Concrete Filled, Fiber Reinforced Polymer (FRP) Composite Tubes

“Bridge-in-a-Backpack”

A collaborative innovation together with:

MaineDOT

AEWC

Advanced Structures & Composites Center
What is the “Bridge-in-a-Backpack” System
Fiber Composite + Concrete Arch Superstructure

“A Hybrid bridge system combining benefits of high-performance composites with durability and cost savings of cast-in-place concrete”
UMaine AEWC Composites Center
- 87,000 ft² facility
- Researching Hybrid Composite Systems since 1996
- Nearly 12 years development of Bridge-in-a-Backpack

Secretary of Transportation Ray LaHood Speaks about Bridge-in-a-Backpack at UMaine Press Event
National Recognition for Bridge-in-a-Backpack

AASHTO Technology Implementation Group

Engineering Excellence Award Royal River Bridge, Auburn, ME
(Along with Maine DOT & Kleinfelder | SEA)

American Society of Civil Engineers
2011 Charles Pankow Award for Innovation

American Composites Manufacturers Association

ACEC
American Council of Engineering Companies
100 Years of Excellence

Product featured in:
Engineering News Record,
The NY Times,
Concrete International,
Popular Science,
Popular Mechanics,
The Boston Globe
- Develop & patent manufacturing process
- Model development

- Structural testing
- Model refinement
- Material optimization

- Demonstration project
- System refinement

2001 ➔ 2005 ➔ 2008 ➔ Ongoing

Manufacturing of 60’ Span Arch

Arch Structural Testing
- Deflections measured using 3D digital image correlation system
- FE model predictions compared with experimental response
Three Functions of the FRP Arch Tube

1. Stay-in-place form for concrete

Eliminates need for temporary formwork
2. “Structural reinforcement” for concrete confinement

Eliminates need for rebar installation, no steel rebar in superstructure

Enhances concrete performance for safety & structural redundancy
3. Environmental protection for concrete

Concrete Corrosion Cycle:

Steel rusts and expands causing concrete spalling

Spalling concrete exposes more reinforcement

Drastically reduces maintenance requirements

Photo Credit: “Bridge with Sky” thanks to John Hillman and MoDOT
Performance Testing: Arch Testing

Load-Deflection Response of Concrete-Filled FRP Tubular Arch

Applied Load (kip) vs. Vertical Deflection at Crown (in)

- Initial Static Test to Failure
- HL-93 Design Load Equivalent
### Experimental & Predicted Capacity

<table>
<thead>
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<th>Failure Load (kip)</th>
<th>COV</th>
<th>No.</th>
<th>Percent Diff.</th>
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<tr>
<td>Experimental</td>
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<td>Predicted</td>
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<tr>
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<td>7.75%</td>
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<td>1.10%</td>
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<tr>
<td>Predicted</td>
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</table>

**Load-Deflection Response of Concrete-Filled FRP Tubular Arch**

- **Initial hinge at crown**
- **Subsequent hinges at shoulders**

- **Graph Details:**
  - **X-axis:** Vertical Deflection at Crown (in)
  - **Y-axis:** Applied Load (kip)
  - **Legend:**
    - Initial Static Test to Failure
    - Post-Failure Behavior
Performance Testing: Arch Testing

Load-Deflection Response of Concrete-Filled FRP Tubular Arch

HL-93 Design Load Equivalent

Applied Load (kip)

Vertical Deflection at Crown (in)

Initial Static Test to Failure

Post-Failure Behavior
Russian Engineers from the Federation Railway System representing 11 other countries as well

Our shared R&D Center at UMAINE
Composite Arch Production Process

1. Tubes assembled(packaged
2. Inflate tubes
3. Bend around arch form
4. Infuse with resin

Within hours, arches can be removed from form for installation
• AIT’s arches arrive on site ready for installation
• Can be unloaded quickly with hand labor
Filled with Self Consolidating Concrete (SCC)
Simple procedure, no rodding/vibration required
AIT provides standard specifications for concrete mix
SCC is a concrete that uses High Range Water Reducers (HRWR), or superplasticizers, to achieve high flowability.

In our mix we also include:
- Hydration Stabilizer (retarder)
- Shrinkage Compensating Admixture (SCA)
- 3/8” pea stone aggregate

ASTM C1611– Slump Flow

Aggregates evenly distributed throughout spread
No bleed water at leading edge
M 25 Harbor Beach
Proposed AASHTO LRFD Guide Specifications for Design of Concrete-Filled FRP Tubes for Flexural and Axial Members

- Closed-form, simplified method for design of Concrete-Filled FRP Tubes (CFFT’s)
  - Bending ($\phi_{Mn}$), Axial ($\phi_{Pn}$), Shear ($\phi_{Vn}$)
  - Combined Axial and Bending (interaction diagrams)
  - Connection detailing

- Generic in nature – applies to all CFFT’s
- Presented to AASHTO’s T-6 (FRP) Committee in May 2011
- T-6 plans to put forward for ballot to SCOBS in July 2012
Highly Customizable Geometries
Spans up to 75’

- Single or Multiple Spans
- Skewed designs
- Standard geometries or customized for specific sites
- Deep soil cover (45’ and greater)
- Water/stream crossings, Roadway overpass/underpass, Railway, Pedestrian, Tunnels

Inexpensive, Quick Installation, Long-term Reliability
Save on Skew – AIT Arch Advantages

- Orienting the arches and headwalls parallel the roadway
- Reduce total footprint of structure
  - Both width or span
- Reduce or eliminate right-of-way impacts
- Soften horizontal curves in the roadway alignments
Ellsworth Maine -- Maine DOT Skew Bridge Example

38% footprint reduction compared to precast concrete

Option B (Chosen) – AIT Arch Bridge: Skewed Alignment (~1775 sq. ft.)

Option A Initial Design – Precast Concrete Arch: Square Alignment (~2870 sq.ft.)
Skewed Bridges -- AIT Arches Savings Example

Benefits from our ability on skews:

- Reduced superstructure area
- Reduced substructure length
- Less earthwork
- Less right-of-way impact
  - Less legal issues
  - Less permitting issues
- Less environmental impact
  - Simpler permitting process
- Ability for staged construction

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<th>2 - Lane Bridge</th>
<th>4 - Lane Bridge</th>
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** call for more detail on specific
Design Options - Headwalls

Multiple options to meet the Engineering, Economic, and Aesthetic requirements of the site

- FRP Panel Walls
  - MSE or Through-Tied Configurations
  - Compatible with skewed bridges
  - Lightweight, easy to install
  - Durable, and cost competitive

- Concrete – Precast or CIP
  - MSE, Through-Tied, or Gravity
  - PC Panel, PCMG Units, Cast-in-place
  - Versatile design options
  - More conventional aesthetic
Design Options - Aesthetics

Architectural facades, details, rails, can be incorporated for improved aesthetic qualities

Images courtesy of various arch bridge suppliers
Summary and Quick Facts on CFFT Arch Bridges

**Innovative Product Application**
- Rapid fabrication
- Hybrid composite-concrete system improves material performance
- Steel free superstructure
- Reduced carbon footprint

**Performance Tested**
- Design/tested to exceed AASHTO load requirements
- Superior redundancy – safe system
- Corrosion resistant materials
- Field load testing indicates even greater levels of safety

**Cost Effective and Fast Installation**
- Light weight product—reduces equipment transportation needs
- Erected with a small crew, no skilled labor
- Performs up to 2x lifespan of conventional materials
- Accelerated Bridge Construction
- Rapid design, fabrication, and delivery

CONCRETE BRIDGES - CONCRETE SAVINGS.
Product
- AIT designs & manufactures FRP composite tubes for construction
- Ability to supply a complete engineered bridge system
- Packages: FRP arches + composite decking, modular FRP headwalls

Structural Design
- AIT’s engineers design the composite arch bridge superstructure
- Can design the bridge substructure, internally or with consultants
- Optimization to maximize efficiency of structure
- Local manufacturing and installation

Carbon Fiber Bridge Superstructures
- Safe, Fast, Designed with Redundant Strength Characteristics