Panel I: Tech Forum: Using Tech to Extend Infrastructure

ENHANCING LIVE LOAD-CARRYING CAPACITY OF EXISTING INFRASTRUCTURE FOR EXTENDED LIFE SPAN

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OUTLINE

- Fiber-Reinforced Polymers
  - Material Properties
  - Common Types / Application Techniques
  - Advantages of FRP

- Advanced Computing Techniques
  - Advanced Structural Analysis
  - Soil-Structure Interaction
  - Damage Assessment

- Testing and Instrumentation

- Selected Projects
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FIBER-REINFORCED POLYMERS (FRP)

**Constituent Materials**

- Fibers: Glass, Carbon, Aramid
- Resins: Epoxy, Polyester, Vinyl esters

- Glass Fiber Reinforced Polymers (GFRP)
- Carbon Fiber Reinforced Polymers (CFRP)
- Aramid Fiber Reinforced Polymers (AFRP)
FIBER-REINFORCED POLYMERS (FRP)

Constituents vs. Composite

Stress

$\sigma_{Fu}$

$\sigma_{fu}$

$\sigma_{m}$

Fibre

FRP

Matrix

Strain

$\varepsilon_{fu}$

$\varepsilon_{mu}$
FIBER-REINFORCED POLYMERS (FRP)

Mechanical Properties

<table>
<thead>
<tr>
<th>Fiber Type</th>
<th>Stress (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFRP</td>
<td>310</td>
</tr>
<tr>
<td>AFRP</td>
<td>240</td>
</tr>
<tr>
<td>HM CFRP</td>
<td>220</td>
</tr>
<tr>
<td>GFRP</td>
<td>180</td>
</tr>
<tr>
<td>Steel</td>
<td>60</td>
</tr>
</tbody>
</table>

Graph showing stress-strain relationship for different fiber types.
FIBER-REINFORCED POLYMERS (FRP)

Advantages of FRP

- High strength-to-weight ratio
- Excellent durability
- Non-magnetic, Non corrosive
- Low profile when installed
- Fast and easy application

Table 4.2.1—Typical densities of FRP materials, lb/ft³ (g/cm³)

<table>
<thead>
<tr>
<th>Steel</th>
<th>Glass FRP (GFRP)</th>
<th>Carbon FRP (CFRP)</th>
<th>Aramid FRP (AFRP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>490 (7.9)</td>
<td>75 to 130 (1.2 to 2.1)</td>
<td>90 to 100 (1.5 to 1.6)</td>
<td>75 to 90 (1.2 to 1.5)</td>
</tr>
</tbody>
</table>

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FIBER-REINFORCED POLYMERS (FRP)

Common Types of CFRP

- Wet lay-up systems
- Pre-cured Laminates
FIBER-REINFORCED POLYMERS (FRP)

Common Types of FRP

- **Wet lay-up**: Dry fiber sheets or fabrics impregnated with resin on-site
- **Pre-cured**: Pre-cured Composite shapes manufactured off-site
- **Pre-preg**: Pre-impregnated uncured fiber sheets or fabrics
FIBER-REINFORCED POLYMERS (FRP)

Application Techniques

Externally Bonding (EB)
FIBER-REINFORCED POLYMERS (FRP)

Application Techniques

Near-Surface-Mounted (NSM)

NSM Bars

NSM Strips
FIBER-REINFORCED POLYMERS (FRP)

Application Techniques

Wrapping
FIBER-REINFORCED POLYMERS (FRP)

Reasons to Retrofit with FRP

- Increase load-carrying capacity
  - Flexure strengthening, shear strengthening, axial load strengthening
- Impact damaged structures
- Ductility enhancement
- Blast mitigation
- Structural upgrade and seismic retrofit
- Cutouts and penetrations
FIBER-REINFORCED POLYMERS (FRP)

Durability

- Environmental considerations
  - Alkalinity/acidity
  - Thermal expansion
  - Electrical conductivity

- Loading considerations
  - Impact tolerance
  - Creep rupture and fatigue
FIBER-REINFORCED POLYMERS (FRP)

Durability

- Environmental reduction factor (conservative estimates)
  - Fiber type & exposure conditions
- Protective coatings
- Projects that are more than 30 years old

Table 9.4—Environmental reduction factor for various FRP systems and exposure conditions

<table>
<thead>
<tr>
<th>Exposure conditions</th>
<th>Fiber type</th>
<th>Environmental reduction factor $C_E$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interior exposure</td>
<td>Carbon</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>Glass</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>Aramid</td>
<td>0.85</td>
</tr>
<tr>
<td>Exterior exposure (bridges, piers, and unenclosed parking garages)</td>
<td>Carbon</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>Glass</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>Aramid</td>
<td>0.75</td>
</tr>
<tr>
<td>Aggressive environment (chemical plants and wastewater treatment plants)</td>
<td>Carbon</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>Glass</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>Aramid</td>
<td>0.70</td>
</tr>
</tbody>
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ADVANCED COMPUTING TECHNIQUES

Advanced Structural Analysis

Finite Element Analysis (FEA)
Non-linear analysis
Geometrical non-linearities
Shell elements, solid elements
Soil-Structure Interaction

Piles: beam elements

Soil springs (P-y curves)

- Lateral springs
- Vertical springs
ADVANCED COMPUTING TECHNIQUES

Soil-Structure Interaction

Gravity Loads

Lateral Loads

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ADVANCED COMPUTING TECHNIQUES

Damage Assessment

Section loss
Corrosion of steel
Loss of bond
Deterioration

SMART BRIDGE SUITE
OUTLINE

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TESTING AND MONITORING

Load Testing

- Actual behavior of structure (load distribution)
- Strength enhancing factors not included in calculations
  - Composite actions
  - Continuity/fixation
  - Secondary members
- Static tests (proof test and diagnostic test)
- Dynamic tests
TESTING AND MONITORING

Load Testing

Counter weights

Trucks with known weights
TESTING AND MONITORING

Load Testing

390 KIPS TRUCKS

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TESTING AND MONITORING

Non-Destructive Testing

Chloride Ion Penetration

Cover removal and reinforcement inspection
TESTING AND MONITORING

Instrumentation
Instrumentation plans are developed based on analysis of structure.
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SELECTED PROJECTS

Allen Creek Bridge
Clearwater, FL 2005

- Wrapping of piles
- Underwater application
- Splash zone
SELECTED PROJECTS

US 1 Bridge
Melbourne, FL 1994

- Corrosion of main reinforcement
- Girders repair
- Concrete section restoration
SELECTED PROJECTS

Rockaway Line Viaduct
New York, NY 2009

- Corrosion of reinforcement
- Girders repair
- Concrete section restoration
SELECTED PROJECTS

I-10 Bridge Over L&A Railroad
LA 2016

- Strengthening of deck slab
- Instrumentation & proof testing
SELECTED PROJECTS

Bayou Pierre Bridge
Desoto & Red River Parishes, LA 2018

5-Span with total length of 500 ft.
10 PPC girders
10,000 kips (4,500 tons) DRAGLINE

46-AXLES SPMT
390 KIPS TRUCKS
SELECTED PROJECTS

Bayou Pierre Bridge
Desoto & Red River Parishes, LA 2018

G 9 & G10

8326 kips vs 9980 kips
Remove additional 1,654 kips

Compression

Tension
Elastic shortening + Temperature effect = -0.124”
Thank You!