Strengthening of Concrete Members using Fabric Reinforced Cementitious Matrix

Presenters:

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Outline

• Review of Reinforced Concrete Strengthening Methods
• Introduction to Fabric Reinforced Cementitious Matrix Systems
• FRCM Application Process & Considerations
• FRCM Design & Testing
• Project Profile
Review of Concrete Strengthening Methods
Reinforced Concrete

Potential Reasons for Strengthening:

• Corrosion / Deterioration
• Change of Use / Loading
• Structural Modifications
• Seismic Retrofit
• Construction Errors / Omissions
Traditional Strengthening Methods

Bonded Steel Plate

Section Enlargement

Drawbacks

× Accessibility
× Labor intensive
× Increase dead load supported by structure
× Encroaches on useable space
Strengthening using Composites

Composites are relatively new to the construction market

**FRP Laminate**
(Pre-cured carbon laminate is adhered to building with epoxy paste)

**FRP Fabric**
(Carbon / eGlass fabric is saturated in epoxy and then wrapped around column)
Why use Composites?

- Lightweight
- High tensile strength
- Low impact
- Conform to existing shapes
- Resistance to corrosion
- Ease of installation
- Cost-effective alternative
A New Externally Bonded Composite

FRP Fabric  FRP Laminate  FRCM
Fabric-Reinforced Cementitious Matrix (cement-like) (mortar)

FRCM is in the same family as FRP, but it differs in its installation and application benefits.
FRCM Components

Fabric-Reinforced Cementitious Matrix (FRCM) Systems = Carbon-Fiber Grid + Cementitious Matrix
FRCM Placement
Benefits - FRCM v. FRP

- High tensile strength
- Low impact
- Conform to existing shapes
- Fast installation
- Cost-effective solution

Note that these benefits are the same as FRP.

- Matches substrate
- Elevated temperature
- Provides protective barrier
- Repairs as it adds strength (minimal surface prep needed)

Note that these benefits are unique to FRCM.
FRCM Application Process & Considerations
FRCM Components

Cementitious Matrix

Carbon-Fiber Grid
Single-Layer Grid Installation

Prior to application:

- Repair deterioration per ICRI Guideline No. 310.1R
  - Remove delaminated concrete
  - Clean/coat exposed steel
  - Inject/seal cracks
Single-Layer Grid Installation

Prior to application:

Concrete surface profile should be between CSP 6-9 (ICRI)

This means you can repair surface inconsistencies as you add strength.

Fig. 6.6: CSP 6 (medium scarification)
Fig. 6.7: CSP 7 (heavy abrasive blast)
Fig. 6.8: CSP 8 (scabbled)
Fig. 6.9: CSP 9 (heavy scarification—rotomilled)
Prior to application:

Be sure the surface has been wet to ensure a saturated surface-dry (SSD) condition per ICRI guidelines.
Single-Layer Grid Installation

1. Apply first layer of cementitious matrix (CSS-CM), being sure to completely coat area at ¼” to ½” thick
2. Embed grid into wet matrix using a trowel or wood float.

Single-Layer Grid Installation

Grid Alignment

Why so important?

• Grid is designed to resist load in tension
• 5 degree tolerance (1 inch per foot slope max)
• Avoid kinks, folds, waves
Single-Layer Grid Installation

3. Apply second layer of cementitious matrix at \( \frac{1}{4} \)“ to ½” thick
Single-Layer Grid Installation

4. Screed and trowel to desired finish
5. Allow for full cure by keeping wet for 3-5 days after installation
6. Finish coat as desired
Multiple-Layer Grid Installation

Repeat steps 2 and 3 as specified

2. Place grid into wet matrix and embed using a trowel or float

3. Apply additional layer(s) of cementitious matrix at ¼” to ½” thick
Overlapping and Staggering

Overlapping is determined by drawings and specifications, minimum 12” overlap

Stagger Laps
Traditional Shotcrete vs. FRCM

Traditional Shotcrete Repair

FRCM Repair
<table>
<thead>
<tr>
<th>Traditional Shotcrete Repair</th>
<th>FRCM Repair</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ Specialty contractor to tie rebar cage</td>
<td>✓ Same contractor installs FRCM system</td>
</tr>
<tr>
<td>☐ Specialty contractor to spray shotcrete</td>
<td>✓ Carbon-fiber grid installs in minutes, saving time and money</td>
</tr>
<tr>
<td>☐ Rebar installation time-intensive</td>
<td>✓ No steel = no cover requirements. Only $\approx 1”$ volume change in total repair.</td>
</tr>
<tr>
<td>☐ Additional 1.5”–3” shotcrete cover over rebar</td>
<td>✓ Adds negligible weight to structure</td>
</tr>
<tr>
<td>☐ Additional weight needs to be calculated into total building loads</td>
<td>✓ Cementitious matrix is a high-performance mortar with psi at 7,500</td>
</tr>
<tr>
<td>☐ Shotcrete typical psi at 4,000</td>
<td></td>
</tr>
</tbody>
</table>
Grain Concrete Silo Needs Repair

- Concrete on the side of the grain silo has deteriorated
- Damage was caused by grain abrasion
- Repair and additional strengthening is needed
Shotcrete Repair Method

- Considerable volume change results in grain displacement
- More subcontractors needed
- Repair takes longer to installer (+28 days until fully cured)
Composite Strengthening

- Low impact = little to no grain displacement
- Cementitious matrix matches the base material (benefit when compared to FRP)
- Quick installation time.

FRCM Repair Method
Where can I use FRCM?
Project Types

For projects with large, overhead and vertical surface areas
Project Types

For projects where traditional FRP is excessive
Potential Project Types

For projects that require surface repair in addition to strengthening
Potential Project Types

For projects that require higher level of heat resistance
Potential Project Types

For projects that can’t afford a significant reduction in useable space
Potential Project Types

For projects that requires water to be transmitted
Ideal Application: Tunnels and Mines

Substrate damage needs repair

No room for significant enlargement

With FRCM, repair and strengthen at the same time
FRCM Design & Testing
Design Standards

**American Concrete Institute (ACI)**


562-16: Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings

**International Code Council Evaluation Service (ICC-ES)**

Design Considerations

Existing Capacity Demands

Exposure Coefficients

Serviceability

ACI 562-13 Equation 5.51:

\[(\phi R_n)_{\text{existing}} \geq (1.2S_{DL} + 0.5S_{LL})_{\text{new}}\]

meaning…

ACI 562-13 Equation 5.51:

Unstrengthened member should be $\geq 120\%$ of service dead load and $50\%$ of service live load
# Design Considerations

## APPENDIX B—DESIGN LIMITATIONS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Concrete</th>
<th>Masonry</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flexure</td>
<td>Shear</td>
</tr>
<tr>
<td>$\varepsilon_{cf}$ or $\varepsilon_{d}$</td>
<td>Less than 0.012</td>
<td>Less than 0.004</td>
</tr>
<tr>
<td>$\phi$</td>
<td>0.9 to 0.65 based on $\varepsilon_c$</td>
<td>0.75</td>
</tr>
<tr>
<td>$f_{oc}/f_{cd}$</td>
<td>0.2 to 0.55 based on fiber</td>
<td>NA</td>
</tr>
<tr>
<td>Allowable maximum enhancement*</td>
<td>50 percent</td>
<td>50 percent</td>
</tr>
</tbody>
</table>

*Allowable maximum enhancement is above existing capacity. ACI 562-13 supersedes when limits are lower than as listed in this table.
Design Considerations

Existing Capacity Demands

- Ambient and surface temperatures between 41°F and 86°F
- Wet-cure completed FRCM application

Exposure Coefficients

Serviceability

Serviceability

- Ambient and surface temperatures between 41°F and 86°F
- Wet-cure completed FRCM application
The service stresses in the steel must be checked for the desired performance.
Structural Testing: Beams
Structural Testing: Column Testing Results

Control 285,000 lb.

1 Layer 485,000 lb.

2 Layers 650,000 lb.
Quality Control and Assurance

Daily Inspection

• Date and time of installation
• Ambient temperature, relative humidity, and weather conditions
• Substrate surface temperature
• Surface preparation method and ICRI concrete surface profile
• Surface cleanliness description
• Grid batch numbers
• Matrix batch numbers, mix ratios, and mixing times
Field Testing

Pull-Off Test

(ASTM C1583)

– Adhesion test should exceed 200 psi

– When failure at grid-matrix interface, strength computed on net matrix area should be at least 400 psi
Lab Testing

Mortar Cubes Test

(ASTM C109)

- Brass cubes filled with CM
- Test at 7 and 28 days
- Compressive strength of 9,000 psi at 28 days
Lab Testing

Tension Test with Witness Panels

(AC434 Annex A)

- Only required in strengthening applications
- 2 per day, twice daily
- Panels sent to third-party lab for testing
Specifying FRCM is very similar to specifying FRP

FRCM becomes another option to specify when:

- Lower levels of strengthening required
- Elevated temperatures preclude use of FRP
- Excessive moisture precludes use of FRP
- Concrete repair is also required in addition to adding strength
Project Profile
Freeborn County Grandstand
# How Can Manufacturers Help?

<table>
<thead>
<tr>
<th>How Can Manufacturers Help?</th>
<th>Work with EOR to determine if Composites are an option</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feasibility Studies</td>
<td>Engage local trained contractors to provide ROM pricing</td>
</tr>
<tr>
<td>Budget Estimates</td>
<td>Fine-tune to meet project-specific requirements</td>
</tr>
<tr>
<td>Specifications</td>
<td>Develop preliminary sketches &amp; shop drawings</td>
</tr>
<tr>
<td>Drawing Details</td>
<td>Provide for EOR’s reference during submittal review</td>
</tr>
<tr>
<td>Calculations</td>
<td></td>
</tr>
</tbody>
</table>
Thank You

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