Strengthening of Concrete Members using Fabric Reinforced Cementitious Matrix

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Outline

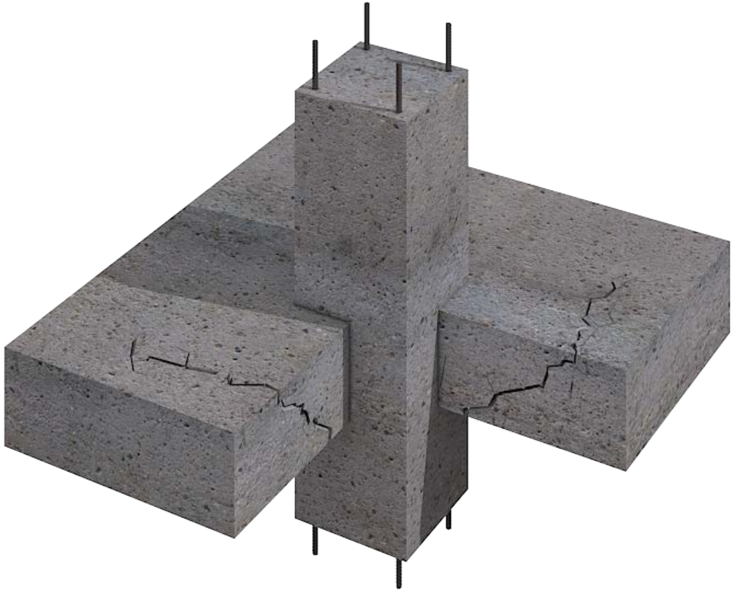
- **Review of Reinforced Concrete Strengthening Methods**
- **Introduction to Fabric Reinforced Cementitious Matrix Systems**
- **FRCM Application Process & Considerations**
- **FRCM Design & Testing**
- **Project Profile**

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

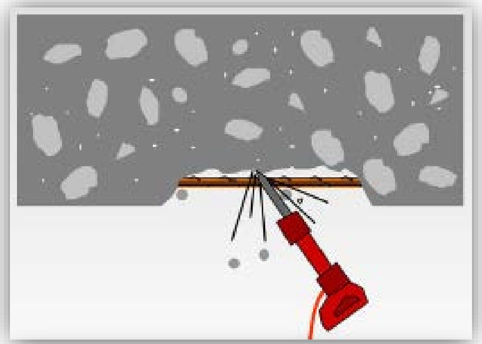
Carbon-Fiber Grid

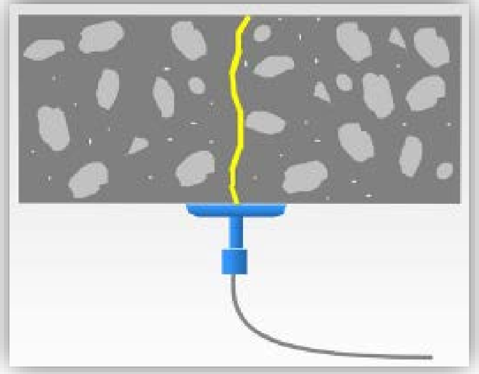
Single-Layer Grid Installation

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)

Single-Layer Grid Installation

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

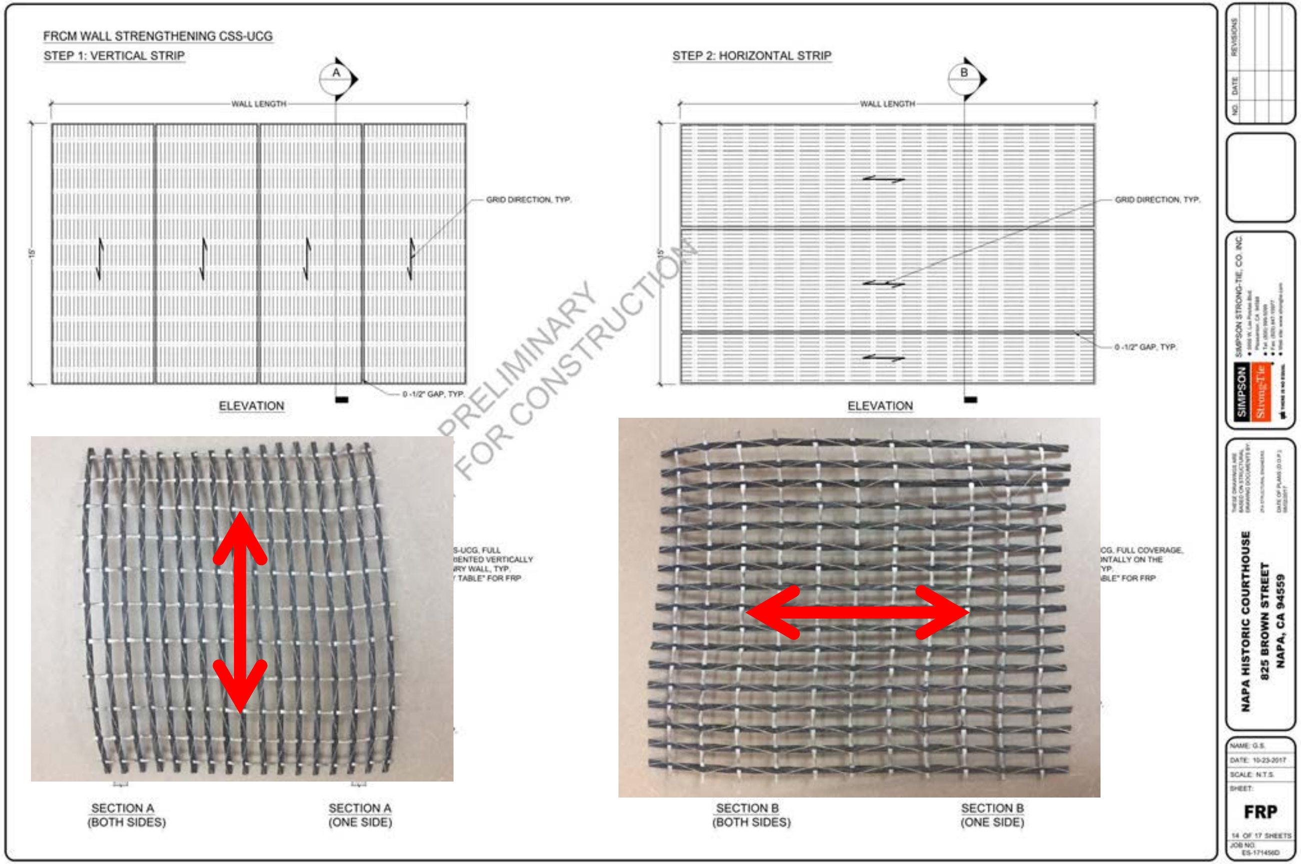
Single-Layer Grid Installation

2.

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



FRCM WALL STRENGTHENING CSS-UCG
STEP 1: VERTICAL STRIP
STEP 2: HORIZONTAL STRIP
A
B
WALL LENGTH
15'
GRID DIRECTION, TYP.
0 -1/2" GAP, TYP.
ELEVATION
PRELIMINARY
FOR CONSTRUCTION
SECTION A
(BOTH SIDES)
SECTION A
(ONE SIDE)
SECTION B
(BOTH SIDES)
SECTION B
(ONE SIDE)
NO.
DATE
REVISIONS
SIMPSON
Strong-Tie
SIMPSON STRONG-TIE, CO. INC.
NAPA HISTORIC COURTHOUSE
825 BROWN STREET
NAPA, CA 94559
NAME: G.S.
DATE: 10-23-2017
SCALE: N.T.S.
SHEET:
FRP
14 OF 17 SHEETS

Single-Layer Grid Installation

3. Apply second layer of cementitious matrix at ¼" 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

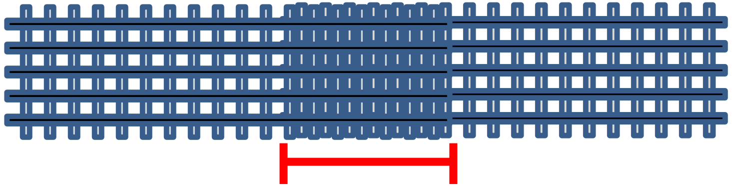
Repeat steps 2 and 3 as specified

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

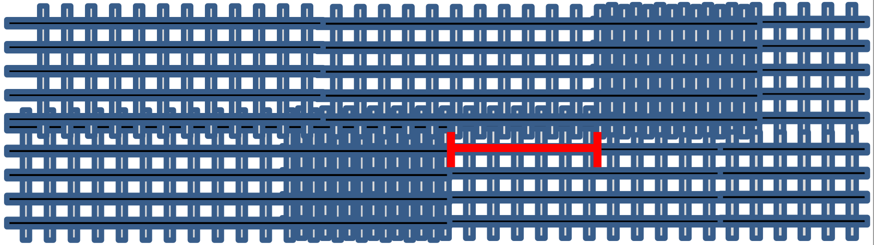
3. Apply additional layer(s) of cementitious matrix at ¼″ to ½″ thick

Overlapping and Staggering

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



Stagger Laps

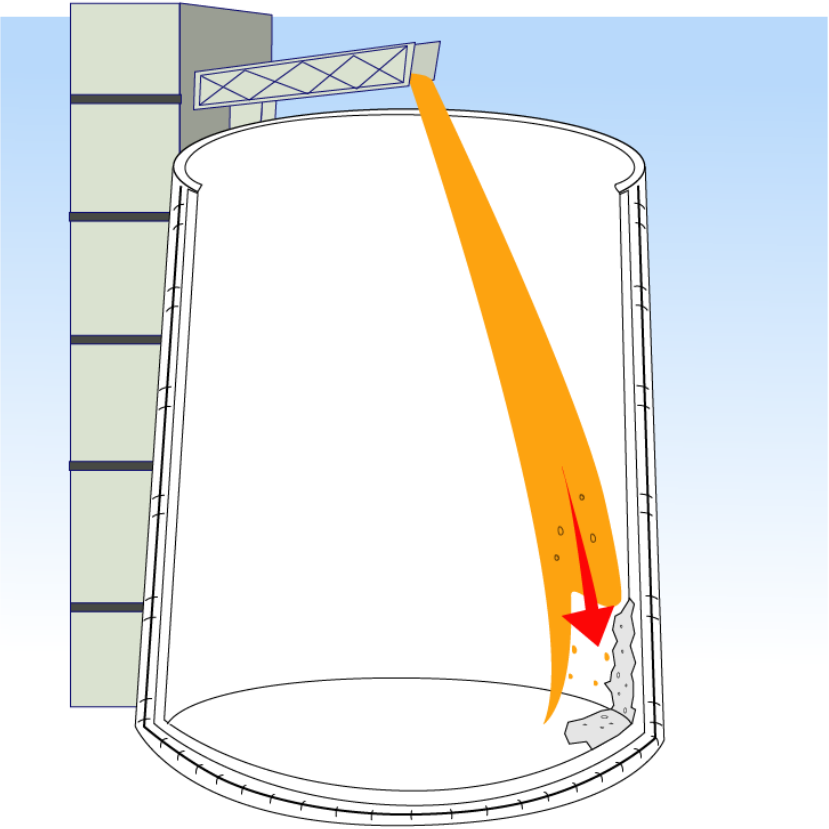


Traditional Shotcrete vs. FRCM

Traditional Shotcrete Repair

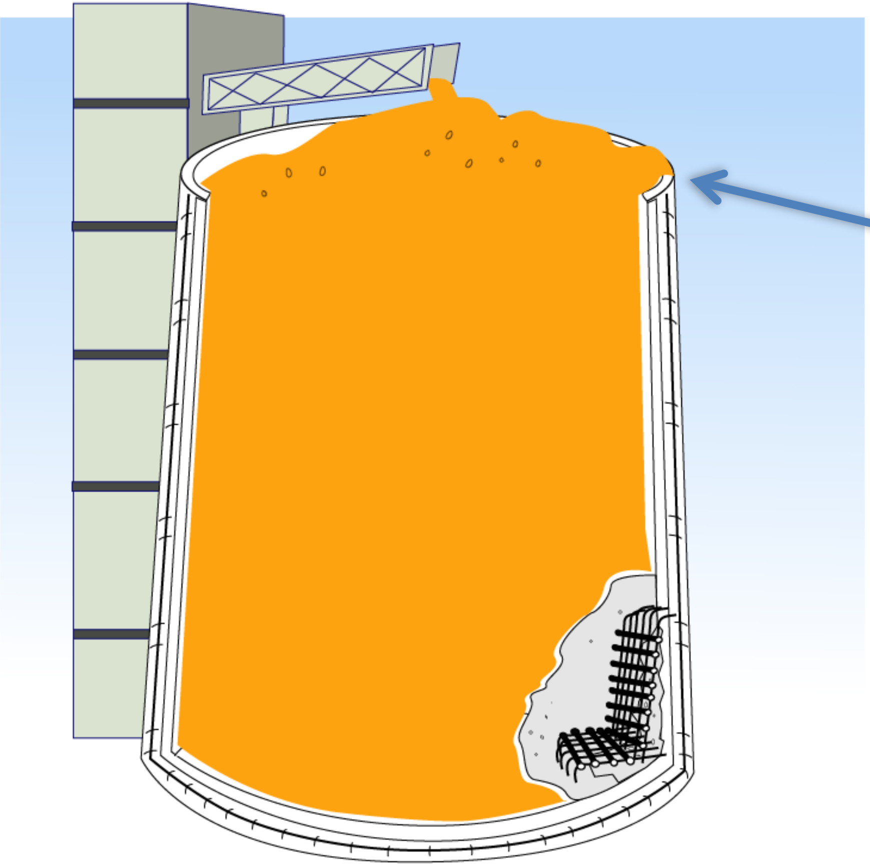
FRCM Repair

Traditional Shotcrete Repair	FRCM Repair
❑ Specialty contractor to tie rebar cage ❑ Specialty contractor to spray shotcrete	✓ Same contractor installs FRCM system
❑ Rebar installation time-intensive	✓ Carbon-fiber grid installs in minutes, saving time and money
❑ Additional 1.5″–3″ shotcrete cover over rebar	✓ No steel = no cover requirements. Only ≈1″ volume change in total repair.
❑ Additional weight needs to be calculated into total building loads	✓ Adds negligible weight to structure
❑ Shotcrete typical psi at 4,000	✓ Cementitious matrix is a high-performance mortar with psi at 7,500



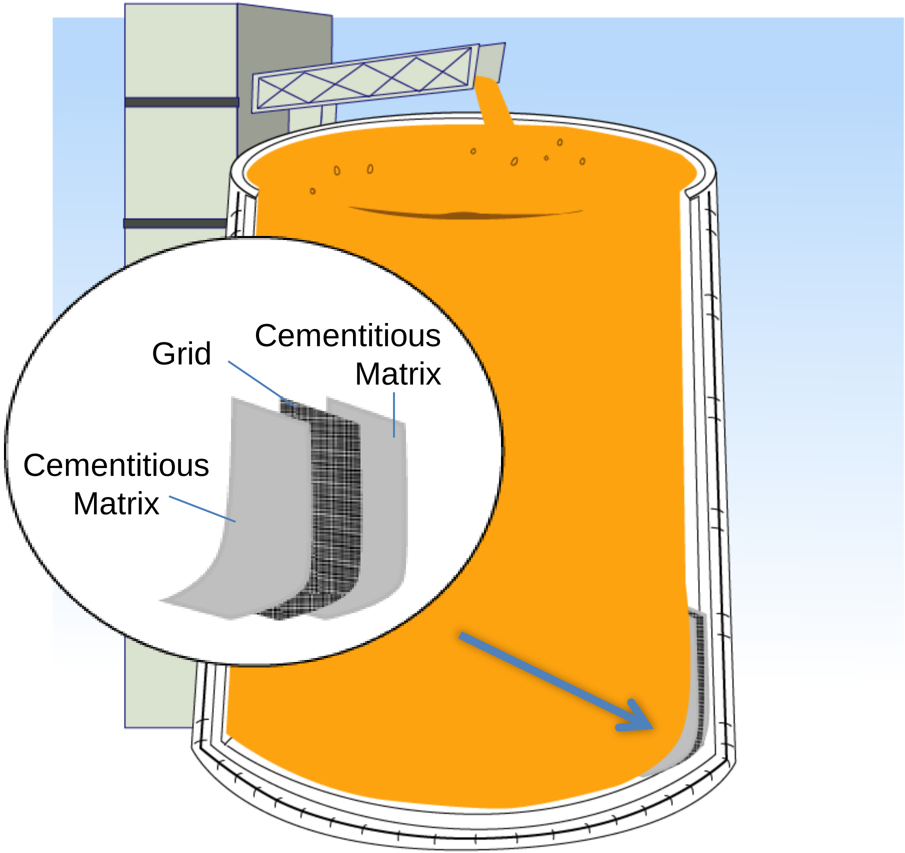
Grain Concrete Silo Needs Repair

- ✓ 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)



FRCM Repair Method

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

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

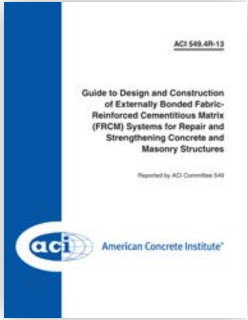
No room for significant enlargement

With FRCM, repair and strengthen at the same time

FRCM Design & Testing

Design Standards

American Concrete Institute (ACI)	**549.4R-13**: Guide to Design and Construction of Externally Bonded Fabric-Reinforced Cementitious Matrix (FRCM) Systems for Strengthening Concrete and Masonry Structures **562-16**: Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings
International Code Council Evaluation Service (ICC-ES)	**AC434**: Acceptance Criteria for Masonry and Concrete Strengthening Using Fabric-Reinforced Cementitious Matrix (FRCM) Composite Systems


ACI 549.4R-13

Guide to Design and Construction of Externally Bonded Fabric-Reinforced Cementitious Matrix (FRCM) Systems for Repair and Strengthening Concrete and Masonry Structures

Reported by ACI Committee 549

American Concrete Institute


ACCEPTANCE CRITERIA FOR MASONRY AND CONCRETE STRENGTHENING USING FABRIC-REINFORCED CEMENTITIOUS MATRIX (FRCM) COMPOSITE SYSTEMS

AC434

Approved August 2014

PREFACE

Design Considerations

Existing Capacity Demands | Exposure Coefficients | Serviceability

ACI 562-13 Equation 5.51:

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

meaning…

ACI 562-13 Equation 5.51:

Unstrengthened member should be ≥ 120% of service dead load and 50% of service live load

Design Considerations

APPENDIX B—DESIGN LIMITATIONS

Parameter	Concrete			Masonry	
	Flexure	Shear	Axial	Out-of-plane	In-plane
ε_{fe} or ε_{fd}	Less than 0.012	Less than 0.004	Less than 0.012 and ε_{ccu} less than 0.01	Less than 0.012	Less than 0.004
ϕ	0.9 to 0.65 based on ε_t	0.75	0.9 to 0.65 based on ε_t	0.6 for flexure 0.8 for shear	0.75
f_{fs}/f_{fd}	0.2 to 0.55 based on fiber	NA	NA	NA	NA
Allowable maximum enhancement*	50 percent	50 percent	20 percent	URM: 6000 lbf./ft (87.6 kN/m); Reinforced masonry: 50 percent	50 percent

*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 | Exposure Coefficients | Serviceability

✓ Ambient and surface temperatures between 41°F and 86°F

✓ Wet-cure completed FRCM application

Design Considerations

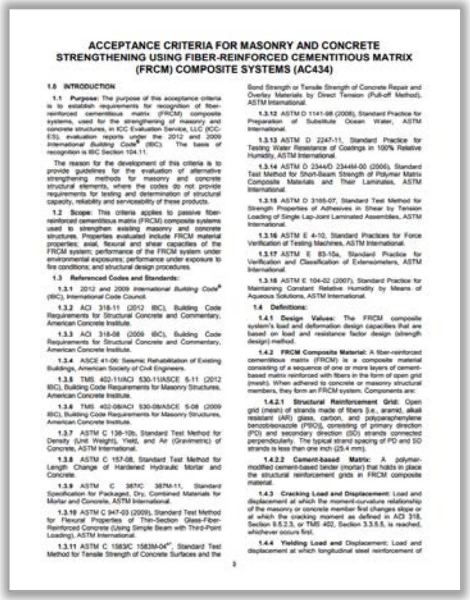
Existing Capacity Demands

Exposure Coefficients

Serviceability

The service stresses in the steel must be checked for the desired performance.

ICC-ES AC434 Testing for Code Report



ACCEPTANCE CRITERIA FOR MASONRY AND CONCRETE STRENGTHENING USING FIBER-REINFORCED CEMENTITIOUS MATRIX (FRCM) COMPOSITE SYSTEMS (AC434)

1.0 INTRODUCTION

1.1 **Purpose:** The purpose of this acceptance criteria is to establish requirements for recognition of fiber-reinforced cementitious matrix (FRCM) composite systems, used for the strengthening of masonry and concrete structures, in ICC Evaluation Service, LLC (ICC-ES), evaluation reports under the 2012 and 2009 *International Building Code*® (IBC). The basis of recognition is IBC Section 104.11.

The reason for the development of this criteria is to provide guidelines for the evaluation of alternative strengthening methods for masonry and concrete structural elements, where the codes do not provide requirements for testing and determination of structural capacity, reliability and serviceability of these products.

1.2 **Scope:** This criteria applies to passive fiber-reinforced cementitious matrix (FRCM) composite systems used to strengthen existing masonry and concrete structures. Properties evaluated include FRCM material properties; axial, flexural and shear capacities of the FRCM system; performance of the FRCM system under environmental exposures; performance under exposure to fire conditions; and structural design procedures.

1.3 **Referenced Codes and Standards:**

1.3.1 2012 and 2009 *International Building Code*® (IBC), International Code Council.

1.3.2 ACI 318-11 (2012 IBC), Building Code Requirements for Structural Concrete and Commentary, American Concrete Institute.

1.3.3 ACI 318-08 (2009 IBC), Building Code Requirements for Structural Concrete and Commentary, American Concrete Institute.

1.3.4 ASCE 41-06: Seismic Rehabilitation of Existing Buildings, American Society of Civil Engineers.

1.3.5 TMS 402-11/ACI 530-11/ASCE 5-11 (2012 IBC), Building Code Requirements for Masonry Structures, American Concrete Institute.

1.3.6 TMS 402-08/ACI 530-08/ASCE 5-08 (2009 IBC), Building Code Requirements for Masonry Structures, American Concrete Institute.

1.3.7 ASTM C 138-10b, Standard Test Method for Density (Unit Weight), Yield, and Air (Gravimetric) of Concrete, ASTM International.

1.3.8 ASTM C 157-08, Standard Test Method for Length Change of Hardened Hydraulic Mortar and Concrete.

1.3.9 ASTM C 387/C 387M-11, Standard Specification for Packaged, Dry, Combined Materials for Mortar and Concrete, ASTM International.

1.3.10 ASTM C 947-03 (2009), Standard Test Method for Flexural Properties of Thin-Section Glass-Fiber-Reinforced Concrete (Using Simple Beam with Third-Point Loading), ASTM International.

1.3.11 ASTM C 1583/C 1583M-04ε1, Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method), ASTM International.

1.3.12 ASTM D 1141-98 (2008), Standard Practice for Preparation of Substitute Ocean Water, ASTM International.

1.3.13 ASTM D 2247-11, Standard Practice for Testing Water Resistance of Coatings in 100% Relative Humidity, ASTM International.

1.3.14 ASTM D 2344/D 2344M-00 (2006), Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates, ASTM International.

1.3.15 ASTM D 3165-07, Standard Test Method for Strength Properties of Adhesives in Shear by Tension Loading of Single Lap-Joint Laminated Assemblies, ASTM International.

1.3.16 ASTM E 4-10, Standard Practices for Force Verification of Testing Machines, ASTM International.

1.3.17 ASTM E 83-10a, Standard Practice for Verification and Classification of Extensometers, ASTM International.

1.3.18 ASTM E 104-02 (2007), Standard Practice for Maintaining Constant Relative Humidity by Means of Aqueous Solutions, ASTM International.

1.4 **Definitions:**

1.4.1 **Design Values:** The FRCM composite system's load and deformation design capacities that are based on load and resistance factor design (strength design) method.

1.4.2 **FRCM Composite Material:** A fiber-reinforced cementitious matrix (FRCM) is a composite material consisting of a sequence of one or more layers of cement-based matrix reinforced with fibers in the form of open grid (mesh). When adhered to concrete or masonry structural members, they form an FRCM system. Components are:

1.4.2.1 **Structural Reinforcement Grid:** Open grid (mesh) of strands made of fibers [i.e., aramid, alkali resistant (AR) glass, carbon, and polyparaphenylene benzobisoxazole (PBO)], consisting of primary direction (PD) and secondary direction (SD) strands connected perpendicularly. The typical strand spacing of PD and SD strands is less than one inch (25.4 mm).

1.4.2.2 **Cement-based Matrix:** A polymer-modified cement-based binder (mortar) that holds in place the structural reinforcement grids in FRCM composite material.

1.4.3 **Cracking Load and Displacement:** Load and displacement at which the moment-curvature relationship of the masonry or concrete member first changes slope or at which the cracking moment as defined in ACI 318, Section 9.5.2.3, or TMS 402, Section 3.3.5.5, is reached, whichever occurs first.

1.4.4 **Yielding Load and** Displacement: Load and displacement at which longitudinal steel reinforcement of

2

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

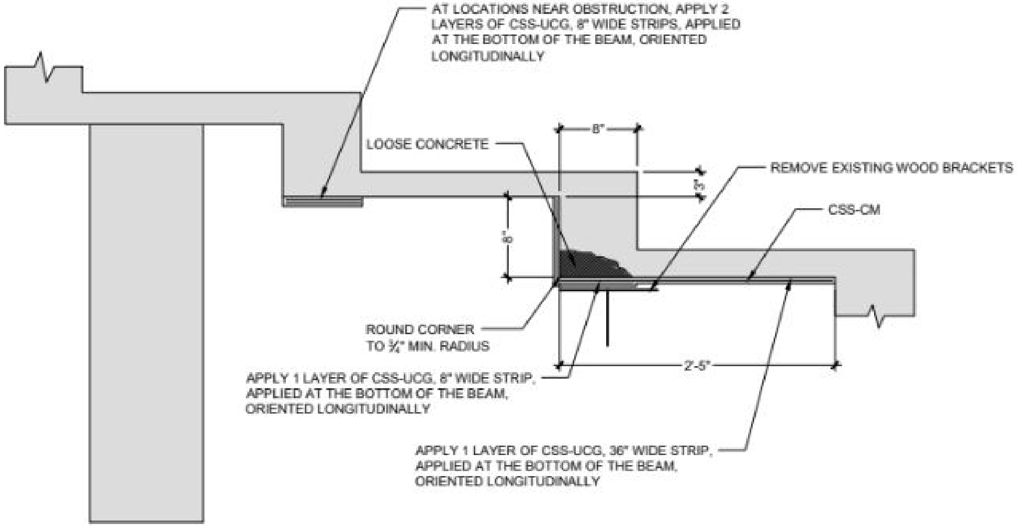
Specification

Specifying FRCM is very similar to specifying FRP

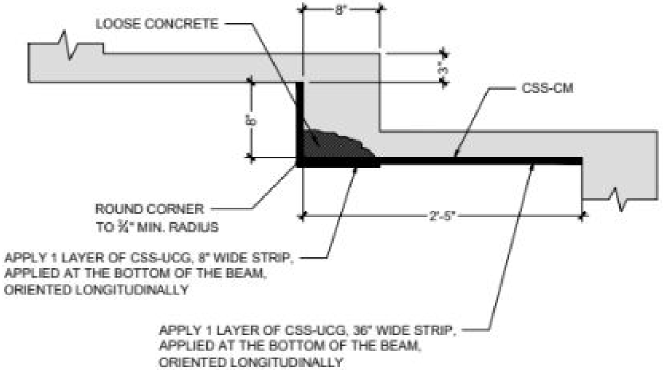
FRCM becomes another option to specify when:

- 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



SECTION A
(TYPE 1)



SECTION B
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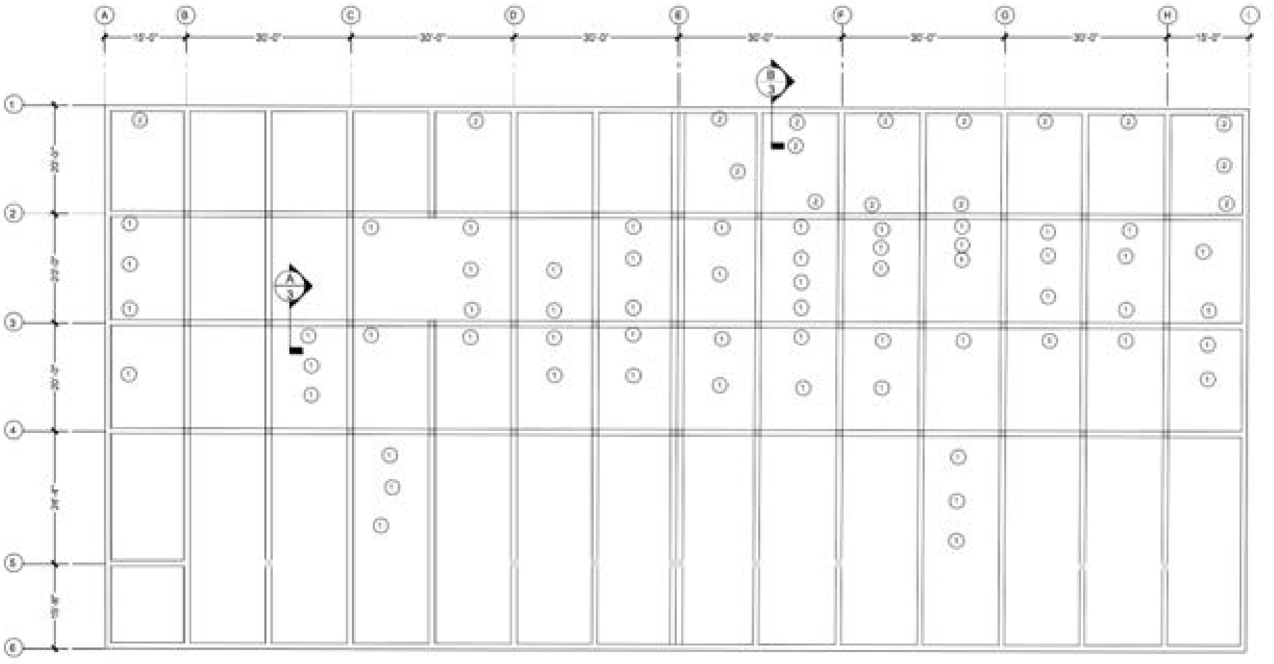

① RISER JOIST WITH WOOD BRACKET (58 LOCATIONS), SEE PAGE 3 FOR FROM DETAIL

② EXPOSED LONGITUDINAL BARS (16 LOCATIONS), SEE PAGE 3 FOR FROM DETAIL

NOTE:
AT REPAIR LOCATIONS ADJACENT TO WALL OR OTHER OBSTRUCTION,
SEE SECTION A TYPE 1 BEAM AT LEFT FOR FROM STRENGTHENING

PLAN VIEW


How Can Manufacturers Help?

Feasibility Studies	Work with EOR to determine if Composites are an option
Budget Estimates	Engage local trained contractors to provide ROM pricing
Specifications	Fine-tune to meet project-specific requirements
Drawing Details	Develop preliminary sketches & shop drawings
Calculations	Provide for EOR's reference during submittal review

Thank You

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