, Considering materials manufactured nationally	**0.0343**	Derived from Table 3 in Orr et al. (2020)
***Material Wastage (A5w)**	- Mild steel: Structural steel - Structural GFRP	**0.016** **0.027**	Derived from Orr et al. (2020)
Recycling (D)	- Mild steel - GFRP	**0.5 – 1.2**** **0.9**	Duflou et al. (2012)

* Material wastage: Waste rates for structural steel 5%, with waste material carried by road (300 kilometers) to the closest place for recycling or reuse. The GFRP was assessed under identical condition.

** For steel recycling, the CO_2 emission calculations applied an ECF value of 0.85, which is the average of the range.

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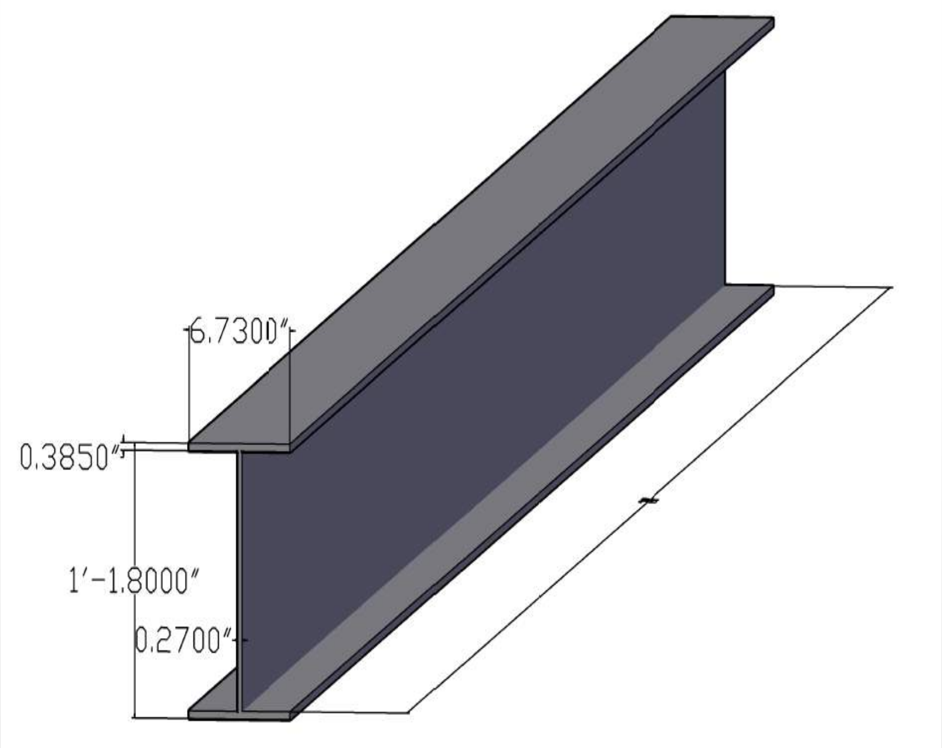
Task 3 & 4 :Calculating Life-cycle CO_2 Emissions

Step-1	• Identification of Embodied Carbon Factors (ECFs)
Step-2	• Estimation of Material Quantities
Step-3	• Calculation of CO_2 Emission Per Unit Performance Per Year

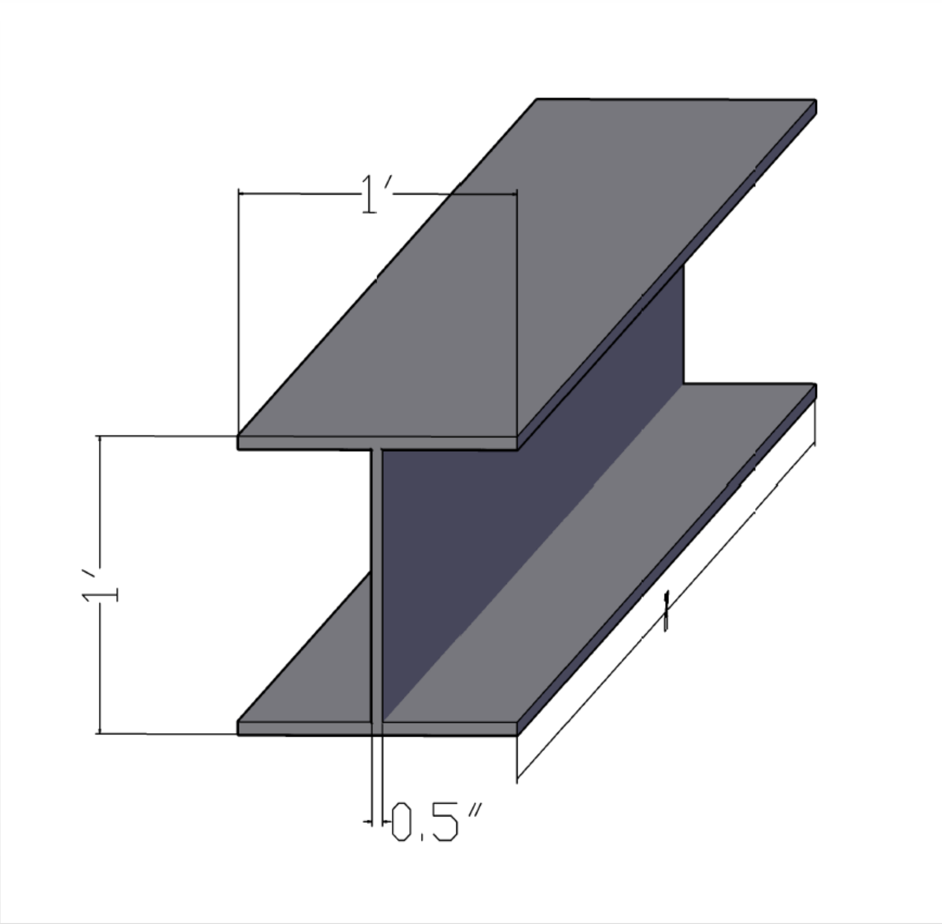
- CO_2 Emissions and Unit Performance:
  - $CO_2\ \text{Emissions} = \mathit{Material\ Quantity\ (weight)} \times \mathit{ECF}$
  - Transform into unit performance
    - Unit lifecycle (kg CO_2 e/year)
    - Unit volume (kg CO_2 e/m^3)
    - Annual unit volume (kg CO_2 e/m^3/year)

LCA demonstration for Beam

Step 1: Design of Steel vs. GFRP Beam



Steel I-Beam (W14×30)



GFRP I-Beam (12”×12”×1/2”)

17

LCA demonstration for Beam

Step 2: Estimation of Material Quantities

- Quantities for the Steel Beam:
  - For W14 $\times$ 30, the weight is 30 lbs/ft.
  - Total weight of W14 x 30 of 24' span is 720 lbs (= 30 lbs/ft $\times$ 24 ft, or **326.68 Kg**).
  - Volume of the steel beam is **1.475 ft³** (= cross-section area (A) $\times$ span length (L) = $\frac{8.85\ in^2}{144\ in^2/ft^2} \times 24\ ft$; **0.042 m³**)

LCA demonstration for Beam

Step 2: Estimation of Material Quantities

- Quantities for the GFRP Beam:

  - For W12×12 ×1/2, the self-weight is 13.98 lbs/ft.
  - Weight of GFRP W12×12 ×1/2 of 24' span is 335.52 lbs (= 13.98 lbs/ft × 24 ft, or **152.23 Kg**)
  - Volume of the GFRP beam is 2.92 ft^3 (= [$\frac{(12 \times {}^{1}/_{2}) \times 2}{144\ in^2/ft^2}$ (for flange) + $\frac{(11 \times {}^{1}/_{2})}{144\ in^2/ft^2}$ (for web)] × 24 ft; **0.079 $\boldsymbol{m^3}$**)

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LCA demonstration for Beam

Step 3: Calculation of CO_2 Emission and Unit Performance

- Steel Beam: **800.46 Kg CO_2 e** (= 326.68 × (1.55 + 0.0343 + 0.016 + 0.85))
- GFRP Beam: **555.90 Kg CO_2 e** (= 152.23 × (2.69 + 0.0343 + 0.027 + 0.9))

We considered pultrusion process for GFRP

Lifecycle Stage	ECF (Kg CO_2 e/Kg)
Production (A1 to A3)	**1.55 (Steel)** **2.69 (GFRP)**
Transport (A4)	**0.0348**
Material wastage (A5w)	**0.016 (Steel)** **0.027 (GFRP)**
Recycling	**0.85 (Steel)** **0.90 (GFRP)**

Material	Material Weight (kg)	Volume (m^3)
Steel	326.68	0.042
GFRP	152.23	0.079

LCA demonstration for Beam

Step 3: Calculation of CO_2 Emission and Unit Performance

Unit lifecycle

- Let the service life of the steel beam be 50 years (Jabelli et al, 2022), and for the GFRP beam be 75 years (Yan and Lin, 2017)
- Annual carbon emission for the steel beam is **16.01 Kg CO_2 e/year** (= $\frac{800.50}{50}$)
- Annual carbon emission for the GFRP beam is **7.41 Kg CO_2 e/year** (= $\frac{555.90}{75}$)

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LCA demonstration for Beam

Step 3: Calculation of CO_2 Emission and Unit Performance

Unit Volume:

- Carbon emission / unit volume (steel beam) is **19235.41** Kg CO_2 e/m^3 (= $\frac{800.50}{0.042}$).
- Annual carbon emission / unit volume (steel beam) is **384.71 Kg CO_2 e/m^3/year** (= $\frac{19235.41}{50}$)
- Carbon emission / unit volume (GFRP beam) is **7016.08 Kg CO_2 e/m^3** (= $\frac{555.90}{0.079}$)
- Annual carbon emission / unit volume (GFRP beam) is **93.55 Kg CO_2 e/m^3/year** (= $\frac{7016.08}{75}$)

Results

Best Case for steel and worst case for GFRP (Steel: 1.55, SL-50 yrs., GFRP: 2.69, SL-75 yrs.)

Design Examples	Steel			GFRP		
	Weight (Kg)	Volume (m^3)	Total CO_2 (kg eq.)	Weight (Kg)	Volume (m^3)	Total CO_2 (kg eq.)
Beam	326.68	0.042	800.49	152.23	0.079	555.91
Roof Truss	1340.79	0.171	3285.43	592.78	0.309	2164.70
Highway Truss	7539.83	0.960	18475.37	3573.00	1.860	13047.77
Signpost	877.19	0.112	2149.44	884.82	0.461	3231.16
Building Portal Frame	4922.87	0.627	12062.85	1729.22	0.900	6314.71
Bridge Portal Frame	2047.19	0.261	5016.37	676.04	0.352	2468.74

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Results

Best Case for steel and worst case for GFRP: Unit Performance

Design Examples	Steel			GFRP			Ratio (Steel/GFRP)		
	Unit LC	Unit V	Annual U V	Unit LC	Unit V	Annual U V	Unit LC	Unit V	Annual U V
Beam	16.01	19235.41	384.71	7.41	7016.08	93.55	2.16	2.74	4.11
Roof Truss	65.71	19235.41	384.71	28.86	7016.08	93.55	2.28	2.74	4.11
Highway Truss	369.51	19235.41	384.71	173.97	7016.08	93.55	2.12	2.74	4.11
Signpost	42.99	19235.41	384.71	43.08	7016.08	93.55	1.00	2.74	4.11
Building Portal Frame	241.26	19235.41	384.71	84.20	7016.08	93.55	2.87	2.74	4.11
Bridge Portal Frame	100.33	19235.41	384.71	32.92	7016.08	93.55	3.05	2.74	4.11

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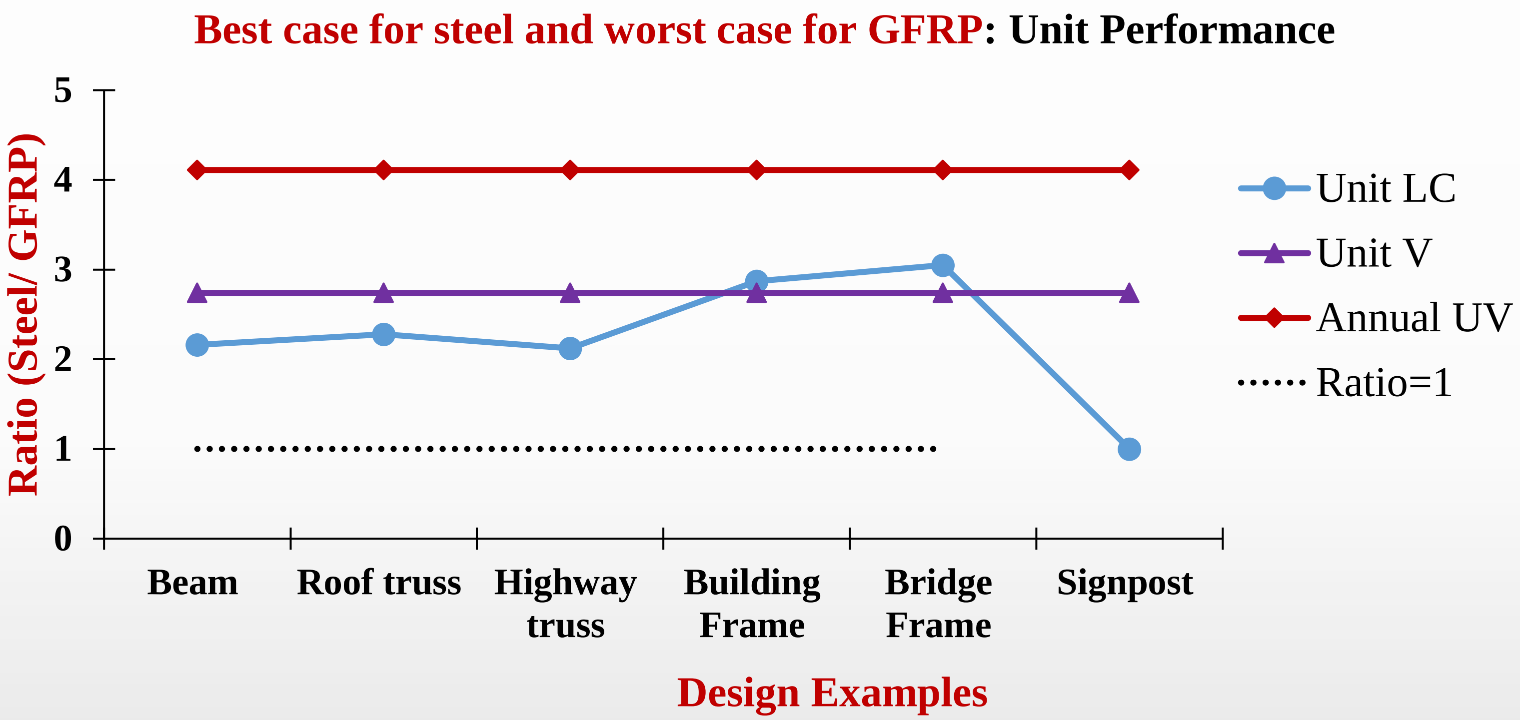
Results



Unit LC: **1.00 ~ 3.05**
Unit V: **2.74**
Annual UV: **4.11**

For almost all design types, GFRP performs better than steel. However, in cases where shear or torsion governs, GFRP performance might not surpass that of steel, based on the available resins that have low shear resistance.

Results

Worst case for steel and best case for GFRP: Unit Performance

Design Examples	Steel			GFRP			Ratio (Steel/GFRP)		
	Unit LC	Unit V	Annual U V	Unit LC	Unit V	Annual U V	Unit LC	Unit V	Annual U V
Beam	26.68	19235.41	641.18	5.56	7016.08	70.16	4.80	2.74	9.14
Roof Truss	109.51	19235.41	641.18	21.65	7016.08	70.16	5.06	2.74	9.14
Highway Truss	615.85	19235.41	641.18	130.48	7016.08	70.16	4.72	2.74	9.14
Signpost	71.65	19235.41	641.18	32.31	7016.08	70.16	2.22	2.74	9.14
Building Portal Frame	402.10	19235.41	641.18	63.15	7016.08	70.16	6.37	2.74	9.14
Bridge Portal Frame	167.21	19235.41	641.18	24.69	7016.08	70.16	6.77	2.74	9.14

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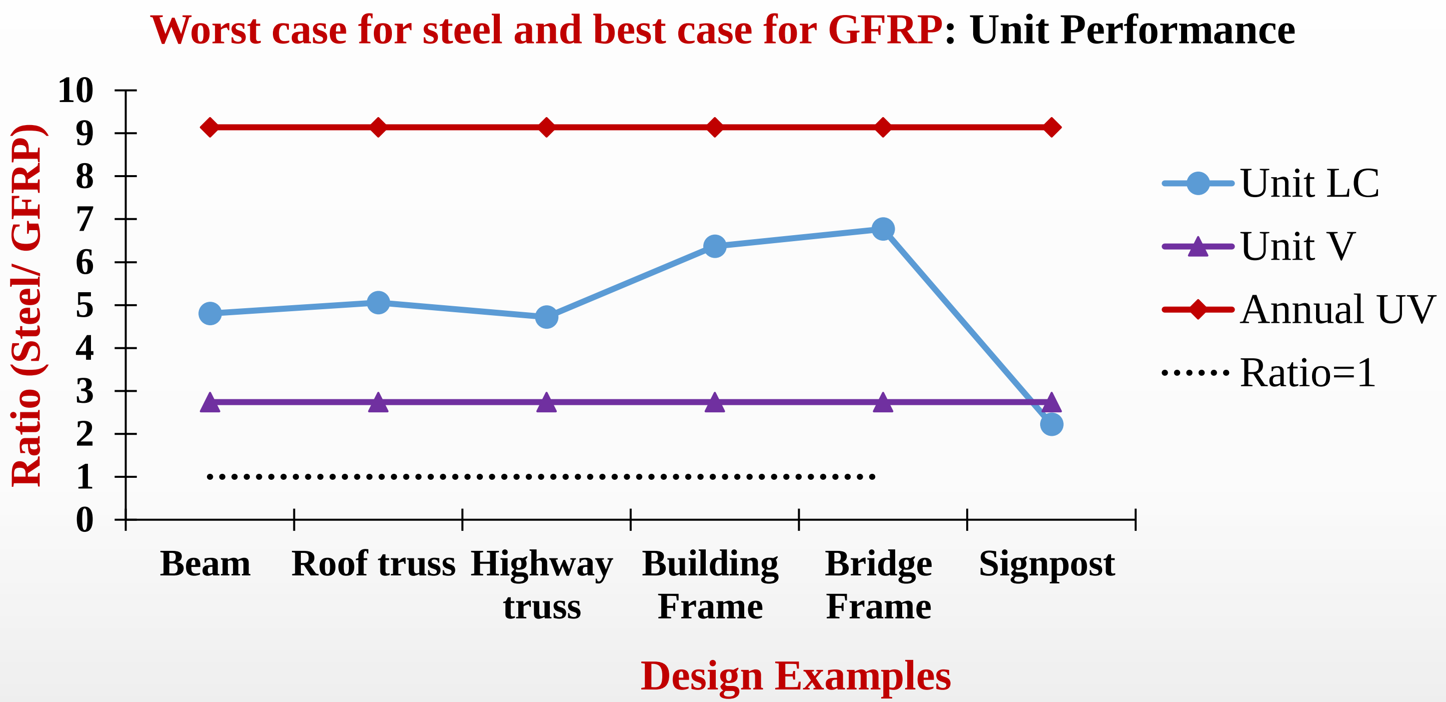
Results



Unit LC: **2.22 ~ 6.77**
Unit V: **2.74**
Annual UV: **9.14**

For worst case of steel and best case for GFRP, almost all design types, GFRP performs more than twice compared to steel

Conclusion

- This analysis evaluated service-life CO_2 emissions for GFRP vs. steel under best-case of steel with worst-case of GFRP and worst-case of steel with best-case of GFRP scenario.
- For all design types, including service life scenarios, GFRP's performance is better than steel in CO_2 emissions.
- However, in certain loading scenario whereas shear and torsion govern the failure, GFRP may not be as favorable with reference to steel. However, recent advances in resins for better shear resistance will alter that "unfavorability".
- Necessary to optimize GFRP sections for structural efficiency and consider factors like hybridization and manufacturing innovations in future designs.

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Thank You
Q&A

Northeastern Peer Exchange for Resilient and Sustainable Bridges

August 7, 2024 – Buffalo, NY.

University at Buffalo

Institute of Bridge Engineering

Puncture and Impact Responses of FRP Composite Jacketing for Railway Tank Car

Ray Liang, Chao Zhang, Eduardo M. Sosa, and Hota V.S. Gangarao,

Constructed Facilities Center (CFC) and Center for the Integration of Composites into Infrastructure (CICI),

West Virginia University, Morgantown, WV 26506, USA

Background: Derailment of Railway Tank Car

- The DOT-117 and the DOT-117R are new specifications to mitigate design flaws of existing DOT-111 tank cars
- The additional weight of these design features increases shipping costs and reduces the carrying capacity
- Our proposed jacket will offer superior fire and puncture resistance with lower life-cycle costs

The Ohio Train Derailment: A Timeline - The New York Times

Background: Side Impact Test of a DOT-117 Tank Car

greenpeace.org

Shell structure

11 gauge steel A1011
0.5 inch ceramic blanket
9/16 inch steel TC-128

DOT-117 Tank Car Design

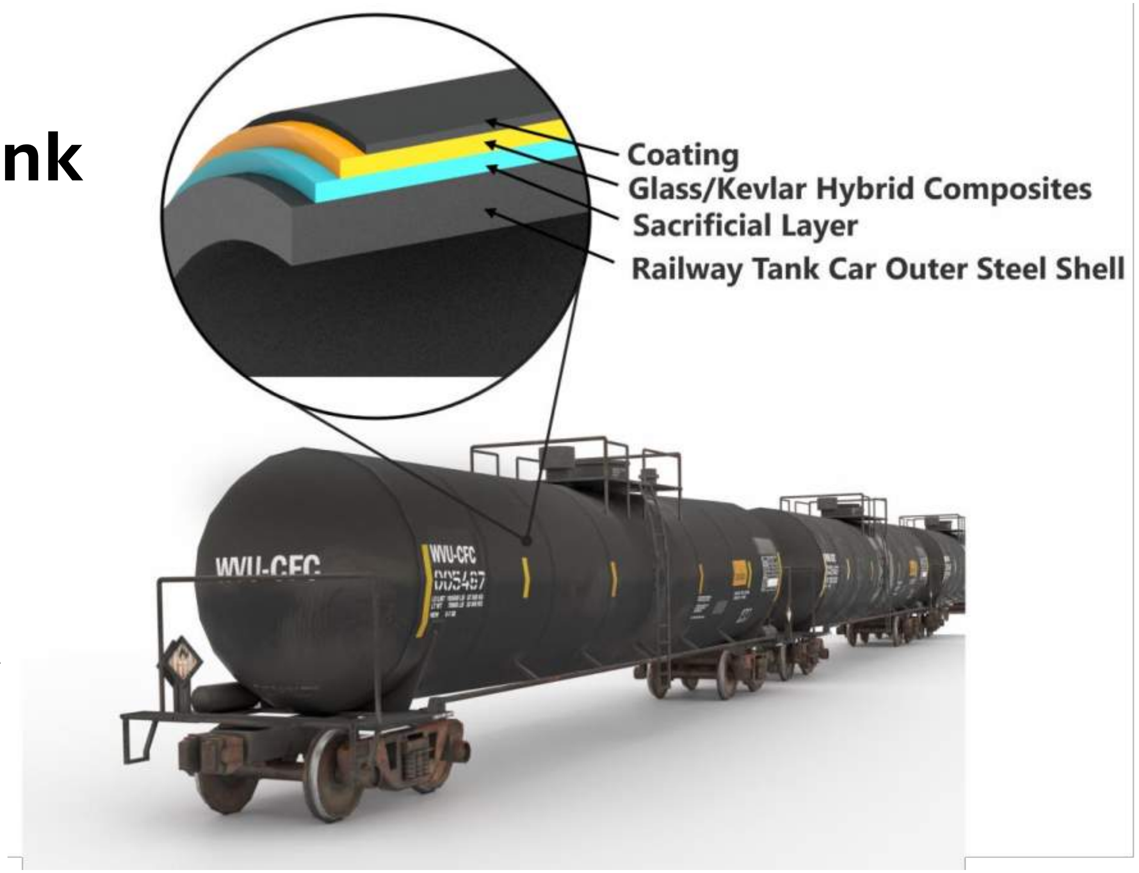
Ram Arm with 12-inch by 12-inch Indenter

Impact speed of 13.5 mph

DOT/FRA/ORD-19/13, May 2019

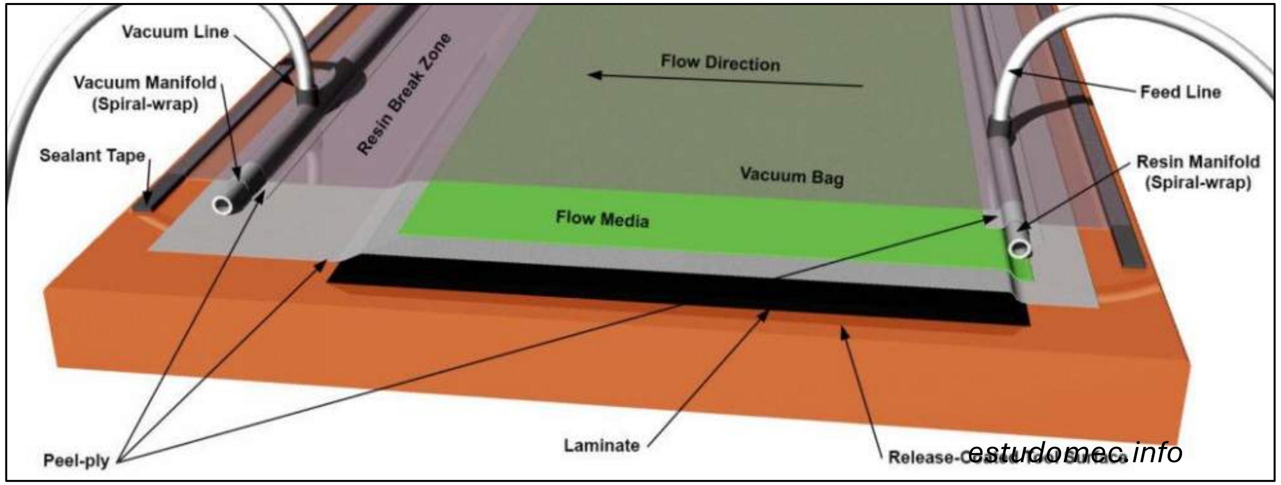
Objectives

- **Manufacturing of test samples**
- **Puncture and impact test with a tank car jacketed by the proposed FRP curvilinear jacket**
- Fire resistance testing
- **Finite element modeling**
- Cost-benefit analysis, including AAR practicability evaluation



Introduction to Vacuum Infusion Process

- The Vacuum Assisted Resin Transfer Molding (VARTM) is a method of infusing porous material using a vacuum pump
- VARTM was chosen over other infusion methods due to its high part quality, ease of on-site application, and lower overall cost



estudomec.info

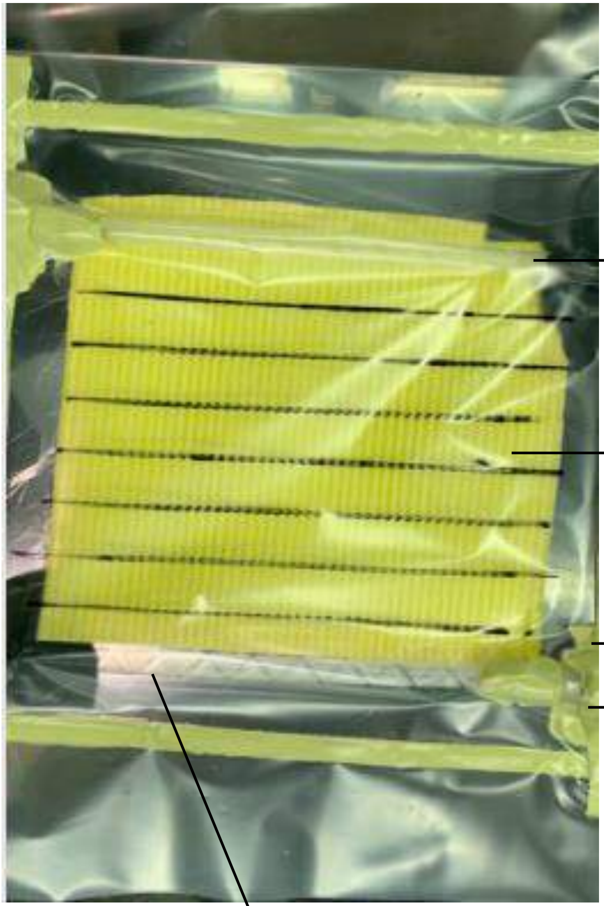
Large scale curved samples

Benefits
- Higher fiber volume fraction (55%)
- Low amount of voids/entrapped air
- Higher strength and stiffness
- Consistent, high-quality results
- Can be formed against molds to create curvature in parts

Drawbacks
- Involved setup
- Requires practice to ensure high quality parts
- Requires disposable supplies

Improving Flow Uniformity - VARTM

- Major Improvements:
  - Flow Media
  - Spiral Tubing
  - Pressure
  - Flow front
  - Distance between vacuum line and feed line
- A major contributor to our improved results thus far is the flow uniformity achieved from the new lay-up.



Manufacturing

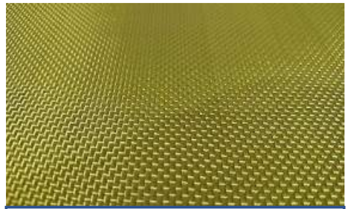
Composite Jacket

- **Parametric study of various components of composite jacket such as:**

1. Different Fiber Combinations and Fiber Stacking

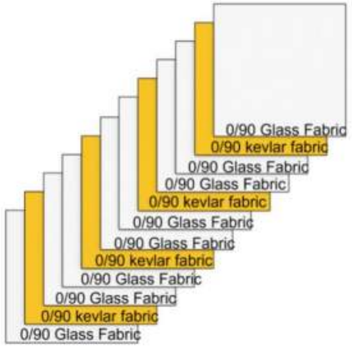
Glass Fabric

Compositesplaza.com



KM-2 Kevlar Fabric

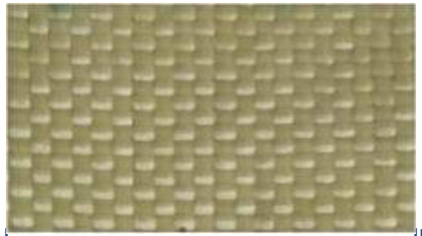
Picclick.com



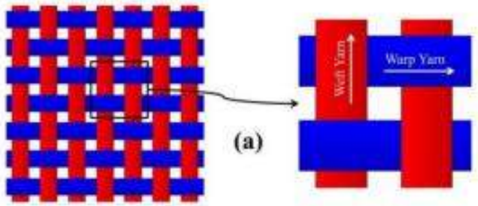
Glass and Kevlar Combined

2. Type of Kevlar

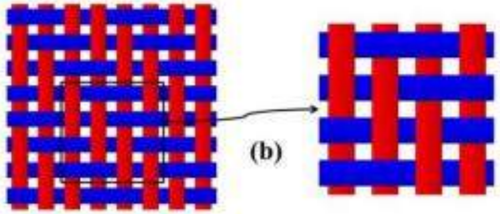
Twill-49 Kevlar Fabric



Plain-49 Kevlar Fabric



Plain woven Fabric



Twill woven Fabric

Sharma et.al., materials today: Proceedings, 2020

Manufacturing

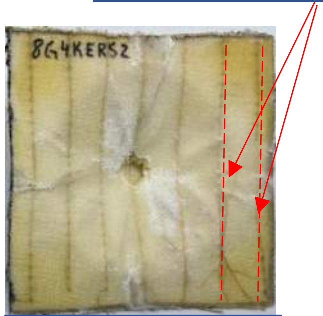
Composite Jacket

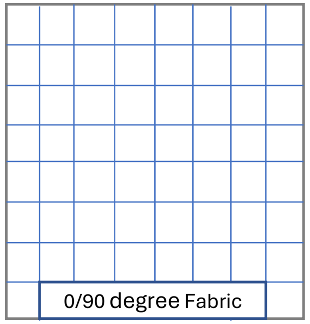
3. **Stitching**

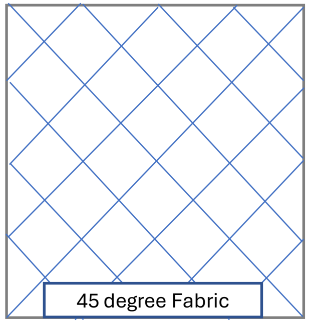
Stitching lines


Unstitched


Stitching machine


Stitched

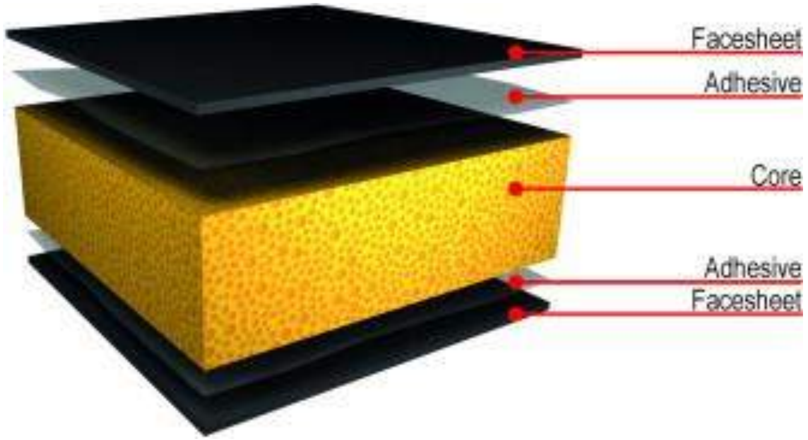




Fabrics with fiber oriented in different directions

4. **Type of resin**
   - Epoxy Resin and Vinyl Ester
5. **Fabric stacking in different directions**
6. **Using Core**
   - Polyurethane, Polystyrene, Elastomeric Pad
7. **Increasing thickness of Jacket**

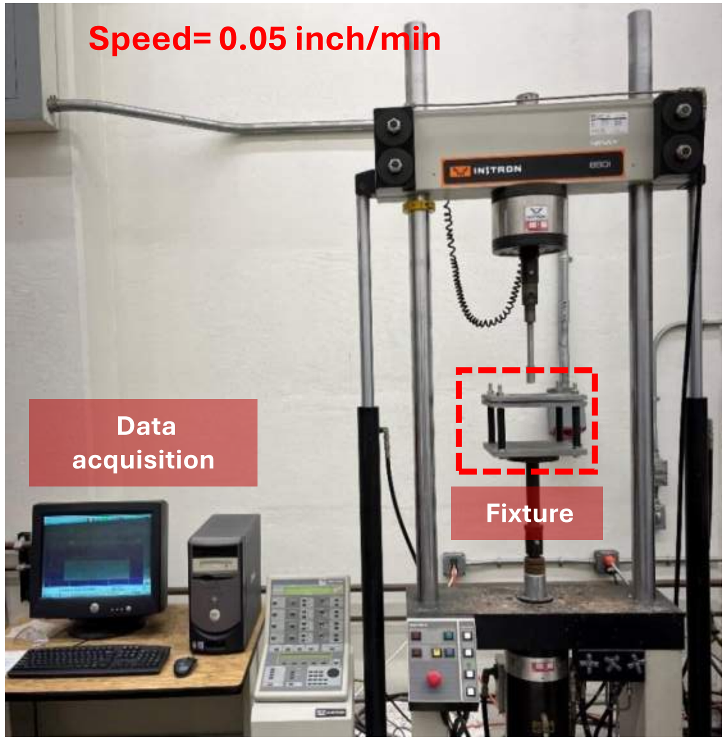
- Static and dynamic impact tests for manufactured composites



Amir Fathi, Composites Part B: Engineering, 2015

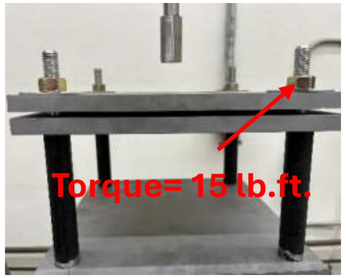
Methodology

Static puncture test (ASTM D6264)



Boundary condition

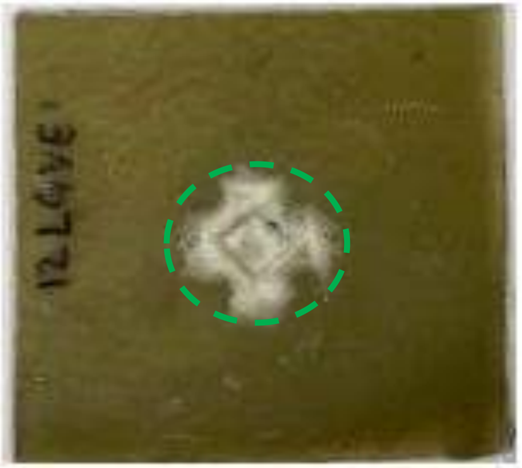
Fix condition



Dynamic impact test (ASTM D7136)

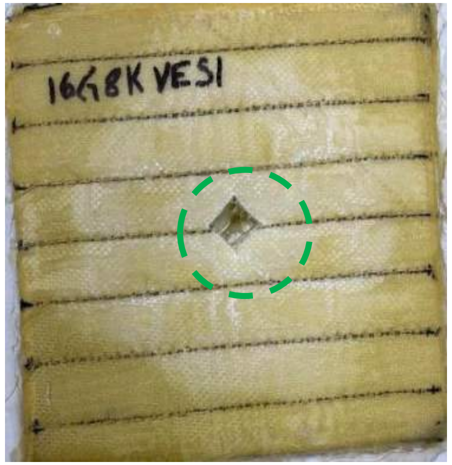
Failure Mechanism

Localized Damage



12 Glass Layers

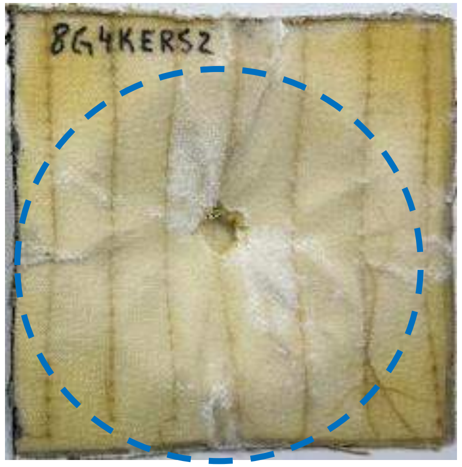
Unstitching



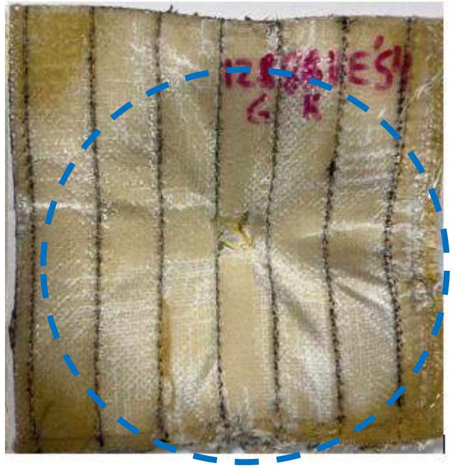
24 Layers

Globalized Damage

8 Glass + 4 Kevlar Layers



Stitching

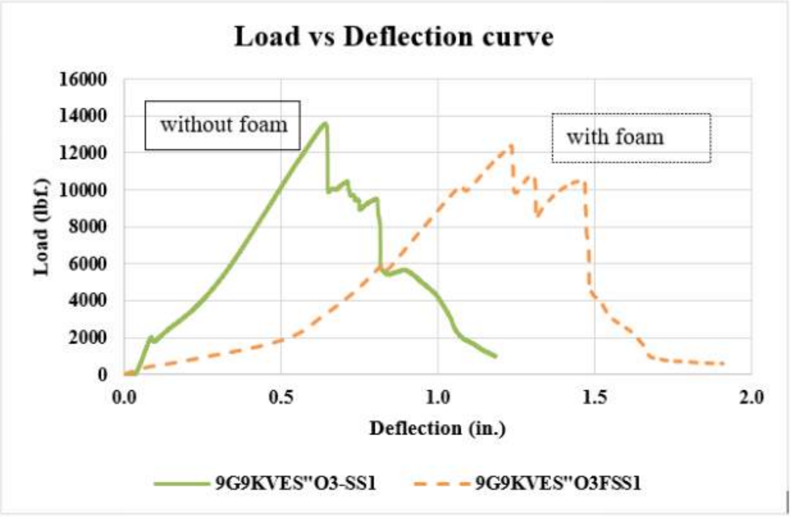


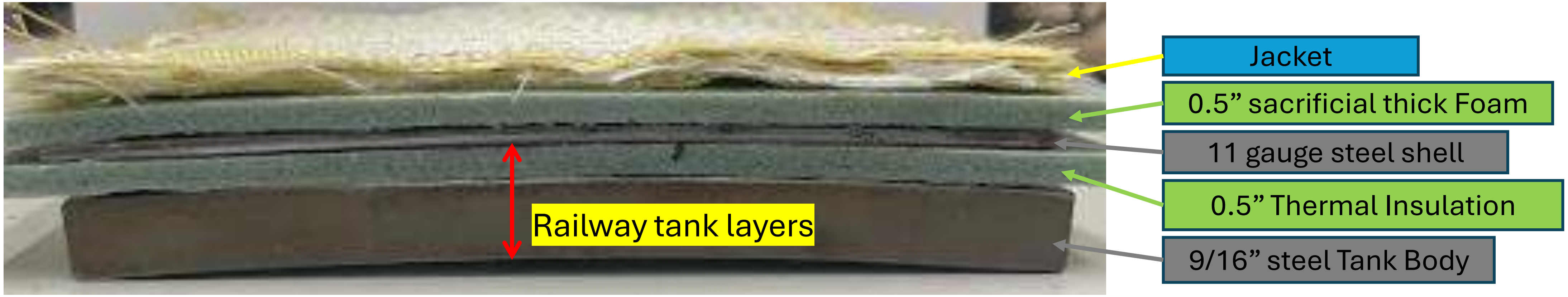
18 Layers

Efficient force distribution from the impact zone to area far from the impact zone, providing the high damage tolerance and impact resistance

Foam

- **Static and dynamic tests of:**
  - Composite jackets with plain steel substrate
  - Curvilinear Composite jackets with Steel substrate

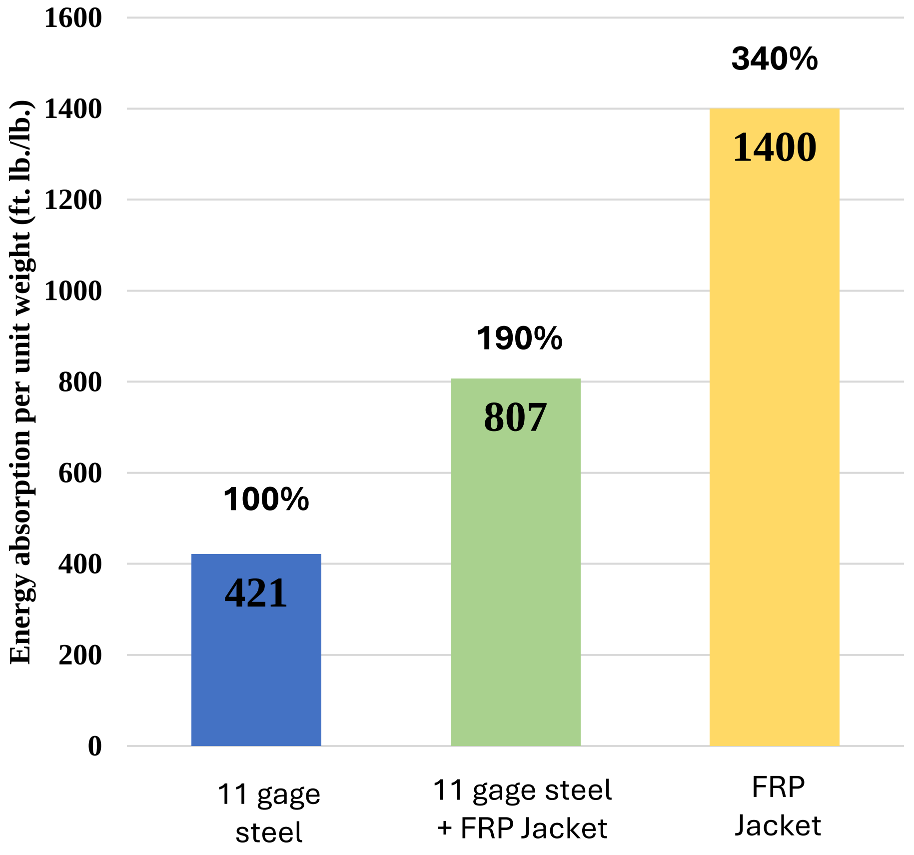




Comparison between DOT117 and FRP jacket

Scale ratio of real tank and composite jacket (2035: 1)

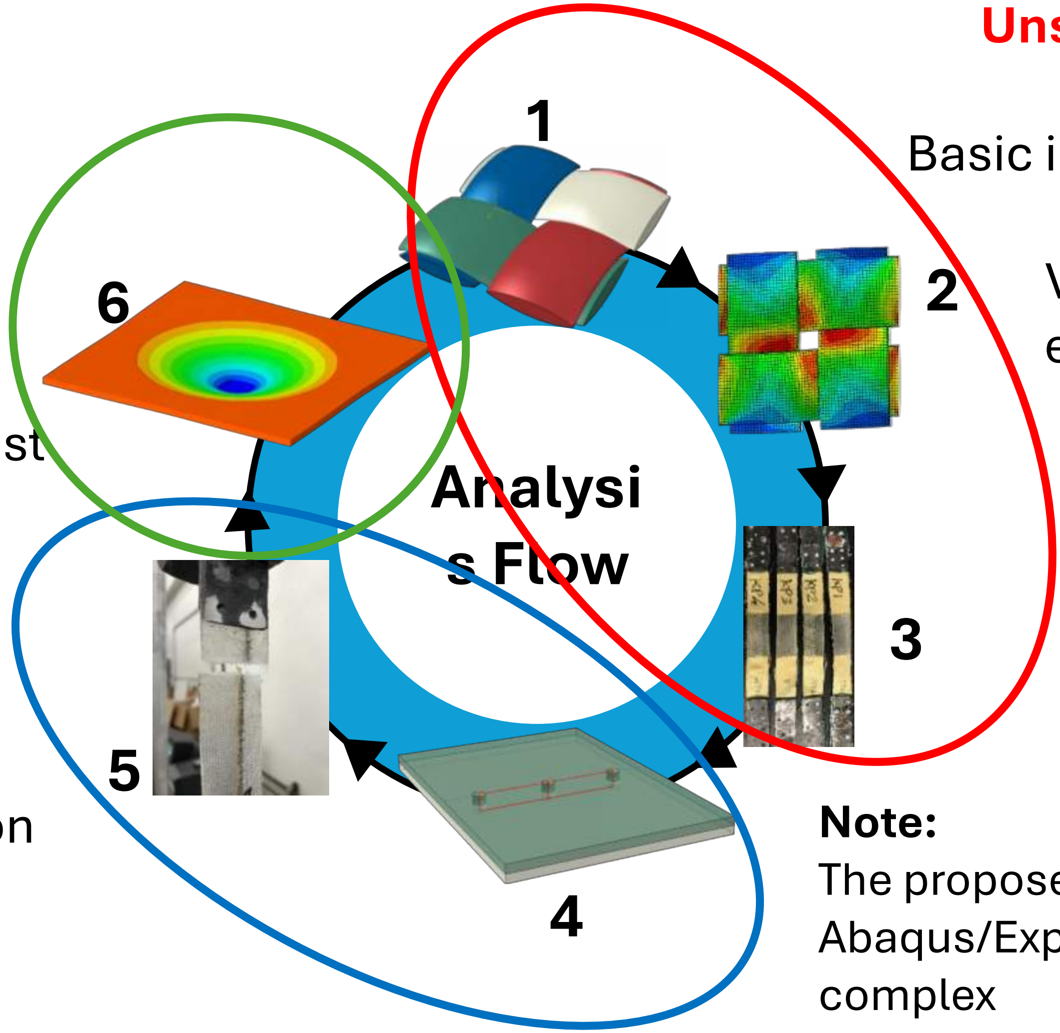
- **DOT 117:**
  - Sample test area (inch^2): 40716
  - Weight (lb.): 1383
  - Energy absorption (kips. ft.): 583
  - Energy absorption per unit weight (ft. lb./lb.): 421
- **11 gauge steel + FRP Jacket:**
  - Sample test area (inch^2): 20
  - Weight (lb.): 0.884 **(130% of DOT 117)**
  - Energy absorption (lb. ft.): 713 **(250% of DOT 117)**
  - Energy absorption per unit weight (ft. lb./lb.): 807 **(190%)**
- **FRP Jacket:**
  - Sample test area (inch^2): 20
  - Weight (lb.): 0.243 **(35% of DOT 117)**
  - Energy absorption (lb. ft.): 340 **(120% of DOT 117)**
  - Energy absorption per unit weight (ft. lb./lb.): 1400 **(340%)**



Multiscale FE Modeling Approach

Macro model
Inputs:
Homogenized constants
stitching strategy
Outputs:
Full composite under puncture test

Stitched material
Inputs:
Homogenized constants
Stitching threads information
Outputs:
Verified stitching strategy

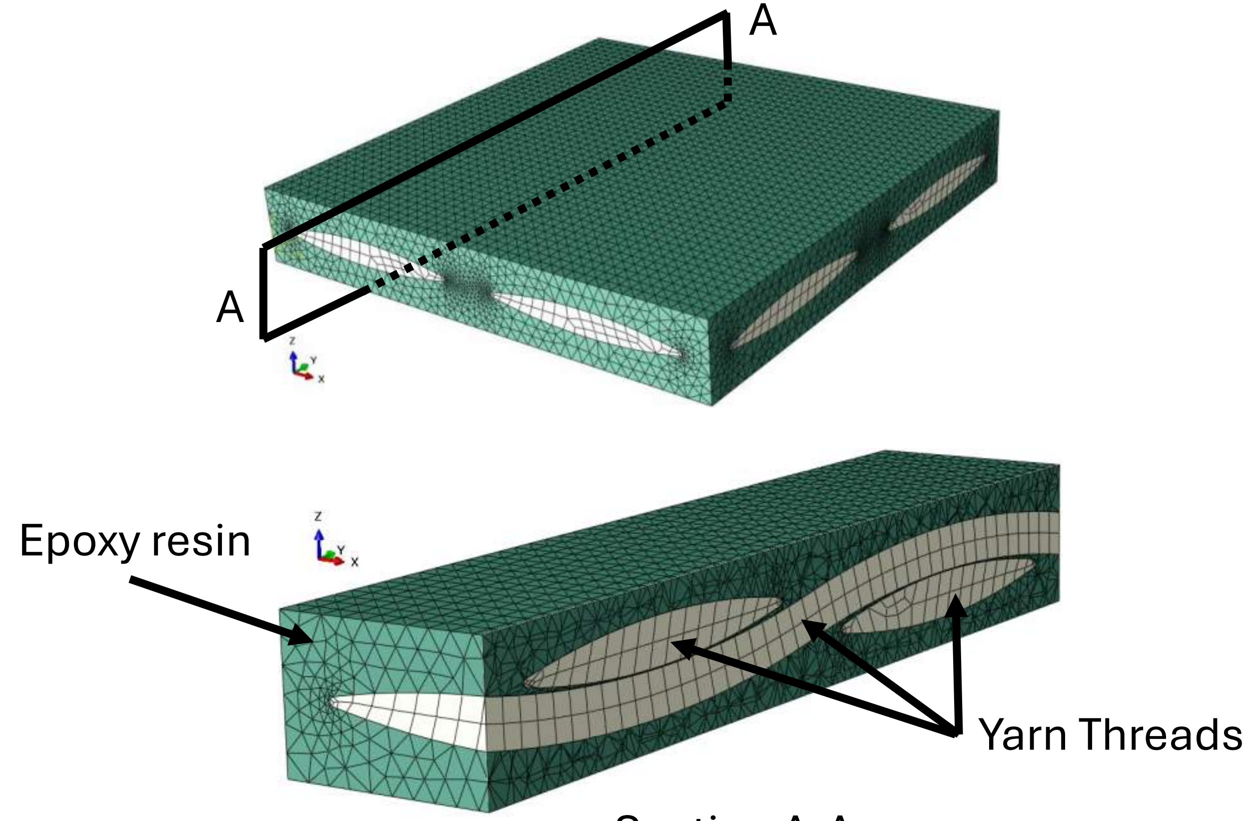


Unstitched fabric material
Inputs:
Basic information and dimensions
Outputs:
Verified homogenized engineering constants

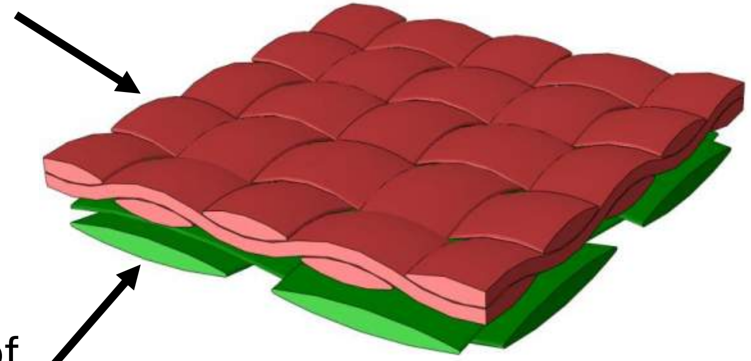
Note:
The proposed FEM approach uses the Abaqus/Explicit solver because of the complex
interactions and geometric nonlinearities

Unstitched microstructure modeling

Mesh generation step for yarns and surrounding epoxy resin

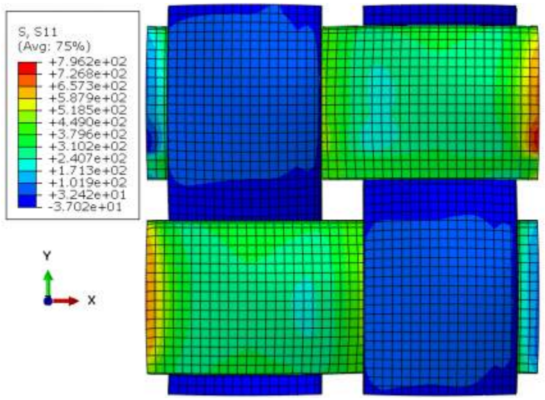


Section A-A

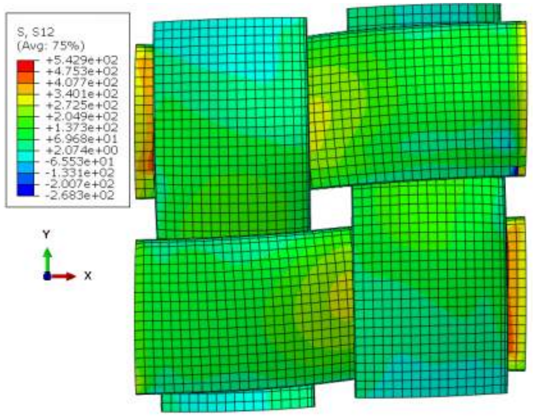


Homogenization Analysis

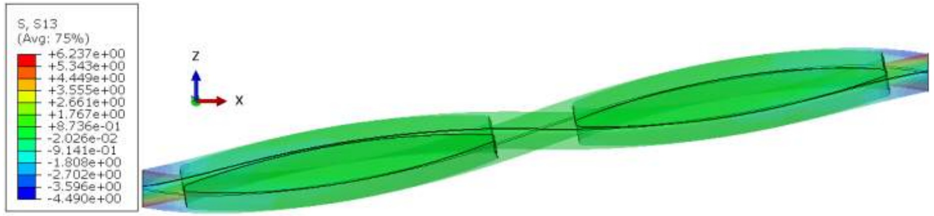
Homogenized engineering constants for each layer



Tension test results (S11)



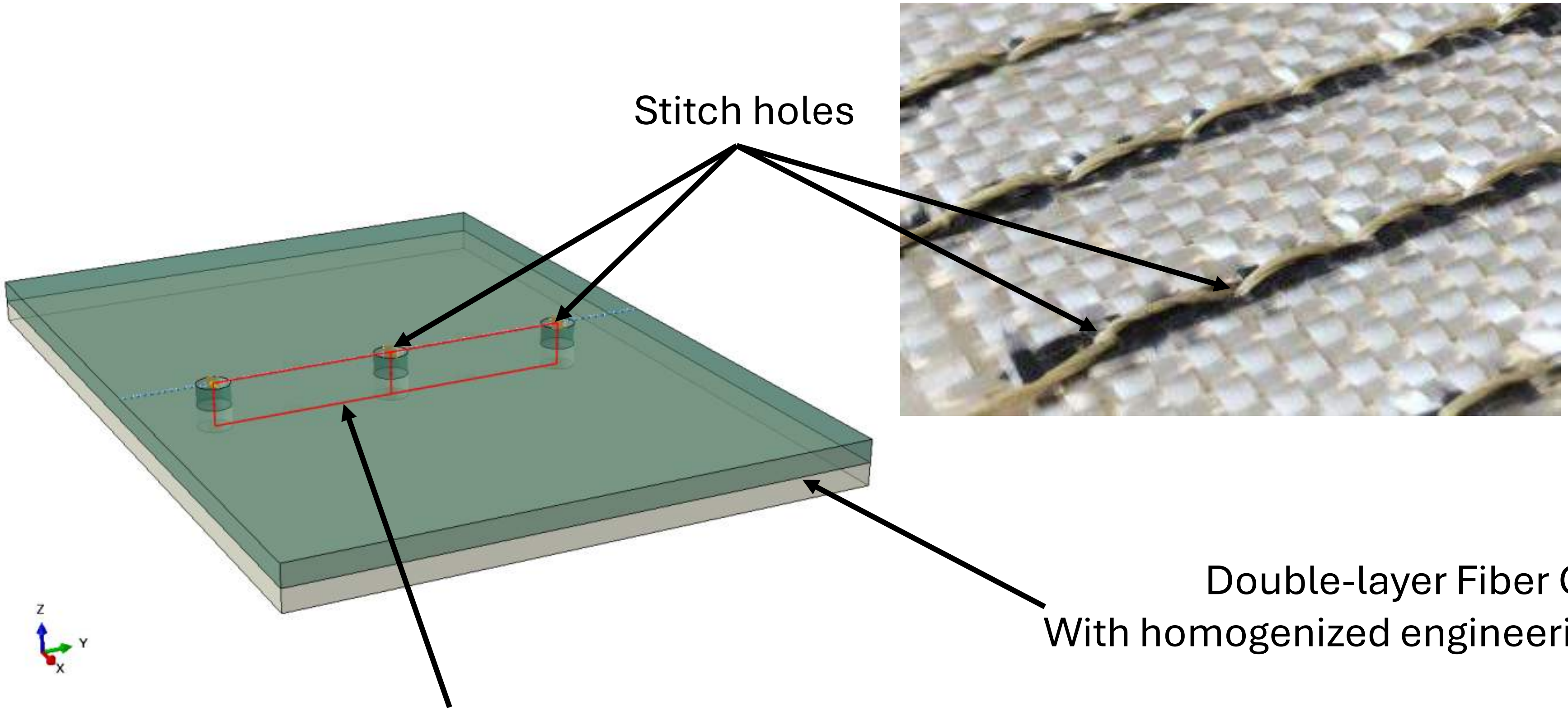
In-plane shear test results (S12)

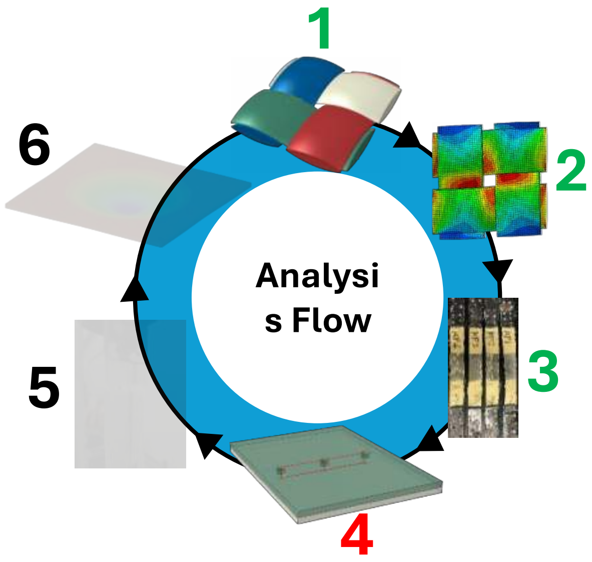


Out-of-plane shear test results (S13)

Homogenized Engineering Constants

	E1 (MPa)	E2 (MPa)	E3 (MPa)	v12	v13	v23	G12 (MPa)	G13 (MPa)	G23 (MPa)
Fiber Glass	12,023	12,023	3,000	0.15	0.23	0.23	1,500	1,845	1,845
Kevlar	17,359	17,359	3,000	0.1	0.23	0.23	1,500	244	244





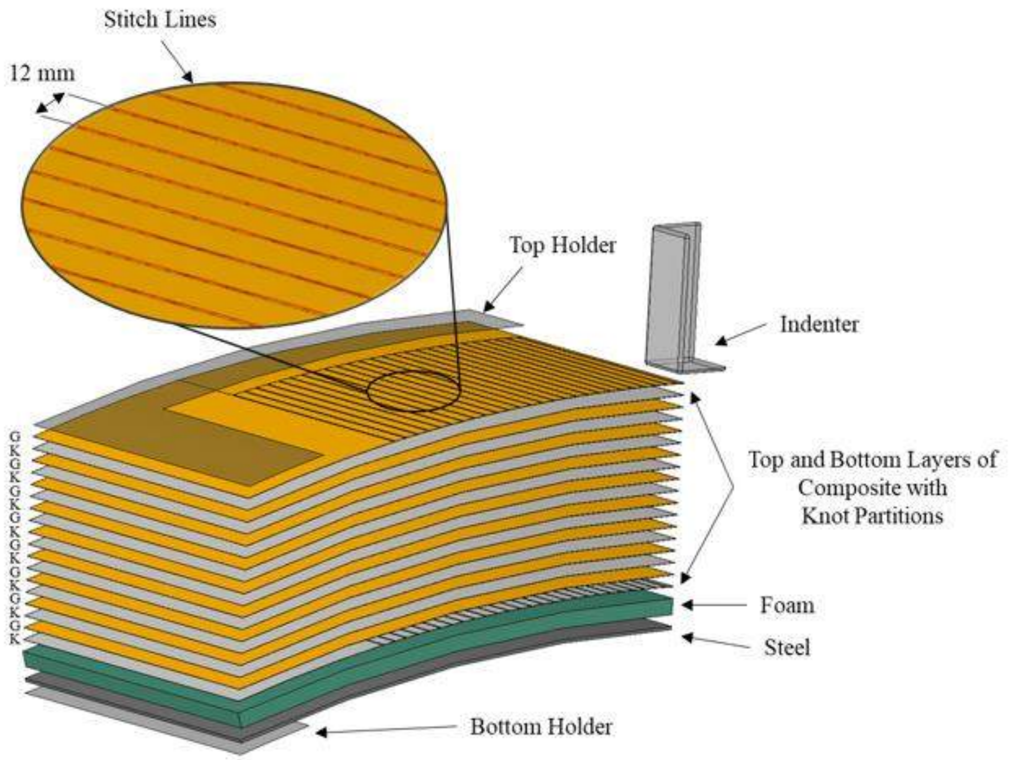
Double-layer Fiber Glass composite
With homogenized engineering constants from Step 3

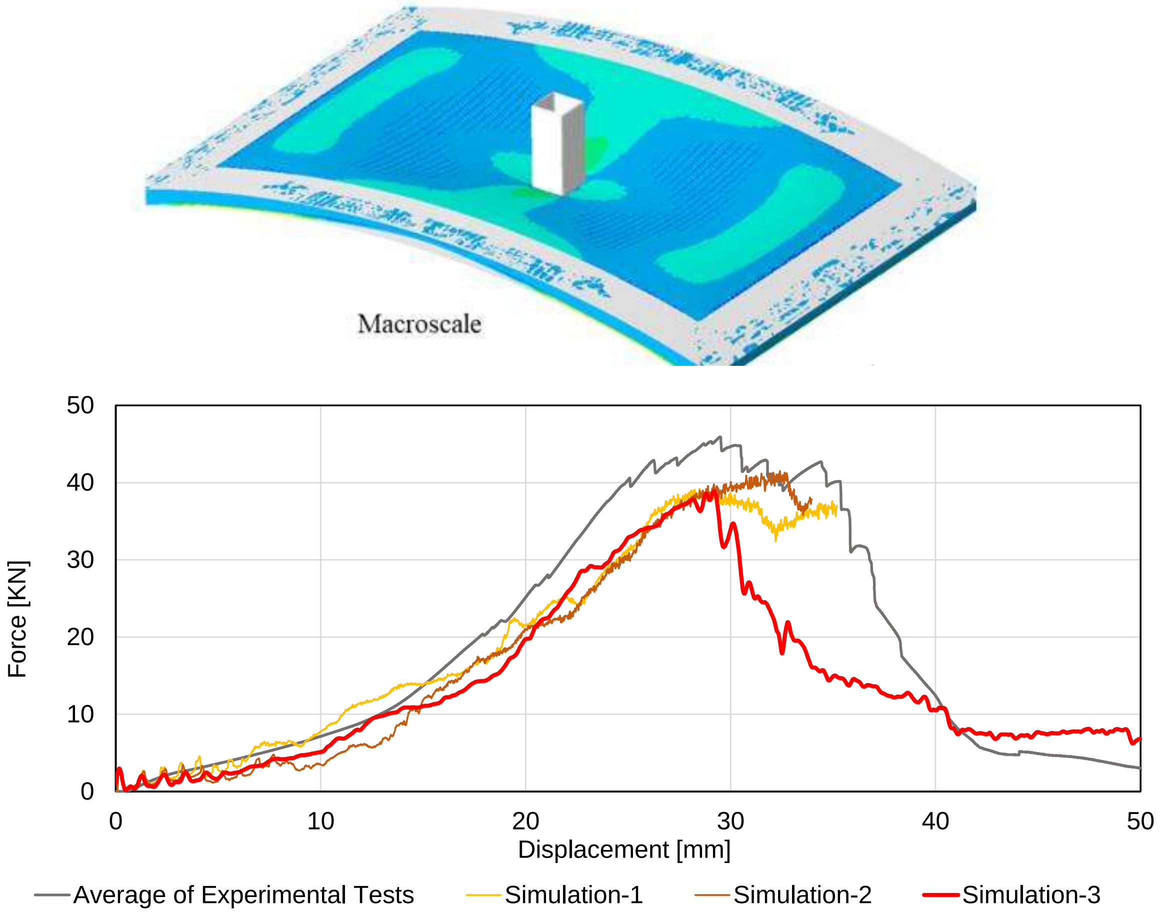
Connector elements as stitching thread

- ✓ Connector elements in ABAQUS provide a simplified way to model the axial members like stitch thread

Stitched Composite: Simplified model

Stitched composite under impact





Curved, 18-layer fabric composite jacket with foam and steel plate substrates.

Conclusion

VARTM Process Optimization

•Developed high-quality composite jackets with 55%-60% fiber volume fraction using Vacuum Assisted Resin Transfer Molding (VARTM).

Key Findings

•Hybrid composites (glass and Kevalr) and epoxy exhibited superior puncture and impact resistance.

•optimized properties with fabric orientations and through-thickness stitching.

Performance Improvements

•Composite jacket is 4.3 times lighter with 1.9 times better specific energy absorption under dynamic impact compared to steel.

•Composite jacket, foam, and steel combination showed 3.4 times higher specific energy absorption at material rupture.

Finite Element Simulations

•Improved understanding of behavior under static puncture and low-velocity impacts using multiscale FE simulation and closely aligned with experimental data, validating the methodology.