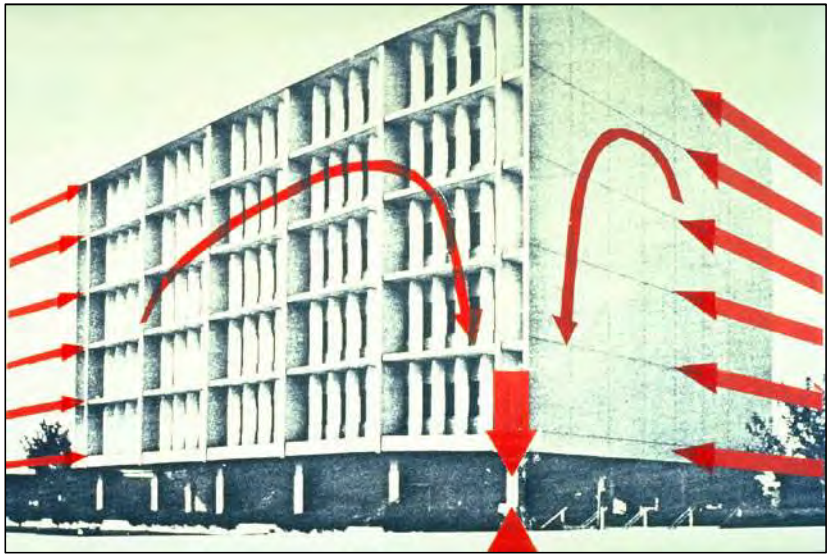

(Photo by C. Rojahn)

~ 200 lbs FRP / column

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CSS Team – Pacific Northwest

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We design FRP to help structural engineers provide a viable solution to their client

- FRP Applications
- Seismic FRP case studies
- Testing
  - Shear walls with anchors
  - Shear transfer joint
  - 3-sided column wrap
  - Shear transfer bracket (STB)
- FRCM with case study
- FRP Installation Videos

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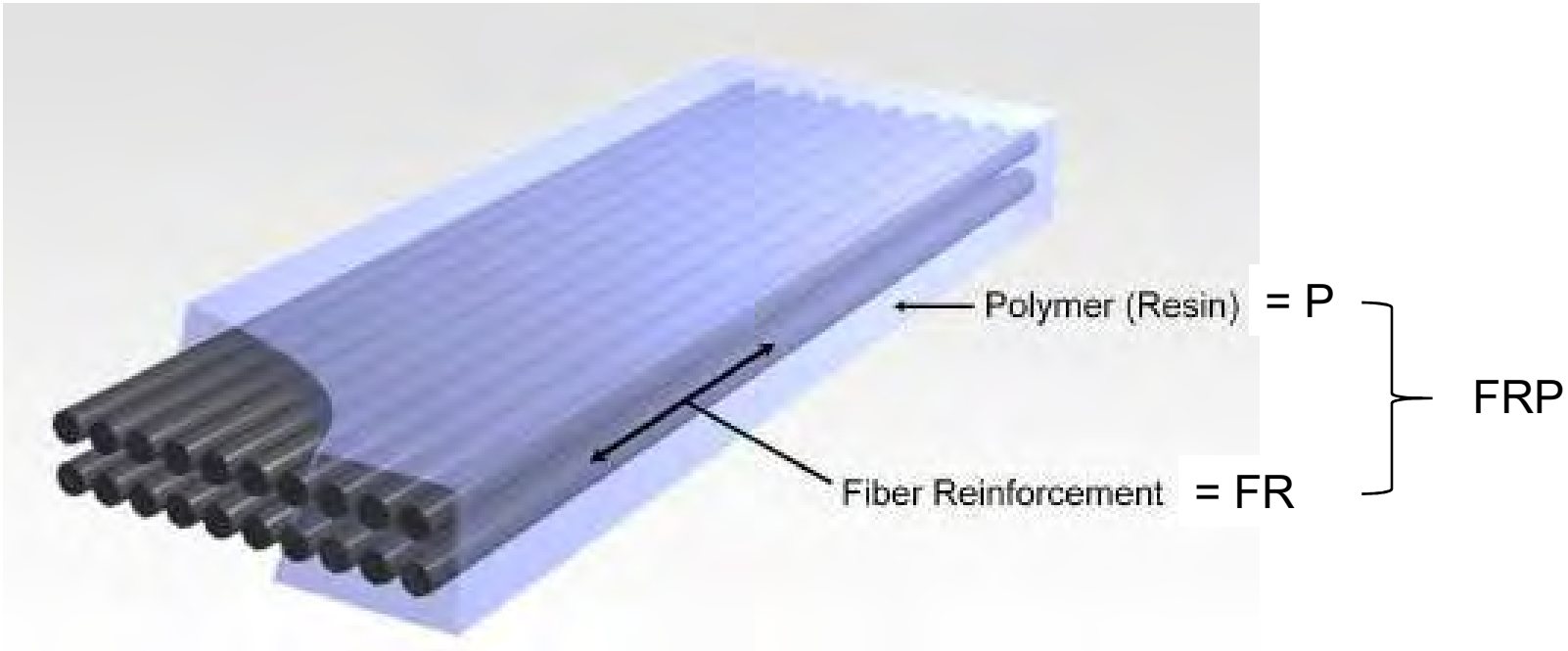
Fiber reinforced polymers are a system for reinforcing a concrete or masonry substrate



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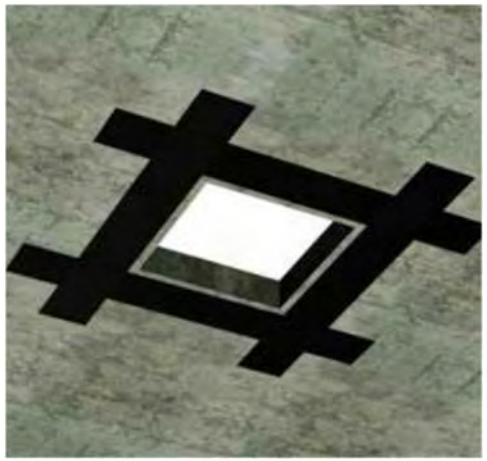
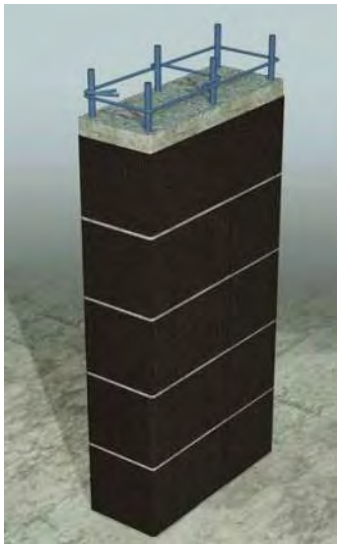
Some common applications

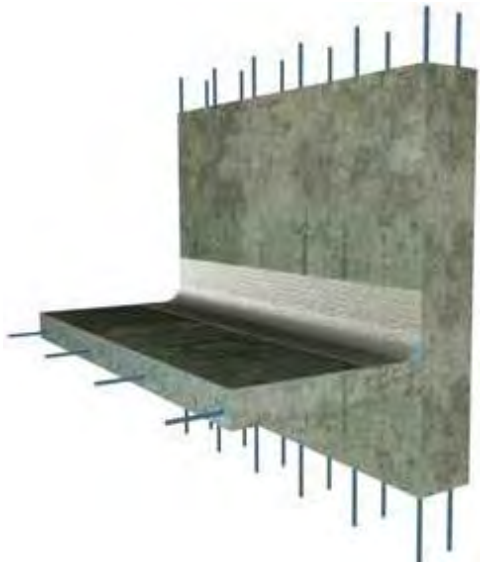


New Slab Openings



Column Confinement

Wall Reinforcement
(in/out-of-plane)



Slab/Wall Shear Transfer

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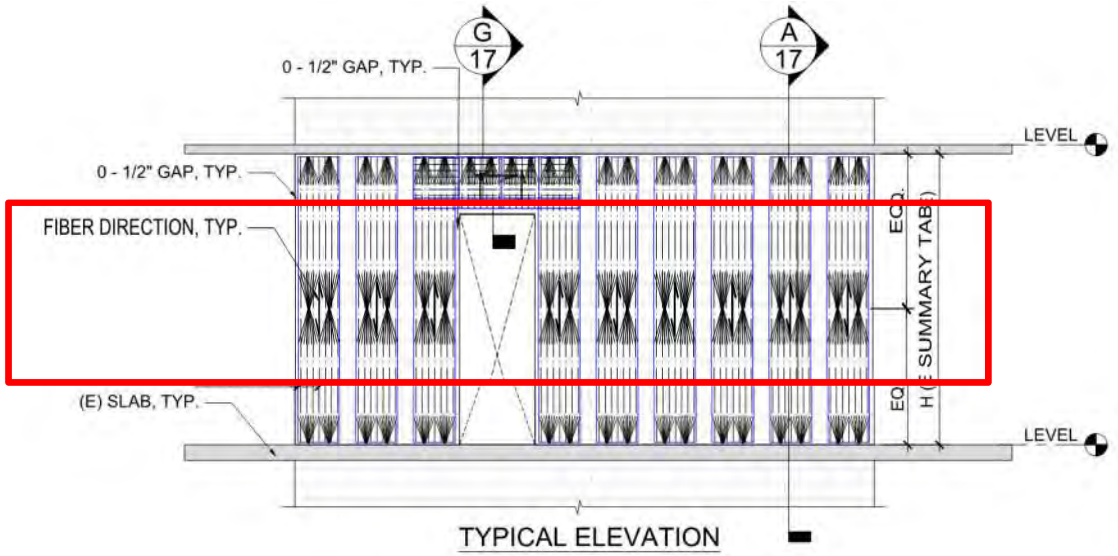
CS1: Repair and strengthening of 1950's era construction

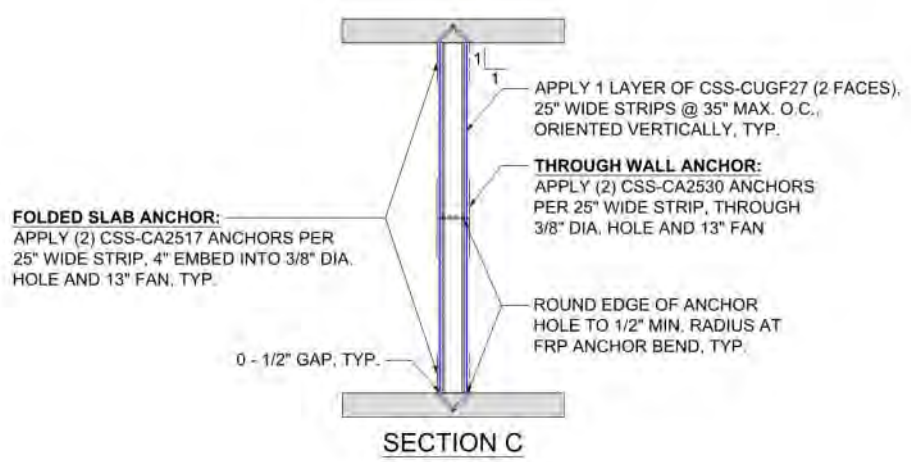
FRP for Repair - OOP bracing

- Masonry partition wall heights vary up 12’
- Many of the masonry partitions have man doors in them
- Existing lead based paint



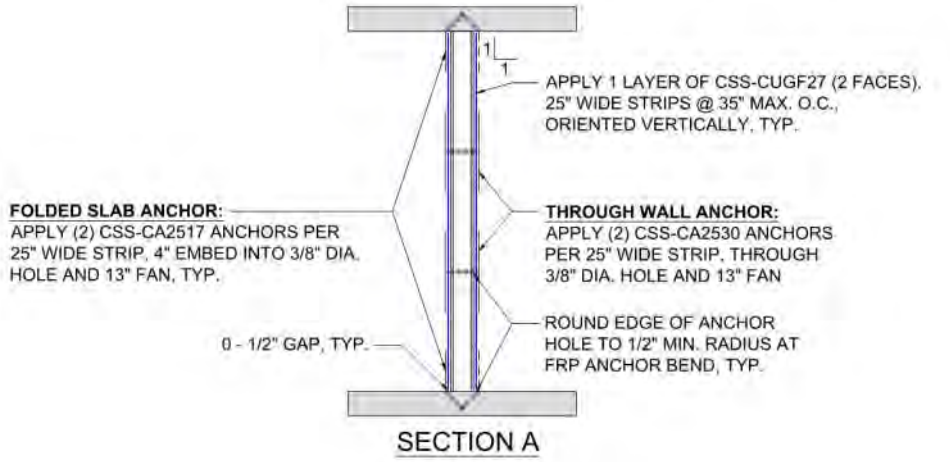
Anchor options for bond strength

CMU WALL OOP FLEXURAL STRENGTHENING - PULL OFF TEST RESULTS >= 200PSI



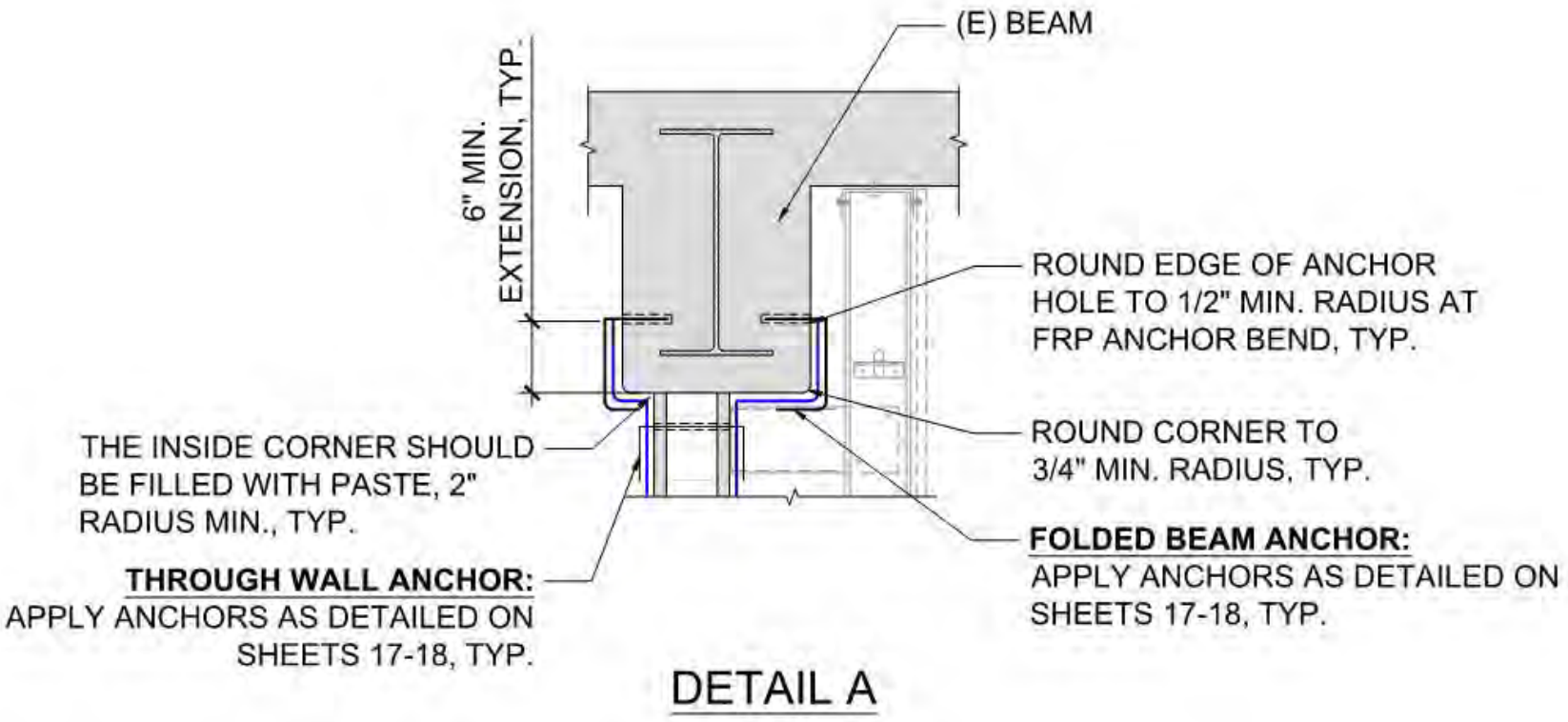
SECTION C

CMU WALL OOP FLEXURAL STRENGTHENING - PULL OFF TEST RESULTS < 200PSI



SECTION A

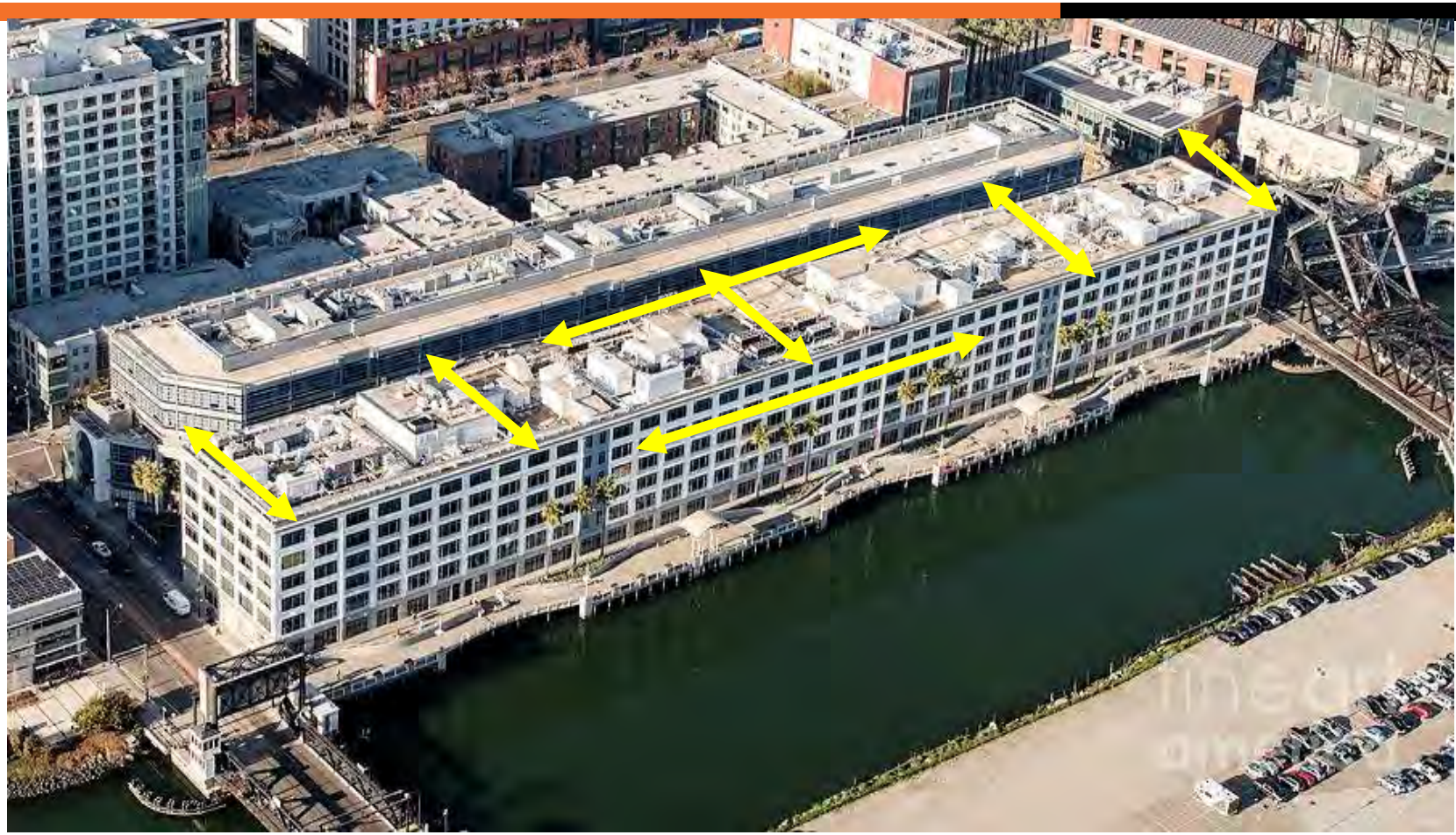
How to anchor at concrete encased steel beams



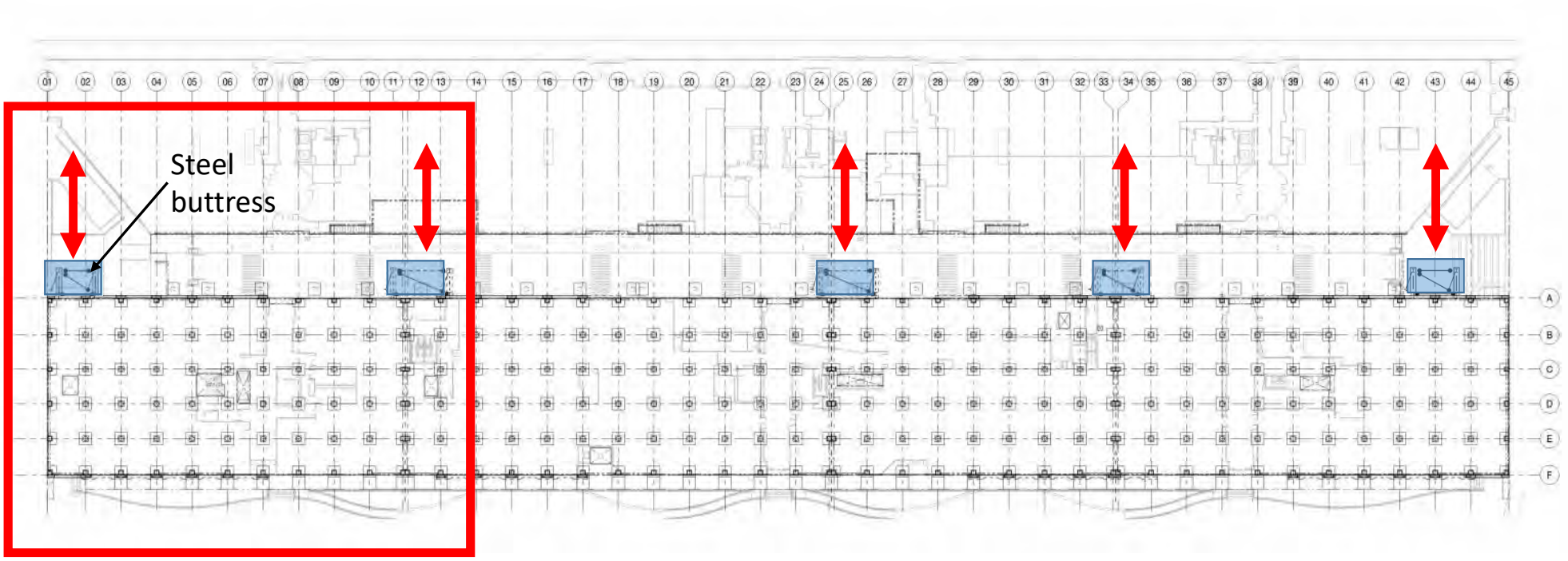
DETAIL A

Detailing installed

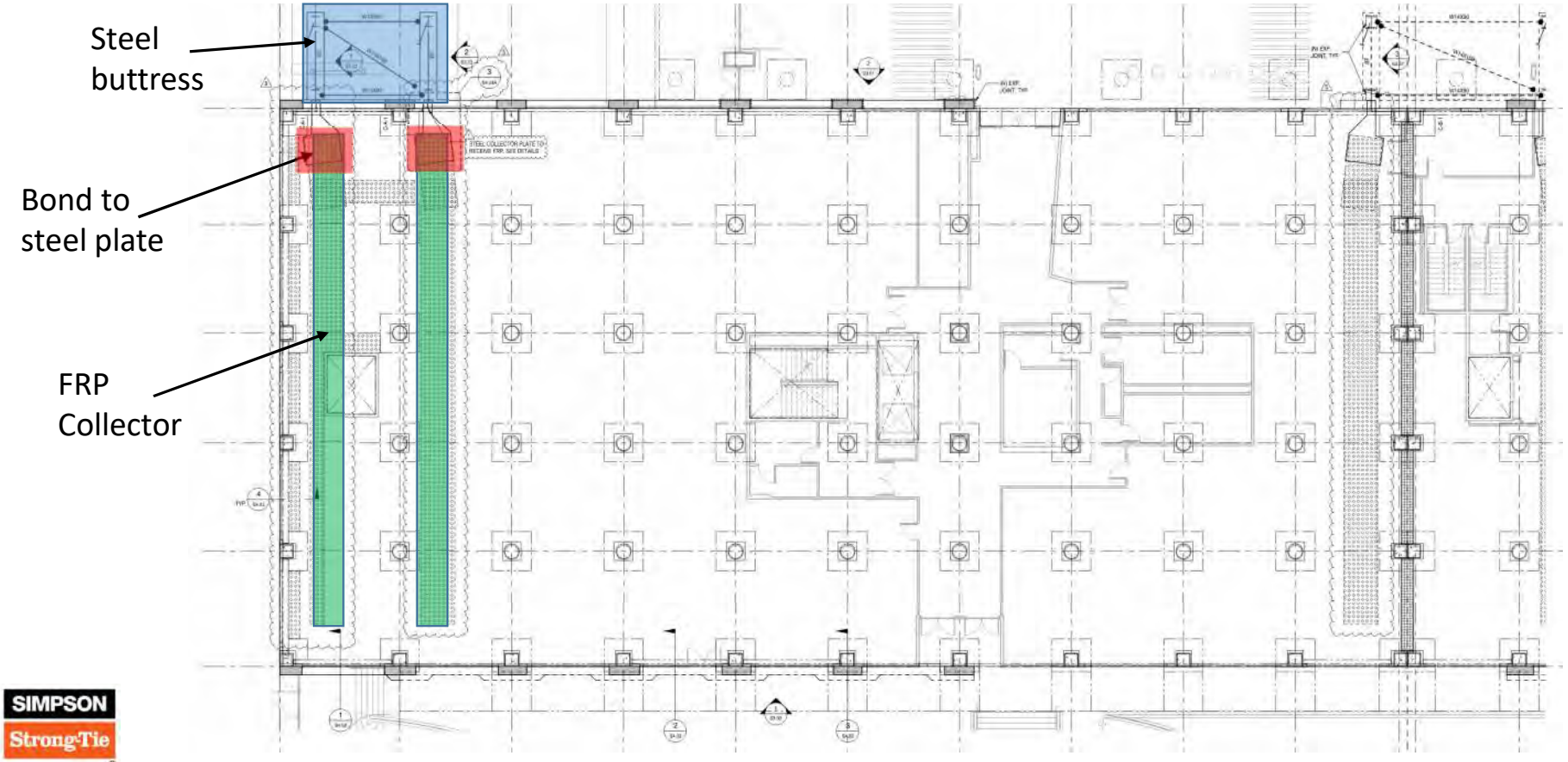
CS2: Owner would like to upgrade building's lateral system



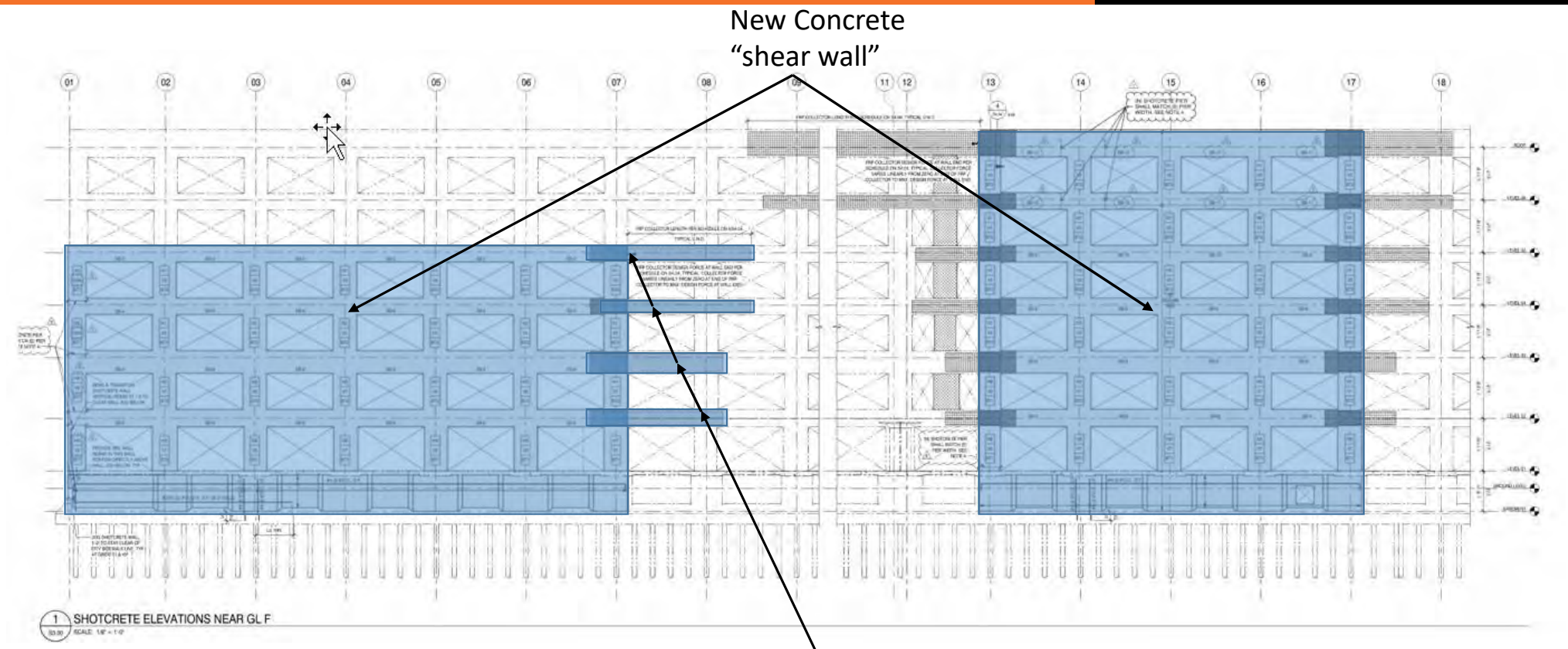
Steel buttresses make up lateral system in the short-direction



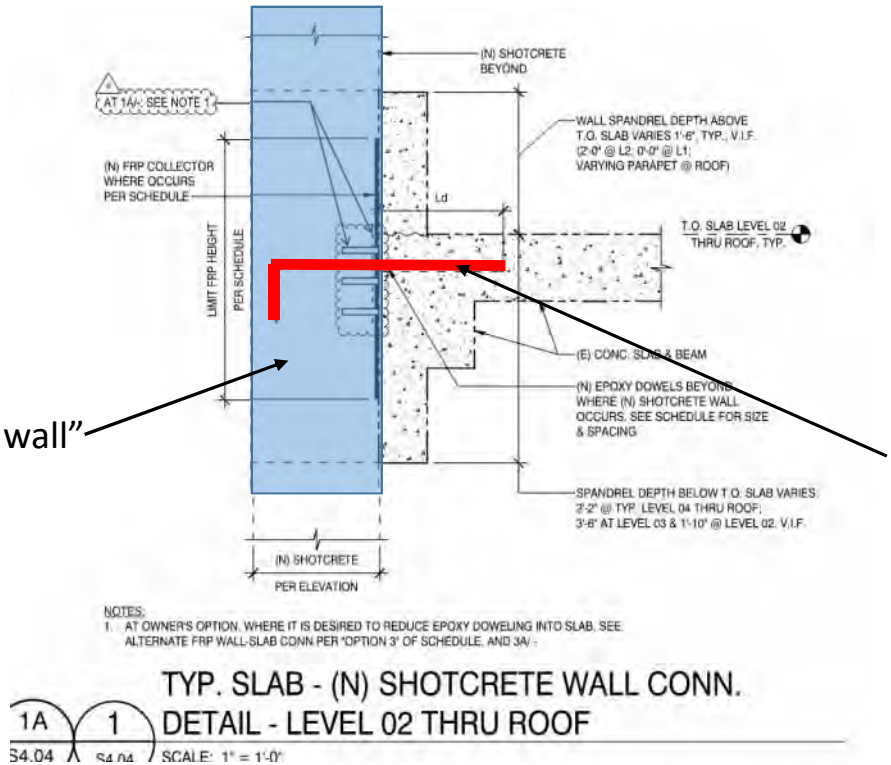
FRP epoxy-resin bonds to steel



New “shear walls” make up lateral system in long-direction



Original design called for the development of #5 rebar

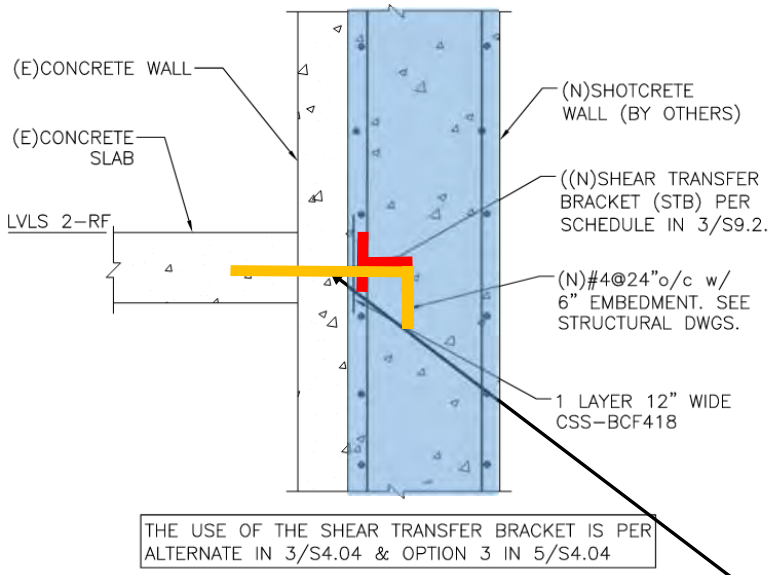


New “shear wall”

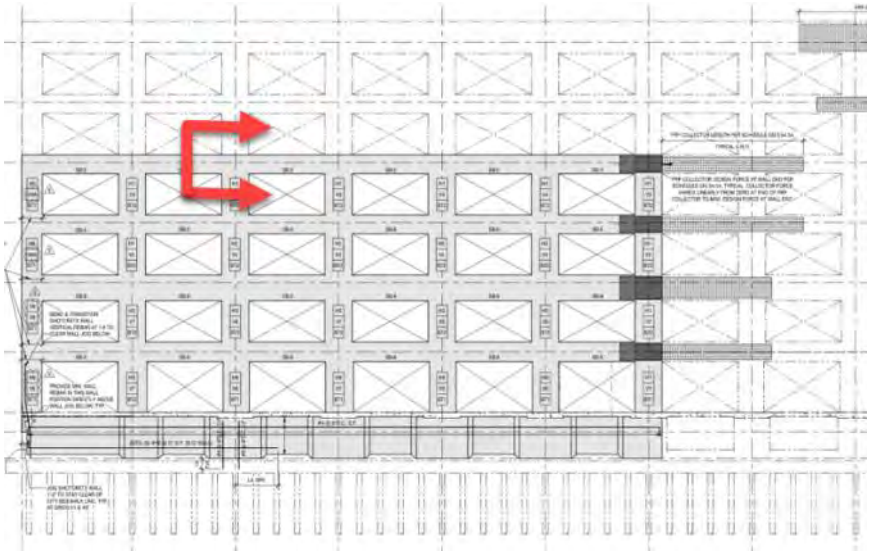
About 5,000 rebar dowels, 16” deep (to handle in-plane shear)

Shear Transfer Bracket (STB) dev. to eliminate dowels

STB transfers in-plane shear between existing slab and new wall



Eliminated 85% of the drilling

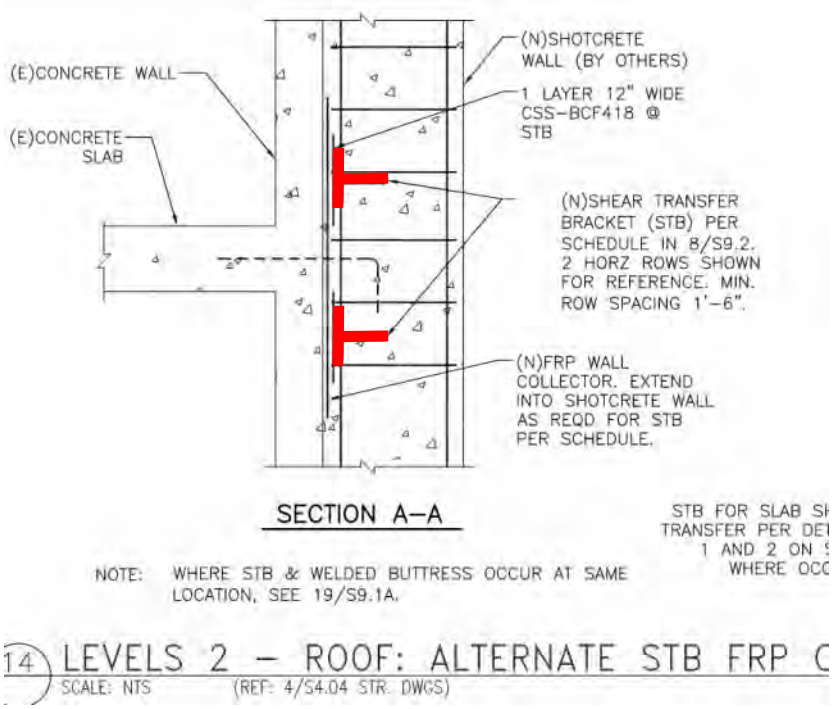


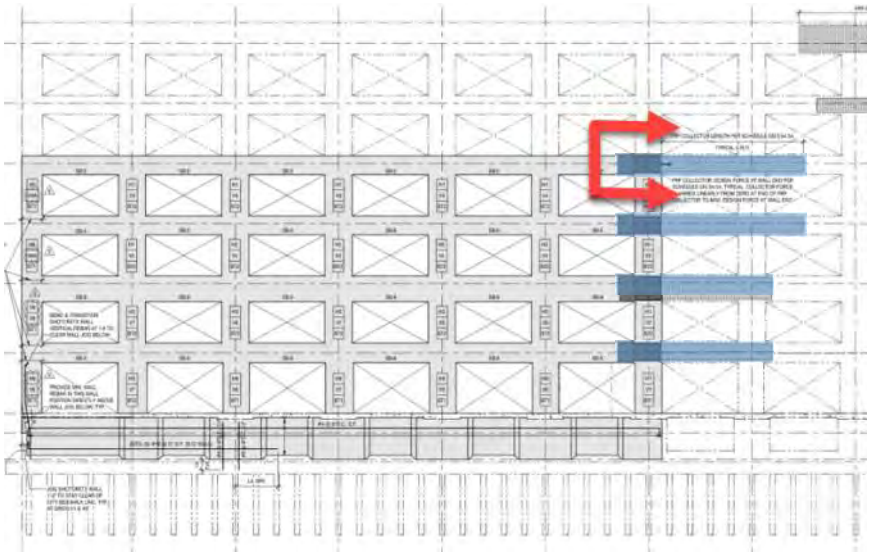
Still need 2,500 rebar dowels, 6" deep

~~5,000 rebar dowels @ 16" embed~~

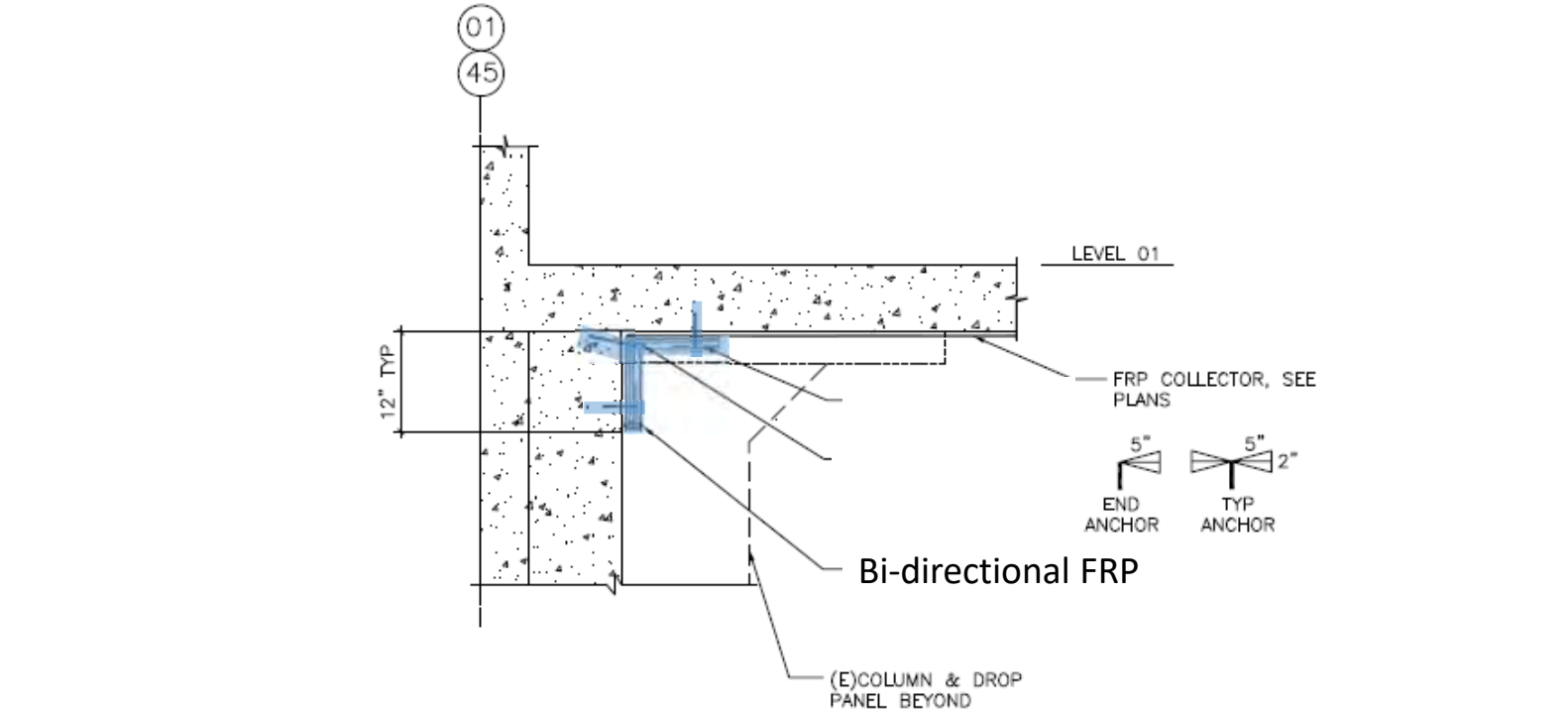
Apply thickened epoxy to STB and secure using Titen Turbo

STB transfers force from FRP collector to new wall



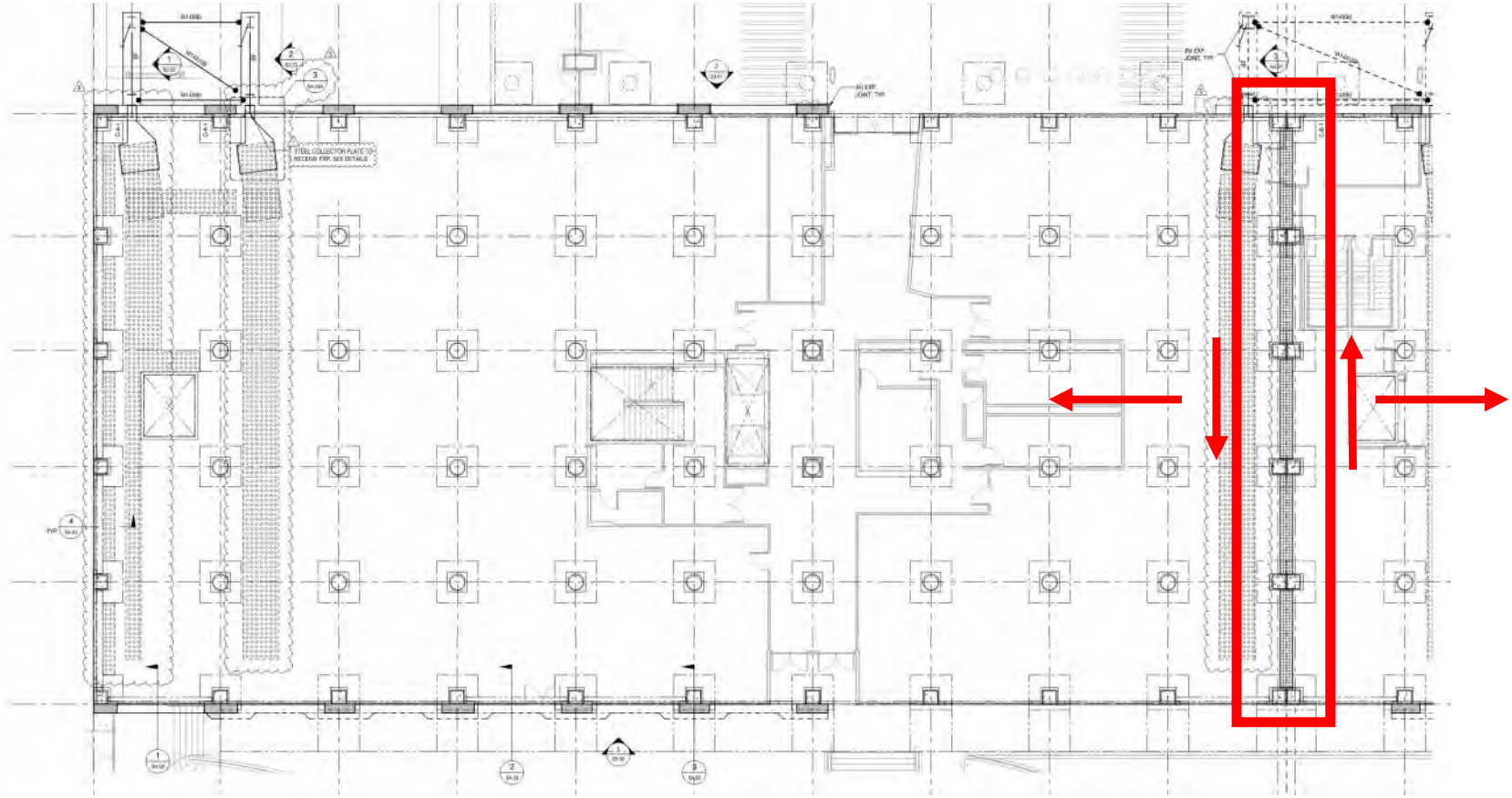


Some slab to wall connections will require strengthening

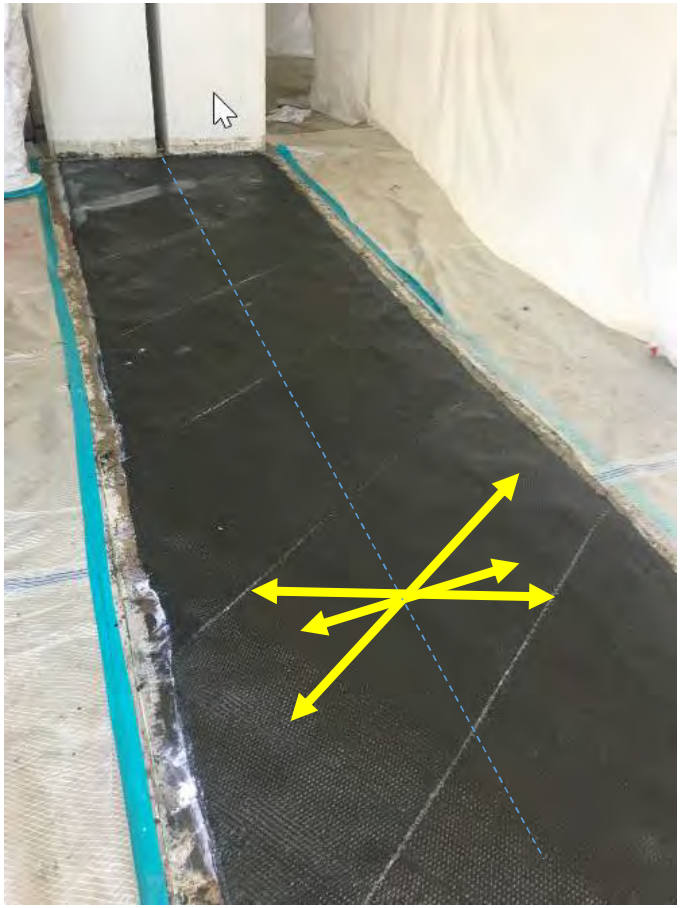


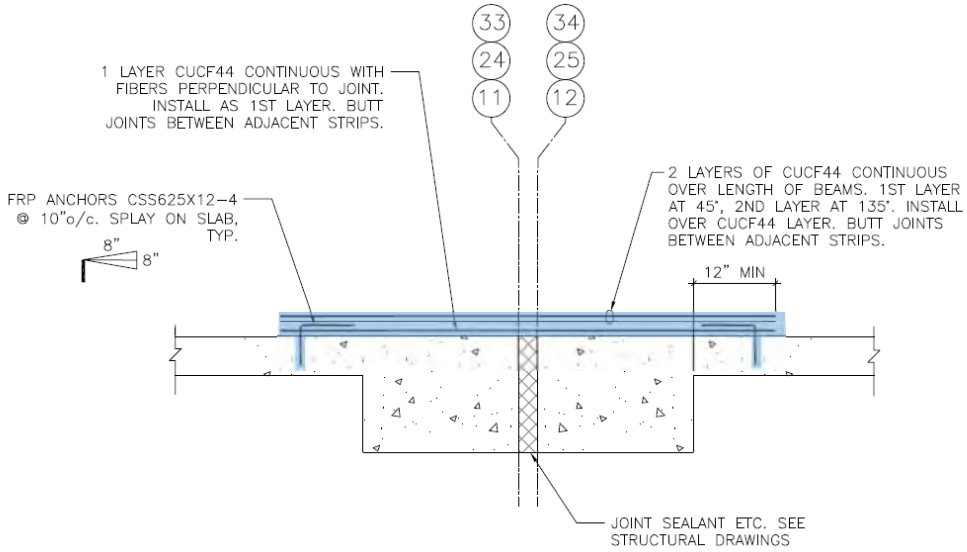
5 SECTION – SLAB–WALL SHEAR TRANSFER @ LINES 1 & 45, LEVEL 1 ONLY
SCALE: 1" = 1'–0"

Expansion joints tied together



FRP applied in 3 unique directions





Shear wall testing – Goals

- Study the effect of using FRP anchors for shear wall strengthening.
- Lack of design guidelines for one face FRP strengthened shear walls.
- Justify using higher strains for walls

Concrete shear wall strengthening – AC 125

7.3.2.6.1 Rectangular Wall Sections: Nominal shear strength enhancement for rectangular wall sections of depth h parallel to the direction of applied shear force, with fiber thickness t_f on both sides of the wall at an angle θ to the members' axis, shall be given by

$$V_{sj} = 2t_f f_j h \sin^2 \theta \quad (24)$$

where

f_j = $0.004 E_j \leq 0.75 f_{uj}$ (for completely wrapped on all four sides).

Where wall sections have fiber bonded to one side only at an angle $\geq 75^\circ$ to the member axis, nominal shear strength enhancement shall be taken as

$$V_{sj} = 0.75 t_j f_j h \sin^2 \theta \quad (25)$$

where

f_j = $0.0015 E_j \leq 0.75 f_{uj}$.

Where wall sections have fiber bonded to one side at an angle $\geq$ 75 degrees to the member axis and with anchorage provided by bonding to the wall ends, the effective strain used to calculate f_j shall be determined through full-scale structural testing.

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Specimen types

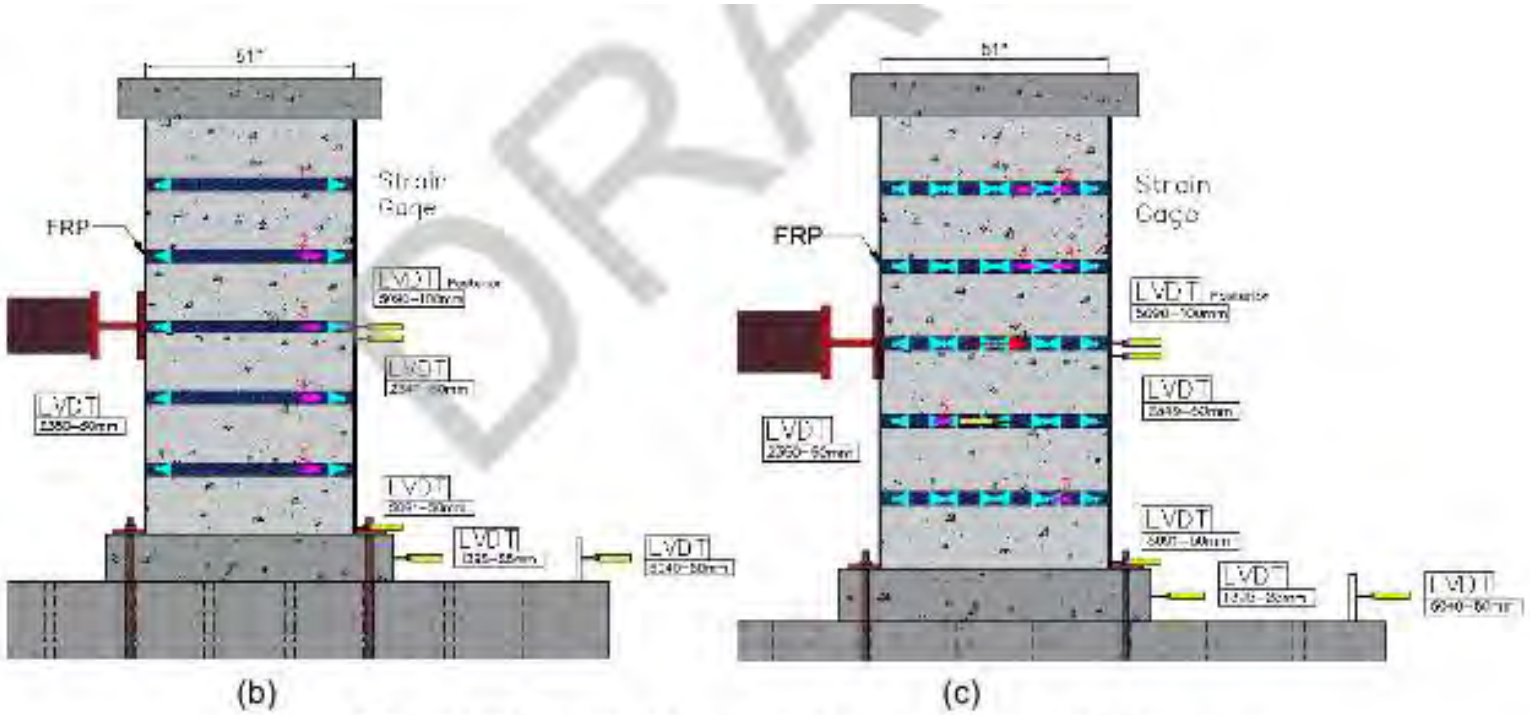
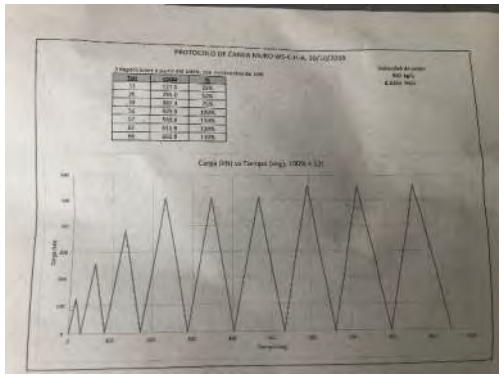
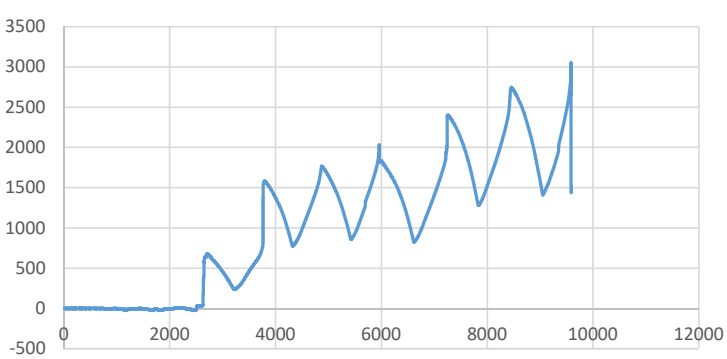


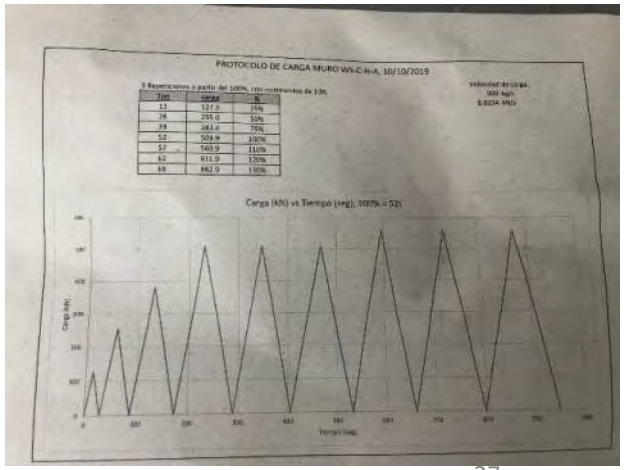
Figure 5.2 – (a) Wall cyclic (dynamic) shear test set-up laboratory view;
(b) instrumentation for SST_CU44-CA_WCS_ LA; and (c) instrumentation for SST_CU44-CA_WCS_ HA

One face FRP with end anchors



One face FRP with field anchors





Concrete shear wall testing – one sided FRP

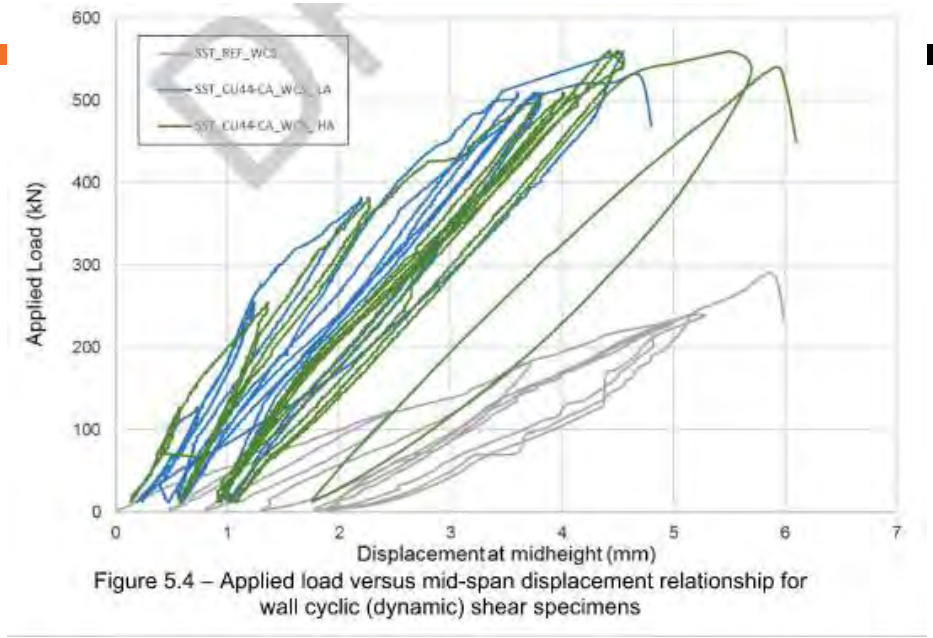


Figure 5.4 – Applied load versus mid-span displacement relationship for wall cyclic (dynamic) shear specimens

Table 5.3 - Results for cyclic (dynamic) shear wall tests

Specimen ID	Peak Lateral Experimental Displacement		Peak Lateral Experimental Load F_{u_exp}		Peak Lateral Theoretical Load F_{u_th}		Ratio Experimental to Theoretical F_{u_exp} / F_{u_th}	Failure Mode
	mm	*in.*	*kN*	*kip*	*kN*	*kip*		
SST_REF_WCS	5.89	0.232	289.5	65.1	321.2	72.2	0.90	Shear
SST_CU44-CA_WCS_ LA	5.11	0.201	559.6	125.8				
SST_CU44-CA_WCS_ HA	6.20	0.244	560.8	126.1				

Shear wall test conclusions

- Field anchors help FRP stay bonded for longer duration.
- Shear wall with field anchors sustains more load cycles as compared to shear walls with end anchorage only, suggesting **higher ductility**.
- Test shows strain of **0.004** can be used **ONLY** with field anchors.

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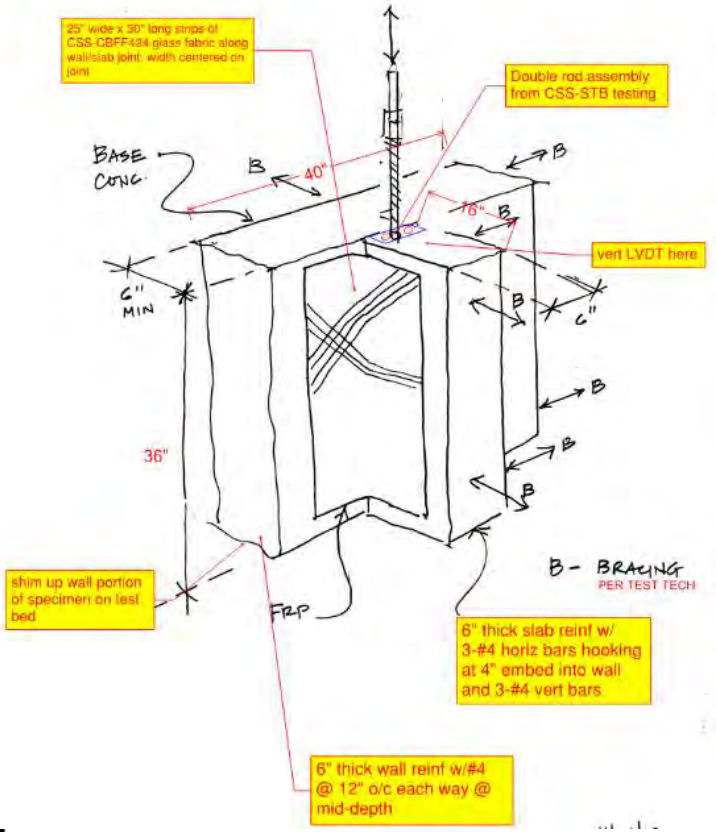
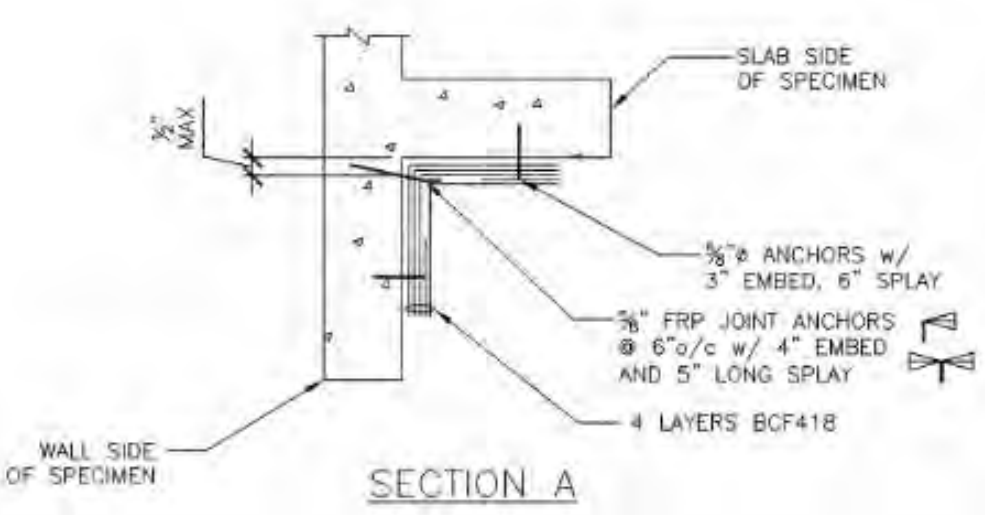
Joint Strengthening Testing

Credits: Nabih Youssef Structural Engineers, ZFA Structural Engineers and DSA

Concrete wall/slab connection joint strengthening goals



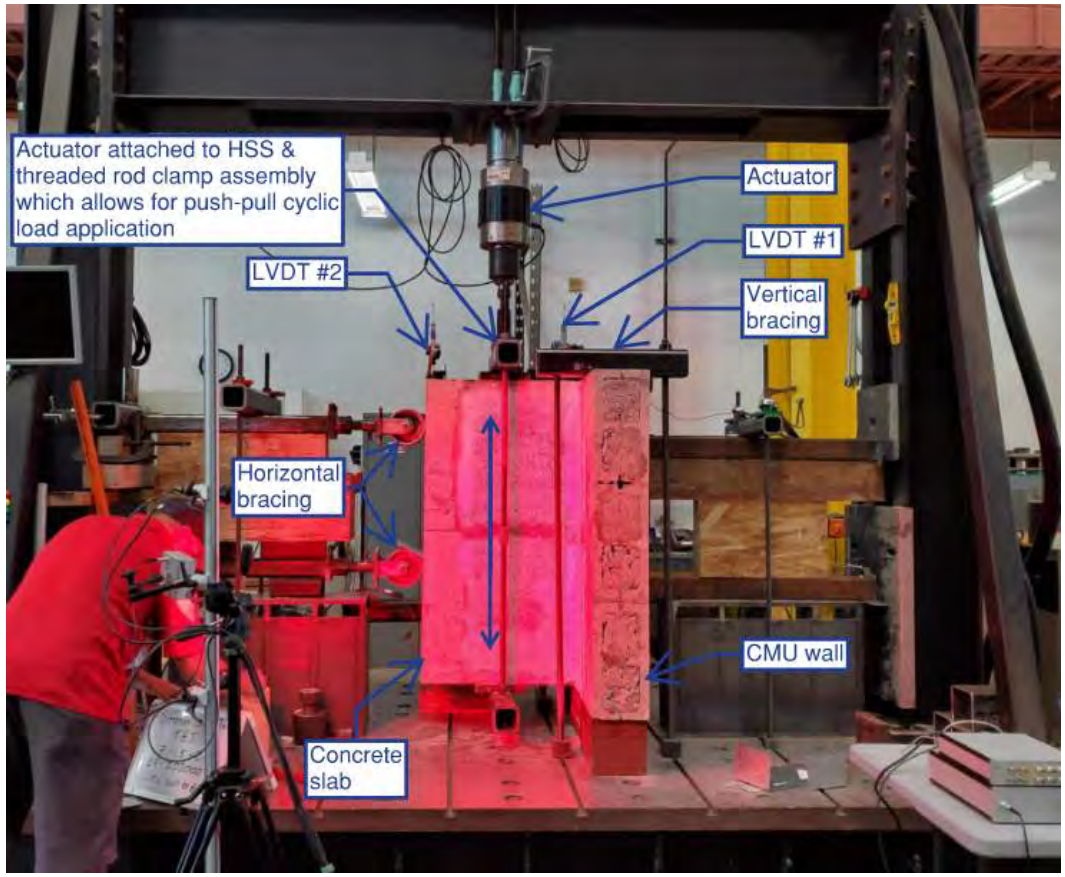
1 layer CSS-CBGF424



4 layers CSS-BCF418 w/ anchors

Joint strengthening test setup – CFRP specimens

Joint strengthening test setup – GFRP specimens / masonry wall



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Joint strengthening conclusions

Wall Slab Connection Testing Summary			
Product	Ultimate Strength (klf)	Allowable Strength (klf)	Allowable Strength (klf)
		ϕ=0.6	ϕ=1.0
1 layer CSS-CBGF424	11.9	6.1	10.1
4 layers CSS-BCF418 with FRP Anchors	22.5	11.5	19.1
1 layer CSS-CBGF424 on Masonry Wall	5.7	3.42	5.04

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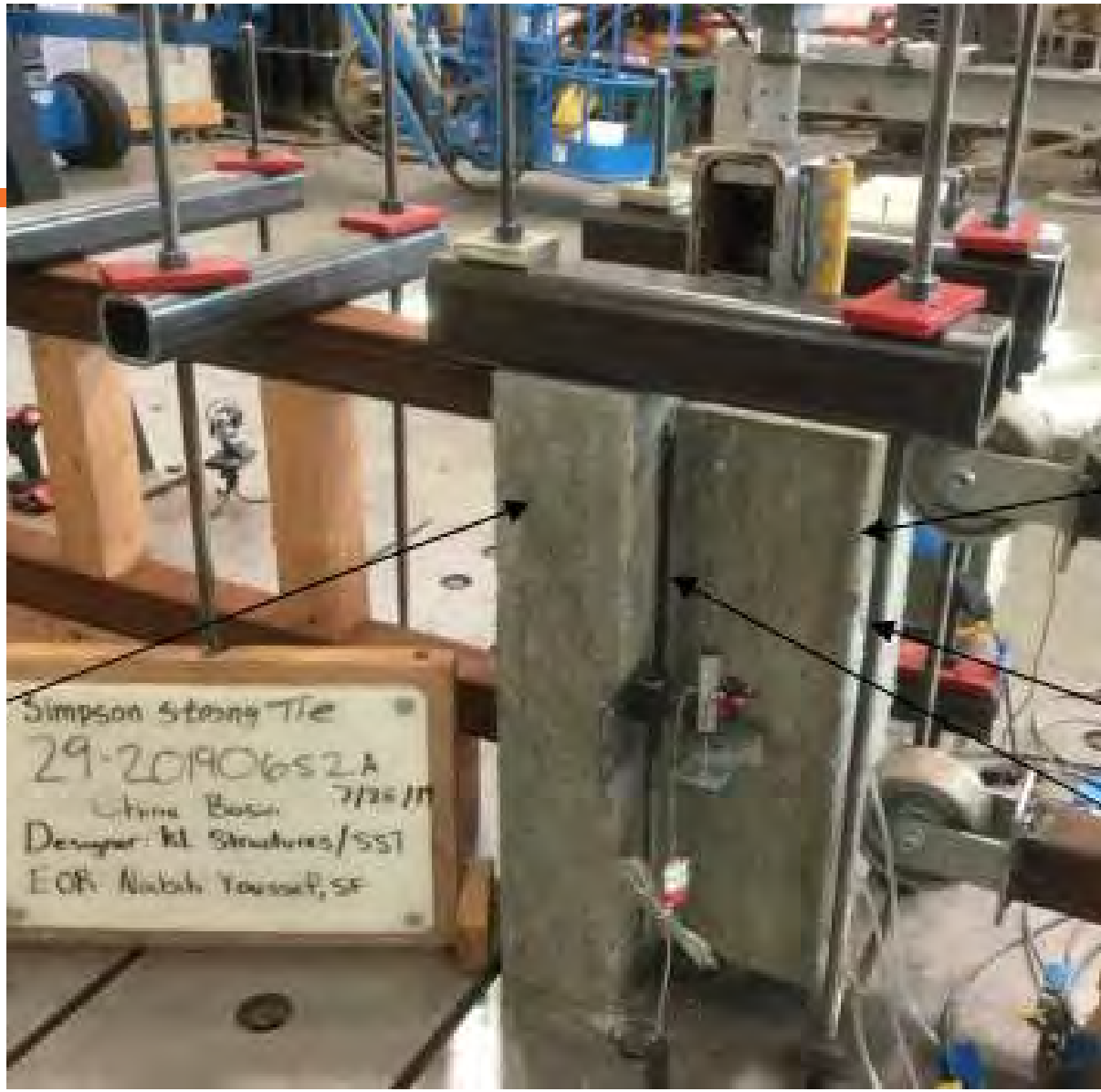
Shear Transfer Bracket Testing CSS-STB



CSS-STB testing goals

- To test and develop an FRP element to effectively transfer shear between an existing concrete element and a new concrete element.

- Project required minimum drilling to avoid noise and vibrations.

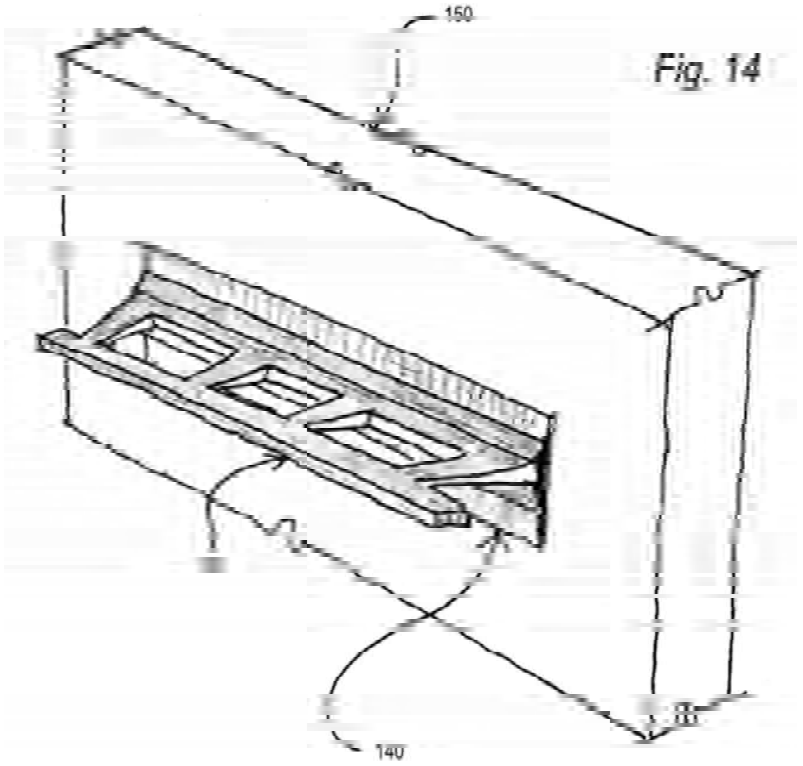
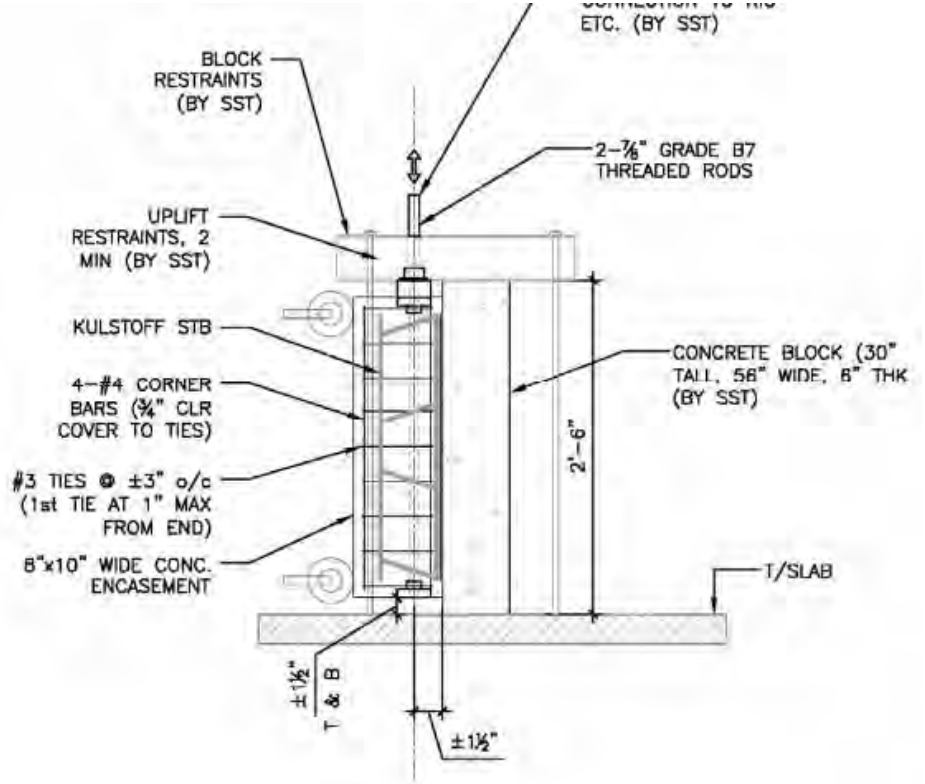
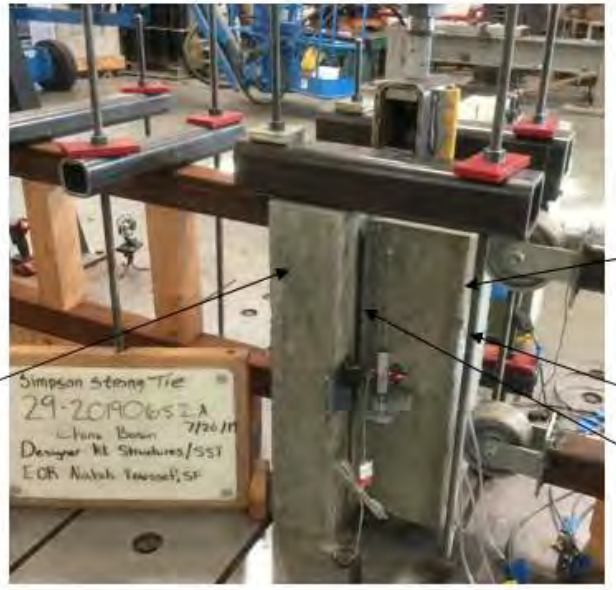


Fig. 14

STB testing





Concrete block representing existing concrete

Encapsulating new concrete block (narrower than base of BA-STB)

BA-STB

BA-STB base bonded to existing concrete

STB test summary

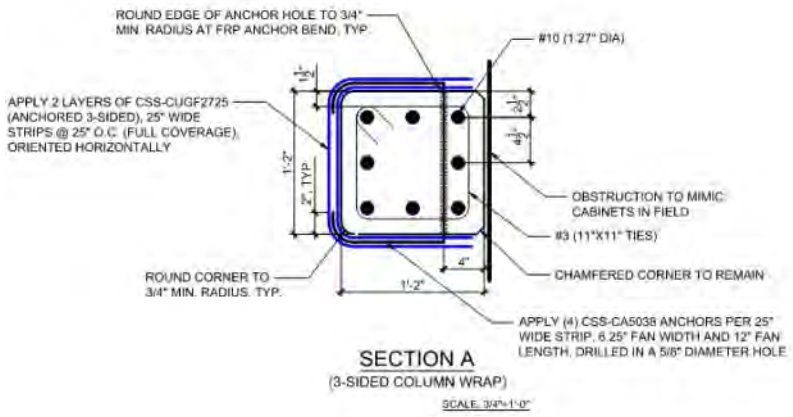
- Mode of Failure: Shear failure of all 4 diagonals.
- 32.5 klf ultimate load
- Test approved by SFDBI plan check and third party reviewer (SGH)

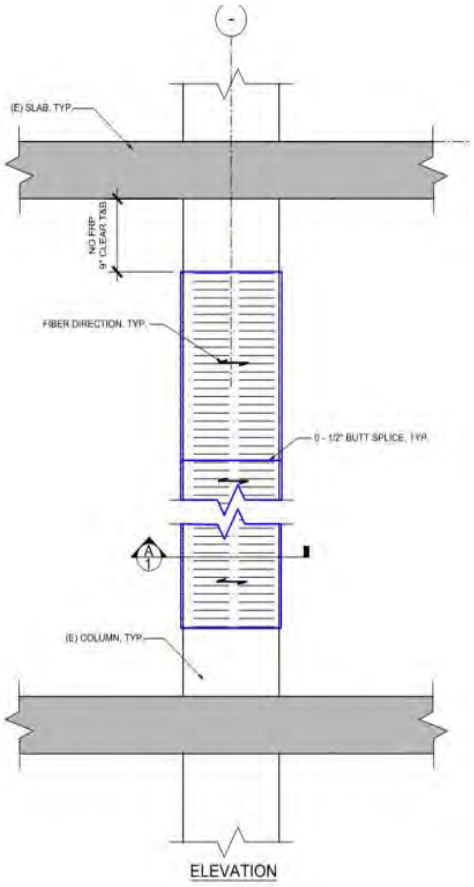
3-Sided Column Wrap Test

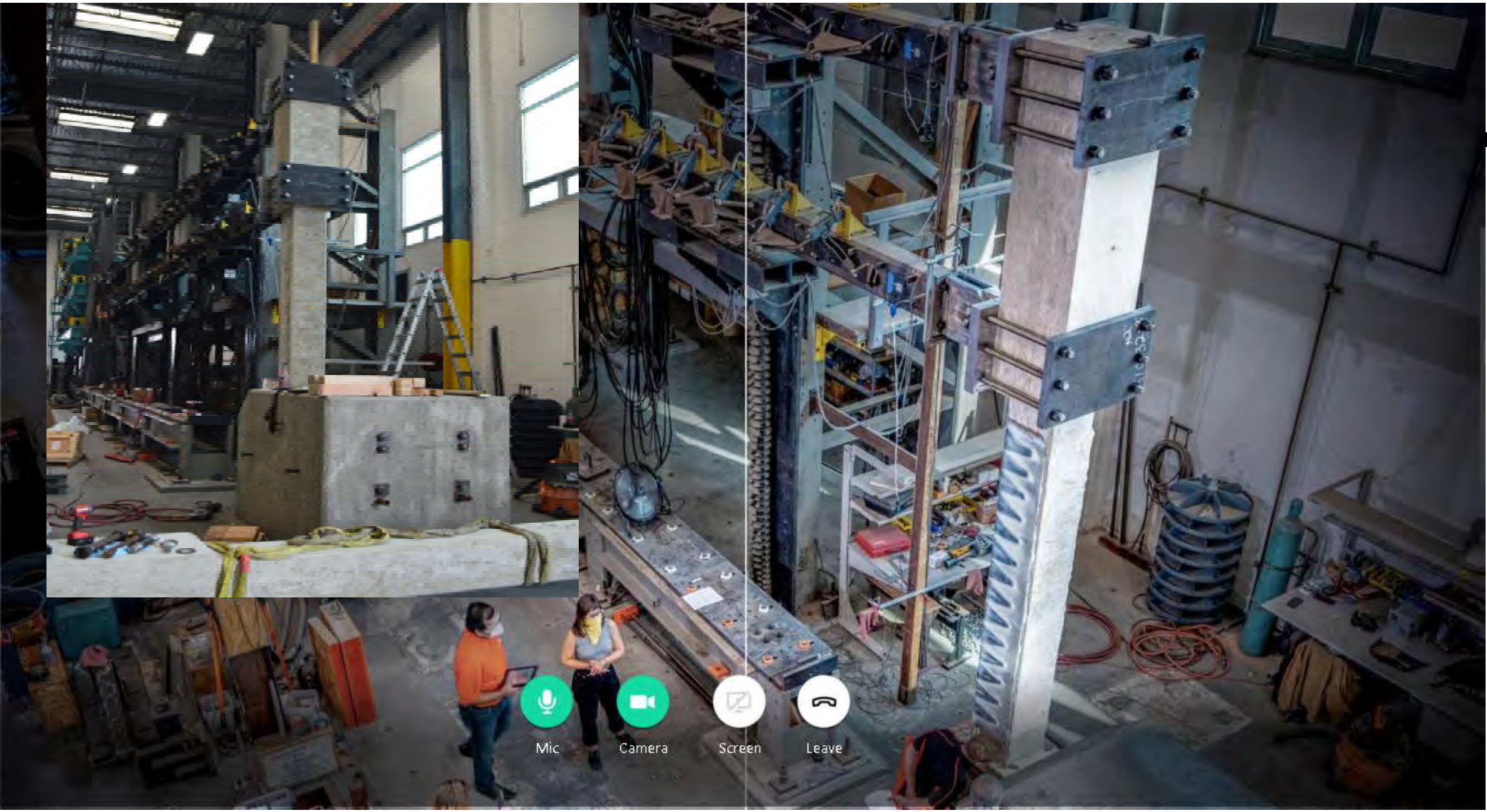
Credits: Tipping Structural Engineers

Project goal

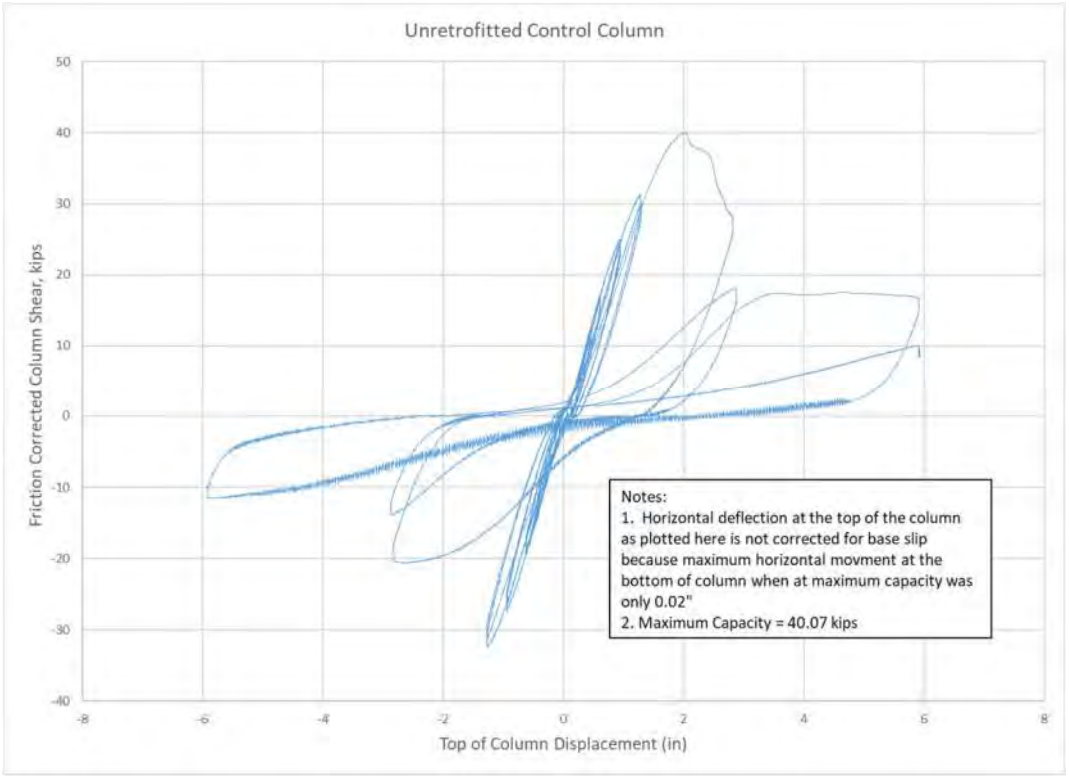
The goal of the test is to increase shear strength of the columns by adding a U-wrap of FRP fabric with FRP anchors creating the fourth side wrap.





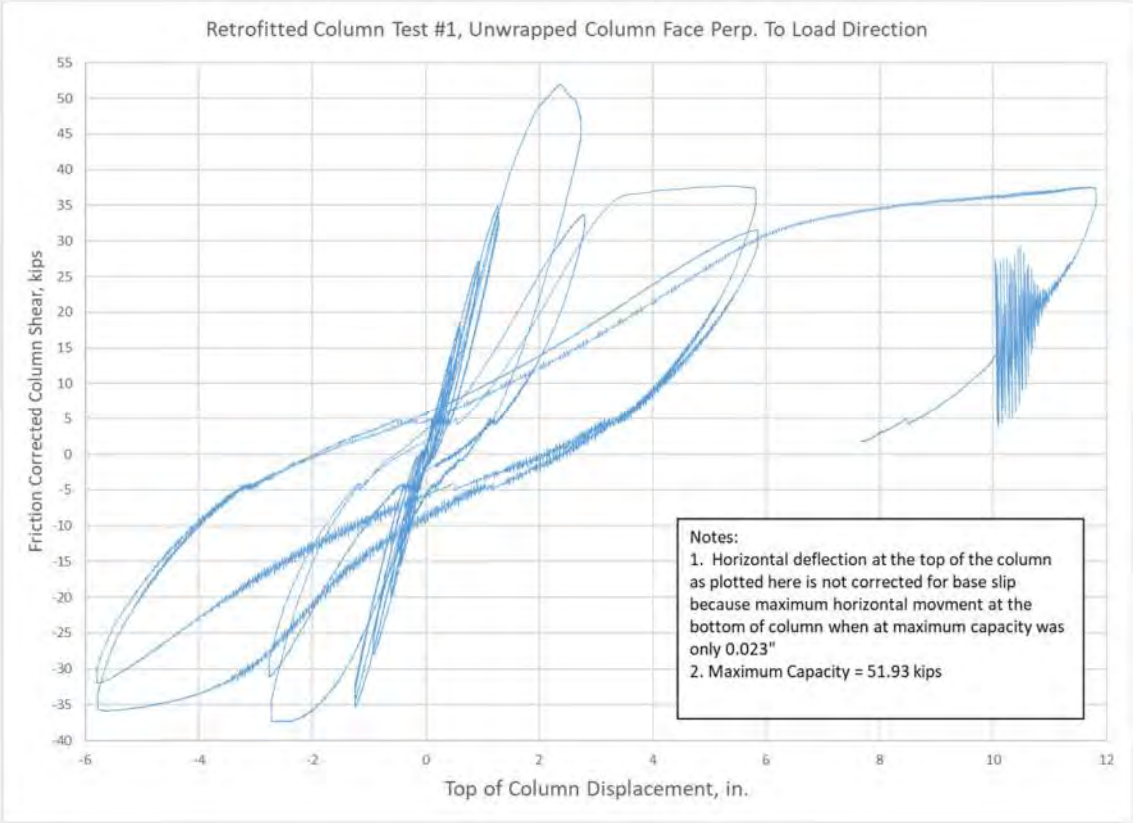

Mic
Camera
Screen
Leave

Control Specimen



Column failed in shear

3-sided GFRP – CA (carbon anchors)



Column failed in flexure

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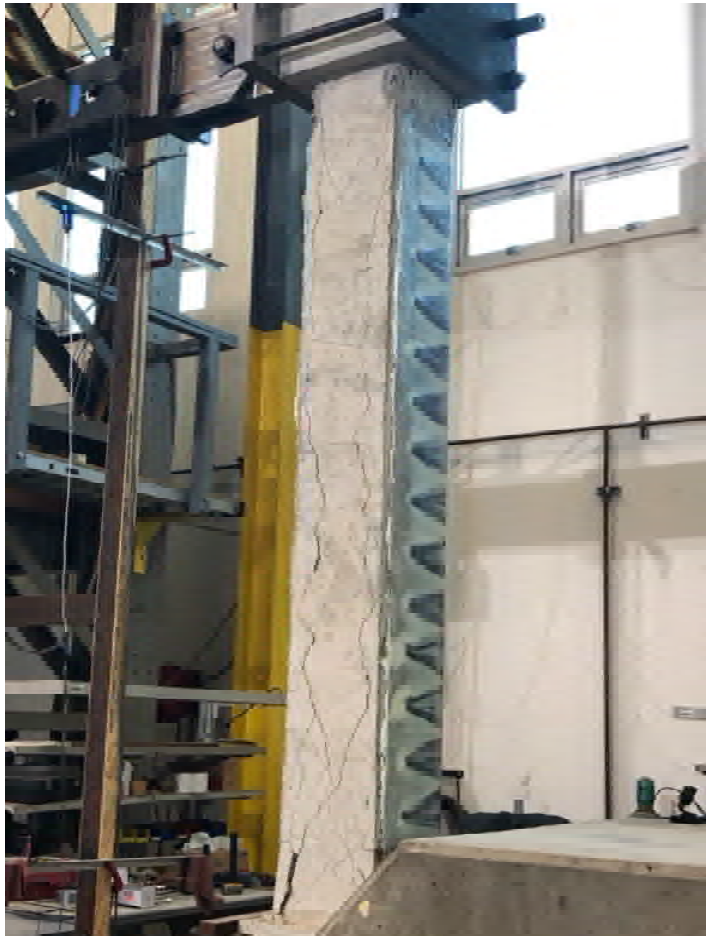
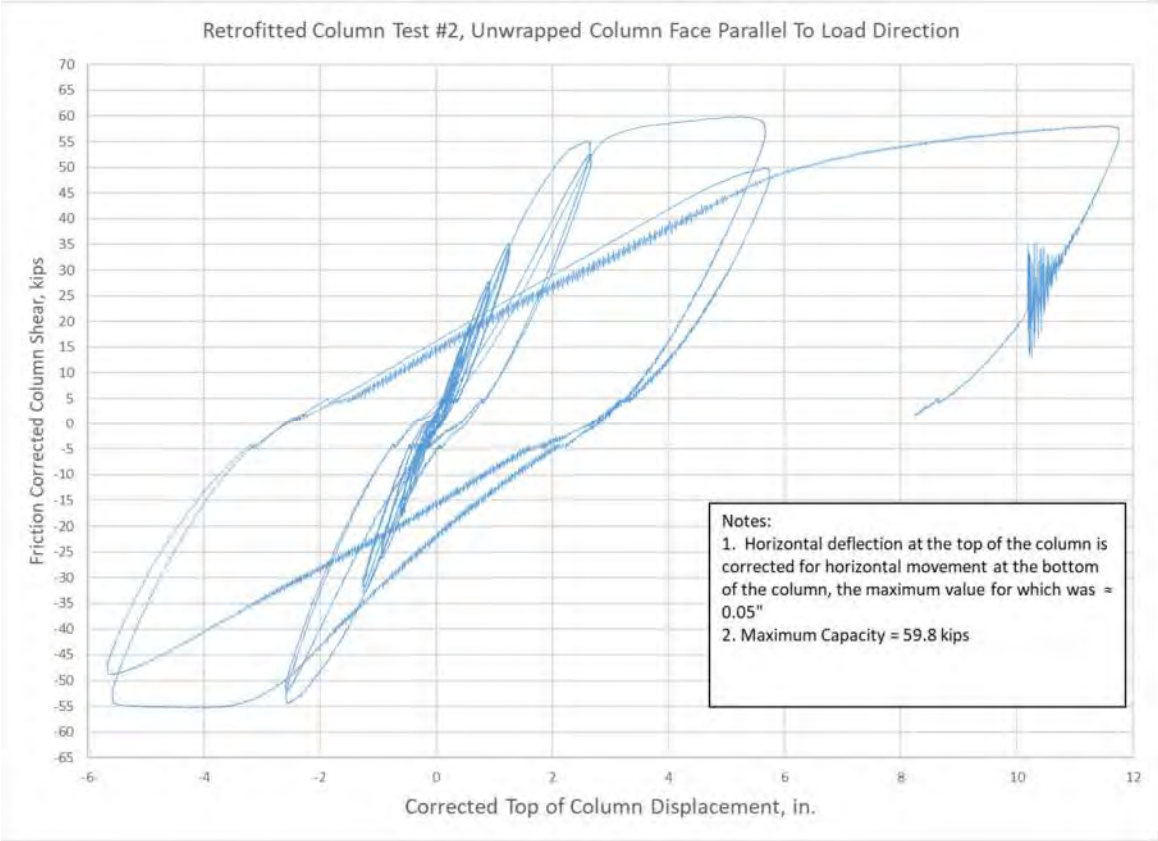
3-sided GFRP – CA (carbon anchors)





Column failed primarily due to flexural yielding.

CA (carbon anchor) performance

Two End FRP Anchors, intact with no substantial damage observed.

End anchor seemed to have elongated by ¾”

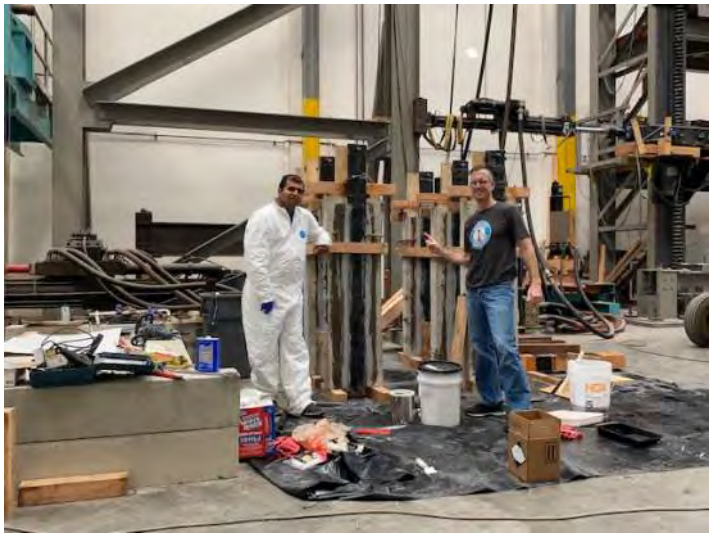
3-sided column conclusions

- 3-sided wrapped columns with GFRP fabric and anchors shows higher ductility and should be preferred oved CFRP fabric.

- 3-sided columns wrapped with FRP increase ductility and load carrying capacity as compared to control specimen.

- Could be used on projects with no access on the 4th face.

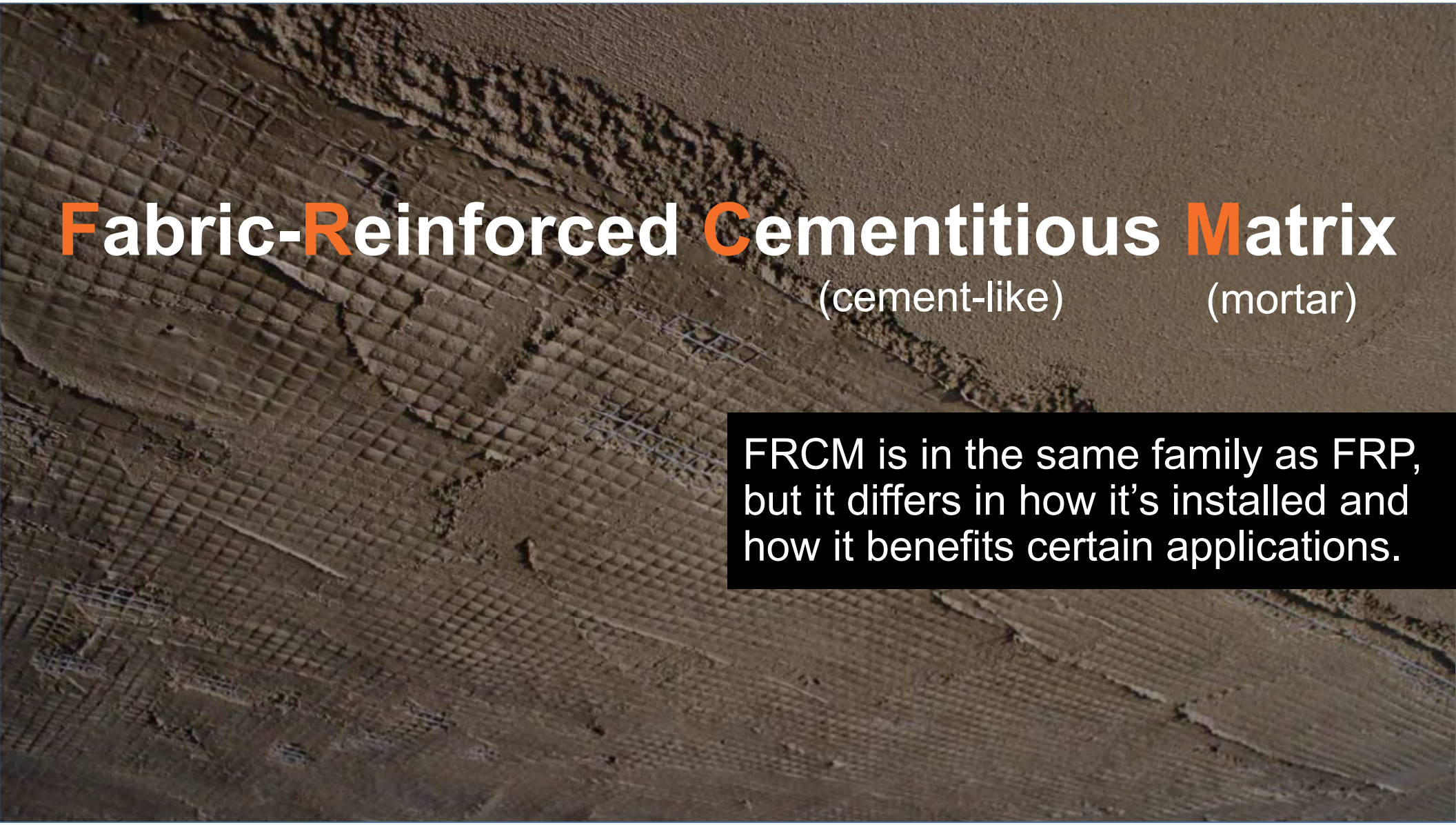
We are currently testing diaphragms



Collector

Shear

Collectors



Fabric-Reinforced Cementitious Matrix

(cement-like) (mortar)

FRCM is in the same family as FRP, but it differs in how it's installed and how it benefits certain applications.

FRP Components

Fabric-Reinforced Cementitious Matrix (FRCM) Systems = Carbon-Fiber Grid + Cementitious Matrix

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Napa County Courthouse – Seismic Upgrade

(Napa, California)

- Building damaged in 2014 Napa Earthquake (6.0 magnitude)
- Unreinforced masonry & Brick building
- EOR – ZFA Structural Engineers
- WHY FRCM?
- Shear strengthening required on most walls
- Nominal strengthening on remaining walls
- Cracking on multiple interior and exterior walls.

SIMPSON Strong-Tie

Napa County **Courthouse – What FRCM Provided?**

- FRCM provided in-plane and out-of-plane strengthening with minimum surface preparation beyond the removal of existing finishes
- The FRCM is also detailed to engage and tie the historic masonry to the new CMU walls
- Cement based FRCM did not seal the historic walls and allowed the walls to breathe as it has for 150 years and provided a favorable surface for installation of plaster finishes

Structural FRCM Repairs – ZFA Structural Drawings

REPAIR SCHEDULE	
REPOINT	REPOINT CRACKED MORTAR JOINTS EXCEPT WHERE GROUT INJECTION OR FIBER REINFORCED CEMENTIOUS MATERIAL IS SPECIFIED
GROUT INJECT	GROUT INJECT ALL CRACKS 1/16" IN WIDTH OR GREATER UNO ON ELEVATIONS
BRICK RECONSTRUCTION	IF SPALL AREA IS LESS THAN 16" SQUARE AND DOES NOT EXTEND FULL DEPTH FILL W/ MORTAR, OTHERWISE RECONSTRUCT AREA WITH BRICK. NOTIFY ENGINEER OF RECORD IF AREA EXCEEDS 24" SQUARE
FIBER REINFORCED CEMENTIOUS MATERIAL (FRCM) OVERLAY	AS INDICATED PER PLAN, ELEVATIONS, AND SPECIFICATIONS. GROUT INJECT ALL CRACKS 1/16" OR GREATER BELOW FIBER REINFORCED CEMENTIOUS MATERIAL. REPOINT/GROUT ON FARSIDE OF EXISTING BRICK WALLS WHEN OVERLAY IS INSTALLED ON ONE FACE ONLY
CMU REPLACEMENT	AS INDICATED PER PLANS, ELEVATIONS, AND SPECIFICATIONS

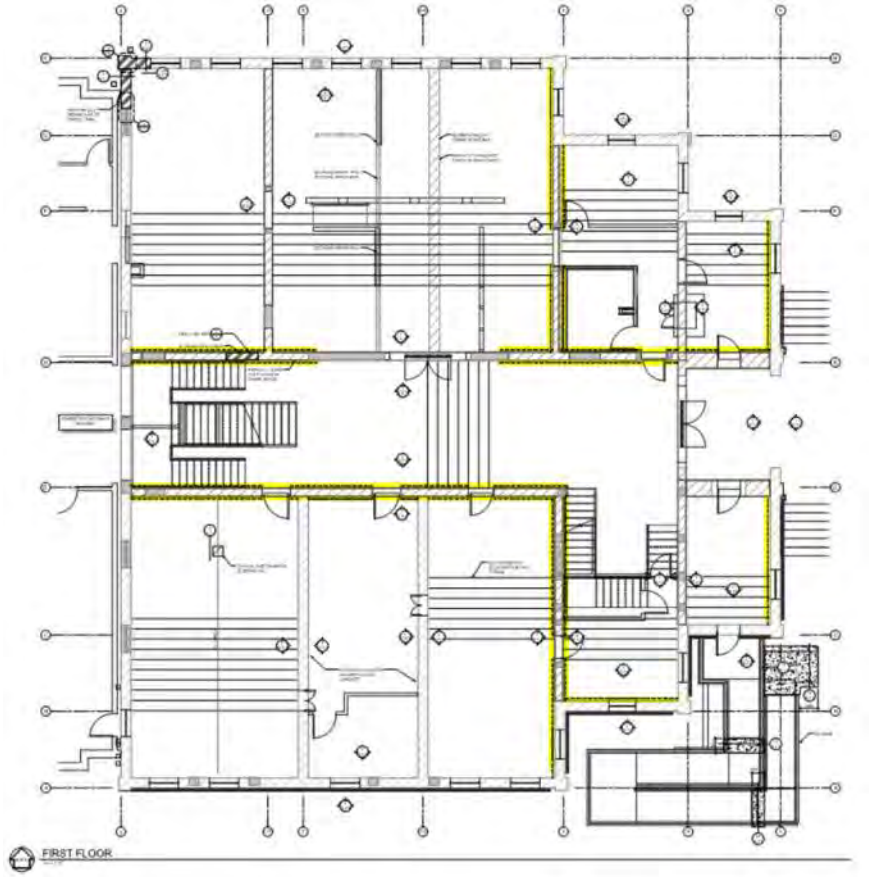
SEE **K/S-0.1** & SPECIFICATIONS FOR ADDITIONAL INFORMATION

STRUCTURAL FRCM REPAIRS				
GRID LINE	FLOOR	THICKNESS	EXISTING CAPACITY	REPAIRED CAPACITY
1	2ND	16"	-	NOMINAL
1.75	2ND	12"	67.5k	90.5k
2	2ND	12"	92.3k	102.5k
4	2ND	8"	55.9k	69.9k
5	2ND	16"	42.7k	51.2k
A	2ND	16" (2)	-	NOMINAL
D	2ND	12"	125.7k	170k
E	2ND	12"	156.8k	174k
H	2ND	16"	-	NOMINAL
3 NORTH	1ST	12"	117.5k	155.3k
3 SOUTH	1ST	12"	122.2k	131.3k
5	1ST	16"	-	NOMINAL
B	1ST	16"	-	NOMINAL
D	1ST	12"	212k	326.3k
E	1ST	12"	212k	326.3k

NOTE:

1. OVERLAY SHALL BE PROVIDED AS SHOWN ON PLAN AND ELEVATIONS (2)
2. SEE **L/S-0.1** FOR ADDITIONAL INFORMATION
3. AT WALLS INDICATED AS "NOMINAL" PROVIDE BIDRICTIONAL OVERLAY AS SOHWN IN ELEVATIONS.

Napa County Courthouse – Structural Plan



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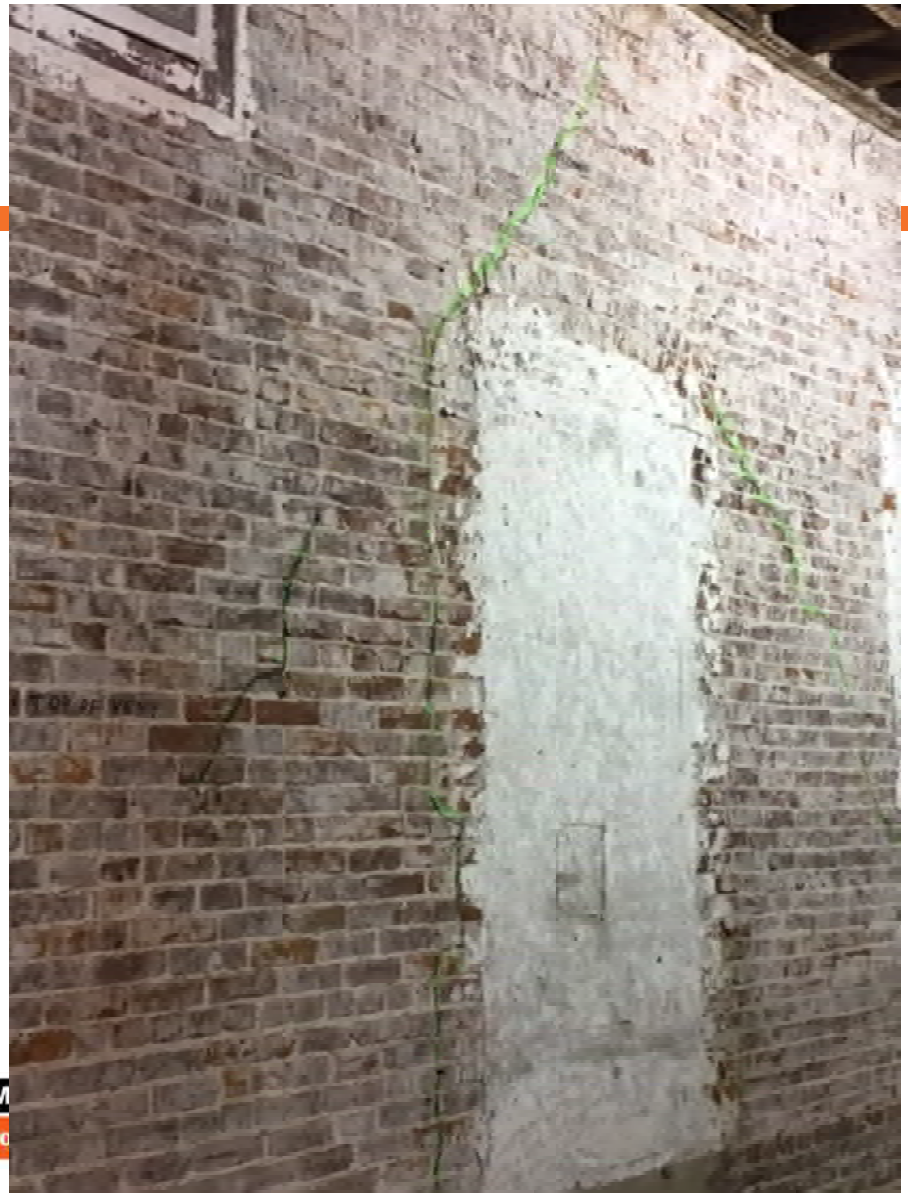

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FRCM APLICATION – NAPA COUNTY COURTHOUSE

Before FRCM

After FRCM

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Gruening Middle School Earthquake Repair, Eagle River, AK

- EOR: Reed Middleton, Anchorage
- GC: Cornerstone
- FRCM Installer: Generation Plaster
- FRCM scope: Strengthening of existing Masonry walls (36,000 sf)

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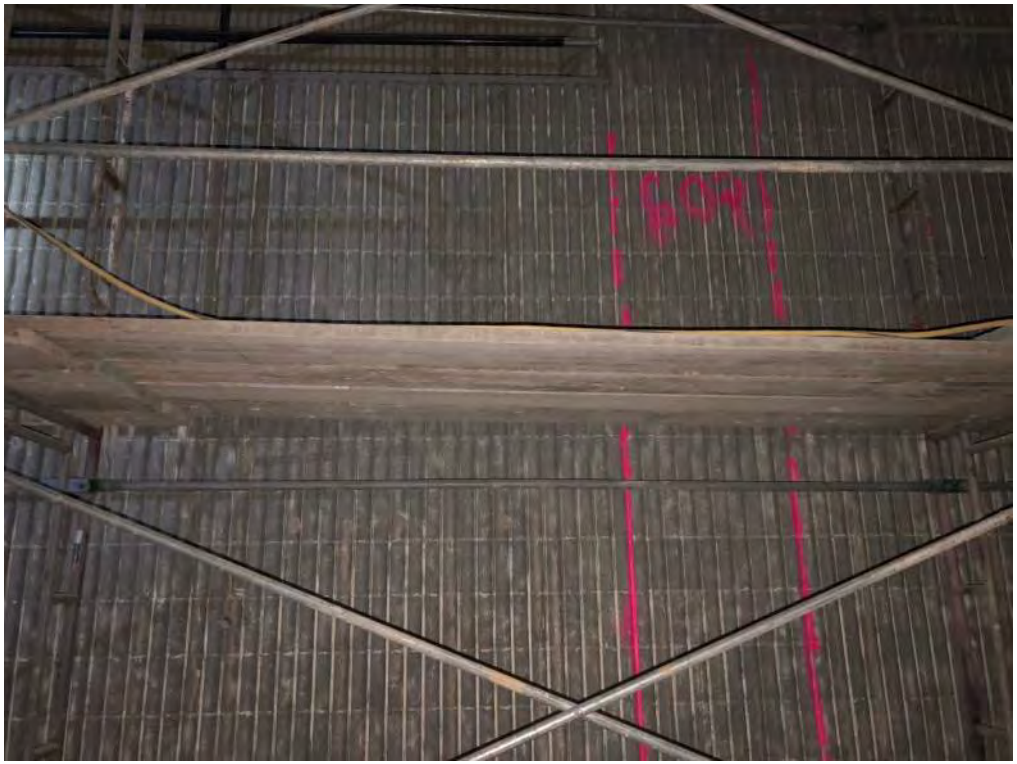
Surface preparation of Masonry Walls



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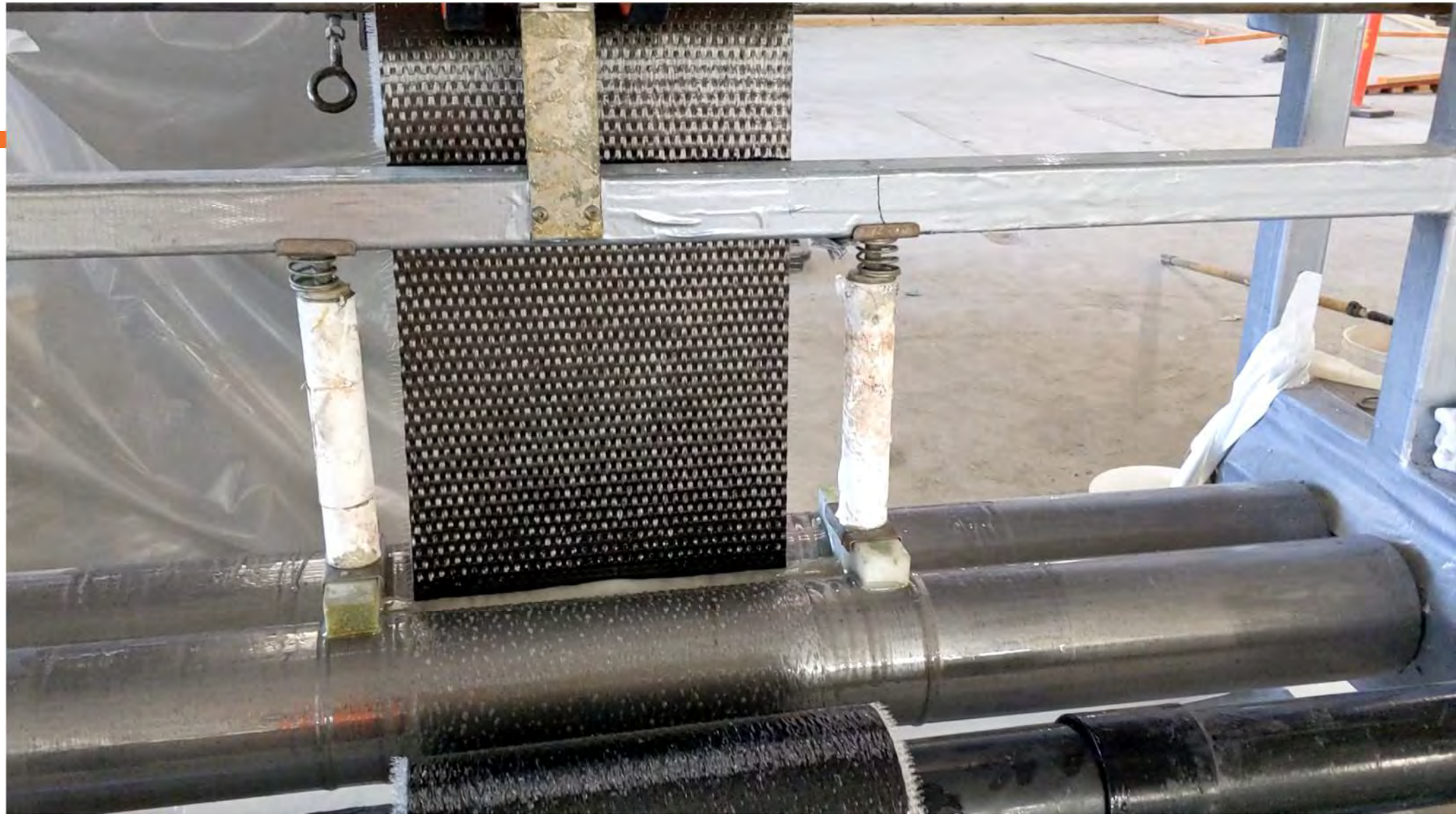
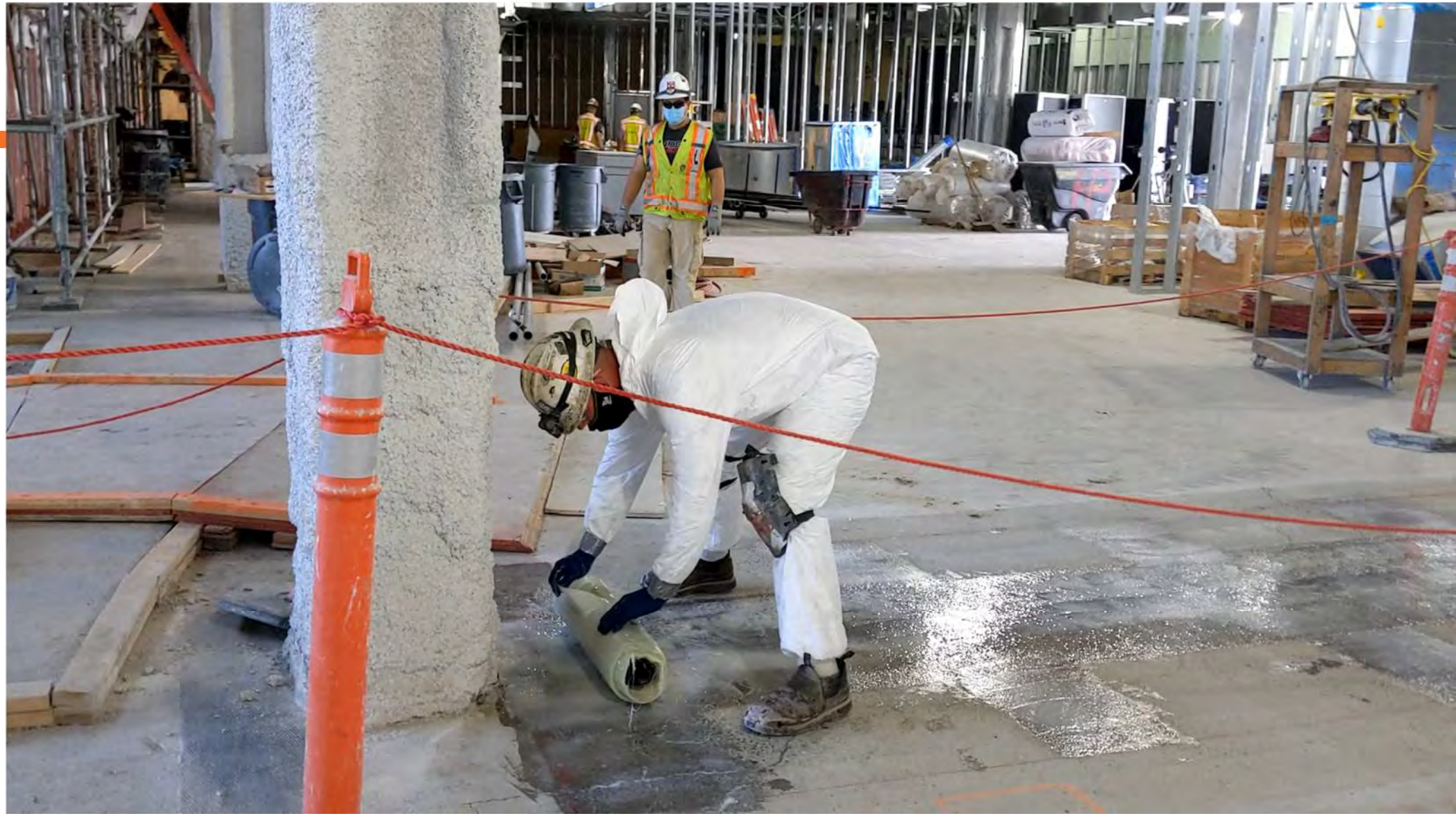
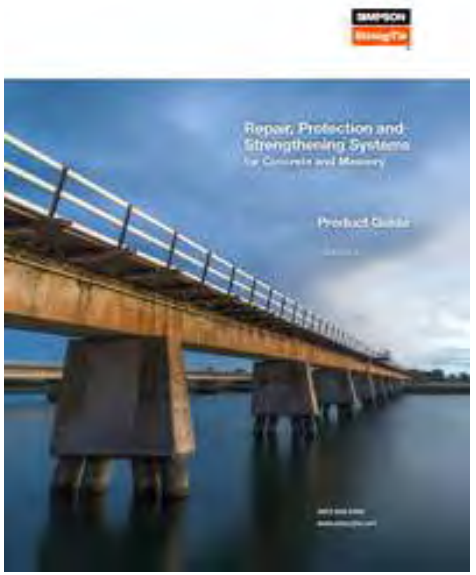




How Can Manufacturer's Help?

Feasibility Studies	Work with EOR to determine if FRP/FRCM 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



FREE SERVICES !!!!!!

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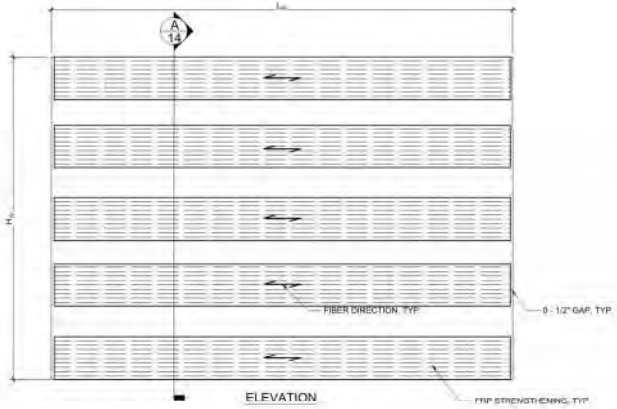
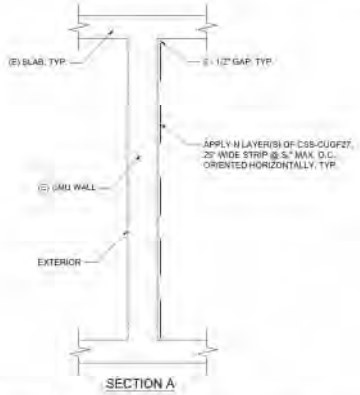
WALL STRENGTHENING

STEP 1: SHEAR STRIP
AT THE WALL WITHOUT OPENING

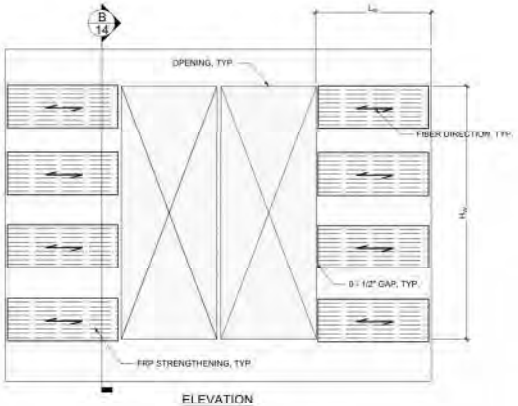


ELEVATION

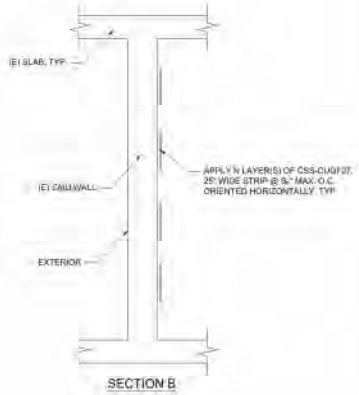


SECTION A

AT THE WALL WITH OPENING



ELEVATION



SECTION B

NOTE:
1. PROVIDE INFILL AT WALLS PRIOR TO FRP INSTALLATION.
2. SEE SUMMARY TABLE - SHEAR STRENGTHENING ON SHEET 16 FOR MORE INFORMATION.

NO.	DATE	REVISIONS

EMPYREAN OAKLAND
344 13TH STREET
OAKLAND, CA 94612

NAME: B.E.
DATE: 01-31-2019
SCALE: N.T.S.
SHEET:
FRP
14 OF 18 SHEETS
JOB NO
ES-183845A

COMPOSITE STRENGTHENING SYSTEMS

DESIGN CALCULATION PACKAGE

Component capacities for
Empyrean Oakland
344 13th Street
Oakland, CA 94612

Prepared for
Pullman

Date of Drawings
January 18, 2019

Date of Input
January 31, 2019

Job No
ES-183845A

Designed by
S.D.

Checked by
B.E.

REGISTERED PROFESSIONAL ENGINEER
BRAD L. ERICKSON
4924
EXP: 6/30/2020
STRUCTURAL
CIVIL
01/31/2019

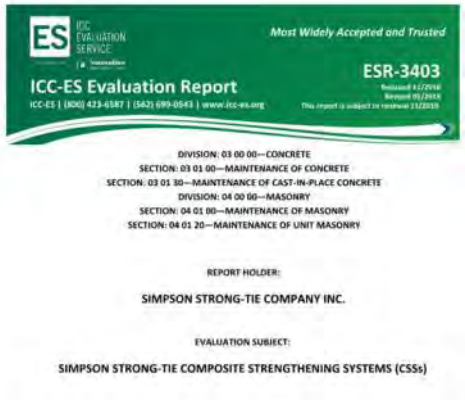
We design FRP to help structural engineers provide a viable solution to their client

- Feasibility studies & Budgeting
- Stamped FRP design drawings and calculations
- No cost

OSHPD

Division of the State Architect

Caltrans



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