

# **Super Strong Carbon Fiber Composites For Use In Bridge Structural Enhancements**

**Jon Woods, Ph.D., P.E.**

*Senior Project Manager – Infrastructure Rehabilitation,  
Dibble Engineering*

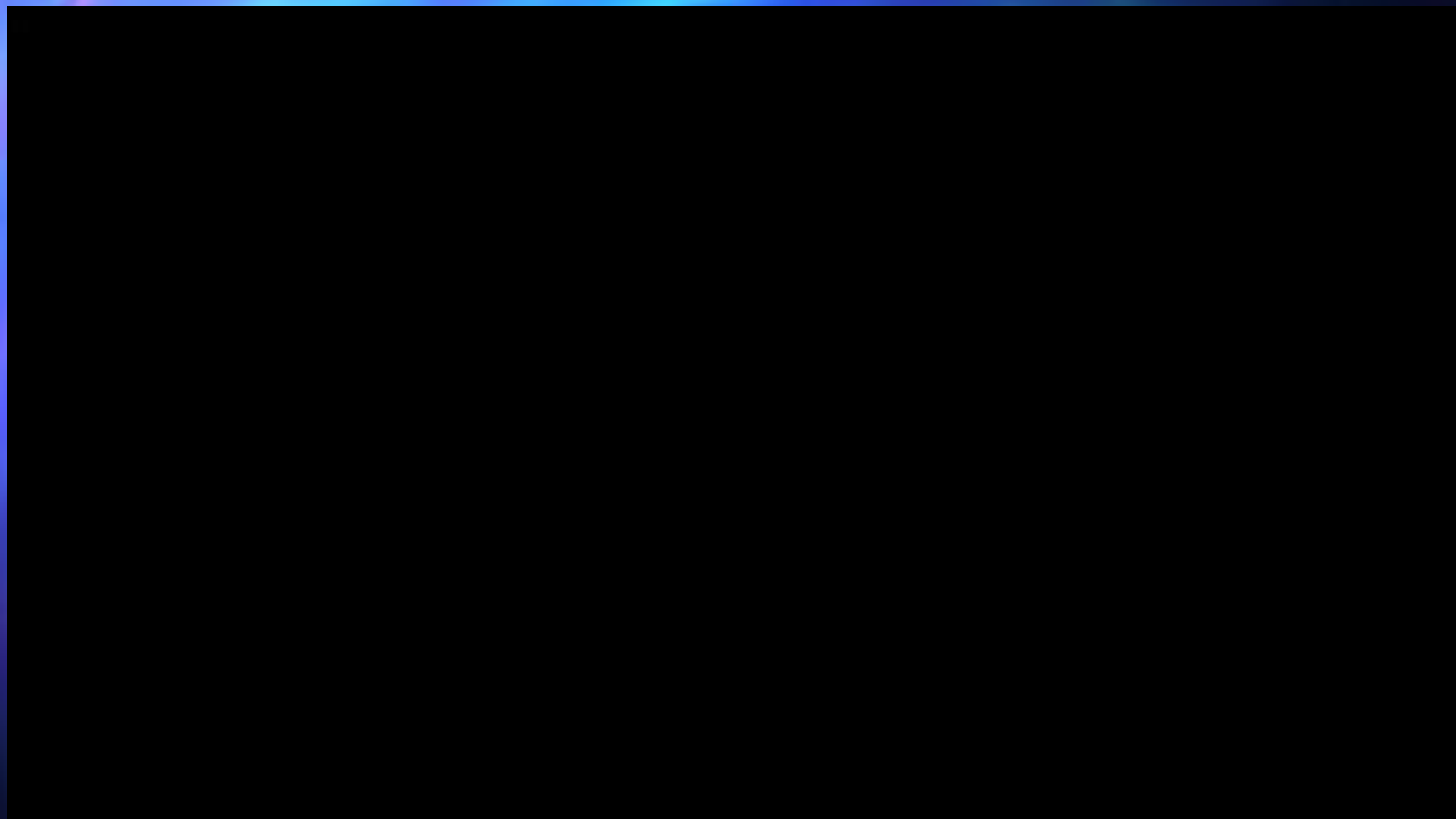
*[jon.woods@dibblecorp.com](mailto:jon.woods@dibblecorp.com)*

*14<sup>th</sup> Arizona Pavements/Materials Conference  
2017 Embracing Pavement Technologies*



# Question...

- Do you know what an FRP is?
- Have you specified, designed or been involved in a project that utilized FRP?



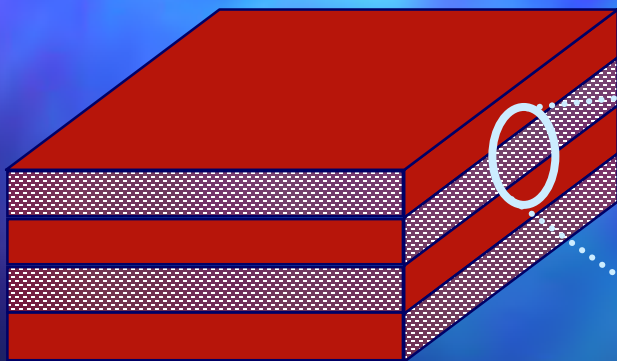
# What is an FRP?

- Fiber Reinforced Polymers
- A type of composite
  - wood
  - bones
  - reinforced concrete
  - any material that consists of combining two or more constituents at the macroscopic level to interact as one

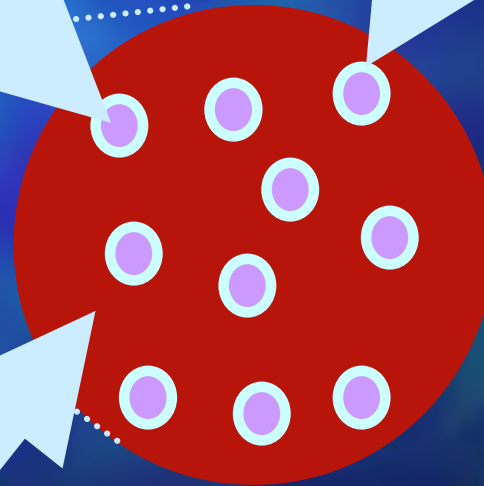
# Components of FRP

Fiber Reinforcement

(Glass, Carbon, Kevlar, etc.)



Interphase  
Coupling  
Agent



Polymer Resin Matrix

(Thermoset or Thermoplastic)



# Types of Fibers Typically Used

## ■ Laminates

- Uni-directional
- Carbon or Glass
- Precured



## ■ Woven Fabrics

- Uni or bi-directional
- Carbon or Glass
- Field cured



# Types of Resins

## ■ Thermosets

- Most common for civil/structural applications
- Requires internal heat source to cure (ie: catalyst)
- Solid after cured and cannot be reprocessed
- Lower failure strains



## ■ Thermoplastics

- Most common for mechanical parts, sporting equipment, armor, etc.
- Requires external heat source to cure (ie: autoclave)
- Solid after cured but can be reprocessed
- High failure strains

# Facts about FRP compared with conventional materials

## ■ Advantages

- higher specific strength= $\sigma/\rho$
- higher specific modulus= $E/\rho$
- good resistance to electro-chemical corrosion
- versatility
- good fatigue properties

## ■ Disadvantages

- fabrication cost
- brittle failure
- mechanical characterization
- poor understanding toward the applications

<i>Fibre</i>	<i>Specific gravity</i>	<i>Ultimate tensile strength (GPa)</i>	<i>Tensile modulus (GPa)</i>	<i>Specific tensile strength (GPa)</i>	<i>Specific modulus (GPa)</i>
A-glass	2.45	3.1	72	1.26	29
E-glass	2.56	3.6	76	1.40	29
R-glass	2.58	4.4	85	1.70	33
S-glass	2.49	4.5	86	1.80	34
Type I, carbon fibre, high modulus	1.87	2.1	330	1.12	176
Type II, carbon fibre, high tensile strength	1.76	2.6	235	1.48	133
Type III, carbon fibre	1.82	2.3	200	1.26	110
Aramid fibre, Kevlar 29	1.44	2.76	58	1.92	40
Aramid fibre, Kevlar 49	1.45	2.94	130	2.03	90
Asbestos	2.5	0.7–1.4	135–170	0.28–0.56	54–68
Cotton	1.6	0.3–0.7	—	0.19–0.44	—
Sisal	1.3	0.8	—	0.61	—
Aluminium (bulk)	2.8	0.5	75	0.18	27
Steel	7.8	1.0	200	0.13	26
Titanium DTD 5173	4.5	0.96	110	0.21	25
Boron	2.62	3.4	344	1.30	130
Beryllium (bulk)	1.82	1.03	310	0.57	170

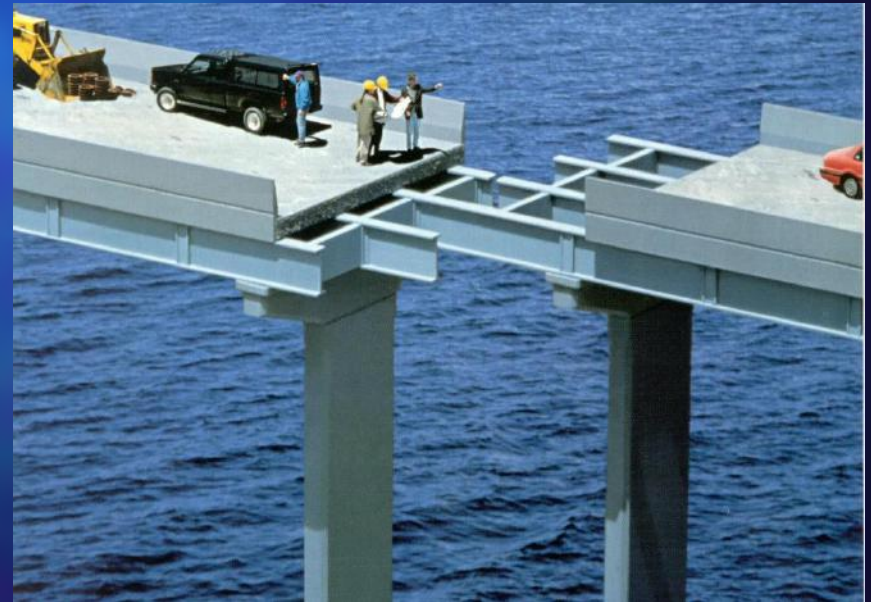


# Infrastructure and FRP Rehabilitation History

- Infrastructure consists of roads, bridges, buildings, dams, airports, etc.
- Approximately 580,000 inventoried bridges in the USA (FHWA 2010)
  - Structurally Deficient or Functionally Obsolete Bridges
    - 2001 – 30.1%
    - 2009 – 26.5%
- Structurally Deficient Bridge:
  - Does not imply that a bridge is unsafe
  - Characterized by deteriorated conditions of significant bridge elements
  - Potentially reduced load-carrying capacity
  - Typically requires significant maintenance and repair to remain in service (ie: poor deck, superstructure, substructure, or culvert/retaining walls condition, poor waterway adequacy appraisal)
- Functionally Obsolete Bridge:
  - Does not meet current design standards (ie: lane width, poor deck geometry, under-clearances, poor approach roadway alignment, or poor waterway adequacy appraisals)
  - Typically requires widening or replacement to remain in service

# Infrastructure and FRP Rehabilitation History

- Structurally Deficient or Functionally Obsolete?





# Infrastructure and FRP Rehabilitation History

- Steel was the primary material used for rehabilitation before FRPs

## Plate Bonding



## External Post-tensioning



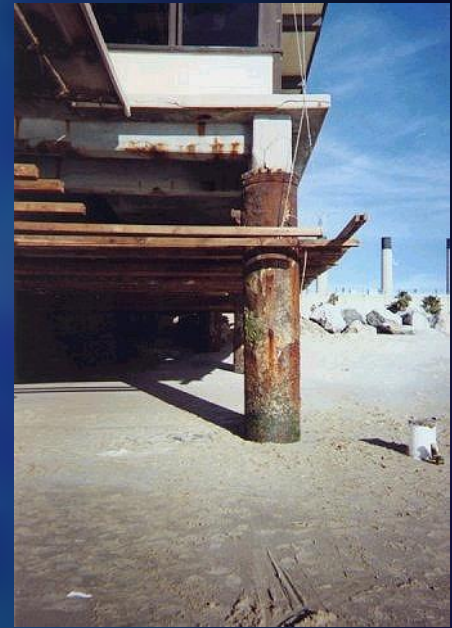
## Column Jackets





# Primary Function of FRP in Civil Engineering Applications

- Retrofitting and Rehabilitation
- Strengthening of existing structures with laminates or wraps
- Bridge deck repair, remediation, new construction



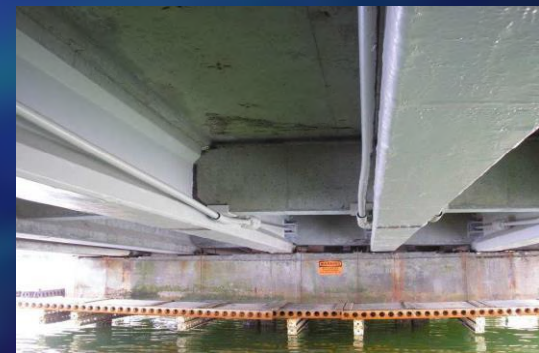


# Common FRP Bridge Repair Applications

## ■ Concrete Beams/Girders

### Advantages

- Increase flexural capacity
- Increase shear capacity
- Allows existing structure to accommodate greater loading
- Repair damaged or cracked (spalled) concrete beam due to reinforcement corrosion
- Protect structure
- Provide supplemental reinforcement due to corrosion, under-design or code upgrade

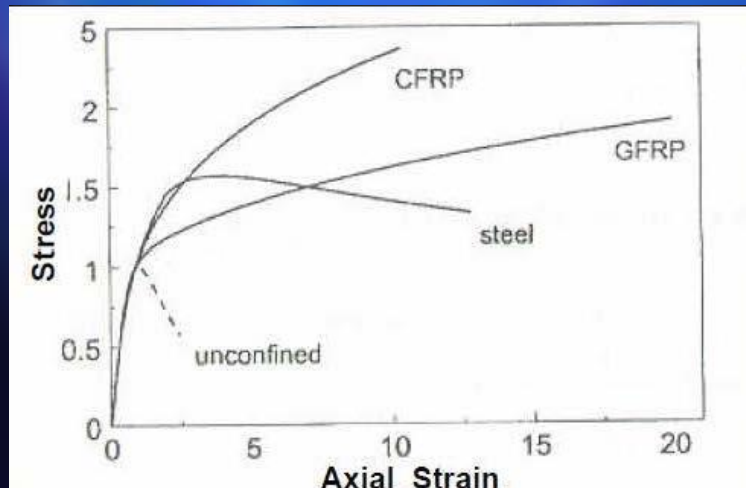
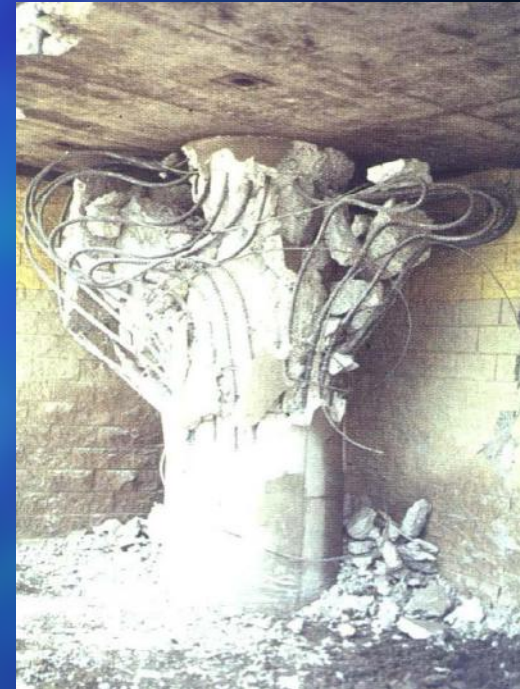


# Common FRP Bridge Repair Applications

## ■ Column Wrapping

### Advantages

- Increase axial capacity
- Increase bending capacity
- Increase shear capacity (confinement)
- Increase ductility
- Protects existing structure



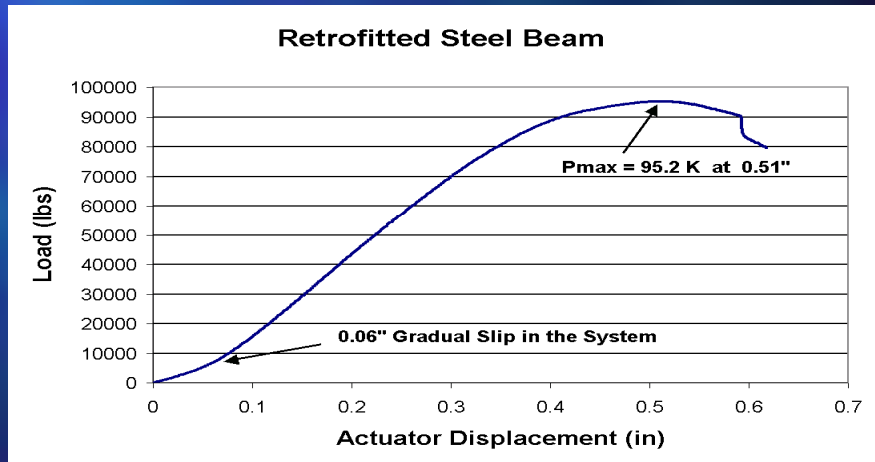


# Common FRP Bridge Repair Applications

## ■ Steel Beams

### Advantages

- Increase flexural capacity
- Increase fatigue life
- Protect from corrosion
- Increase stiffness
- Restore full capacity of cracked member

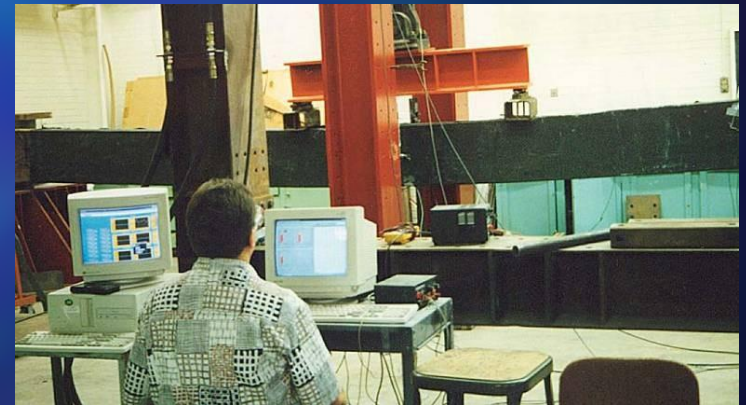
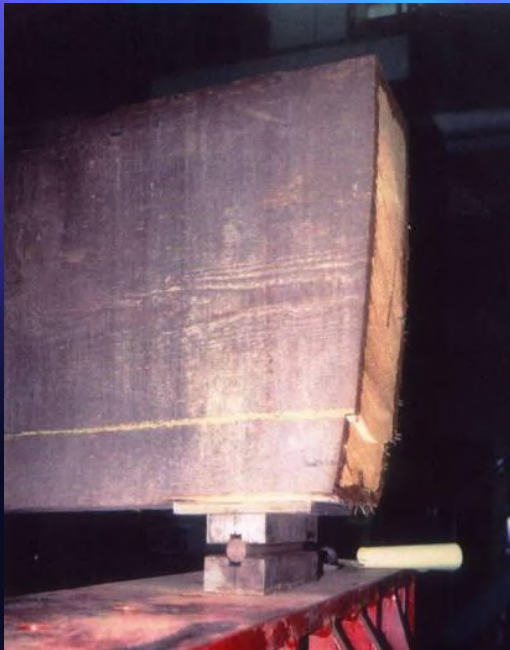


# Common FRP Bridge Repair Applications

## ■ Wood Beams

### Advantages

- Increase flexural capacity
- Increase shear capacity
- Increase stiffness and reduce deflection
- Protect wood



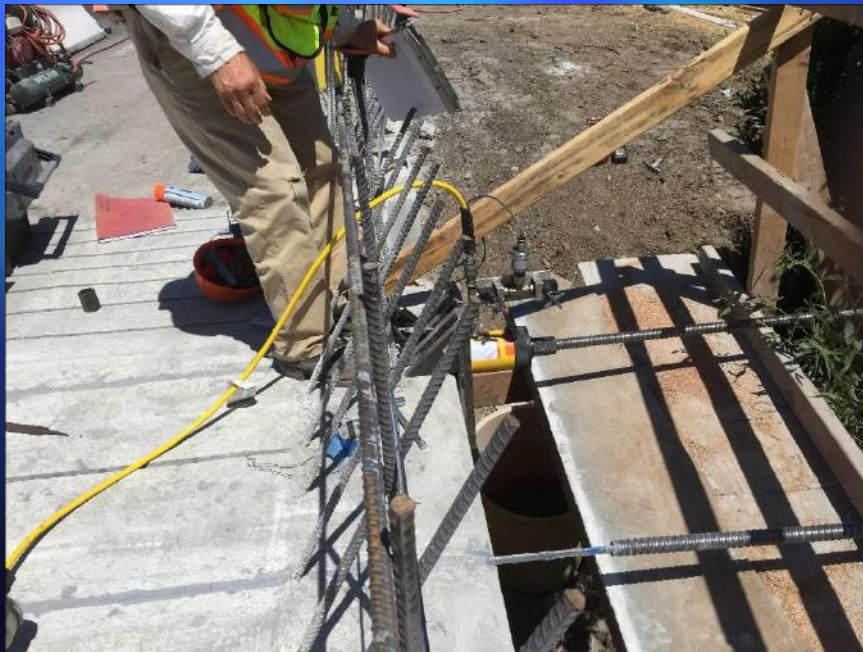


# Common FRP Bridge Repair Applications

## ■ Bridge Deck Repair and Strengthening

### Advantages

- Near Surface Mount (NSM) laminates increase flexural strength without adding to existing dead loads
- Eliminates spalling and cracking caused by reinforcement corroding





# Why else should we use FRPs?

## Bridge Deck Replacement



Bentley's Bridge, located near Elmira, New York, was rehabilitated in Sept. 1999.

Originally, the structure had a steel reinforced concrete deck cast over steel stringers.

Due to deterioration of the bridge, load restrictions were posted.

## Benefits of Using FRPs for Deck Rehabilitation



Allow vehicle weight restrictions to be removed

Eliminate the need for a costly and time-consuming bridge replacement project along a heavily trafficked road.

Reduce the deck dead load on the structure by 265 tons.

Prolong the life of steel truss bridge.

# New FRP Bridge Deck Repair Applications

## ■ Bridge Deck Repair

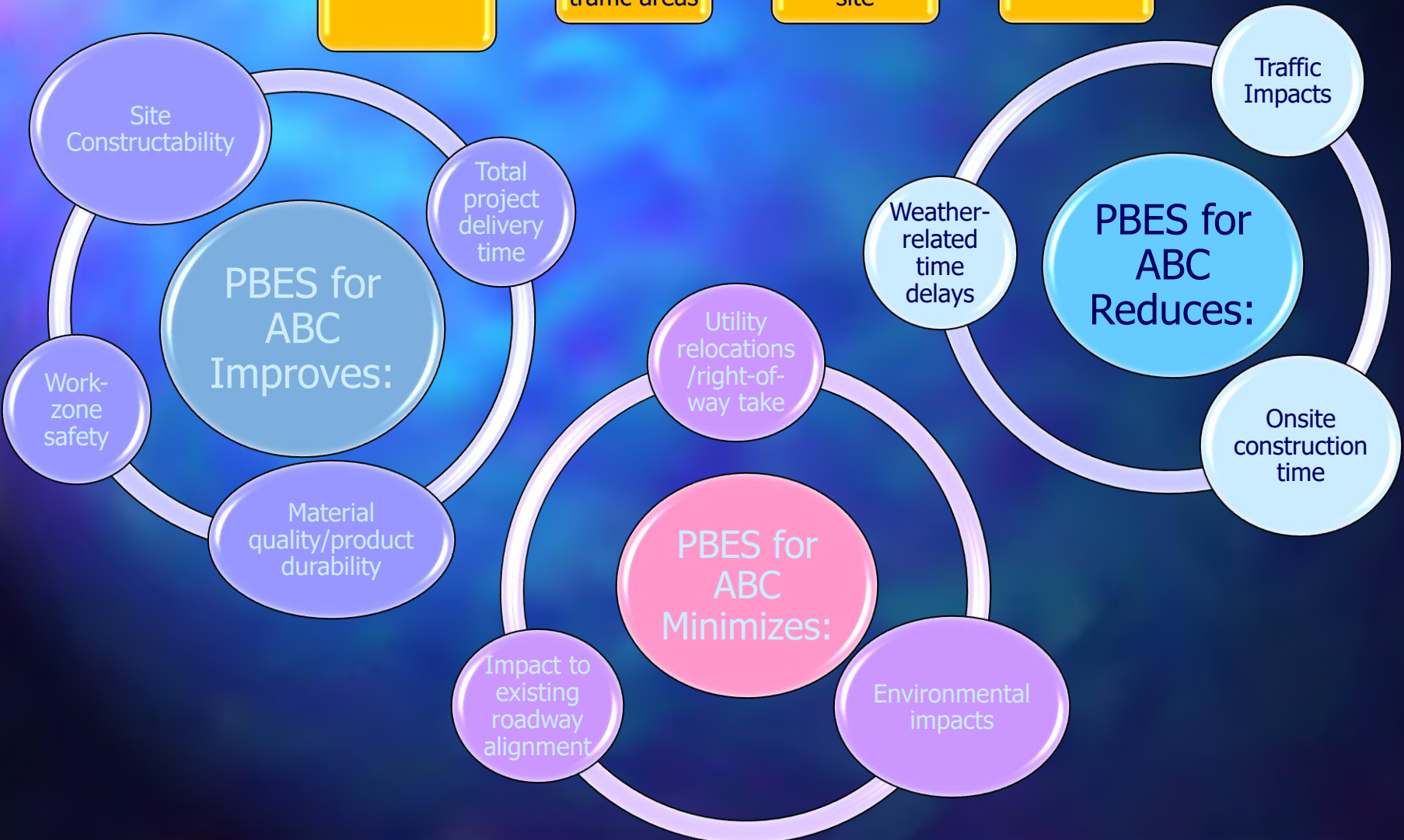
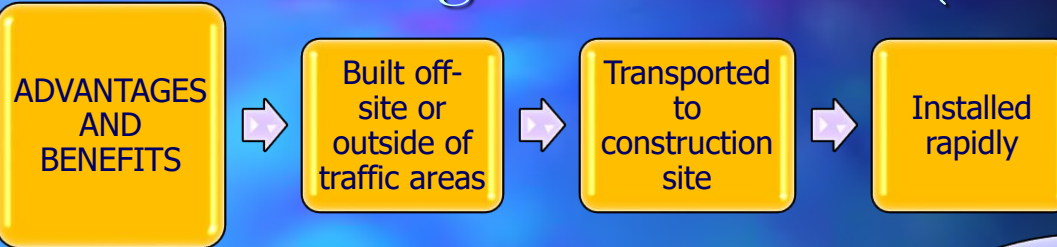
### Advantages

- Composite decks are light weight (one-fifth the weight of reinforced concrete deck)
- Durable (75+ years) with very low maintenance
- Ideal for movable bridges and load rated trusses
- Fast installation without the need for heavy crane equipment
- Fully pre-fabricated product delivered to site
- Corrosion resistant
- Superior strength





# Prefabricated Bridge Elements and Systems (PBES) for Accelerated Bridge Construction (ABC)





# Columbia River Skywalk: Double Duty Suspension Bridge Trail, British Columbia





## ■ Loading

- Uniform live load of 84 psf (4 kPa)
- $L/500$  deflection
- Concentrated load of 2,248 lb on 1.08 ft<sup>2</sup> (10 kN on 0.10 m<sup>2</sup>)
- Uplift load of 10 psf (0.5 kPa)
- Wind lateral (shear) load of 253 lb/ft (3.7 kN/m)
- Rail post moment of 2,430 ft-lb (3.3 KN-m)
- Minimum Safety Factor of 5

- Deck dead load weight of 8.4 psf (0.407 kN/m<sup>2</sup>) –  $t \approx 6$  inch  
(Equivalent Concrete weight=75psf, Equivalent Exodermic Deck=55psf)

## ■ Deck Size

- Main span is 738 ft x 13.1 ft (225m x 4m)
- Back span is 230 ft x 23 ft (70m x 7m)
- Total area is 14,960 ft<sup>2</sup> (1,390 m<sup>2</sup>)



# FRP Deck Panels



Facesheet Laminate



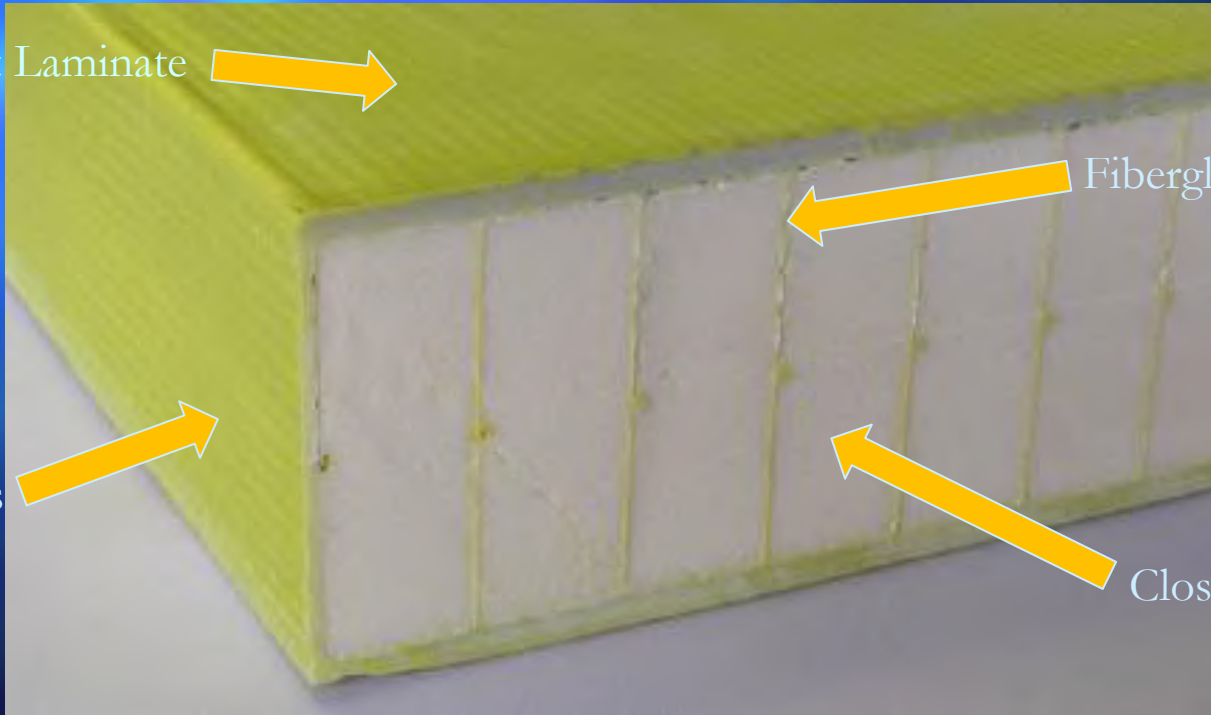
Fiberglass shear webs



Fiberglass fabrics  
wrap around edges



Closed cell foam



Composite Sandwich Structure

## ■ Functional Requirements

- Crown with slope of 2%
- Curbs
- Drainage scuppers
- Access hatches for utilities
- Transitions between widths and around towers
- Accommodate girder splices every 5m
- Girder supports are 2.5m on center
- Non-slip overlay

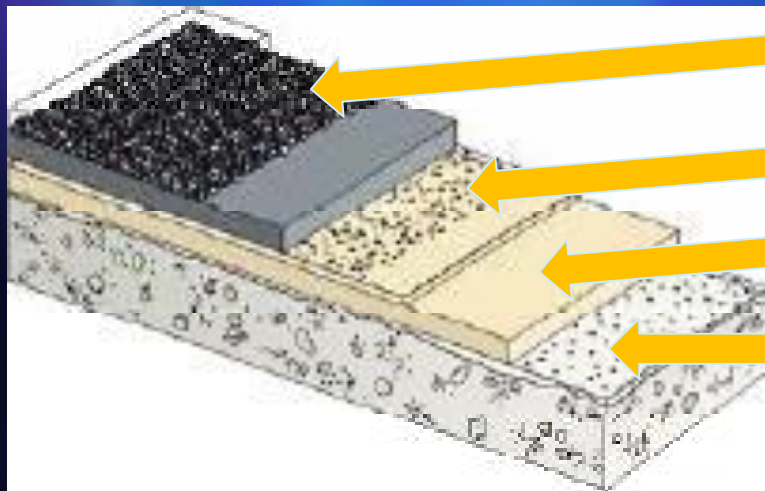
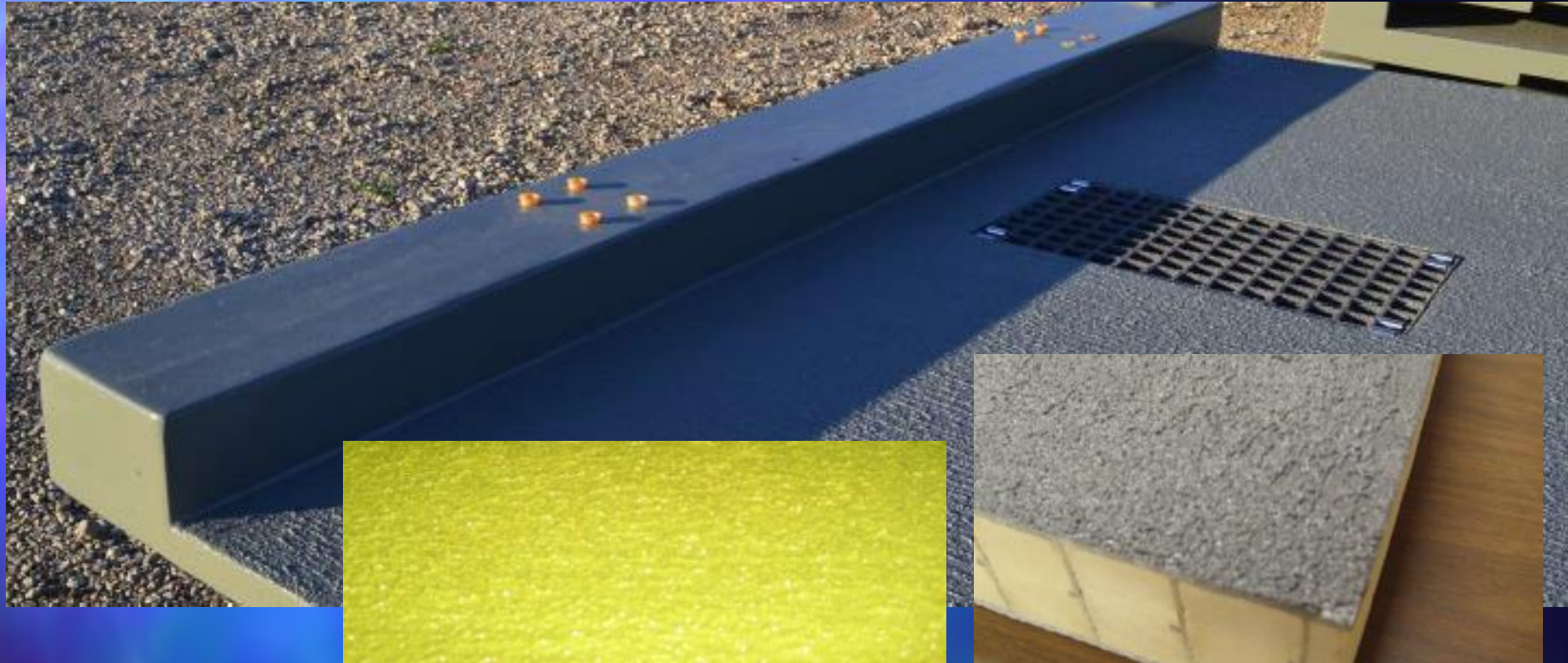
## ■ FRP Deck Layout

- 110 panels
- 9 panel types
- Length of 8.17 ft (2.49 m)
- Widths of 23 ft (7m) and 13.1 ft (4m)





# Nonslip Wear Surface



Topcoat Layer

Broadcast Wearing Layer

Waterproofing Membrane Layer

Primer/Natural Quartz Layer



# FRP Bridge Deck Installation

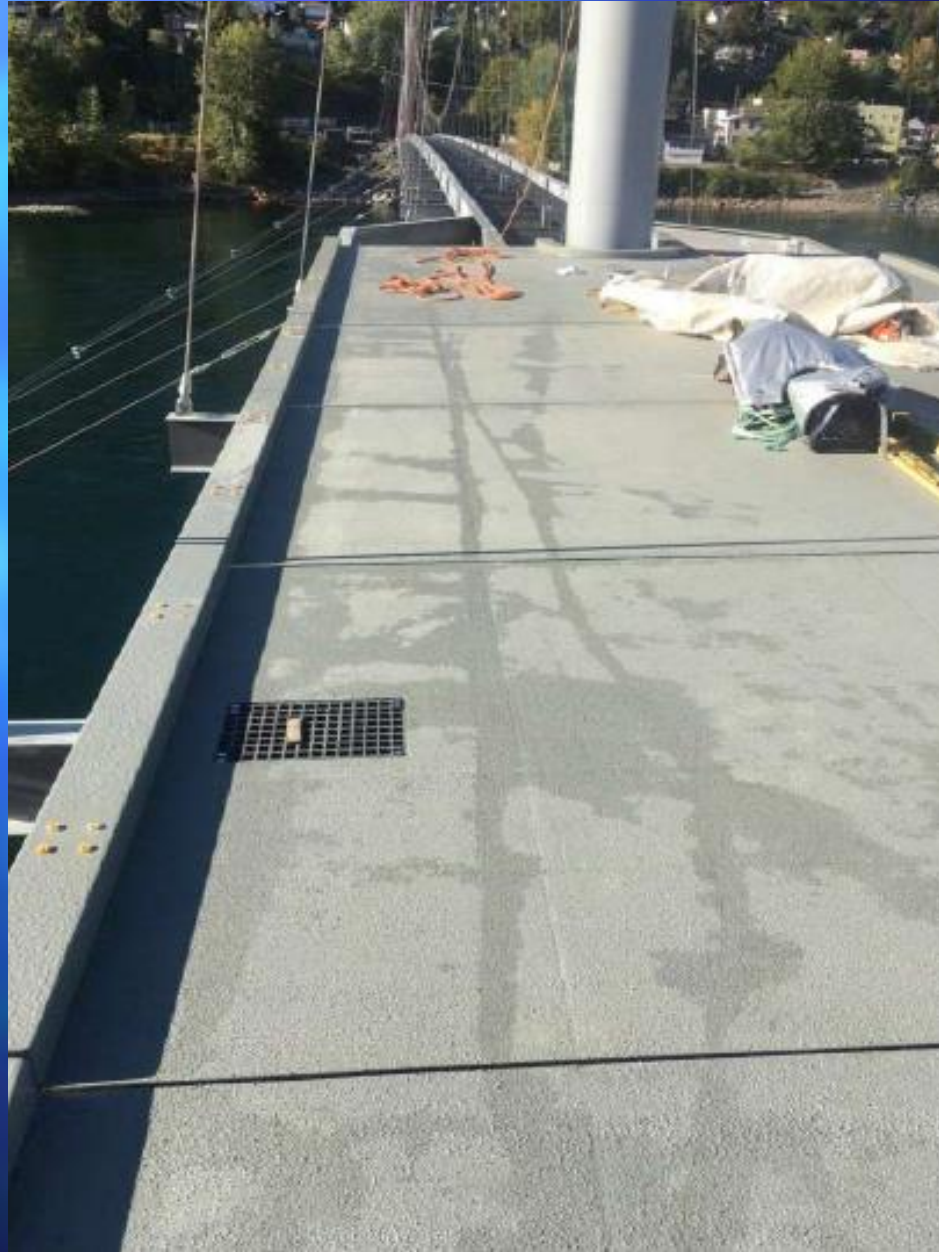




# FRP Bridge Deck Installation



# FRP Bridge Deck Installation





# FRP Bridge Deck Installation (Finished Structure)



# FRP Bridge Deck Installation (Finished Structure)





# FRP Bridge Deck Installation (Finished Structure)



# FRP Bridge Deck Installation (Finished Structure)





# Swing Span Truss Bridge, Rocks Village Bridge, Haverhill, MA



# Swing Span Truss Bridge, Rocks Village Bridge, Haverhill, MA

- Bridge Parameters
  - Deck Size:
    - Six spans (809 feet total)
  - Deck Width:
    - Spans 1 to 3 = 21.25 feet
    - Spans 4 to 6 = 25.3 feet
  - Deck Area:
    - 18,776 SF
  - Loading:
    - HS-25 with L/500 Deflection
  - Superstructure:
    - Steel Truss with Longitudinal Beams
  - Guard Rail:
    - Attached to Deck (Side and Top)



# Original Bridge Deck (Before)

(Bituminous Concrete Wearing Surface)



# FRP Bridge Deck (After)

(Nonslip Wearing Surface)





# FRP Bridge Deck (After)

(Nonslip Wearing Surface)



# FRP Bridge Deck Panels

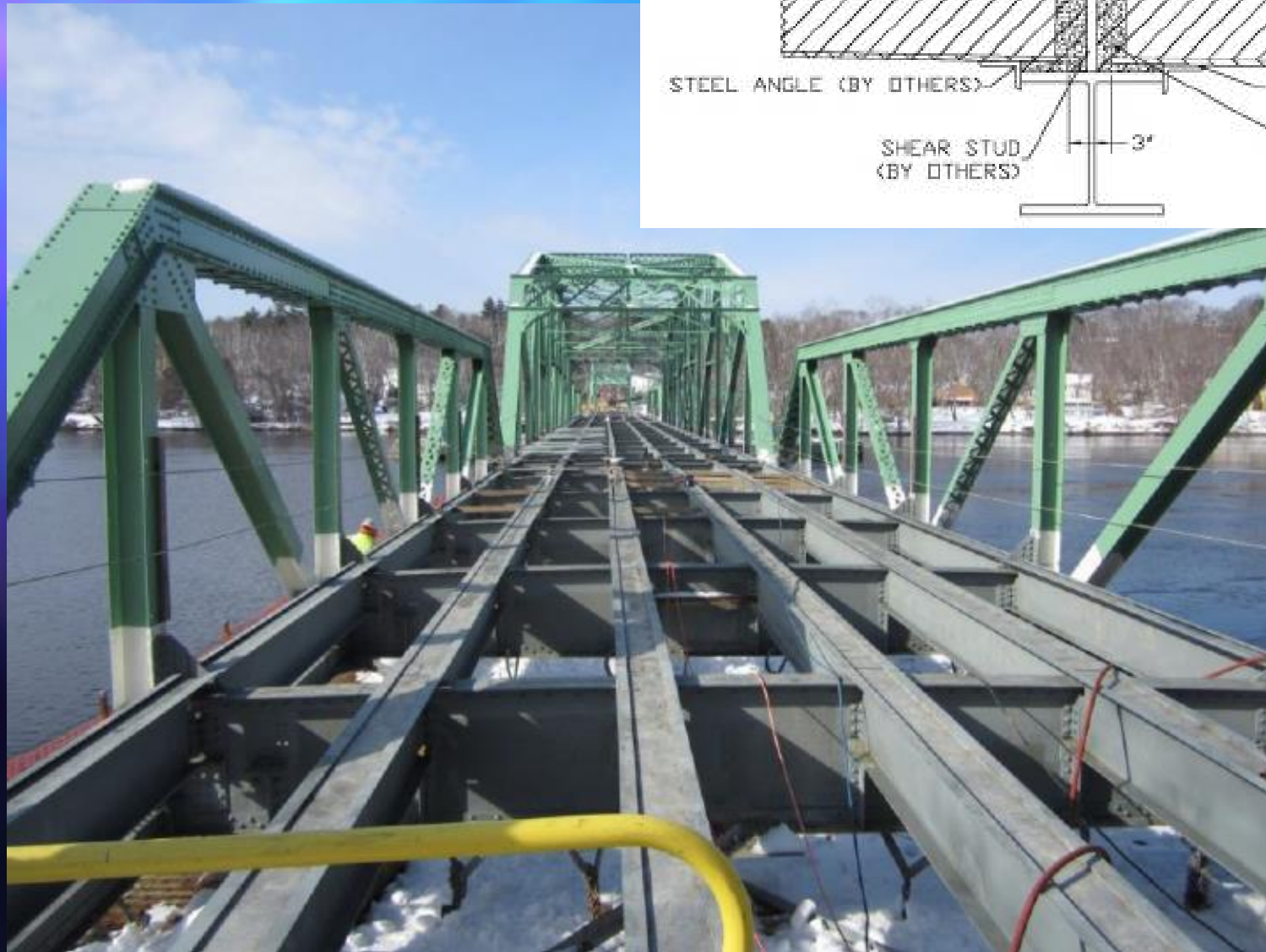
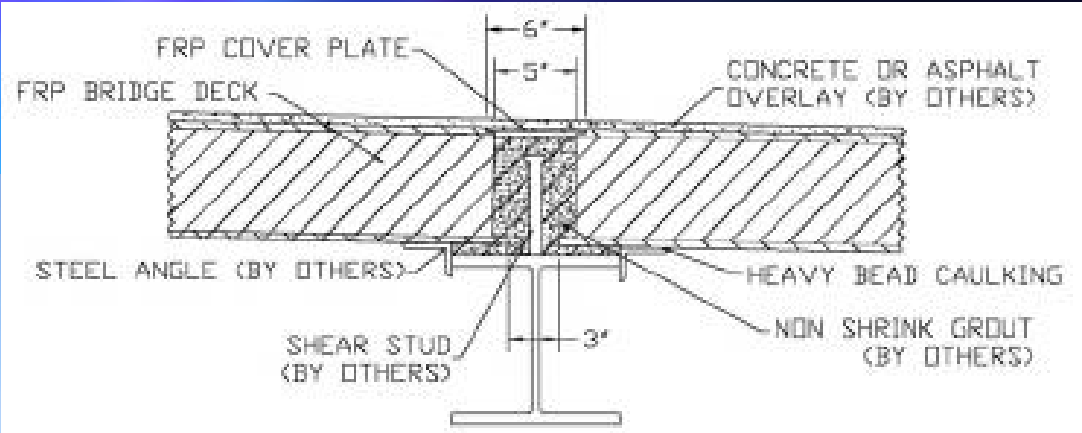


- Depth of 7 inches
- Crown
- Deck Weight = 19psf
- Polymer Concrete Wear Surface





# Bridge Superstructure



# FRP Bridge Deck Installation





# FRP Bridge Deck Installation



# FRP Bridge Deck Panels

(Deck Connection to Superstructure – Grouted Shear Studs)





# FRP Bridge Deck Installation

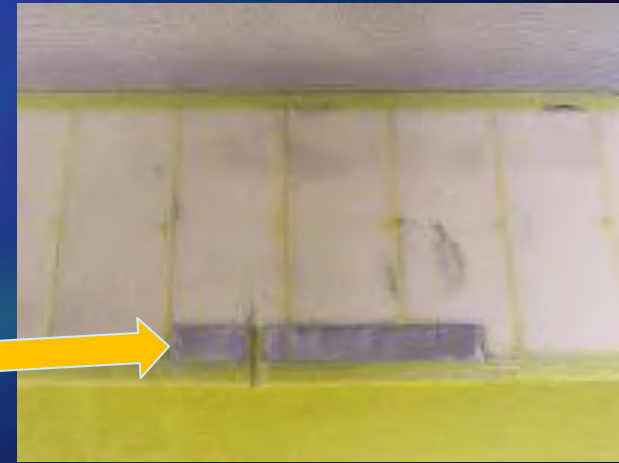


# FRP Bridge Deck Panels

## (Deck Connection to Superstructure – Clips)



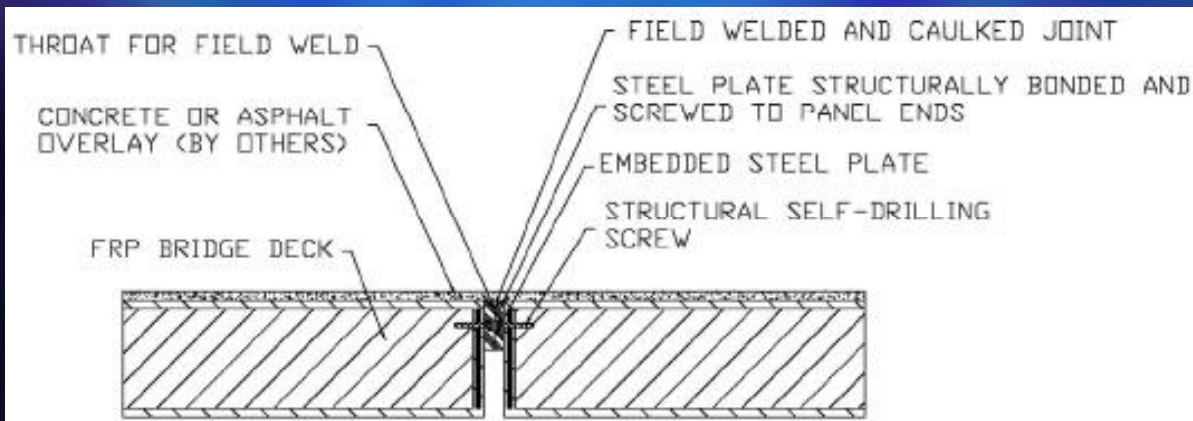
- Mechanical connection
- Clips to capture any type of beam
- Provides vertical constraint; allows for longitudinal thermal expansion
- Bolted into embedded steel that is drilled and tapped





# FRP Bridge Deck Panels

## (Panel to Panel Connections)



- Stitch welded steel strips are bonded/bolted to panel ends

# FRP Bridge Deck Panels





# FRP Bridge Deck Panels

(Expansion Joints at Span Ends)



- Galvanized steel plates
- 1/2" matches TPO topping thickness
- At end of deck spans for impact resistance
- Attached in the shop
- Includes rail for neoprene seal



# FRP Bridge Deck Panels (Expansion Joints at Span Ends)





# FRP Bridge Deck Panels

(Expansion Joint Panels at Swing Span)



Span 4

Swing Span 3

# FRP Bridge Deck Panels

(Custom Fit – Notch in deck around gussets)





# FRP Bridge Deck Panels

(Finished Structure)





Thank you!

Questions?

**BEAR DOWN!**