Quick Overview of Simpson Strong-Tie Product Lines
Simpson Strong-Tie’s Product Lines

Connectors
- Wood Connectors
- Cold-Formed Steel Connectors
- Integrated Component Systems (Truss Plates)

Anchoring Systems
- Adhesive Anchors
- Mechanical Anchors
- Powder & Gas Actuated Technology

Fastening Systems
- Screws
- Nails

Lateral Systems
- Moment Frames
- Shearwalls
- Anchor Tiedown Systems

Repair-Protect-Strengthening Systems
- General Repair
- Pile Protection
- Composite Strengthening Systems (FRP)
Learning Objectives

Upon completion of this learning event, the attendee will be able to:

• Identify various FRP products for **protecting** and **strengthening** structures

• Determine when & where FRP products are suitable for use

• Describe the steps of the design process when using FRP products
Traditional Strengthening Techniques

- External post-tensioning
- Bonded steel plates
- Section enlargement
What is FRP?

FRP = FR + P \hspace{1cm} (Eq. 1-1)

Where:

- **FR** = Fiber Reinforcement
  - Provides strength and stiffness
- **P** = Polymer resin: commonly epoxy
  - Makes fibers composite
  - Transfers load to structural element
  - Protects fibers

FR & P combine to make a fiber-reinforced polymer composite

The *FRP composite* provides capacity in the direction of fibers
Details of Externally Bonded FRP
Simpson Strong-Tie’s FRP Offering

Products
- Fabric
  - Carbon
  - Glass
- Laminates
  - Carbon
- Epoxy
  - Saturant
  - Paste

Services
- Design
  - Initial/feasibility studies
  - Complete engineering packages
- Factory trained installers
Advantages to using FRP for Strengthening

- High tensile strength/stiffness to weight ratio
- Lightweight (great for seismic retrofits)
- Low impact on space (1/16” per layer)
- Easily conforms to existing shapes (fabrics)
- Fast installation (limited downtime)
- Can be most cost effective if/when considering all factors
Fiber Reinforcement

**Carbon** (higher upgrades)
- High strength and modulus, low strain
- Excellent resistance to environments, creep and fatigue

**E-glass** (lower upgrades or protection)
- High strength and strain, low modulus
- More sensitive to environments, creep and fatigue
Externally Bonded Composite Strengthening Systems

- Precured Laminate
  - Laminate is manufactured off site
  - Paste is used to bond the cured laminate to the substrate
<table>
<thead>
<tr>
<th>Fabric System Advantages</th>
<th>Laminate System Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Wraps around softened corners</td>
<td>• Factory lamination</td>
</tr>
<tr>
<td>• Larger widths</td>
<td>• Higher tensile properties</td>
</tr>
<tr>
<td>• Lower material costs</td>
<td>• Quicker installation</td>
</tr>
<tr>
<td>• Overlap splicing</td>
<td>• Cleaner application</td>
</tr>
<tr>
<td>• Multilayer composite</td>
<td>• Up to 2-layers</td>
</tr>
</tbody>
</table>
Potential Composite Strengthening System Uses

- **Structures**
  - Buildings
  - Bridges
  - Parking Garages
  - Chimneys
  - Piers/wharfs
  - Tunnels
  - Pipe

- **Capacity Increase**
  - Shear
  - Flexural
  - Axial
  - Shear Transfer
  - Tension

- **Elements**
  - Columns
  - Beams
  - Slabs
  - Walls
  - Piles
  - Pier Caps
Potential Composite Strengthening System Uses

- **Seismic retrofit**
  - Shear strengthening
  - Displacement/ductility

- **Load rating upgrade**
  - Increased live/dead loads
  - New equipment

- **Damage repair**
  - Deterioration/corrosion
  - Blast/vehicle impact
  - New openings

- **Defect remediation**
  - Size/layout errors
  - Low concrete strength

- **Blast Mitigation**
  - Hardening
  - Progressive collapse
Typical Placement – Internal Steel Reinforcing

So where does the FRP go?

- Flexural cracks
- Shear cracks
- Cracks resulting from axial load (splitting)
Typical Placement –
Externally Bonded FRP Reinforcing

= indicates direction of fibers
Design of Composite Strengthening Systems

- American Concrete Institute (ACI)
  - 440.2R: Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures
  - 562: Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings
- American Association of State Highway and Transportation Officials (AASHTO)
  - Guide Specifications for Design of Bonded FRP Systems for Repair and Strengthening of Concrete Bridge Elements
- International Code Council Evaluation Service (ICC-ES)
  - AC125: Acceptance Criteria for Concrete and Reinforced and Unreinforced Masonry Strengthening Using Externally Bonded Fiber-Reinforced Polymer (FRP) Composite Systems
Design Considerations

• **Existing capacity and new demands to be supported**
  - ACI 440.2R-08 Eq. 9-1: $(\varphi R_n)_{existing} \geq (1.1S_{DL} + 0.75S_{LL})_{new}$
  - ACI 562-13 Eq. 5.5.1: $(\varphi R_n)_{existing} \geq (1.2S_{DL} + 0.5S_{LL})_{new}$

• **Exposure Conditions**
  - $C_E$ material property reduction factor (interior, exterior, aggressive)
  - FRP composites are completely lost in a fire
    - Check that existing member can support service loads for required rating (i.e. 2-hour)
  - Installation temperatures must stay between 45°F and 95°F
    - May need to tent working areas
  - Water can affect resin cure
    - Ensure areas stay dry during installation and curing process

• **Serviceability**
  - Check service stresses in steel, concrete, and composite
Design Philosophy

• Debonding Failure
  • Failure mode for ~90% of FRP strengthened members
  • Occurs in the concrete substrate

1. Debonding strain is calculated per ACI or AASHTO design guides
2. Corresponding resultant force is calculated
   a. For flexure, c is calculated using force equilibrium
3. Capacity of strengthened member is calculated
FRP and Fire Resistance

- FRP is bonded to the concrete substrate with an epoxy resin
- Epoxy resin exhibits lower stiffness at elevated temperatures
- Stiffness drops off sharply at the glass transition temperature, $T_g$
- Glass Transition Temperatures of most FRP systems is typically in the range of 140 - 180°F
Fire Endurance

- Use of an insulation system can improve the overall fire rating of strengthened reinforced concrete member
- Insulation system can delay strength degradation of concrete and steel, increasing the fire rating of the member
- The contribution of the FRP system can be considered if it is demonstrated that the FRP temperature remains below a critical temperature
Installation Procedures: Substrate Preparation

- Repair deterioration per ICRI Guideline No. 310.1R
  - Remove/replace concrete, clean/coat steel, inject/seal cracks
- Abrasively prepare bond-critical (everything but columns) wrapping surfaces to achieve a CSP-3 in accordance with ICRI Guideline No. 310.2R (grinding, blasting)
Installation Procedures: Fabrics

- Mix epoxy
- Prime surfaces
- Fill/transition uneven surfaces with paste
- Saturate fabric
- Apply saturated fabric, removing entrapped air
- Feather seams and edges with paste
- Allow for full cure
- Lightly sand epoxy
- Finish as desired
Externally Bonded Composite Strengthening Systems

- **Wet Layup**
  - Fabric is impregnated with saturating resin on site
  - Primer and putty is used to bond the saturated fabric to the substrate
Installation Procedures: Laminates

- Clean laminate with solvent
- Mix paste
- Fill/transition uneven surfaces with paste
- Coat laminate with paste
- Apply laminate, removing air and excess paste
- Allow for full cure
- Lightly sand epoxy
- Finish as desired
Quality Control & Assurance - Testing

- **ASTM D3039 – Tension**
  - Send witness panels to independent lab
  - Verify tensile modulus, strength, & strain

- **ASTM D4541 – Adhesion**
  - Before and after installation
  - > 200psi
  - Perform in low stress areas or representative mockups
Structural Testing: Columns

- Control: 515,000#
- 1 Layer: 703,000#
- 2 Layer: 1,061,000#
Structural Testing: Columns
The level of additional strength from FRP will vary based on MANY factors. Each application is unique!!!

The following are some guidelines on what maximum level of strengthening FRP provides depending on the application.

<table>
<thead>
<tr>
<th>Component</th>
<th>Maximum Level</th>
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<tbody>
<tr>
<td>Flexural</td>
<td>40%-150%</td>
</tr>
<tr>
<td>Shear</td>
<td>20%-150%</td>
</tr>
<tr>
<td>Axial</td>
<td>20%-100%</td>
</tr>
</tbody>
</table>
What about cost $$
Near-Surface-Mounted (NSM) Laminates
Project Examples

SECTION A

Apply 1 strip of CSS-CUCL128-RL at top of the joist, typ.

Existing Slab

Existing Joist

space sawcuts equally across top of slab, typ.

1 precured laminate strip per sawcut, typ.

Section at CSS-CUCL sawcut

3/8”

5/8”
FRP anchors

Folded Anchor

Through Anchor
How are they used?
How are they used?
How are they used?
Project Examples

(Typical interior corbel)

Step 1

Step 2

Step 3
How Can We Help?

- **Feasibility Studies**
  - Work with EOR to determine if FRP strengthening is possible

- **Budget Estimates**
  - Engage local trained contractors to provide ROM pricing

- **Specifications**
  - Fine-tune to meet the project requirements

- **Drawing Details**
  - Create for construction documents

- **Calculations**
  - Provide for EOR’s reference during submittal review
What Do We Need to Help?

- Existing drawing details
  - Section dimensions and span length
  - Steel reinforcing layout
  - Material properties (steel yield and concrete compressive strengths)

- Loads and Capacities
  - Existing factored capacity (kips or kip-ft, accounting for any corrosion)
  - New ultimate demand (kips or kip-ft)
  - Service dead load and live load demands (kips or kip-ft)

- We have fillable questionnaire

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Simpson Strong-Tie® Composite Strengthening System™ (CSS) Design Questionnaire

**Project Information**
1. Project Name & Location:
2. Structure Type (e.g. building, bridge, pier, garage):
3. Element(s) to be Strengthened/Repaired:
   - Beam
   - Column
   - Wall
   - Others
4. Type of Fiber:
   - Polymer
   - FRP
   - Steel

**Structural Information**
5. Existing Factored Capacity of Section(s) & Age (kips, kip-ft):
6. Ultimate Demand to be Supported (kips, kip-ft):
7. Existing Concrete Compressive Strength:
8. Existing Moment Capacity:
9. Existing Reinforcement Layout:
   - Depth to Bar Center
   - Number of Bars
   - Bar Size
10. Existing Dimensions:
   - Width
   - Height
   - Length
11. Relevant Existing Drawing Sheets and/or Pictures:
12. Finish Coating Requirements/Preferences:
Pile Restoration and Protection
FX-70® SYSTEM
Precured glass composite jackets

- Glass composites
- Custom shapes/sizes
- Tongue & groove connection
Precured glass composite jackets

Section Loss ≤ 25%

- FX-763 Hydro-Ester® Low-Modulus Trowel Grade Epoxy
- Beveled top seal of FX-763 Hydro-Ester® Low-Modulus Trowel Grade Epoxy
- High water level
- FX-70® Fiberglass Jacket
- 6" layer of FX-71-6 Hydro-Ester® Multi-Purpose Marine Epoxy Grout
- Bottom seal
- Spacer

Section Loss > 25%

- Beveled top seal of FX-70® Hydro-Ester® Low-Modulus Trowel Grade Epoxy
- 4" layer of FX-70-6 Hydro-Ester® Multi-Purpose Marine Epoxy Grout
- High water level
- FX-70® Fiberglass Jacket
- FX-225 Non-Shrink Non-Metallic Underwater Grout
- Reinforcing steel (optional)
- 6" layer of FX-70-6 Hydro-Ester® Multi-Purpose Marine Epoxy Grout
- Bottom seal
- Spacer

Self-tapping stainless steel screw

FX-763 Hydro-Ester® Low-Modulus Trowel Grade Epoxy
First Question?

F. Keith Bohren, PE
469-816-7784