Fiber-Reinforced Polymer (FRP)
Simpson - Composite Strengthening Systems

F. Keith Bohren, PE

Quick Overview of
Simpson Strong-Tie Product Lines

SIMPSON
Strong-Tie
®

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)

tie.com

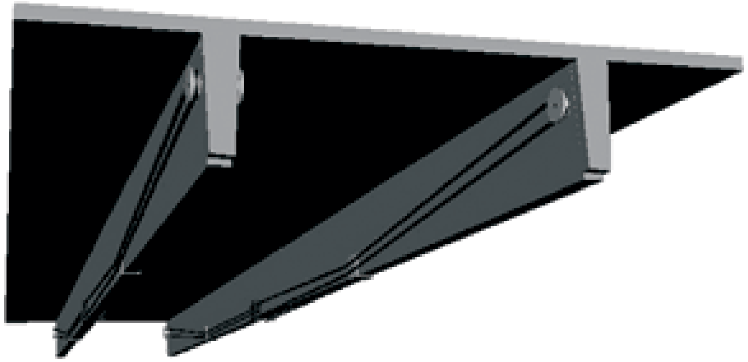
Learning Objectives

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

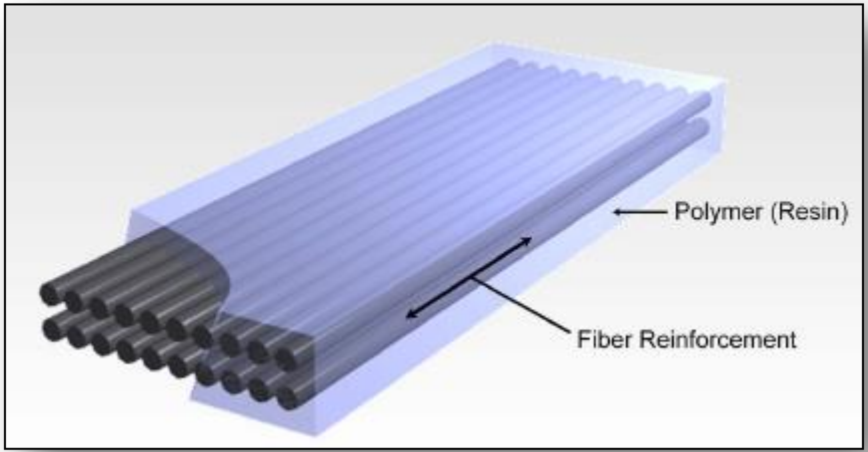
- Section enlargement

What is FRP?

FRP = FR + P *(Eq. 1-1)*

Where:

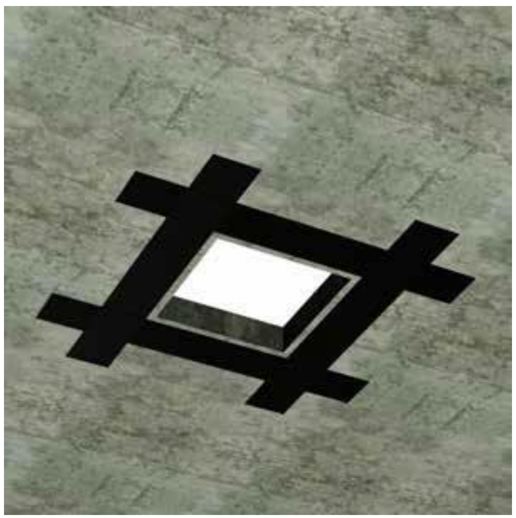
- **FR =** <u>**F**</u>iber <u>**R**</u>einforcement
  - Provides strength and stiffness
- **P =** <u>**P**</u>olymer resin: commonly epoxy
  - Makes fibers composite
  - Transfers load to structural element
  - Protects fibers

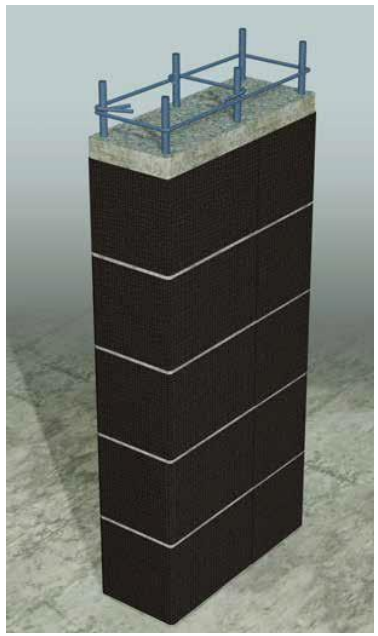


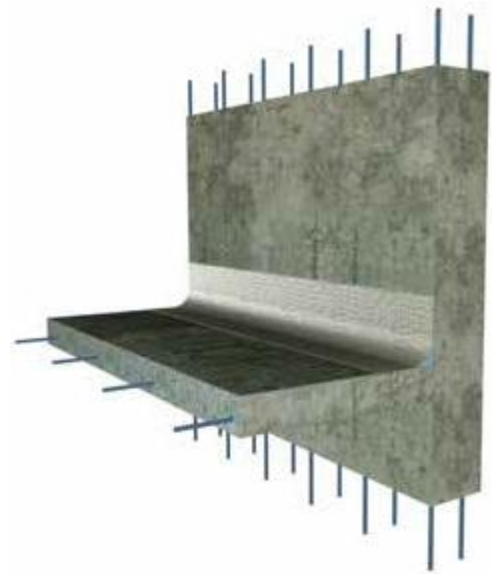
FR & P combine to make a fiber-reinforced polymer **composite**

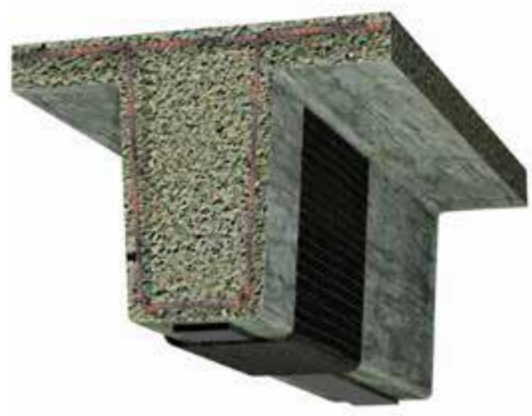
The *FRP composite* provides capacity in the direction of fibers

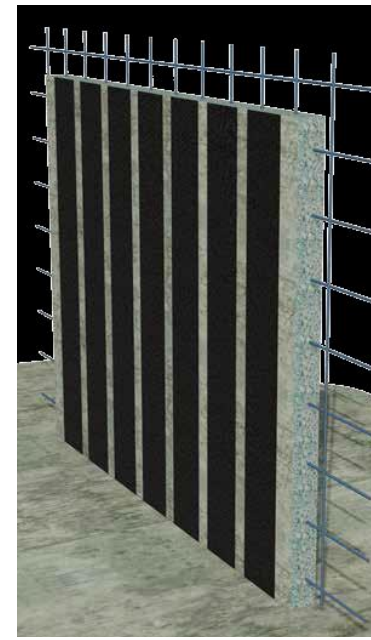
Details of Externally Bonded FRP











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

Fabrics and Laminates – What's the Difference?

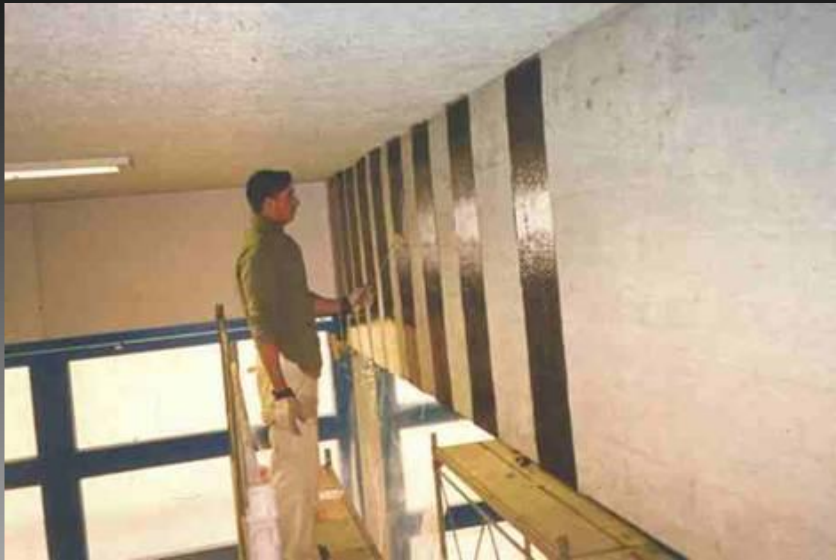
Fabric System Advantages	Laminate System Advantages
• Wraps around softened corners	• Factory lamination
• Larger widths	• Higher tensile properties
• Lower material costs	• Quicker installation
• Overlap splicing	• Cleaner application
• Multilayer composite	• Up to 2-layers

Potential Composite Strengthening System Uses

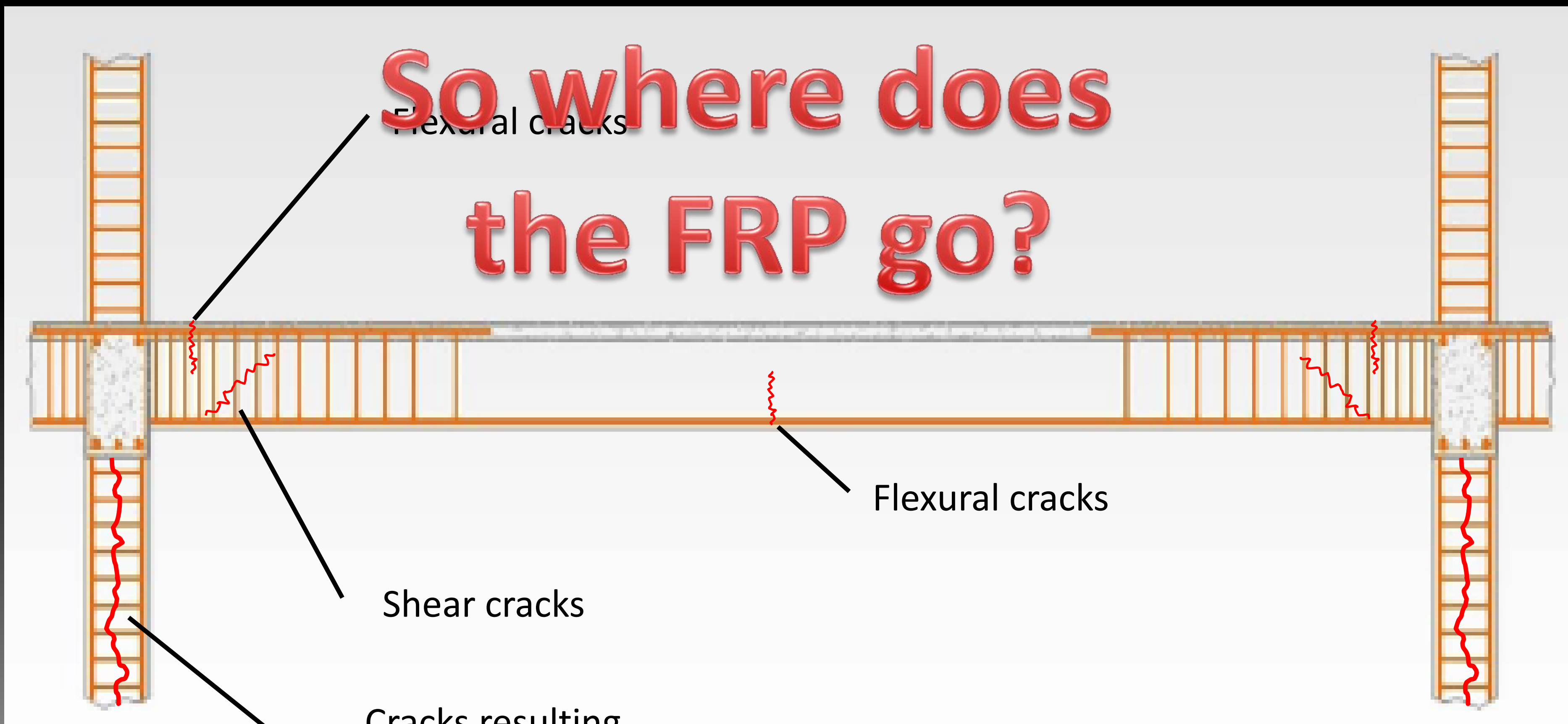
- Structures
  - Buildings
  - Bridges
  - Parking Garages
  - Chimneys
  - Piers/wharfs
  - Tunnels
  - Pipe
- Capacity Increase
  - Shear
  - Flexural
  - Axial
  - Shear Transfer
  - Tension
- Elements
  - Columns
  - Beams
  - Slabs
  - Walls
  - Piles
  - Pier Caps

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

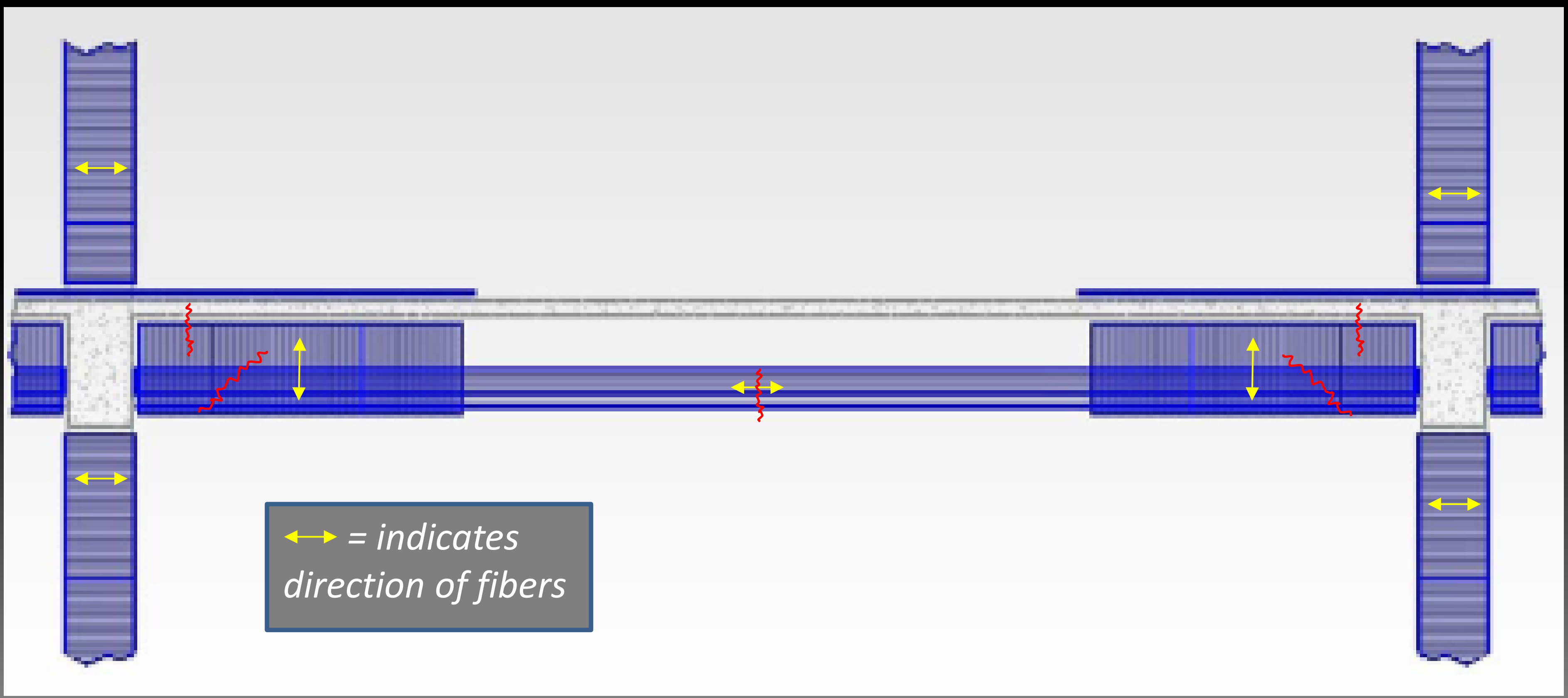


Typical Placement –
Internal Steel Reinforcing



Cracks resulting from axial load (splitting)

Typical Placement – Externally Bonded FRP Reinforcing



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**
  - 440.7R: Guide for the Design and Construction of Externally Bonded Fiber-Reinforced Polymer Systems for Strengthening Unreinforced Masonry 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

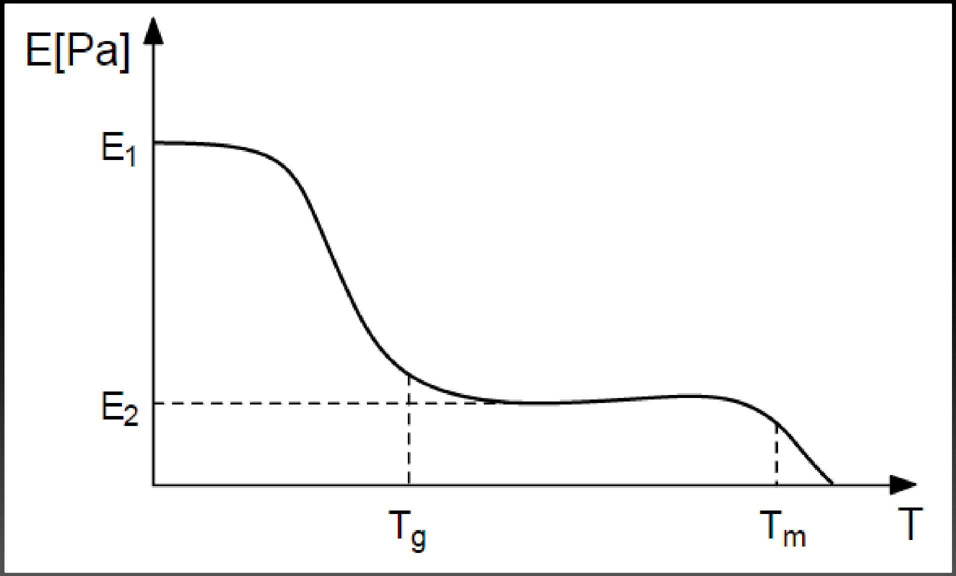
Design Philosophy

- 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

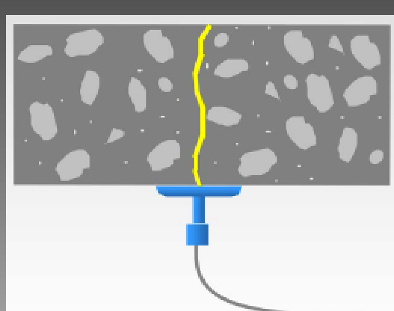


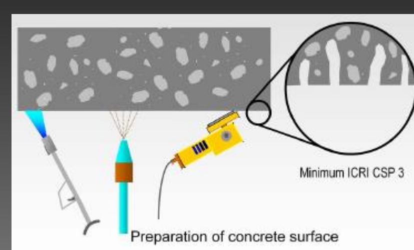
Fire Endurance

- 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

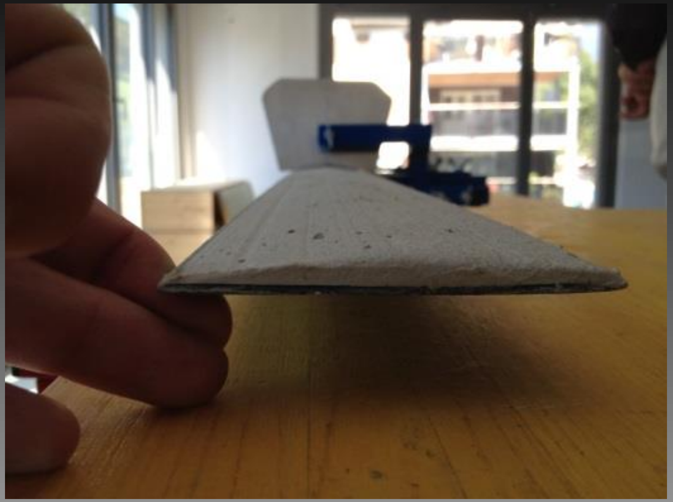
- Mix epoxy
- Prime surfaces
- Fill/transition uneven surfaces with paste
- Saturate fabric
- Apply saturated fabric, removing entrapped air
- Feather seams and edges with paste
- Allow for full cure
- Lightly sand epoxy
- Finish as desired

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!!!

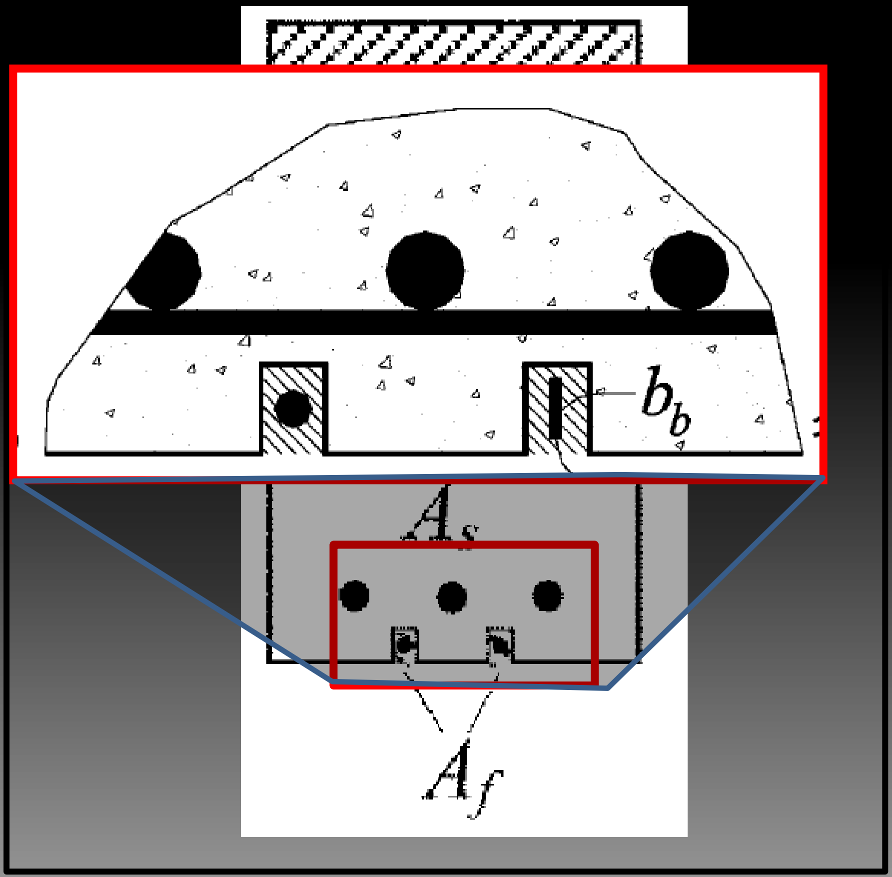
The following are some guidelines on what maximum level of strengthening FRP provides depending on the application.

Flexural	40%-150%
Shear	20%-150%
Axial	20%-100%

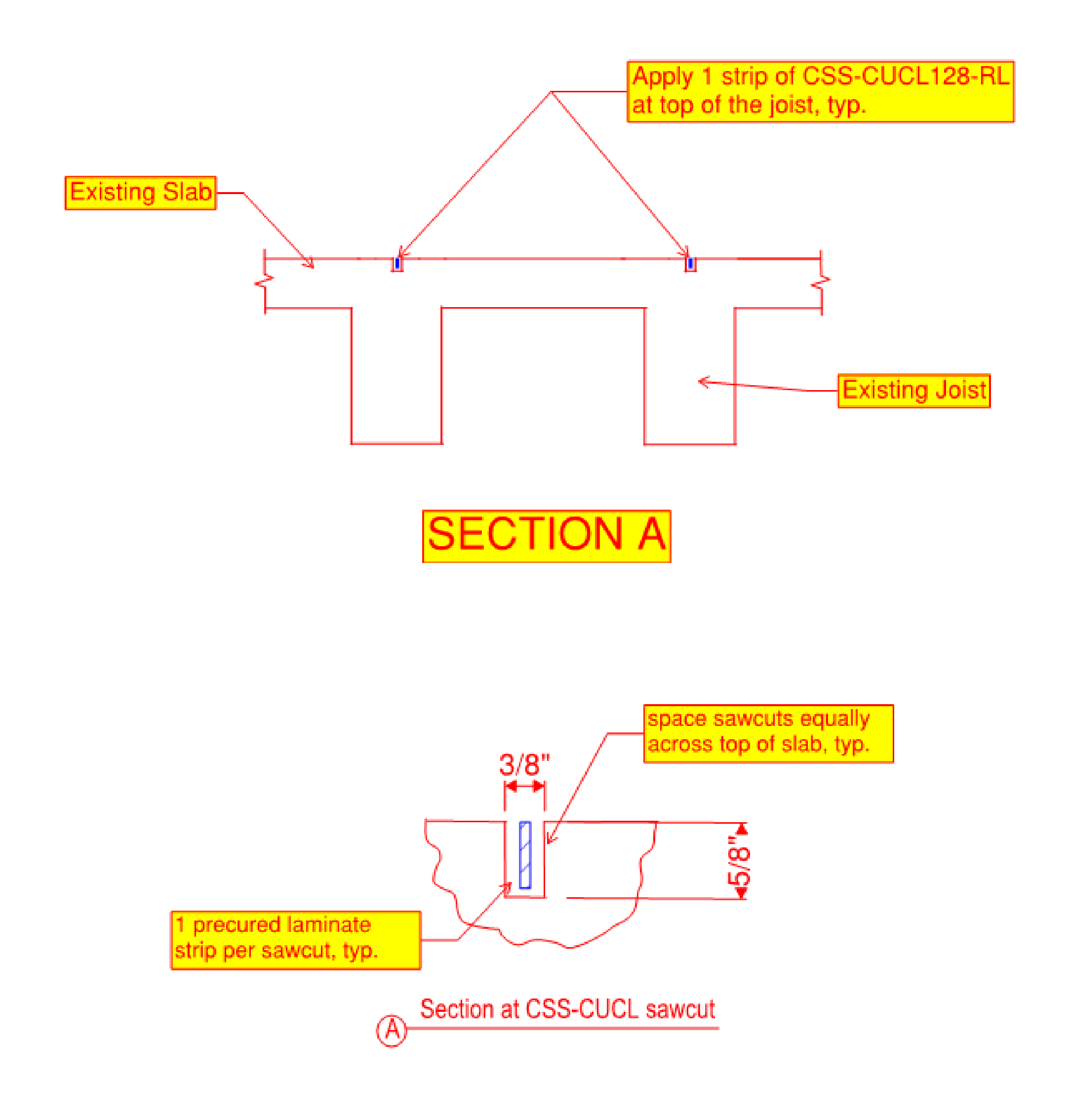
What about cost $$

Other Products?

Near-Surface-Mounted (NSM) Laminates



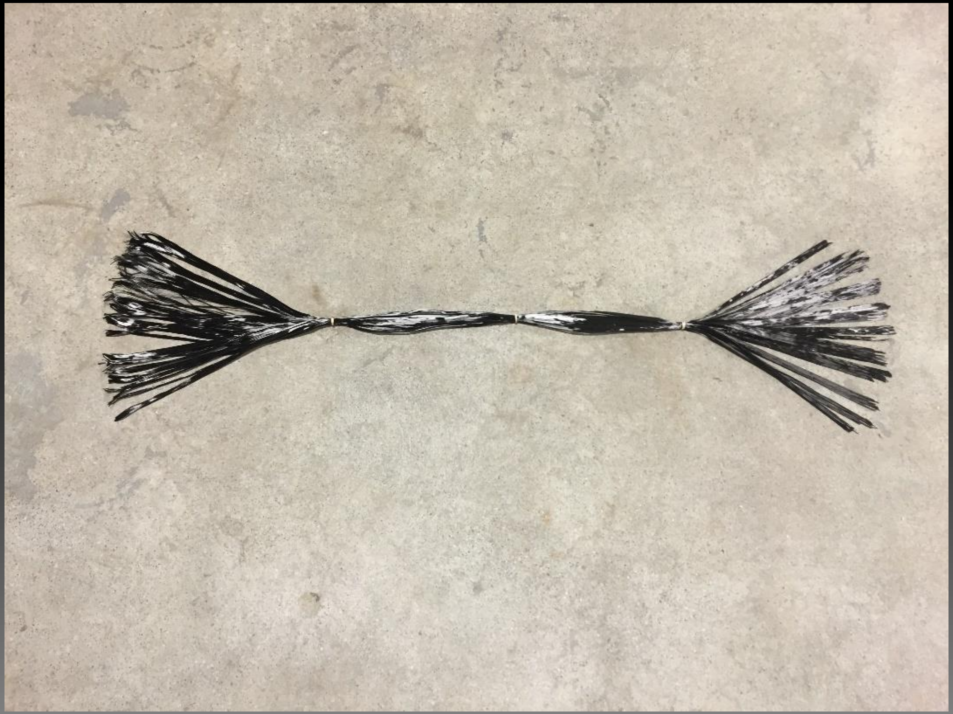
Project Examples



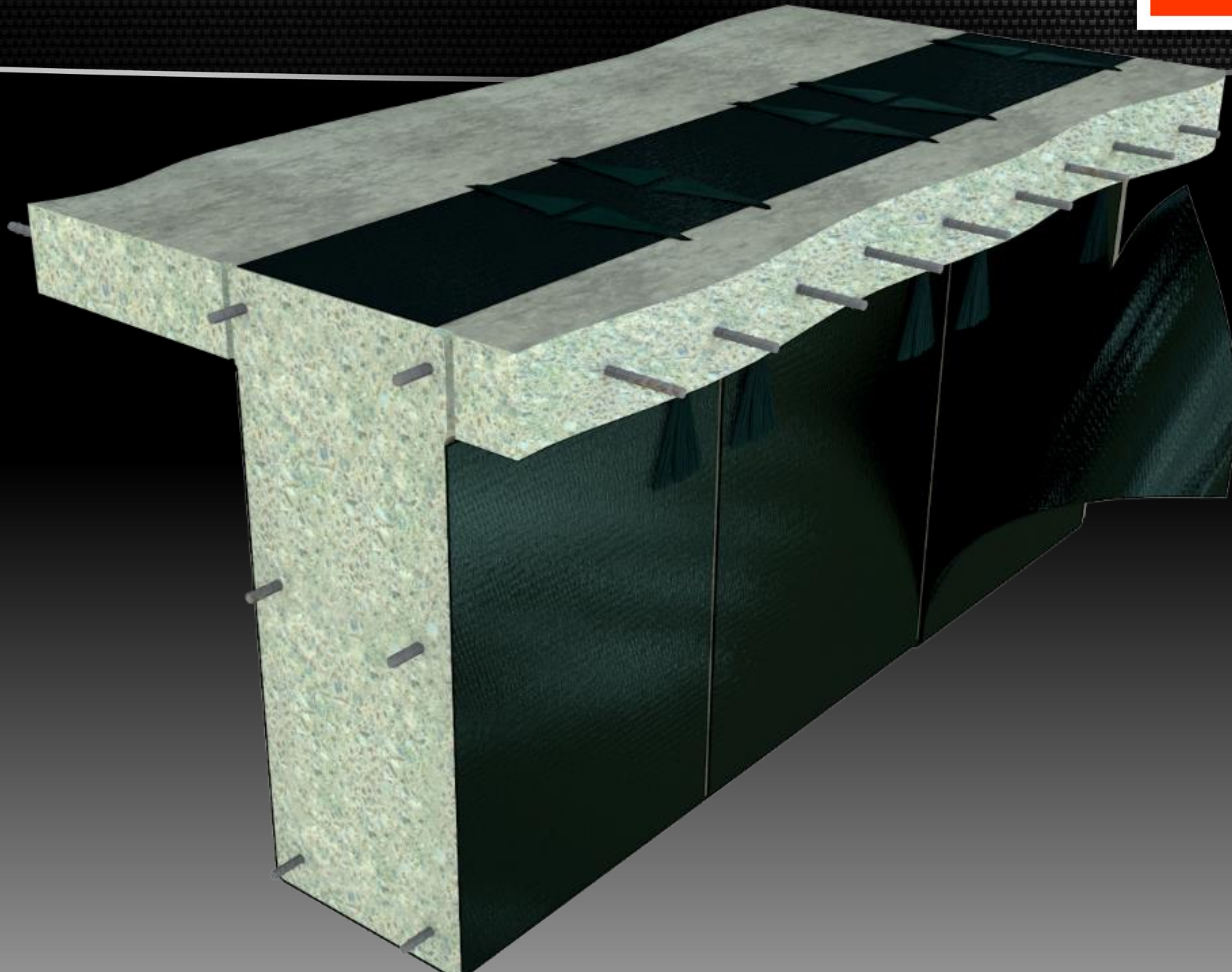
FRP anchors

Folded Anchor

Through Anchor



How are they used?



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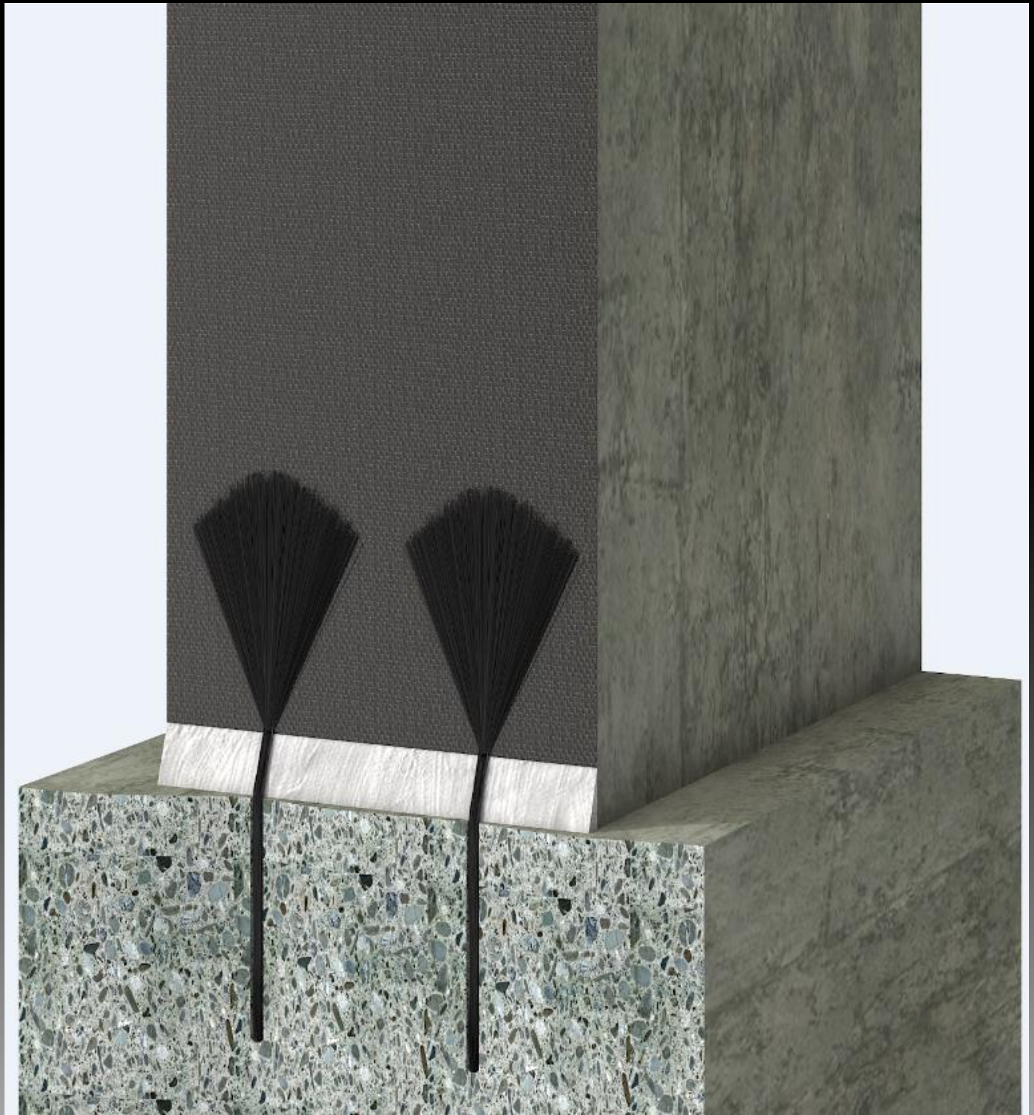

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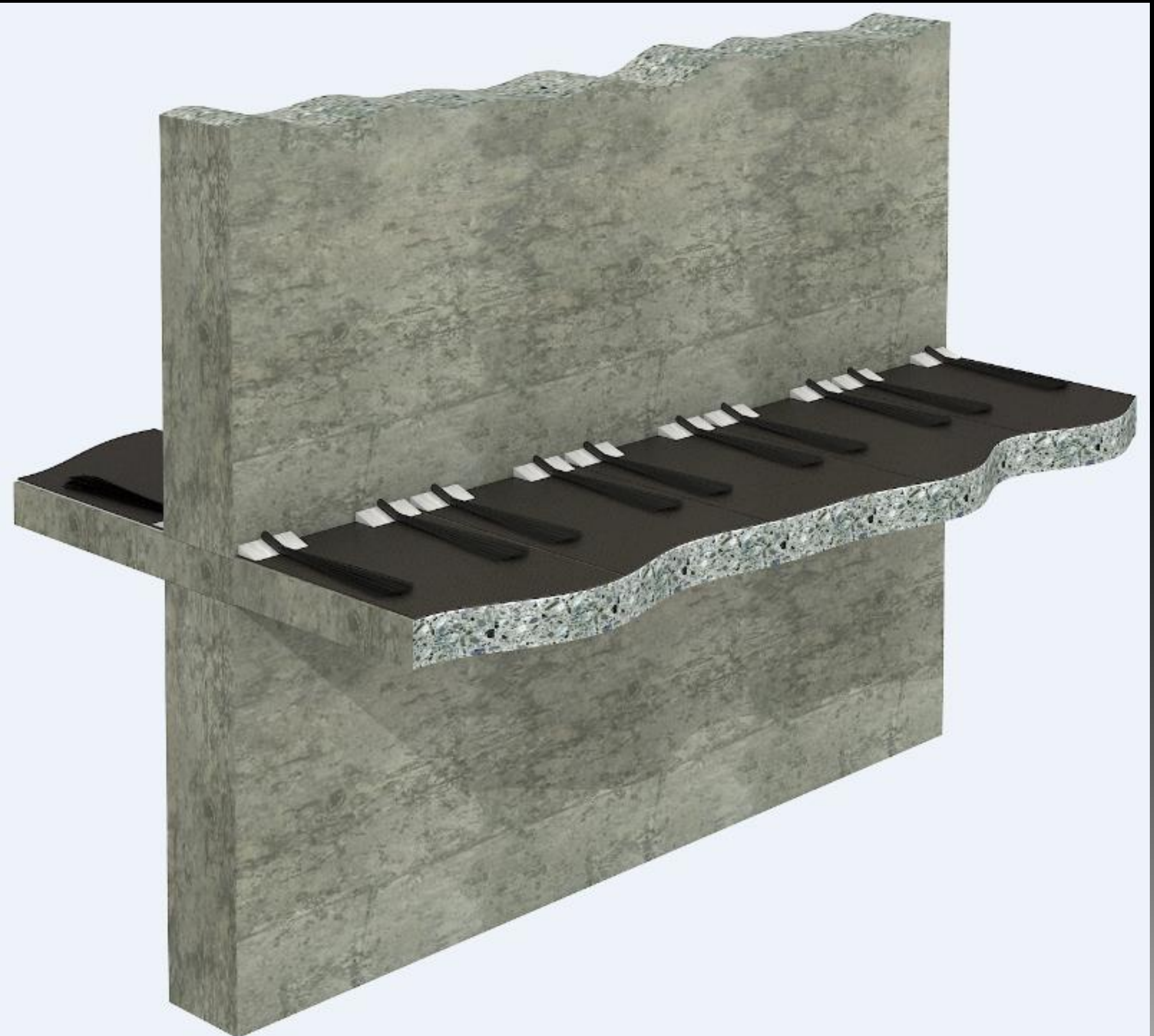
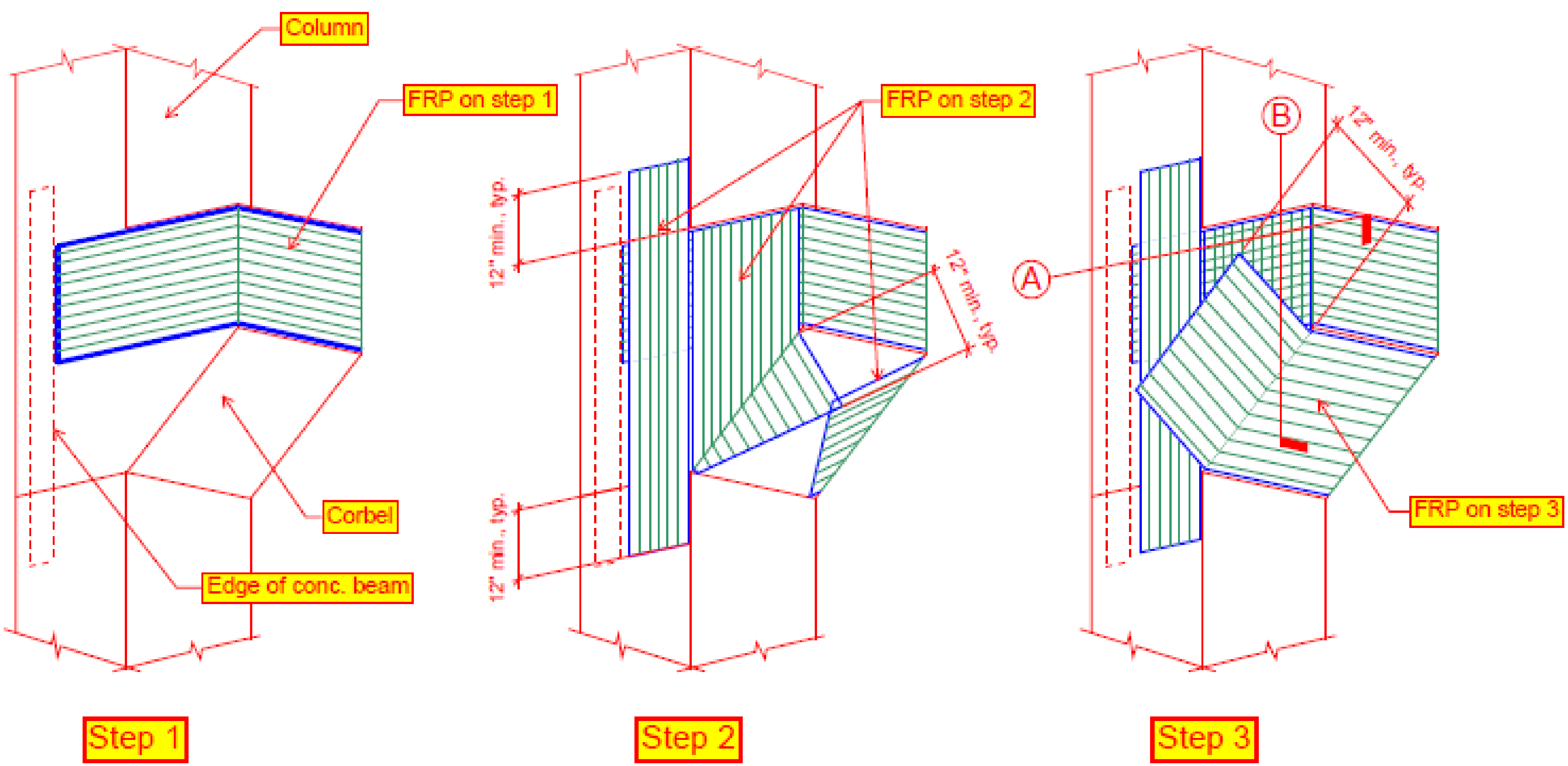


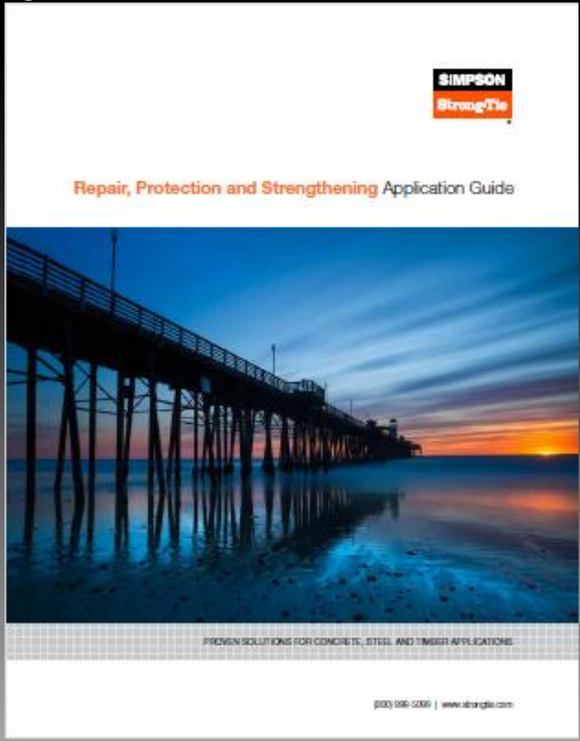
Project Examples

(Typical interior corbel)



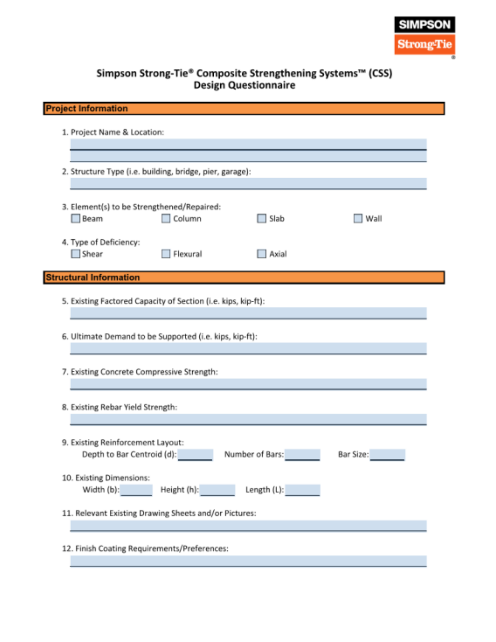
How Can We Help?

- 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-------------------→



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

Project Information

1. Project Name & Location:
2. Structure Type (i.e. building, bridge, pier, garage):
3. Element(s) to be Strengthened/Repaired:
   ☐ Beam ☐ Column ☐ Slab ☐ Wall
4. Type of Deficiency:
   ☐ Shear ☐ Flexural ☐ Axial

Structural Information

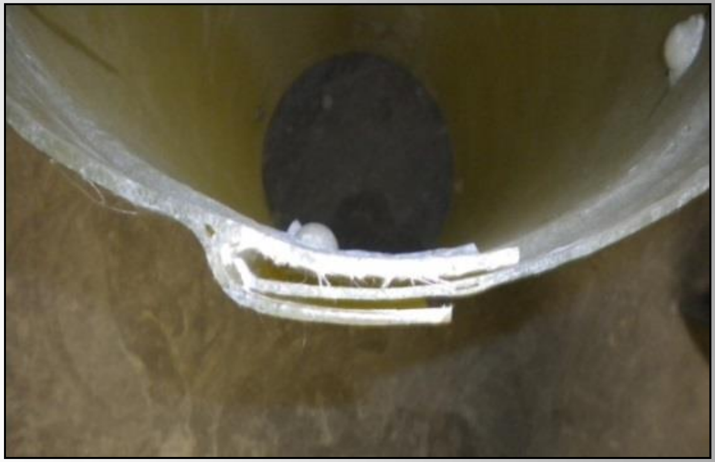
5. Existing Factored Capacity of Section (i.e. kips, kip-ft):
6. Ultimate Demand to be Supported (i.e. kips, kip-ft):
7. Existing Concrete Compressive Strength:
8. Existing Rebar Yield Strength:
9. Existing Reinforcement Layout:
   Depth to Bar Centroid (d): Number of Bars: Bar Size:
10. Existing Dimensions:
    Width (b): Height (h): Length (L):
11. Relevant Existing Drawing Sheets and/or Pictures:
12. Finish Coating Requirements/Preferences:

Pile Restoration and Protection

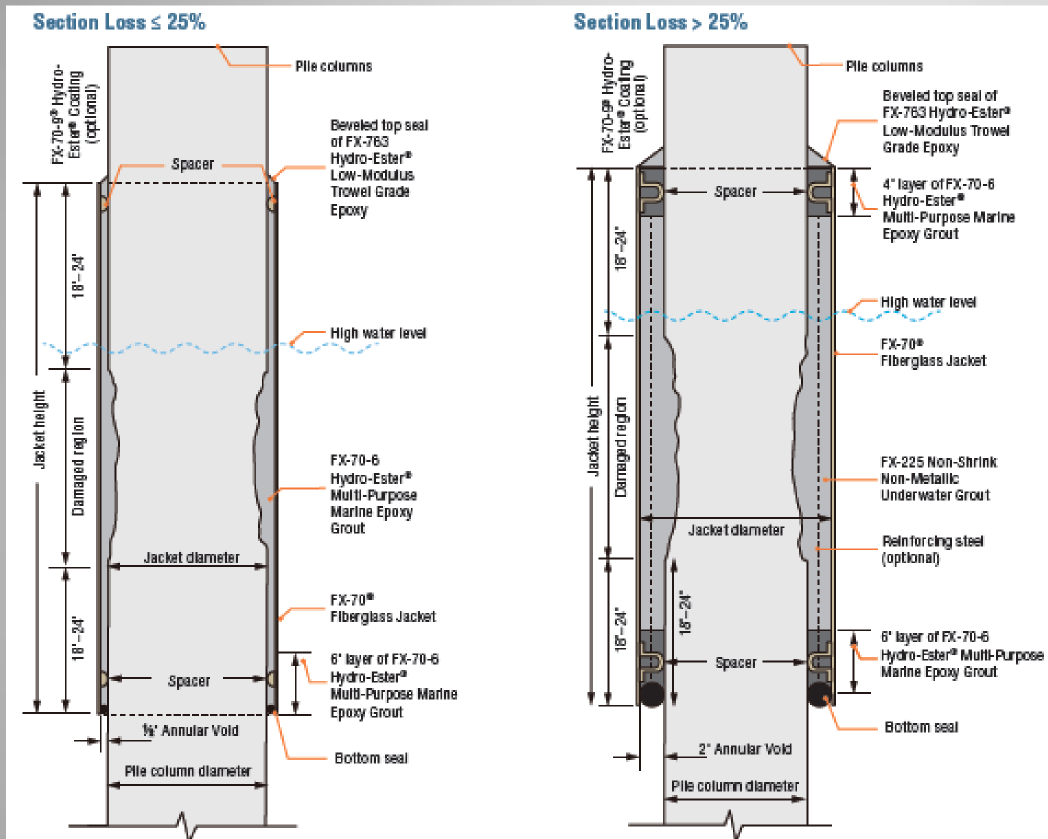
FX-70® SYSTEM

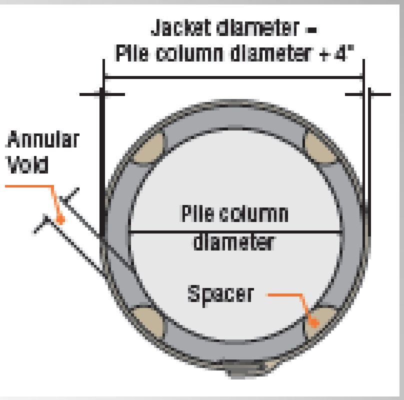
Precured glass composite jackets

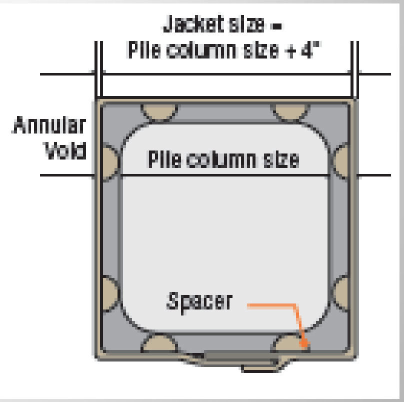
- Glass composites
- Custom shapes/sizes
- Tongue & groove connection

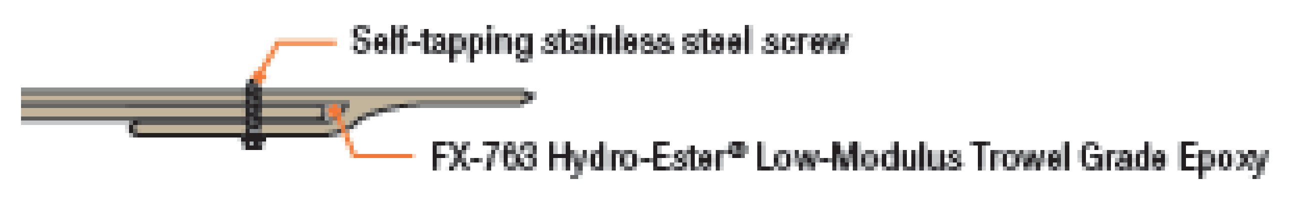


Precured glass composite jackets









First Question?

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