Bascule Bridge Lightweight Solid Deck Research Project - UPDATE
Florida Department of Transportation

AASHTO Technical Committee Presentations
T-8 Movable Bridges
April 20, 2015

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Introduction

Purpose: Identify/Develop Viable Lightweight Deck System with Solid Surface to Replace Steel Open Grid Deck on Typical Florida Bascule Bridges

- Weight Limitations on Existing Bridges
  - Trunnions, Main Girders

- 5-inch Aluminum Orthotropic Deck with FSW Joints Scored Highest during Alternatives Screening Phase
  - FRP, SPS, UHPC Waffle Slab also Considered
  - 5-inch Depth not Originally Available
  - Working with SAPA/AlumaBridge to Develop
  - Derivative of Reynolds Alumadeck

- Project advanced to Deck System Development and Laboratory Testing Phase
Aluminum Orthotropic Deck

Advantages:

- Solid Surface (Functionality and Safety)
- Weight Neutral Solution (21 psf)
- Durability and Service Life
  - Robust Design
    - Meets all AASHTO Limit States
    - High Stiffness
  - Corrosion Resistant
  - Fatigue Resistant (FSW Yields Improvements)
- Configuration
  - Adaptable to Different Bascule Configurations
  - Minimal Bridge Modifications
  - Accelerated Bridge Construction (ABC)
Aluminum Orthotropic Deck

Advantages:

- Available AASHTO LRFD Design Specifications
- Material Familiarity and Predictability
- Previous Testing and Research
  - Technology since 1936 (Smithfield Bridge)
  - Derivative of Reynolds Alumadeck
  - FHWA/VDOT/Virginia Tech Testing Program: ‘95-’98
- Previous Installations
  - Rte. 58 over Little Buffalo Creek Bridge, VA
  - Sandisfield Bridge, MA
  - 70+ Bridges in Europe
Aluminum Orthotropic Deck

Disadvantages:

- Relatively High Initial Cost
  - $100-$120/sf after Recent Enhancements
- New Product (Derivative)
- Coefficient of Thermal Expansion
  - $12.8 \times 10^{-6}/F$ (Alum.) vs. $6.5 \times 10^{-6}/F$ (Steel)
  - Panel Joints Recommended
- Wearing Surface (Periodic Replacement)
- Galvanic Corrosion (Mitigation)
- Fasteners (Hollow Profile)
- Proprietary Product
- Misconceptions
Aluminum Orthotropic Deck

- 6063-T6 Aluminum Alloy
- 32-foot Max. Extrusion Lengths
- 5-inch Deep x 13½-inch Wide Main Extrusions
- 5-inch Deep x 5¼-inch Wide End Extrusions
Aluminum Orthotropic Deck

- Extrusions Friction Stir Welded (FSW) to Create Panels
- Infinite Range of Panel Widths
  - Extrusions in Multiples of 4½” (9”, 13½”)
  - End Extrusion Flanges Trimmed from 3” to 5¼”
Aluminum Orthotropic Deck

- 5-inch Deck Spans Transversely across Stringers
  - Typical Existing Bascule Spacing 4.0 to 4.5 feet
  - Increased Strength/Stiffness Provides Opportunity to Respace Stringers
  - 6.0 feet Span (Optimal Spacing for Most Bascules)
  - 2.0 feet Cantilever (Avoid Support on Main Girders and Floorbeams)
Aluminum Orthotropic Deck

- **Accelerated Bridge Construction (ABC)**
  - Shop Bolt New Stringers to Deck Panels
    - Facilitate Alignment, Minimize Field Work
  - Stringers Clear Floorbeam Flange
  - WT Connection Stiffeners/Splice Type Connections
Aluminum Orthotropic Deck

- Accelerated Bridge Construction (ABC)
  - Shop Bolt New Stringers to Deck Panels
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Friction Stir Welding (FSW)

- Renewed Interest in Aluminum Deck
- The Welding Institute, UK – 1991
- Solid-State, Hot Shear Joining Process
  - Rigidly clamped plates
  - Profiled pin plunges into material
  - Shoulder in firm contact with surface
  - Tool rotates rapidly and advances along joint
  - Friction generates heat, softens material
  - Produces plastic deformation and flow
  - Material re-deposited from front to trailing edge
  - Material forges into solid-state as it cools

- Complex Thermo-Mechanical Process
  - Varying temperature (0.7 to 0.9 melting point)
  - Varying deformation
  - Yields varying recrystallization
  - Different zones and microstructures
  - Translation and rotation yields asymmetric profile
Friction Stir Welding (FSW)

- Higher Quality Joint than previous Metal Inert Gas (MIG) Welding
  - Significantly Less Heat Input with Lower Distortion and Residual Stress
- Flaws still Possible:
  - Voids, Lack of Fusion, Lack of Penetration, Faying Surface Defects, Presence of Entrapped Oxides
- Quality Influenced by
  - Tooling (Shoulder Size, Probe Size, Depth and Thread Details)
  - Support (Alignment, Clamping Force)
  - FSW Process (Rotation/Advancement Speed, Force, Inclination Angle)
- Quality Control/Weld Inspection
  - AWS D1.2 Structural Welding Code – Aluminum (2014)
  - WPS, PQR, WPQR
  - Bend and Macroetch Tests (Weld Tabs), Visual, RT/UT
Wearing Surface

- Euclid Flexolith (Low Modulus Epoxy Coating w/ Broadcast Overlay) - Recommended
- Skid/Wear Resistance (Basalt/Alum. Oxide Aggregate Blend)
- Two Layers (¼” Thickness, 3 to 4 psf Unit Weight)
- Adhesion/Cohesion Bond Strength
  - Environmental Factors (Temperature, Humidity)
  - Surface Preparation (Anchor Profile, Chemical Treatment, Cleaning)
  - Bond Strength Tests
- Stiff Substrate permits Epoxy Polymer Binder
- Resurfacing
  - 10 to 15 Year Service Life Anticipated
  - 17+ Year Service Life (Rte. 58 over Little Buffalo Creek, VA)
  - Resurface before Aluminum Substrate Exposed
    - Simplify Prep
    - Avoid Field Applied Chemical Treatment
Panel Joints

- Locate over Floorbeams and at Stringer Mid-Span
- Reduce Thermal Forces (End Connection Moments)
- Accommodate Panel Tolerances
- WABO Evazote UV Seal (1” Joint) – FDOT Preference
- Ultra Low Modulus Silicone Sealant (1/2” Joint)
Deck to Stringer Fasteners

- Treat Deck as Non-Composite for Stringer Design
- Anticipate Composite Behavior for Connections (Slip Critical)
- Class ‘B’ Surface Condition (Certified by RCSC)
  - Abrasion Blast Aluminum Surface
  - Steel with Hot Dip Galvanized or Inorganic Zinc Primer Coatings
- Proof Load (28 kips – ¾” Dia. ASTM A325 Bolt)
- Design for No Slip from Live Load
  - High Number of Cycles
  - Prevent Fretting (Premature Wear of Protective Coatings)
  - Prevent Bolt Fatigue (Reverse Bending)
  - Prevent Loosening from Vibration
- Allow Slip from Thermal Load
  - Low Number of Cycles
  - Forces Relieved after Slip Occurs
Conventional Fasteners - Recommended

- ASTM A325 Bolts (¾” Dia.)
  - Heavy Hex
  - Tension Control Bolts
- Hollow Profile Installation Challenges
  - Requires Special Installation/Tightening Tools
Blind Type Fasteners – Not Recommended

- Böllhoff Rivnuts
- Lindapter Hollo-Bolts
- Not Recommended as Primary Fastener
  - Limited Bridge Applications (Used for Appurtenances)
  - Limited Pre-load Capability (Not used for Slip-critical)
- Possible Use for Maintenance Purposes
Fastener Design

- Compute Fastener Pitch for Partial Composite Behavior (Live Load Shear Flow)
  - Discontinuity in Deck at Mid-Span Joint Yields “Spike” in Horizontal Shear Flow
- Bottom Plate Fully Effective (Slip Critical Connection)
- Top Plate Partially Effective (Attached to Bottom Plate through Inclined Webs)
General Corrosion

- 6063-T6 Alloy – Excellent Corrosion Resistance
  - Tightly Bonded Aluminum Oxide Film
- Experiences Superficial Pitting
  - Maximum Pit Depth is Fraction of Material Thickness
- Limit Standing Water
- Wetness from Condensation (Limited Duration)
- Rainwater Runoff through Joints/Edges
  - Seal Joints and Openings in Hollow Extrusions
- Experience
  - FDOT, et al have Significant Experience with Galvanized Fasteners in Marine Environments with No Significant Issues
  - Railings, Sidewalk Planking, Light Poles
Galvanic Corrosion

- Dissimilar Metals (Galvanic Series)
- Less Noble (Anodic) Material Sacrifices to Protect More Noble (Cathodic) Material
- Galvanized Steel Bolts/Stringers
  - Zinc Less Noble than Aluminum
  - Zinc Sacrifices to Protect Aluminum
  - Maximize Zinc with Hot Dip or Mechanically Galvanized Coatings
- After Zinc Material Spent
  - Uncoated Steel is More Noble
  - Aluminum Deck Corrodes but is Negligible
  - Surface Area of Cathodic Material (Bolts/Stringers) Significantly Less than Surface Area of Anodic Material (Aluminum Deck)
AASHTO LRFD Bridge Design Specifications

- Section 7 (Aluminum Structures) and Article 9.8.4 (Orthotropic Aluminum Decks)
  - Analysis Similar to Orthotropic Steel Decks
  - Load Distribution Similar to Concrete Decks
  - Current Design Specifications Developed with Stiffening Ribs Parallel to Traffic
  - Additional Investigation Recommended for Stiffening Ribs Perpendicular to Traffic
  - Extensive FEA Program followed by Testing Program

- HL-93 Design Truck and Tandem (Placement for Max. Effect)
  - Maximum Positive, Negative, and Cantilever Negative Bending

- Limit States
  - Service I (Deflections)
  - Strength I
  - Strength II (Overload Permitting)
  - Fatigue I (Infinite Life)
Aluminum Orthotropic Deck Analysis

- **System 1**
  - Deck Longitudinal Forces (Axial and Flexure) from Stringer Flexure with Composite Deck

- **System 2**
  - Deck Transverse Forces (Flexure) from Loading between Stringers
  - Positive, Negative and Cantilever Flexure

- **System 3**
  - Localized Flexure of Deck from Wheel Patch Loading
  - Hollow Profiles behave as Rigid Frames
Aluminum Orthotropic Deck Analysis

- Load Distribution
  - Similar to Concrete Decks
  - Equivalent Strip Width Equations (Simplified Analysis)
  - Combined Effects – System 3 (Local) with Systems 1 and 2 (Global)
- Shear Lag Effects
  - Effective Flange Width Concept (Similar to Segmental Box Girder Provisions)
  - Multiplication Factor
Aluminum Orthotropic Deck Analysis

- System 2 – Load Distribution – 3D Plate and Shell FEA

Deck Top Stress (Positive Moment – Tandem Loading) Section thru between Stringers
Aluminum Orthotropic Deck Analysis

- System 2 – Load Distribution – 3D Plate and Shell FEA

Deck Top Stress (Positive Moment – Truck Loading) Section thru Deck between Stringers

Shear Lag

Direction of Traffic

Local Effect
### Aluminum Orthotropic Deck Analysis

#### SYSTEM 2 POSITIVE FLEXURE MAXIMUM STRESSES AND DEFLECTIONS

<table>
<thead>
<tr>
<th>Limit State</th>
<th>Loading</th>
<th>Max. Stress (ksi)</th>
<th>Max. Deflection (in)</th>
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<td>Tension (Bottom)</td>
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<td>Service I</td>
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<td>FL-120 Permit Truck</td>
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<td>Limits</td>
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#### SYSTEM 2 NEGATIVE FLEXURE MAXIMUM STRESSES AND DEFLECTIONS

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#### SYSTEM 2 CANTILEVER NEGATIVE FLEXURE MAXIMUM STRESSES AND DEFLECTIONS

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<td>27.5</td>
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**Aluminum Orthotropic Deck Analysis**

- **Design for Infinite Fatigue Life**
- **Fatigue Sensitive Details**
  - Base Metal: Cat. ‘A’
  - FSW Joint (Stress Normal to Weld Axis): Cat. ‘C’
    - Consistent with CJP Welds Ground Smooth
    - Conservative Based on MIG Welding
    - Testing demonstrates FSW Joints yield Greater Fatigue Resistance than Base Metal
- **Conservative Design**
  - Design Nominal Fatigue Resistance = \( \frac{1}{2} \times \text{Constant Amplitude Fatigue Threshold} \)
  - \( (\Delta F)_N^{\frac{1}{2}} = \frac{1}{2} (\Delta F)_T^{\text{TH}} \)

### System 3 - Fatigue Life Values

<table>
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<tr>
<th>Variable</th>
<th>Category ‘A’</th>
<th>Category ‘C’</th>
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<tr>
<td>( (\Delta F)_T^{\text{TH}} )</td>
<td>9.5 ksi</td>
<td>4.0 ksi</td>
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<tr>
<td>Design ( (\Delta F)_N^{\frac{1}{2}} )</td>
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<tr>
<td>( Y (\Delta f) \leq (\Delta F)_N )</td>
<td>4.35 ksi</td>
<td>1.95 ksi</td>
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Aluminum Orthotropic Deck Analysis

- System 3 – Fatigue
- 3D Solid Element FEA
Test Program - Goals

- Deck System Performance per AASHTO LRFD Design Provisions
- Compare Measured Stresses and Deflections to FEA
- Applicability of AASHTO LRFD Equivalent Strip Width Equations
  - Load Distribution
  - Required Adjustments for Shear Lag Effects
  - Combined System 2 and System 3 Effects
- Fastener Performance/Design Parameters
- Performance of Wearing Surface
Test Program – Phase 1 (Component Testing)

- Verify FEA Results
- Deck Panel Performance (Static)
- Connection Testing
- Constructability
Test Program – Future Phases

- Phase 2 (Full System Testing)
  - Two Floorbeam Bays w/ Deck Panels, Stringers and Floorbeams
  - Reuse Panels from Phase 1 Testing
  - Heavy Vehicle Simulator (Moving Wheel Load)
  - Evaluate System Response
  - Fatigue Investigation

- Phase 3 (Field Testing)
  - Install Test Panels on Existing Bascule Bridge
  - Reuse Panels from Laboratory Testing
  - Two Floorbeam Bays, Half Roadway Width

Dynatest Mk IV Heavy Vehicle Simulator
Latest Developments/Other Projects

- AlumaBridge/LB Foster Collaboration
- Projects in Canada
  - St. Ambroise Bridge, Ontario, Canada - Under Construction
  - Other Projects - Under Consideration
  - Seeking Opportunities for 5-inch Deck
- Extrusion/FSW Refinements
  - Wider Extrusions (Reduced Number of Welded Joints)
  - Single Sided FSW Joints
  - Matched Top and Bottom Flange Thickness
  - Deck Unit Price Reduction: From $150/sf to $120/sf
Questions/Discussion?