FRP Strengthening

Strengthening Concrete Structures with Fiber-Reinforced Polymers

Webinar Sponsored by MAPEI Corporation

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FRP Strengthening

Strengthening concrete structures with fiber-reinforced polymers

Reasons for Strengthening Existing Structures

- Increase load bearing capacity
    - Change in use
    - New load conditions
    - Design or construction errors

- Replace capacity lost to damage and/or deterioration
    - Corrosion of reinforcing steel
    - Cut or damaged reinforcing steel
    - Impact damage
    - Fire or other natural disasters

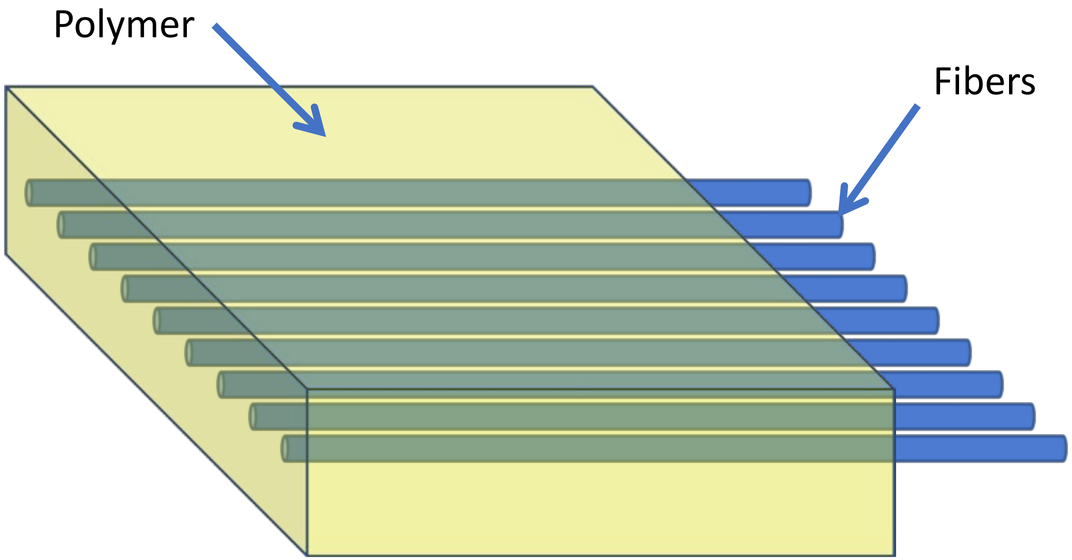
- Increase seismic performance of a structure

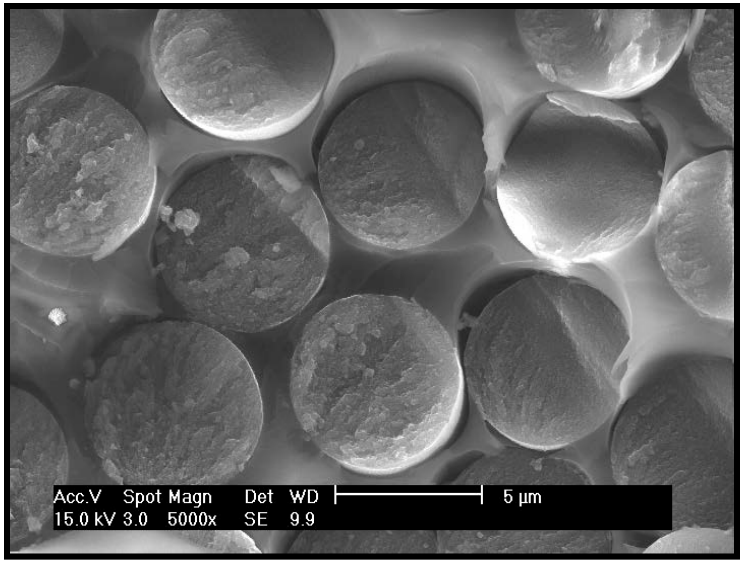
- Blast resistance

FRP Strengthening Systems

- Low-profile repairs
- Installed thickness generally less than 1/16”
- Easily concealed with a variety of topcoats
- Minimal equipment required
- Does not add any appreciable dead load to the structure

What are Fiber Reinforced Polymers (FRP)?





Composites in Construction

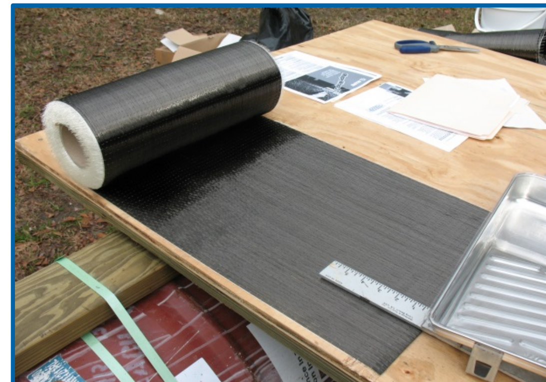
Structural Strengthening

Composite Bridge Decks

FRP Mesh

FRP Bars

Types of FRP Strengthening Systems



Fabric Strengthening Systems

- Flexible sheets of carbon and glass fibers, both uniaxial and bidirectional
- Applied with proprietary epoxy resins, MFR specific
- Versatility provided by FRP fabrics allows for use in all applicable strengthening scenarios

Pre-Cured Laminate Strengthening Systems

- Precured carbon fiber reinforced polymer plates
- Applied to flat surfaces using proprietary epoxy adhesive materials unique to each manufacturer
- Ideal for slabs, walls, and beams requiring flexural strengthening, particularly CMU

FRP Bars

- Carbon and glass fiber reinforced polymer bars
- Installed into shallow grooves cut into the concrete and backfilled with an epoxy adhesive

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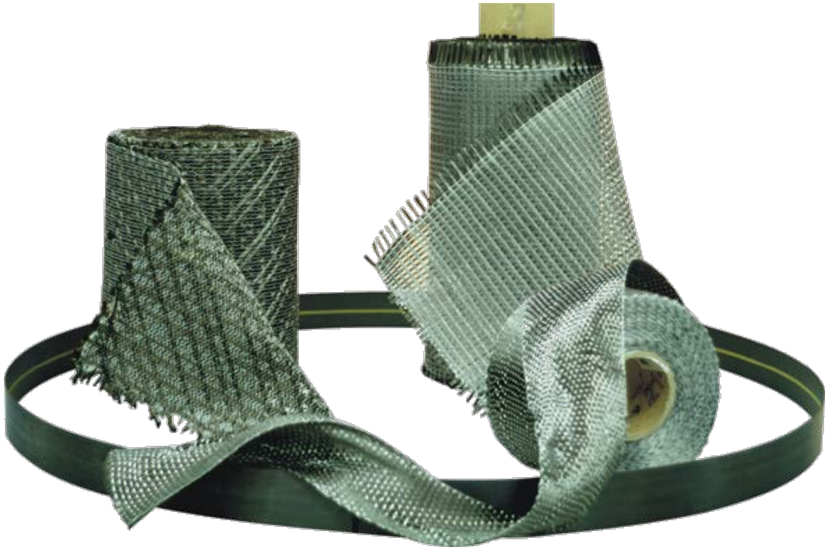
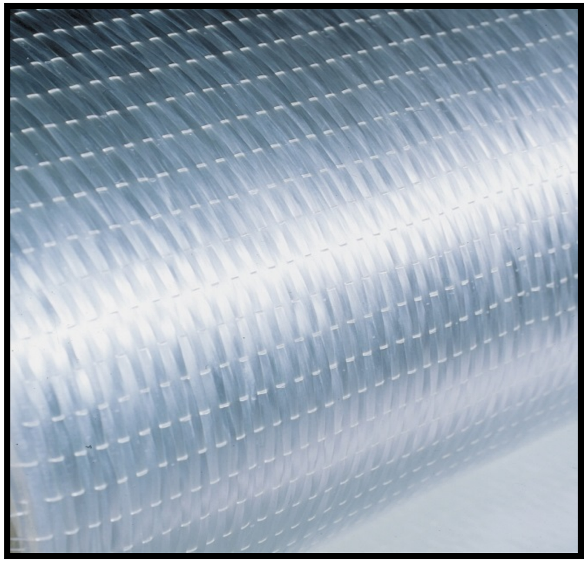
Fiber Types Used in Structural Strengthening

- Carbon Fibers
- Glass Fibers
- Aramid (a.k.a. Kevlar)

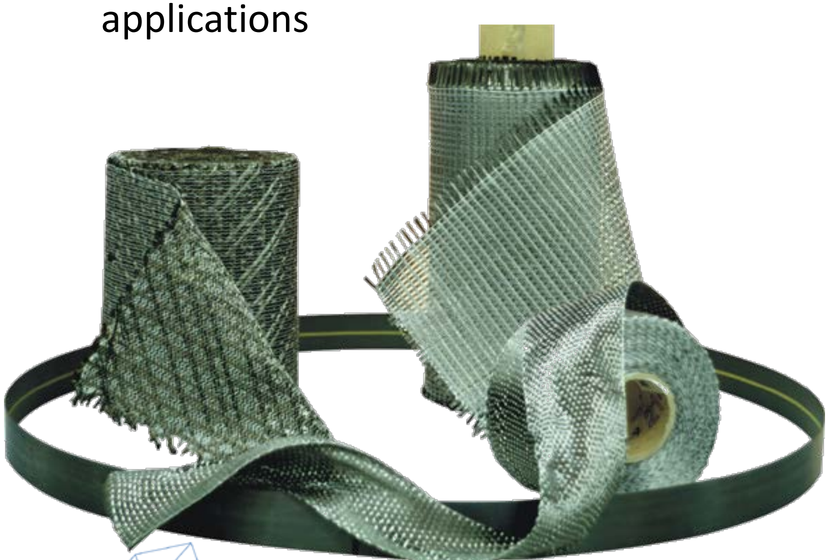


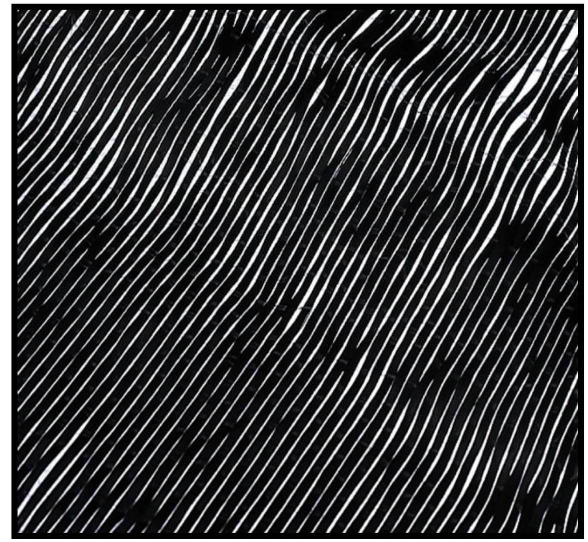


Fiber Characteristics – Carbon Fibers

Benefits

- High Strength
- High Stiffness
- Excellent Durability and Endurance
- Use for majority of strengthening applications





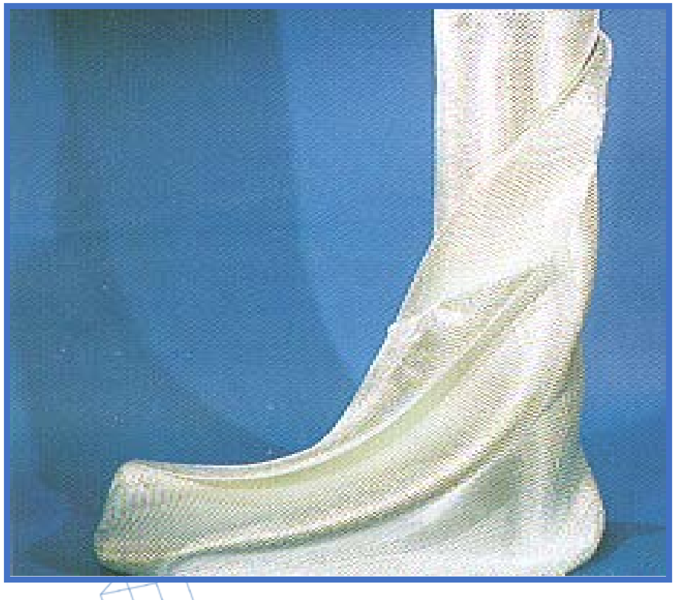
Limitations

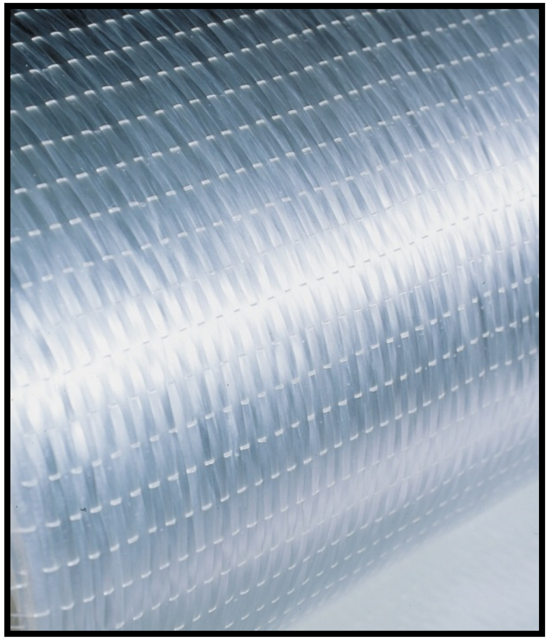
- Conductive

Fiber Characteristics – Glass Fibers

Benefits

- High Strength to Weight Ratio
- Non-Conductive
- Ideal for single events, i.e. seismic activity, and basic protection





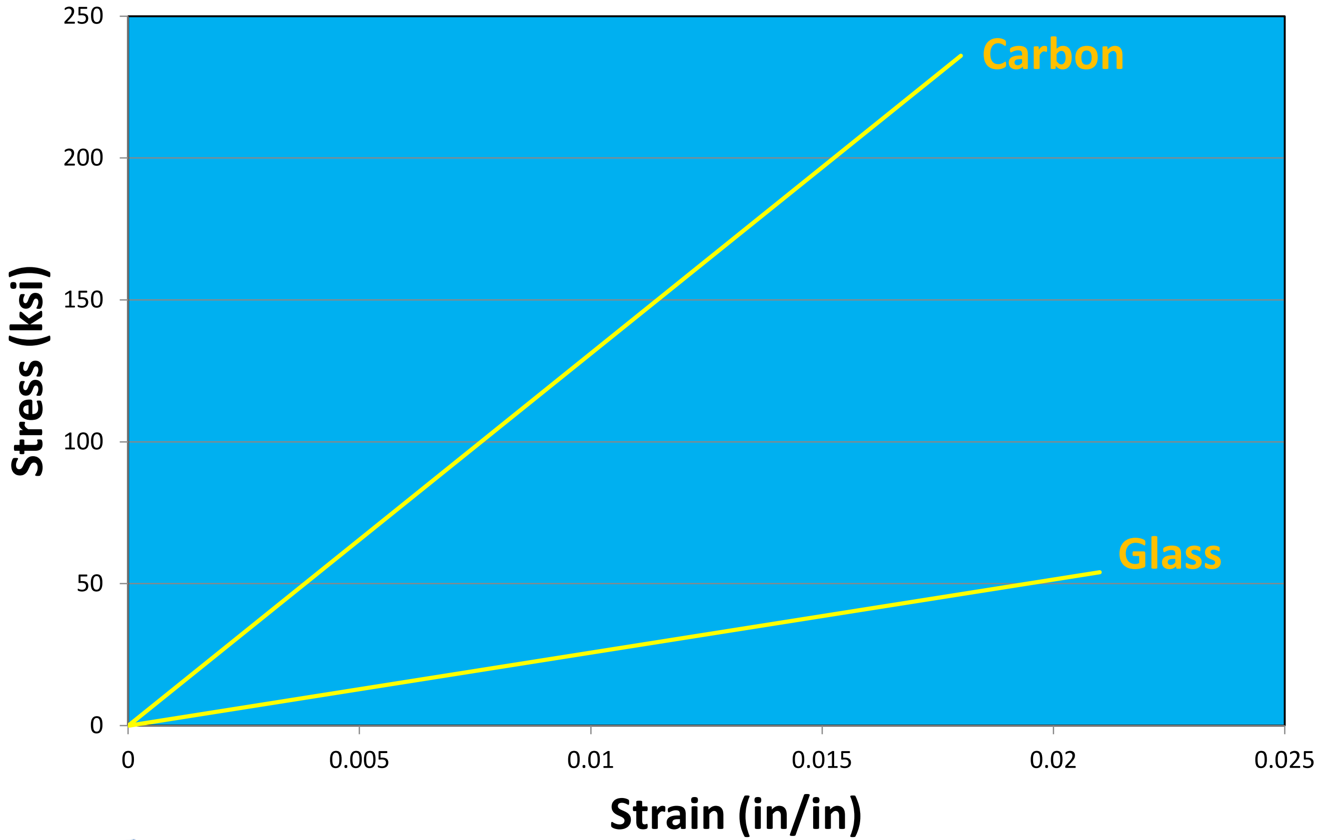
Limitations

- Poor Durability
- Low Endurance
- Low Stiffness

Typical FRP Material Properties

	300 gsm Carbon	600 gsm Carbon	900 gsm Fiberglass
Design Thickness	0.02"	0.04"	0.07"
Ultimate Tensile Strength	216 ksi	210 ksi	42 ksi
Elastic Modulus	12,161 ksi	11,875 ksi	2,586 ksi
Rupture Strain	1.70%	1.70%	1.80%

FRP Stress-Strain Relationship



FRP Design Considerations

Strengthening Limits – Primary versus Secondary Reinforcing

$$(\phi R_n)_{existing} \geq (1.1 S_{DL} + 0.75 S_{LL})_{new}$$

ACI 440.2R-17 Eq. 9.2

$$(\phi R_n)_{strengthened} \geq (1.2 S_{DL} + 1.6 S_{LL})_{new}$$

ACI 440.2R-17 Section 9.1

In order to utilize FRP as a means of strengthening, the structure must have enough existing capacity such that it is not in danger of structural failure in it's present state. The FRP is applied to allow the structure to meet the factored load required by current building code.

FRP Strengthening Systems – Typical Applications

Typical FRP Applications

Flexural Strengthening

- Applicable to traditionally reinforced, post-tensioned and prestressed elements
- Limitations on moment redistribution
- Does not effectively reduce deflections
- Can typically achieve approximately 70% increase in bending capacity

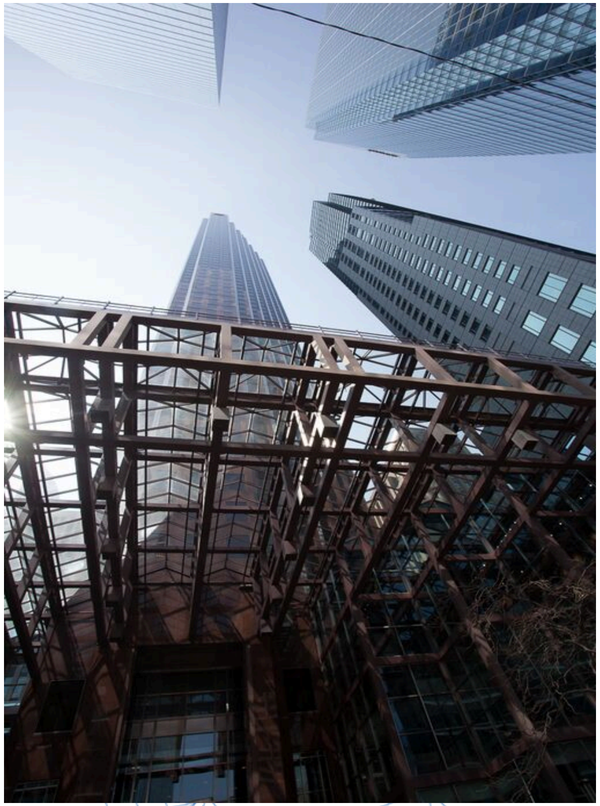
Matrix Corporate Center Parking Garage

Danbury, CT

MAPEI

Scotia Bank Conference Center

Toronto, Ontario, Canada

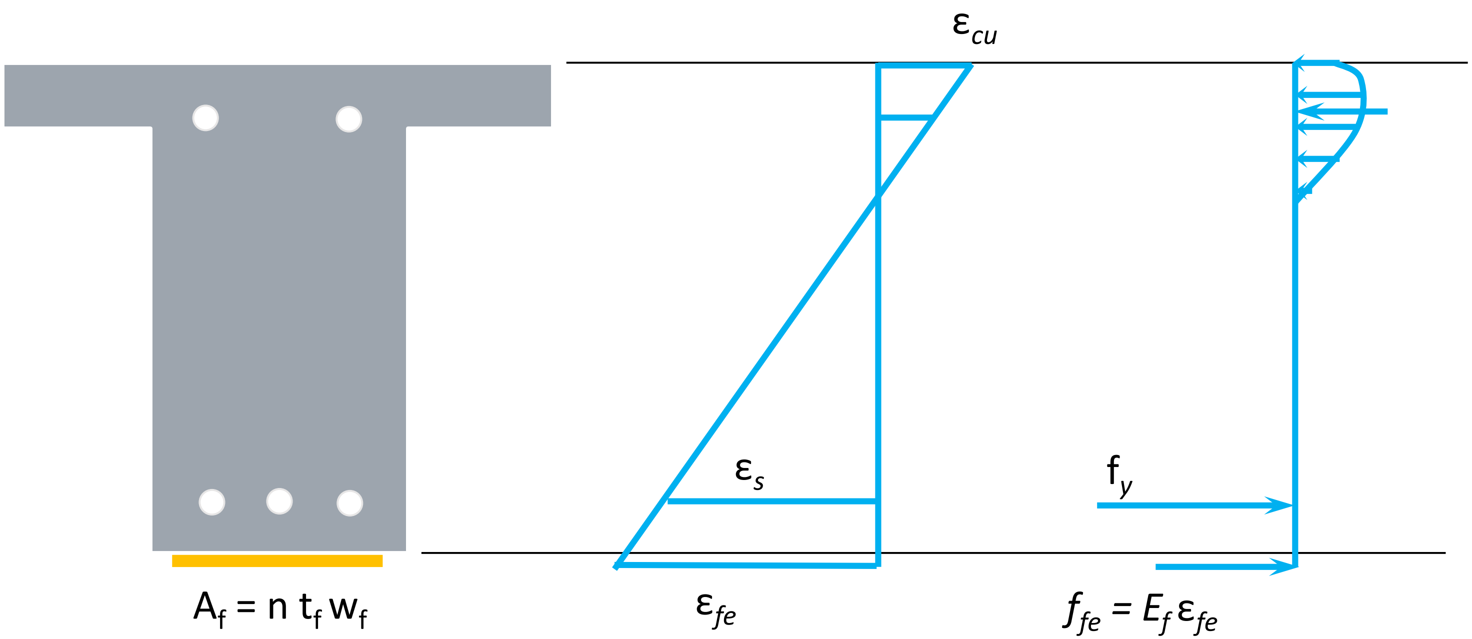


Scotia Bank Conference Center

Toronto, Ontario, Canada

Typical FRP Applications - Flexural

Typical Stress/Strain Diagram



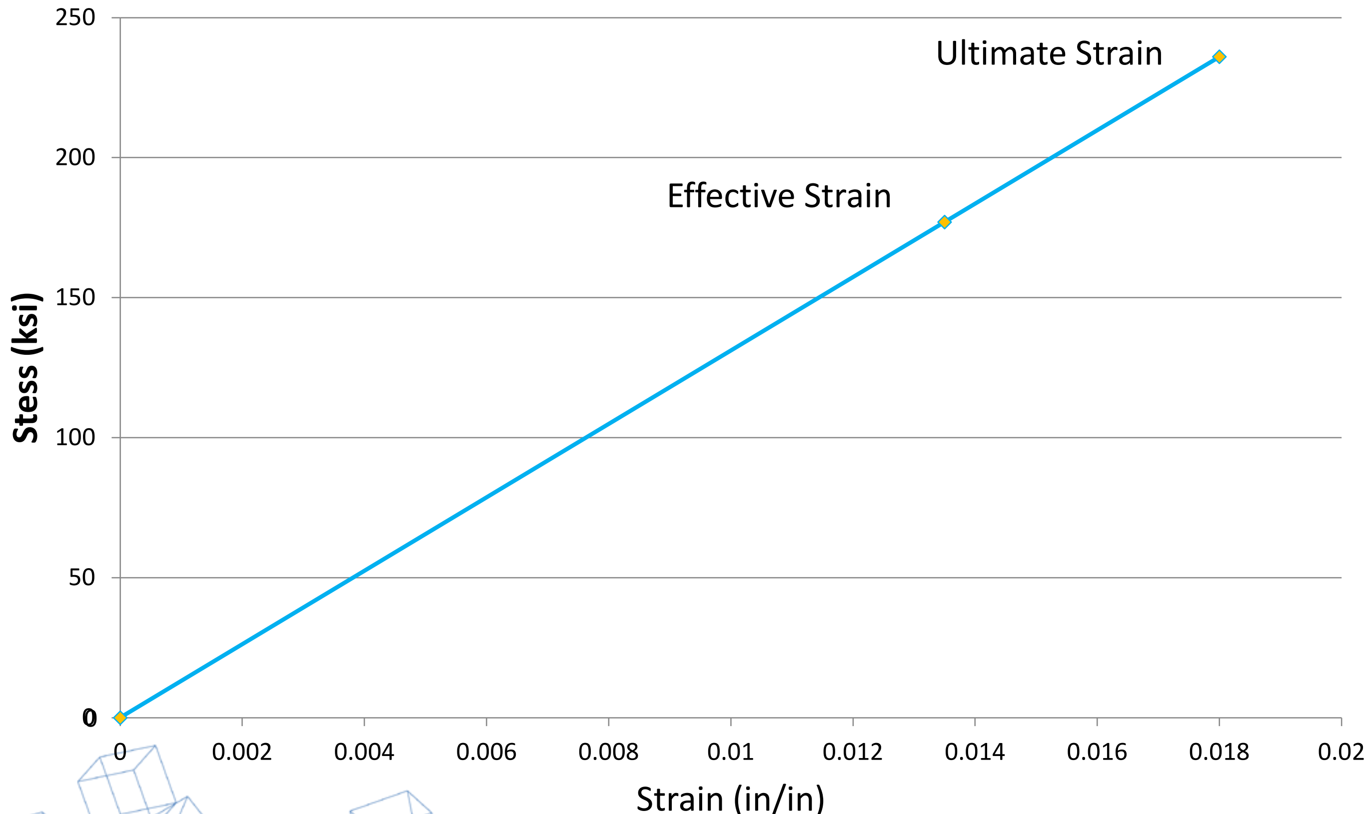
$$M_n = A_s f_s\left(d - \frac{\beta_1 c}{2}\right) + A_f f_{fe}\left(h - \frac{\beta_1 c}{2}\right)$$

Steel Contribution

FRP Contribution

Typical FRP Applications – Effective Strain

Flexural Strengthening



Typical FRP Applications - Flexural

Debonding Strain, ε_{fd}

$$\varepsilon_{fd} = 0.0083\sqrt{\frac{f_c^{'}}{nE_f t_f}} \leq 0.9\,\varepsilon_{fu}$$

ACI 440.2R-08 Eq. 10-2

- The controlling strain level for an FRP system is typically governed by that which would lead to debonding of the cured system

- As stiffness increases, the likelihood of debonding increases
    - This leads to diminishing returns as additional layers are added

- As the compressive strength of the host concrete decreases, the likelihood of debonding increases

Typical FRP Applications

Shear Strengthening

- Adds increased shear resistance to beams, shear walls, and shear diaphragms
- An increase of approximately 2-kips per inch of beam/wall depth can be reasonably expected
- FRP systems are not an effective means of strengthening for punching shear

Black Creek Bridge
Danbury, CT

Champlain Bridge

Montreal, Quebec, Canada

Oracle Parking Garage

Burlington, MA

Oracle Parking Garage

Burlington, MA

Typical FRP Applications – Column Confinement

New Matamoras Bridge
New Matamoras, OH

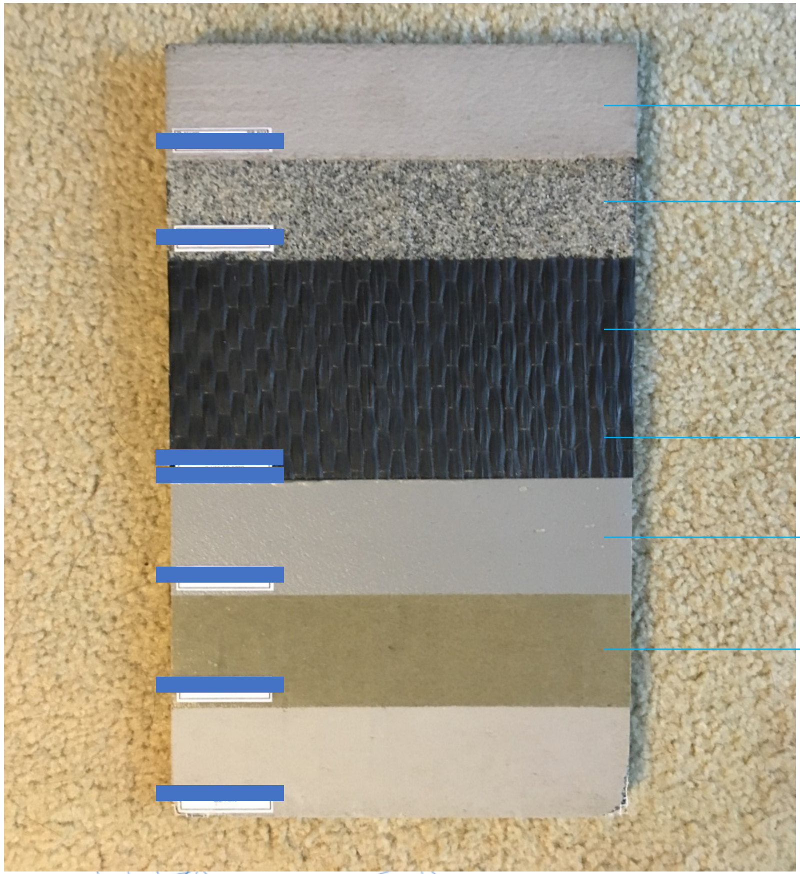
Column Confinement

- Unlike flexural and shear strengthening with FRP, there is no upper limit on the amount of confinement that can be provided
- The larger the diameter of the column the smaller the additional pressure provided
- Rectangular columns are acceptable with limitations:
    - Side aspect ratio is less than 2
    - Face dimensions all less than 36 in

BASF Plant Facility Clarifier Tank

Savannah, GA

MapeWrap™ Fabric Installation Process



Topcoat

Topcoat of Saturating Epoxy

FRP Fabric

Putty

Primer

FRP Fabric Installation Procedure – Dry Lay-up Method

1 - Apply the primer component

2 - Apply the putty component

FRP Fabric Installation Procedure – Dry Lay-up Method

3 – Apply a basecoat of the saturating component

4 - Place the FRP fabric into the still wet basecoat of saturant

FRP Fabric Installation Procedure – Dry Lay-up Method

5 – Roll FRP fabric to remove wrinkles & achieve a tight installation

6 – Apply a topcoat of the saturating epoxy component

FRP Fabric Installation – Wet Lay-up Method

- Using the Wet Lay-up Method, a saturating machine is used to pre-wet the fabric prior to placement
- The FRP fabric is rolled through a trough filled with the saturating component, and rollers ensure complete saturation of the fabric
- The pre-wet fabric is placed on the substrate and rolled tight using drum rollers.
- The substrate must already have been properly prepared and the primer & putty components must be applied prior to commencing fabric placement using the wet lay-up method.

Protective Coating Application

- If the FRP system is exposed to UV a topcoat must be applied to protect the system
- May also be required indoors for aesthetical purposes
- Broadcast sand to refusal into the final topcoat application of the saturating component and allow to reach a tack free state before applying the topcoat material

FRP Pre-cured Laminate Installation

- All surface prep requirements remain the same as fabric applications
- Prime the substrate with the appropriate priming epoxy as recommended by the manufacturer
- Remove the peel-ply from the side of the laminate to receive epoxy
- Apply a uniform layer of the manufacturer recommended epoxy to one side of the laminate and press firmly against the substrate to achieve bond

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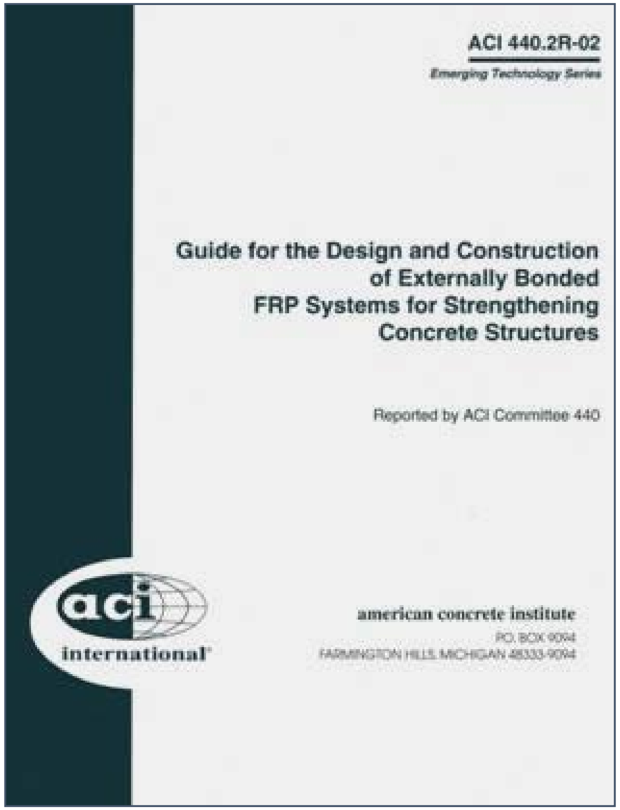
Design and Construction Guidelines



United States

- ACI 440.2R-17 – Design Guide
- ACI 440.8-13 – Material Specification

Canada

- CSA S6-06 – Bridges
- CSA S 806 – Buildings
- CSA S 807 – Specification for Fiber-Reinforced Polymers

MAPEI FRP Strengthening Systems

Thank You!

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