DESIGN MANUAL FOR FORTRESS CARBON GRID STRAP

FRP STRENGTHENING COMPOSITE SYSTEM FOR MASONRY STRUCTURES

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ICC-ES AC 125

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Document Approval Signature:

I indicate that I have reviewed this Design Manual and agree with the technical contents it presents, and find it meets all applicable requirements and policies. I approve for its release to the customer.

Name: Rick Doeden

Signature: 

Date: December 21, 2017

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1. INTRODUCTION

1.1. PURPOSE

The objective of this design manual is to satisfy the design requirements for the ESR (evaluation service report) No., 3815 in recognition of Acceptance Criteria AC 125 International Code Council Evaluation Service (ICC-ES) Acceptance Criteria for Concrete and Reinforced and Unreinforced Masonry Strengthening Using Externally Bonded Fiber-Reinforced Polymer Composite Systems (AC 125), Section 7.3; for the use of the Fortress Carbon Grid Strap FRP composite system for strengthening of masonry walls in flexural (out-of-plane) applications.

This document contains the experimental and design, material specifications, design equations, installation instructions, reference to design tools for the licensed professional, and a design example for reference purposes.

1.2. DESIGN MANUAL HOLDER INFORMATION

FORTRESS STABILIZATION SYSTEMS
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2. FORTRESS CARBON GRID STRAP

2.1. FRP COMPOSITE SYSTEM DESCRIPTION

The **Fortress Carbon Grid Strap** FRP is a high-strength grid composed of three or more customable uni-directional carbon fiber tows precured in tension with an epoxy matrix bonded together with a transverse fiber producing an open grid. It is supplied in varying widths from 0.5 in. (10mm) to 50 in. (1250mm). Fortress Carbon Grid Strap FRP has a storage life of 10 years.

The Fortress Carbon Grid Strap is applied over the substrate continuously in a single layer, and adhered to the substrate and environmentally protected with the **Fortress 4000** adhesive epoxy, a two-component ambient cured epoxy resin system. The Fortress 4000 adhesive is packaged in a double-cylinder epoxy cartridge with a static mixing tube available in 300ml x 150ml, 600ml x 300ml tube sets; as well as in 3-gallon (11 L) and 165-gallon (624 L) kits. Mixing ratio is 2:1 by volume (100:35 by weight) for components A and B, respectively. Fortress 4000 has storage life of two years.

2.2. FRP EXPERIMENTAL PROPERTIES

The following reported experimental properties of the Fortress Carbon Grid Strap FRP system are absolute values based on experimental test specimens. These values do not include safety factors; refer to Section 4 of this document for design properties. Safety factors must be applied to experimental values in accordance with design guides and licensed professional engineering value, as applicable.

Test Standard Reference Number	Average Property	Symbol	Experimental Value	
ASTM D3039 / D7565	Ultimate Tensile Strength	f_{uj}	1,960 MPa	284.2 ksi
	Tensile Modulus	E_f	118.2 GPa	17.16 Msi
	Ultimate Strain	ε_{fu}	0.0166 mm/mm	0.0166 in./in.
	Tensile strength per tow	P_u/tow	6.32 kN/tow	1,421 lbs/tow
ASTM D792	FRP laminate thickness	t_f	0.697 mm^2/mm	0.0274 in.^{2}/in.
	Average single tow area	A_{tow}	3.242 mm^2	0.0050 in.^{2}
ASTM E1640	Glass Transition Temperature (DMA)	T_g	60.9 °C	141.6 °F
ASTM E831	Coef. Of Thermal Expansion:			
	> Parallel to fiber	α_{00}	11.1 µm/m/°C	6.2 µin./in./·°F
	> Perpendicular to fiber	α_{90}	38.5 µm/m/°C	21.4 µin./in./·°F

3. INSTALLATION of FORTRESS CARBON GRID STRAP

3.1. INSTALLATION INSTRUCTIONS

Installation of the Fortress Carbon Grid Strap FRP composite system on masonry wall structures must follow the instructions as stated in the most recent version of document '**Installation sheet-6596-0200**'. Fortress Stabilization Systems also provides installation training and demonstrations. Note that no spacing between straps longer than 48 in. (4 ft.) is allowable.

3.2. SUBSTRATE PREPERATION

Where the performance of the FRP composite material depends on bond, such as flexural strengthening of masonry walls, the bond strength of the Fortress Carbon Grid Strap FRP system to a properly prepared surface must equal to or exceed the tensile strength of the masonry substrate. Testing in accordance with ASTM D7234 or ASTM D7522 may be used to estimate the bond strength of bond-critical installations. The test must indicate failure in the host substrate. Sufficient bond area must be used to prevent bond failure.

An improperly prepared surface can result in debonding or delamination of the FRP system before achieving the design load transfer. General guidelines presented here are applicable to the installation of the FRP system. Additionally refer to best practices as specified in the International Concrete Repair Institute (ICRI) guide No. 330.2-2016.

Substrate repair
Problems associated with the condition of the original substrate can compromise the integrity of the FRP system and must be addressed before surface preparation begins. The licensed professional should be consulted to verify the compatibility of materials used for repairing the substrate as necessary.

Surface preparation
Surface preparation requirements shall be specified as needed and might involve, sandblasting, roughening, grinding, or hydrojetting to abrade the surface, as well as grinding excess mortar in the joints in masonry. All paint and other coatings must be removed from the substrate surface. The **Fortress 4000** adhesive epoxy can be used to fill the mortar joints and provide continuity as well as reducing stress concentrations. Particular care should be taken to ensure that the surface is clean from dust and laitance, and to avoid unintentional damage to the substrate by using excessive force.

Installation Kit
All necessary tools are provided in the Fortress Carbon Grid Strap FRP composite system Kit for its installation, including:

- Fortress Carbon Grid Strap
- Mylar overlay
- Fortress 4000 Epoxy 150/300 Cartridge with mixer
- Trowels
- Gloves
- Installation sheet

3.3. ENVIRONMENTAL CONSIDERATIONS

Room temperature at the time of installation shall be 13 ºC to 38ºC (55 ºF to 100 ºF), while the surface temperature shall be 13ºC to 38ºC (55 ºF to 100 ºF). The Fortress Carbon Grid Strap FRP composite system can be applied over a moist surface condition (without the presence of water droplets) where the license engineer and/or manufacture can determine the appropriate level of moisture presence. Auxiliary heat sources can be used to raise the ambient and room and/or surface temperature during installation as well as reducing moisture as applicable. Heat sources should be clean and not contaminate the surface or the FRP system*. No additional conditions.*

3.4. PRODUCT IDENTIFICATION

All Fortress Carbon Grid Strap FRP composite system products are labeled in accordance with the approved quality control documentation including the manufactures name (Fortress Stabilization Systems) and address, product name, and evaluation report number. Prior to installation, verify that the Fortress Carbon Grid Strap FRP is legitimate.

4. WALL FLEXURE DESIGN with FORTRESS CARBON GRID STRAP

4.1. GENERAL DESIGN CONSIDERATIONS

The design for the strengthening in flexure or out-of-plane of masonry walls using the Fortress Carbon Grid Strap FRP composite system is based on strength design in accordance with Chapter 19 and 21 of the IBC and UBC. The owner and registered design professional are responsible for determining, through analysis, the strengths and demands of the structural elements to be strengthened by the Fortress Carbon Grid Strap FRP system, subject to the approval of the code official.

Structural design provisions for the Fortress Carbon Grid Strap FRP system are based on test results and principles of structural analysis as prescribed in IBC Section 1604.4, in addition to extensive research literature and design guides like ACI 440.2R. The basis of design includes strain compatibility, load equilibrium and limit states. All designs must follow procedures as detailed in the IBC and UBC, as applicable described in this section.

4.2. FRP DESIGN PROPERTIES

Test Standard Reference Number	Design Property	Symbol	Design Value	
ASTM D3039 / D7565	Guaranteed Tensile Strength[1]	f_{ffu}	1,618 MPa	234.7 ksi
	Tensile Modulus	E_f	112.3 GPa	16.30 Msi
	Guaranteed Ultimate Strain[1]	ε_{ffu}	0.0129 mm/mm	0.0129 in./in.
	Guaranteed Tensile strength per tow	P_{ffu}/tow	5.22 kN/tow	1,172 lbs/tow
ASTM D792	Nominal FRP thickness	t_f	0.697 mm^2/mm	0.0274 in.^{2}/in.
	Nominal single tow area	A_{tow}	3.23 mm^2	0.005 in.^{2}
AC125	Environmental-reduction factor[2]	C_E	0.95 – Interior exposure 0.85 – Exterior/Aggressive exposure	
	Creep-Rupture and Fatigue stress limits		0.55 f_{uj}	

[1]Experimental value minus three times the standard deviation.
[2]Exterior/Aggressive exposure includes (bridges, piers, and unenclosed parking garages) and aggressive environment (chemical plants and wastewater treatment plants).

4.3. DESIGN NOMENCLATURE

Symbol	Description
A_f	Area of FRP reinforcement per unit length, mm^2/m (in.^{2}/in.)
A_n	Section area of masonry block, cm2/m (in.2/ft)
C_E	Environmental-reduction factor
E_f	FRP tensile modulus of elasticity, MPa (ksi)
E_m	Elastic modulus of masonry block, MPa (ksi)
f_{fe}	Effective FRP tensile stress, MPa (psi)
f_{ffu}	Guaranteed FRP tensile strength, MPa (psi)
f_{fu}	Design tensile strength, MPa (psi)
f_{uj}	Ultimate tensile strength, MPa (psi)
f'_m	Nominal compressive strength of masonry block, MPa (psi)
f_r	Nominal tensile strength of masonry block, MPa (psi)
h_{eff}	Height to resultant of lateral forces, mm (in.)
H_w	Height of the wall, mm (in.)
l_{df}	Development length of FRP system, mm (in.)
L_w	Length of the wall, mm (in.)
M_{cr}	Cracking moment, kN-m/m (lbf-ft/ft)
M_n	Nominal flexural strength, kN-m/m (lbf-ft/ft)
n	Number of FRP plies (always =1 for Fortress Carbon Grid Strap)
p_{ffu}	Guaranteed FRP load per unit width, kN/mm (lb/in.)
p_{fm}	Force per unit width (lb/in.)
Q_u	Applied factored axial load, kN (kip)
S_f	Spacing of FRP strip, mm (in.)
S_o	Static moment of area, cm3/m (in.3/ft)
t_f	FRP nominal laminate/grid thickness, mm (in.)
t_{shell}	Thickness of the masonry block shells,mm (in.)
t_w	Thickness of the wall / masonry block, mm (in.)
V_n	Out-of-plane shear strength, kN (kip)
V_u	Factored shear force, kN (kip)
W_f	Width of FRP strip, mm (in.)
β_1	Ratio of depth of equivalent rectangular stress block to depth of the neutral axis
ϕ	Strength reduction factor
κ_m	Bond-reduction factor
ε_{fe}	Effective FRP tensile strain, mm/mm (in./in.)
ε_{ffu}	Guaranteed FRP ultimate tensile strain, mm/mm (in./in.)
ε_{fu}	Ultimate tensile strain, mm/mm (in./in.)
ε_{mu}	Compressive ultimate strain of masonry block, mm/mm (in./in.)
ε_c	Compression strain in unit base material of the masonry, mm/mm (in./in.)

4.4. DESIGN EQUATIONS

Equation	Reference
$\varepsilon_{fe} = 0.45\,\varepsilon_{fu}$	AC125 (3a)
$f_{fe} = E_f\,\varepsilon_{fe}$	AC125 (3b)
$p_{fm} = n\,t_f\,f_{fe} \leq 1500$ lb/in.	AC125 (4)
$f_{fu} = C_E\,f_{ffu}$	ACI 440.2R (9-3)
$\varepsilon_{fu} = C_E\,\varepsilon_{ffu}$	ACI 440.2R (9-4)
$\phi M_n \geq M_u$	ACI 440.2R (10-1)
$M_{cr} = f_r S$	ACI 530 Section (3.1.8.2)
$\gamma f_m^{'} \beta_1 C_u = n_f A_f f_{fe}$	Masonry structure Section (5.5.1)
$M_n = A_f f_{fe}(t - \frac{\beta_1 C_u}{2})$	Masonry structure Section (5.5.1)
$M_n = \gamma f_m^{'} \beta_1 C_u (t - \frac{\beta_1 C_u}{2})$	Masonry structure Section (5.5.1)
$\phi_v V_n = \phi_v \times Min\{3.8A_n\sqrt{f_m^{'}};300A_n;56A_n + 0.45N_u\} + 0.5(\frac{A_v}{S})f_y d$	ACI 530 Sec.3.2.4 (a,b,c)

4.5. DESIGN EXAMPLE

Refer to Appendix A, which contains a general design example for the flexural strengthening of unreinforced masonry wall subject to out-of-plane loads with FRP. This design example provides a reference for the registered design professional, whom is responsible for determining, through analysis, the strengths and demands of the structural elements to be strengthened by the Fortress Carbon Grid Strap FRP system, subject to the approval of the code official.

5. DESIGN TOOL

5.1. FORTRESS CARBON GRID STRAP WALL SPACING TABLES

These tables provide the recommended center-to-center spacing of Fortress Carbon grid strap FRP composite system bonded to ungrouted, 8-inch nominal hollow or solid masonry and 8-inch concrete basement walls. The following applies to the tables:

a) Spacing dimensions are Strap center-to-center.
b) Walls shall be adequately restrained from out-of-plane movement at both the top and bottom of the wall.
c) For basement applications, the exterior grade shall be flat or sloping down and away from the wall a distance equal or greater to the Unbalanced Fill Height.
d) Variations between Unbalanced Fill Heights and Equivalent Fluid Pressures shown may be interpolated linearly.
e) Walls constructed with concrete masonry units (CMU) shall have a minimum compressive strength of 1,250 psi with Type N mortar or better in good condition.
f) Cast-in-place concrete walls shall have a minimum compressive strength of 2,500 psi.
g) Masonry shall be laid in running bond.
h) Refer to the latest Fortress Installation Guide for other restrictions and use

6. SPECIAL INSPECTION REQUIRIMENTS

6.1. INSPECTION BACKGROUND

FRP composite systems and all associated work should be inspected as required by the applicable local codes. In the absence of such requirements, inspection should be conducted by or under the supervision of a licensed professional or qualified inspector. Inspectors should be knowledgeable of and trained in the installation of FRP systems. The qualified inspector should require compliance with design drawings and project specifications. During installation of the FRP system, the scope of the inspection should include, but is not limited to:

a) Date and time of installation
b) Ambient temperature, relative humidity, and general weather observations
c) Surface temperature of substrate
d) Surface preparation methods and resulting profile
e) Qualitative description of surface cleanliness
f) Type of auxiliary heat source, if applicable
g) Reinforcement batch number(s) and approximate location in structure
h) Batch numbers, mixture ratios, mixing times, and qualitative descriptions of the appearance of all mixed matrix and additional materials such as primers, putties, and coatings mixed for the day
i) Conformance with installation procedures
j) Substrate tensile pull-off test results completed or supervised by an licensed professional or owner's independent testing agency, if required
k) FRP properties from tests of field sample panels or witness panels, if required
l) Location and size of any defects
m) General progress of work

The inspector should provide the licence professional or owner's representative with inspection records and witness panels when required. The installation contractor should retain sample mortar cubes or cylinders and maintain a record of the placement of each batch as applicable.

6.2. INSPECTION REQUIRIMENTS AND ACCEPTANCE

Special inspection must comply with the applicable requirements in Sections 1704 through 1709 of the IBC or Section 1701 of the UBC. Special inspection during the installation of the FRP system must be in accordance with the ICC-ES Acceptance Criteria for Inspection and Verification of Concrete and Unreinforced Masonry Strengthening Using Fiber-reinforced Polymer (FRP) Composite Systems (AC178).

7. REFERENCES

AC434, February 2013, “Acceptance Criteria for Masonry and Concrete Strengthening Using Fiber-Reinforced Cementitious Matrix (FRCM) Composite Systems” ICC-ES. (2013)

ACI 440.2R, Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures. American Concrete Institute (2010)

ACI 440.7R, Guide for Design & Construction of Externally Bonded FRP Systems for Strengthening Unreinforced Masonry Structures. American Concrete Institute (2017)

ACI 530, Building Code Requirements and specification for Masonry Structures, TMS 402-11/ACI 530-11/ASCE 5-11), Reported by the Masonry Standards Joint Committee (2011).

ASTM D3039, Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials (2014)

ASTM D7234, Standard Test Method for Pull-Off Adhesion Strength of Coatings on Concrete Using Portable Pull-Off Adhesion Testers. ASTM International (2012)

ASTM D7522, Standard Test Method for Pull-Off Strength for FRP Laminate Systems Bonded to Concrete Substrate. ASTM International (2015)

ASTM D7565, Standard Test Method for Determining Tensile Properties of Fiber Reinforced Polymer Matrix Composites Used for Strengthening of Civil Structures (2017)

ASTM D792, Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement (2013)

IBC, International building code International Code. International Code Council (2015, 2012, 2009 and 2006)

ICC-ES AC125, Acceptance Criteria for Concrete and Reinforced and Unreinforced Masonry Strengthening Using Externally Bonded Fiber-Reinforced Polymer Composite Systems. International Code Council Evaluation Service (ICC-ES) (2015)

ICRC, Guide specifications for externally bonded FRP fabric systems for strengthening concrete structures, No., 330.2-2016 International Concrete Repair Institute (2016)

IRC, International Residential Code, International Code Council (2015, 2012, 2009 and 2006)

Li, T., Galati, N., Tumialan, J., Nanni, A. Analysis of Unreinforced Masonry Concrete Walls Strengthen

Tan, Kiang Hwee, and M. K. H. Patoary. "Strengthening of masonry walls against out-of-plane loads using fiber-reinforced polymer reinforcement." Journal of Composites for Construction 8.1 (2004)

Triantafillou, Thanasis C. Strengthening of masonry structures using epoxy-bonded FRP laminates. Journal of composites for construction 2.2 (1998)

Tumialan G., J.J. Myers, and A. Nanni. Field Evaluation of Unreinforced Masonry Walls Strengthened with FRP Composites Subjected to Out of Plane Loading. ASCE Structures Congress (2000)

UBC, Uniform Building Code, Internarial Conference of Building Officials (1997)

APPENDIX A

Design example for the flexural strengthening of unreinforced masonry wall subject to out-of-plane loads with FRP:

- **Geometrical properties**

Height of the wall $H_w := 18 \cdot ft$

Thickness of the wall $t_w := 11.63 \cdot in$

Length of the wall $L_w := 17.67 \cdot ft$

Thickness of the block shells $t_{shell} := 1 \cdot in$

If clay bricks or fully grouted concrete blocks are used, then use 0.5 tw.

Height to resultant of lateral forces $h_{eff} := 16 \cdot ft$

Section area $A_n := 36 \cdot \frac{in^2}{ft}$

Static moment of area $S_o := 160 \cdot \frac{in^3}{ft}$

- **Mechanical properties of masonry**

Nominal compressive strength $f'_m := 1500 \cdot psi$

Compressive ultimate strain $\varepsilon_{mu} := 0.0025$

Masonry elastic modulus $E_m := 550 \cdot f'_m$

Nominal tensile strength $f_r := 20 \cdot psi$

- **Flexural strength without FRP**

Existing nominal flexural strength $M_n := 270 \cdot \frac{lbf \cdot ft}{ft}$

Phi-factor $\phi_m := 0.6$

Existing design flexural strength $\phi M_n := 160 \cdot \frac{lbf \cdot ft}{ft}$

- **Anticipated conditions**

New distributed factored lateral load $p_{uNew} := 20 \cdot psf$

Applied factored axial load $Q_u := 576 \cdot \frac{lbf}{ft}$

New maximum ultimate bending moment $M_{uNew} := 620 \cdot \frac{lbf \cdot ft}{ft}$

Thickness $t_f := 0.014 \cdot in$

Tensile modulus of elasticity $E_f := 10500 \cdot ksi$

Ultimate tensile strength $f_{ffu} := 220 \cdot ksi$

Ultimate tensile strain $\varepsilon_{ffu} := 0.021$

Environmental-reduction factor $C_E := 0.65$

Bond-reduction factor $\kappa_m := 0.45$

Strength-reduction factor $\phi_{mf} := 0.6$

Number of FRP plies $n_f := 1$

Width of FRP strip $w_f := 4 \cdot in$

Spacing of FRP strip $s_f := 36 \cdot in$

$$Check\_Spacing := \begin{cases} \text{"OK"} & \text{if } s_f < 3 \cdot t_w + w_f \\ \text{"Not Good"} & \text{else} \end{cases}$$

$Check\_Spacing = \text{"OK"}$

Area of FRP reinforcement per unit length $$A_f := n_f \cdot t_f \cdot \frac{w_f}{s_f} = ?\ \frac{in^2}{ft}$$

- **Step 1 - Calculate the FRP design tensile strain and strength**

Design tensile strain $$\varepsilon_{fu} := C_E \cdot \varepsilon_{ffu} = 0.01365$$

Design tensile strength $$f_{fu} := C_E \cdot f_{ffu} = ?\ ksi$$

- **Step 2 - Calculate the new design flexural strength**

Assume failure mode $$FailureMode := \text{"FRP debonding"}$$

Select FailureMode equal to "FRP debonding" or "Masonry crushing"

The effective tensile strain and stress in the FRCM reinforcement for flexure-controlledfailure can be calculated.

Effective FRP tensile strain $$\varepsilon_{fe} := min\left(\kappa_m \cdot \varepsilon_{ffu}, \varepsilon_{fu}\right) = 0.00945$$

Effective FRP tensile stress $$f_{fe} := min\left(\kappa_m \cdot f_{ffu}, f_{fu}\right) = ?\ ksi$$

The following stress block factors can be assumed:

$$\gamma := \begin{cases} \text{if } FailureMode = \text{"FRP debonding"} \\ \quad 0.7 \\ \text{if } FailureMode = \text{"Masonry crushing"} \\ \quad 0.8 \end{cases}$$

$$\beta_1 := \begin{cases} \text{if } FailureMode = \text{"FRP debonding"} \\ \quad 0.7 \\ \text{if } FailureMode = \text{"Masonry crushing"} \\ \quad 0.8 \end{cases}$$

Compatibility:

$$\varepsilon_f(x) := \begin{cases} \text{if } FailureMode = \text{"FRP debonding"} \\ \quad \varepsilon_{fe} \\ \text{if } FailureMode = \text{"Masonry crushing"} \\ \quad \left(\left(\frac{t_w - x}{}\right) \cdot \varepsilon_{mu}\right) \end{cases}$$

Equation of equilibrium:

$$f(x) := Q_u + A_f \cdot E_f \cdot \varepsilon_f(x) - \gamma \cdot f'_m \cdot \beta_1 \cdot x$$

$$c_u := \textbf{root}\left(f(x), x, 0, t_w\right)$$

The neutral axis depth is:

$$c_u = ?\ in$$

The new nominal flexural strength is:

$$M_{nNew} := \gamma \cdot f'_m \cdot \beta_1 \cdot c_u \cdot \left(\frac{t_w}{2} - \beta_1 \cdot \frac{c_u}{2}\right) + A_f \cdot f_{fe} \cdot \frac{t_w}{2} = ?\ \frac{lbf \cdot ft}{ft}$$

The new design flexural strength is:

$$\phi M_{nNew} := \phi_{mf} \cdot M_{nNew} = ?\ \frac{lbf \cdot ft}{ft}$$

[ ]

$$M_{uNew} = ?\ \frac{lbf \cdot ft}{ft}$$]

Check flexural strength

$$CheckFlexuralStrength := \begin{array}{l} \text{if } \phi M_{nNew} \geq M_{uNew} \\ \quad \text{“OK”} \\ \text{else} \\ \quad \text{“Not Good!”} \end{array}$$

$$CheckFlexuralStrength = \text{“OK”}$$

- **Step 3 - Verify failure mode**

$$Verify\_FailureMode := \begin{array}{l} \text{if } \varepsilon_{fe} \cdot \left(\frac{c_u}{t_w - c_u}\right) \leq \varepsilon_{mu} \land FailureMode = \text{“FRP debonding”} \\ \quad \text{“OK”} \\ \text{also if } \left(\frac{t_w - c_u}{c_u}\right) \cdot \varepsilon_{mu} \leq \varepsilon_{fe} \land FailureMode = \text{“Masonry crushing”} \\ \quad \text{“OK”} \\ \text{else} \\ \quad \text{“Not good”} \end{array}$$

$$Verify\_FailureMode = \text{“OK”}$$

- **Step 4 - Cracking moment not exceeding design flexural strength**

$$M_{cr} := \left(f_r + \frac{Q_u}{...}\right) \cdot S_n = ?\ \frac{ft \cdot lbf}{...}$$

$$M_{cr} := \left(f_r + \frac{P_u}{A_n}\right) \cdot S_o = ?\ \frac{lbf \cdot ft}{ft}$$

$$Check\_Mcr := \begin{array}{l} \text{if } \phi_{mf} \cdot M_{nNew} \geq M_{cr} \\ \quad \text{“OK”} \\ \text{else} \\ \quad \text{“Not Good”} \end{array}$$

$Check\_Mcr = \text{“OK”}$

- **Step 5 - Maximum force in the FRP reinforcement**

Maximum force in the FRP reinforcement $A_f \cdot \varepsilon_{fe} \cdot E_f = ?\ \frac{lbf}{in}$

$$Check\_MaximumForce := \begin{array}{l} \text{if } A_f \cdot \varepsilon_{fe} \cdot E_f < 1500 \cdot \frac{lbf}{in} \\ \quad \text{“OK”} \\ \text{else} \\ \quad \text{“Not Good”} \end{array}$$

$Check\_MaximumForce = \text{“OK”}$

- **Step 6 - Out-of-plane shear strength**

The out-of-plane design shear strength is calculated according to ACI 530.

Shear strength reduction factor $\phi_v := 0.8$

$$V_n := min\left(\frac{\left(3.8 \cdot A_n \cdot \frac{ft}{in^2} \cdot \sqrt{f'_m}\right)}{\sqrt{psi}}, \frac{(300 \cdot A_n)}{\frac{in^2}{ft}}, \frac{\left(56 \cdot \frac{lbf}{ft^2} \cdot A_n\right)}{\frac{lbf}{ft}} + \frac{(0.45 \cdot Q_u)}{\frac{lbf}{ft}}\right) \cdot \frac{lbf}{ft}$$

$$\phi_v \cdot V_n = ?\ \frac{lbf}{ft}$$

The factored shear force acting on the wall can be computed as follows:

$$V_u := p_{uNew} \cdot \frac{H_w}{2} = ?\ \frac{lbf}{ft}$$

$$Check\_ShearStrength := \begin{array}{l} \text{if } \phi_v \cdot V_n > V_u \\ \quad \text{“OK”} \\ \text{else} \\ \quad \text{“Not Good”} \end{array}$$

$Check\_ShearStrength = \text{“OK”}$

$Check\_ShearStrength = \text{"OK"}$

- **Step 7 - Development length**

$$l_{df} := \begin{cases} \text{if } f'_m \le 20 \cdot MPa \\ \quad \sqrt{\dfrac{E_f \cdot n_f \cdot t_f \cdot in}{2 \cdot f'_m}} \\ \text{else} \\ \quad \left(0.057 \cdot \sqrt{\dfrac{n_f \cdot E_f \cdot t_f \cdot in}{\sqrt{f'_m \cdot psi}}}\right) \end{cases} = ?\ in$$

- **Step 8 - Serviceability**

The serviceability check is required for URM walls resisting sustained lateral loads.

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