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2024 SPRING CONVENTION

APRIL 21-24, 2024
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Seismic Strengthening of Bridge Columns with FRP
Value Engineered to Replace Steel Jackets

Sarah Outzen, P.E.

Senior CSS Field Engineer

soutzen@strongtie.com

(415) 656-9405

https://www.instagram.com/strongtie_sarah_cs

FRP Basics

Background

A brief introduction to fiber-reinforced polymer (FRP) for those less familiar with the technology.

Case Study

Highway US50 in California

Highway US50 in Sacramento, California as a case study in the value engineered capabilities of FRP over steel jackets, and the benefits for a Design/Build project type.

Questions

Live Q&A

Ask away!

FRP BASICS

What is fiber-reinforced polymer and how is it applied to structures?

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What is FRP?

Fiber Reinforcement:
Carbon or E-glass

Provides tensile strength and stiffness

Corrosion Resistant

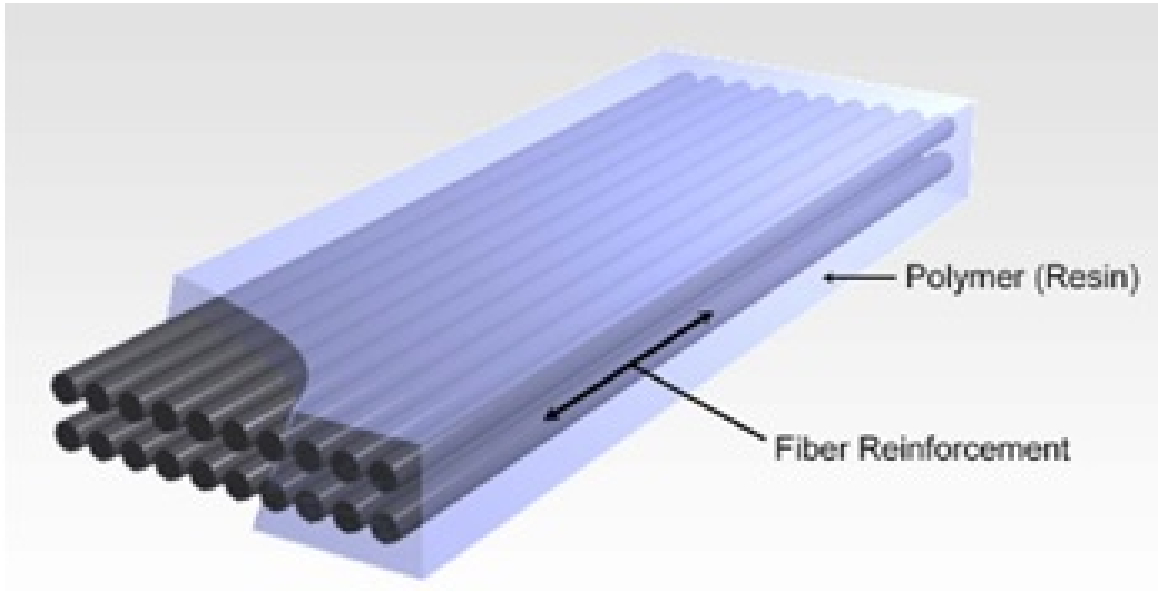
+

Polymer Resin:
Epoxy

Transfers load (bond) and protects fibers against deterioration

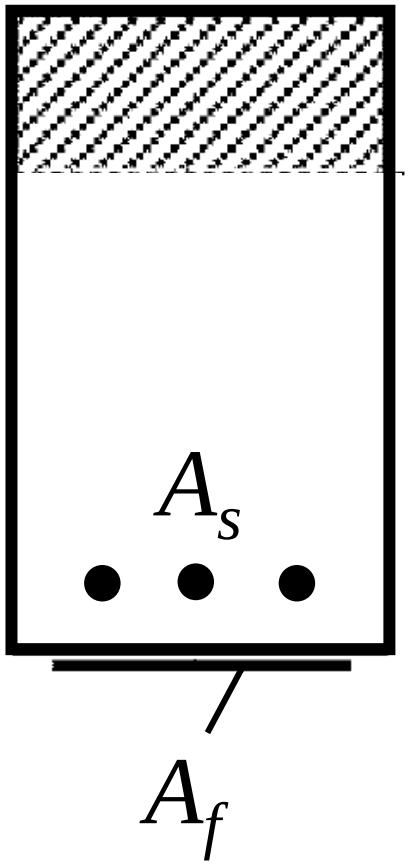
=

Fiber-reinforced polymer (FRP) composite

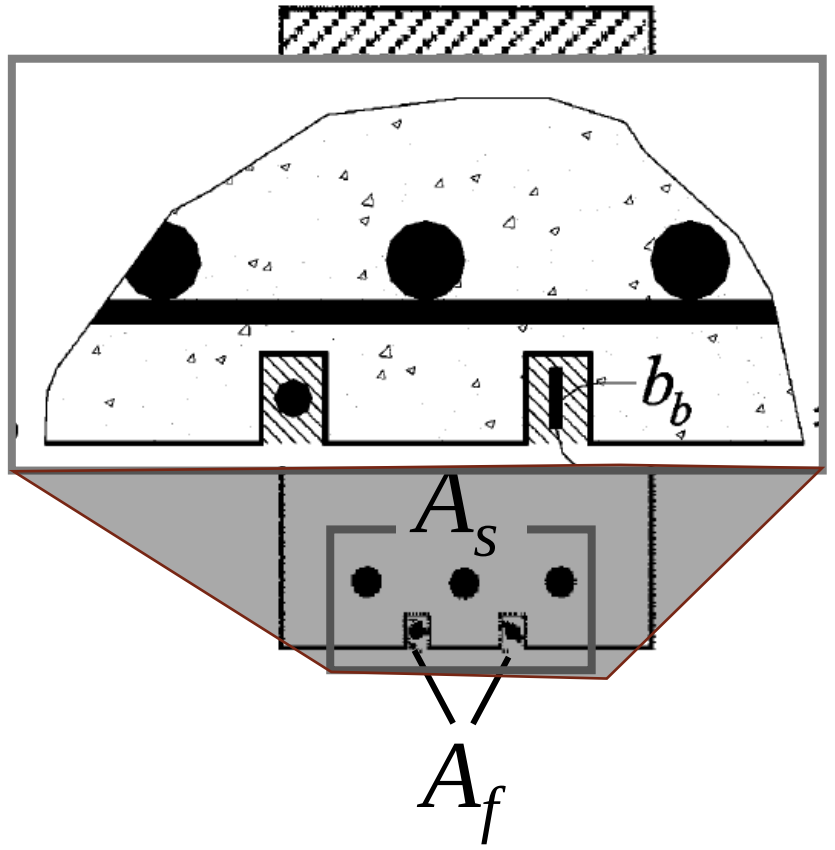


Types of Externally Bonded FRP

Surface Mounted

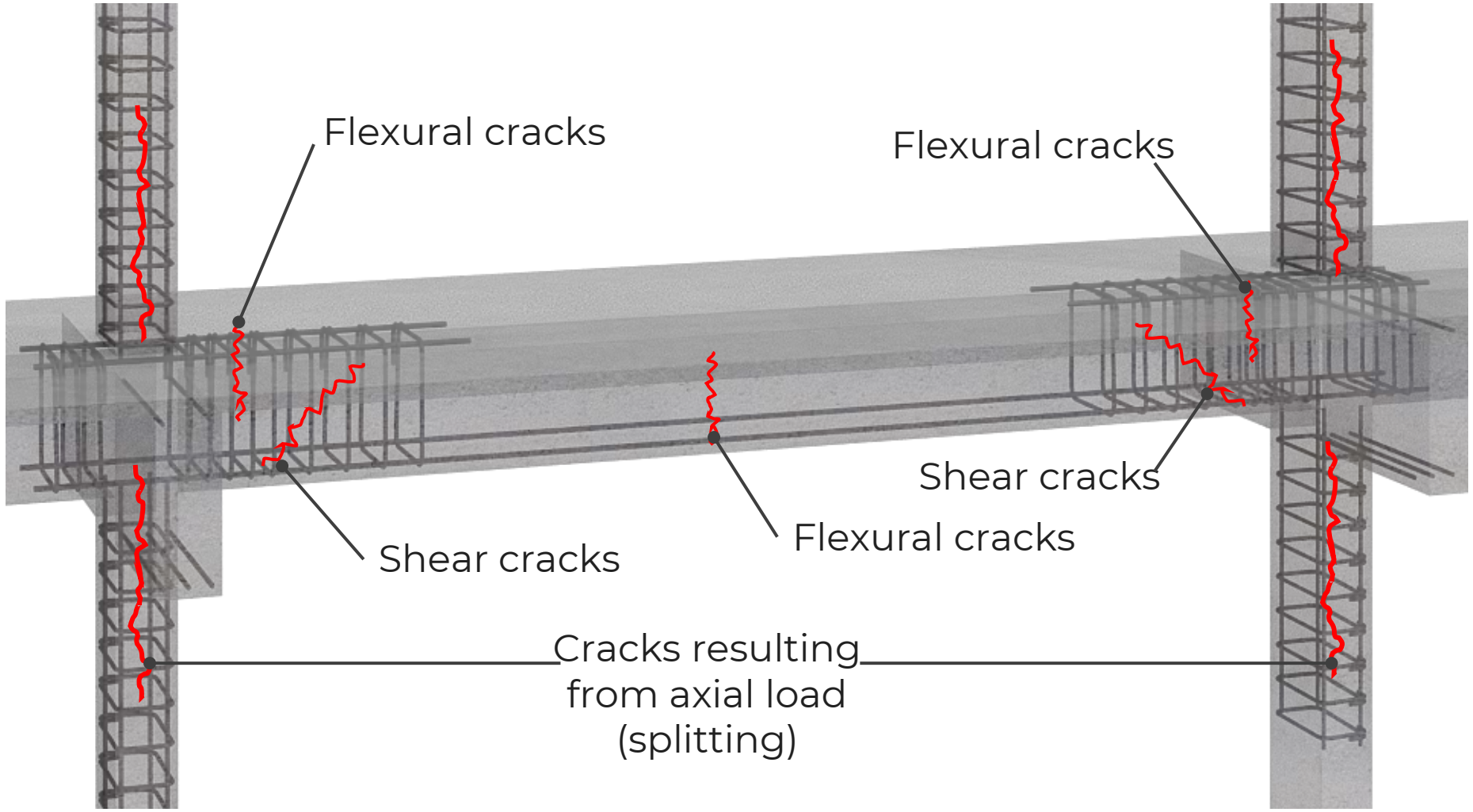


Near Surface Mounted



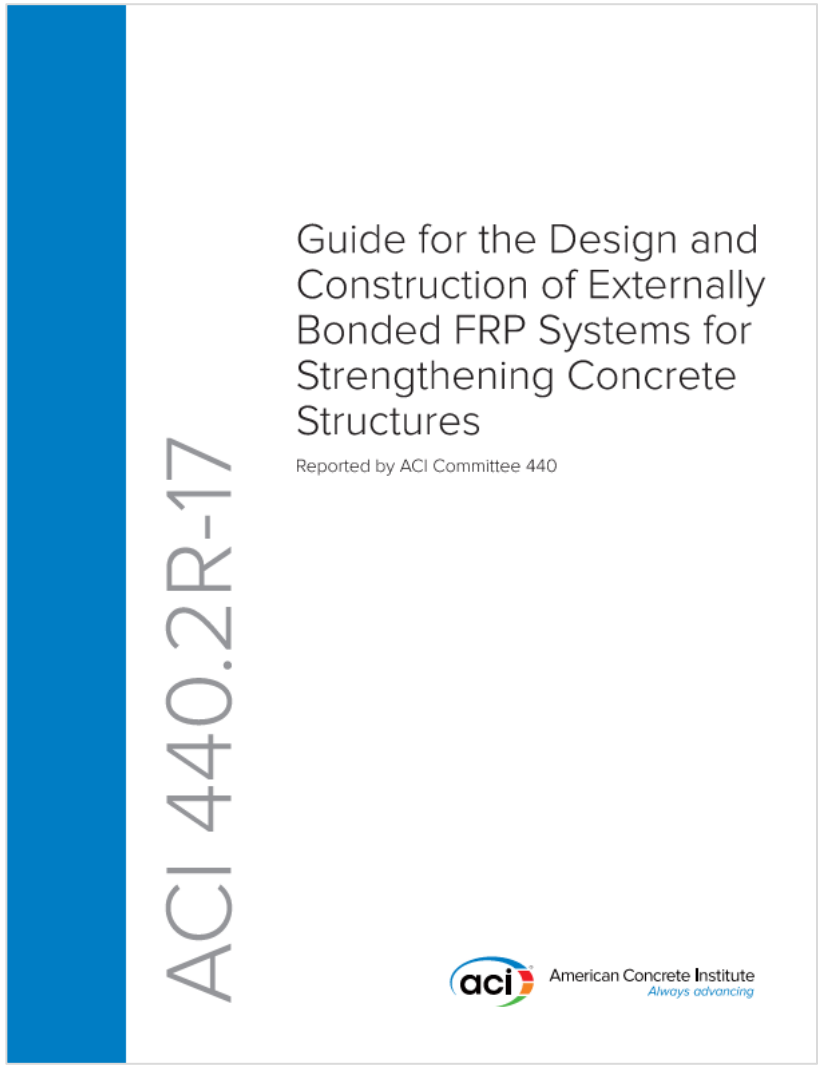
Typical Placement – Internal Steel Reinforcing

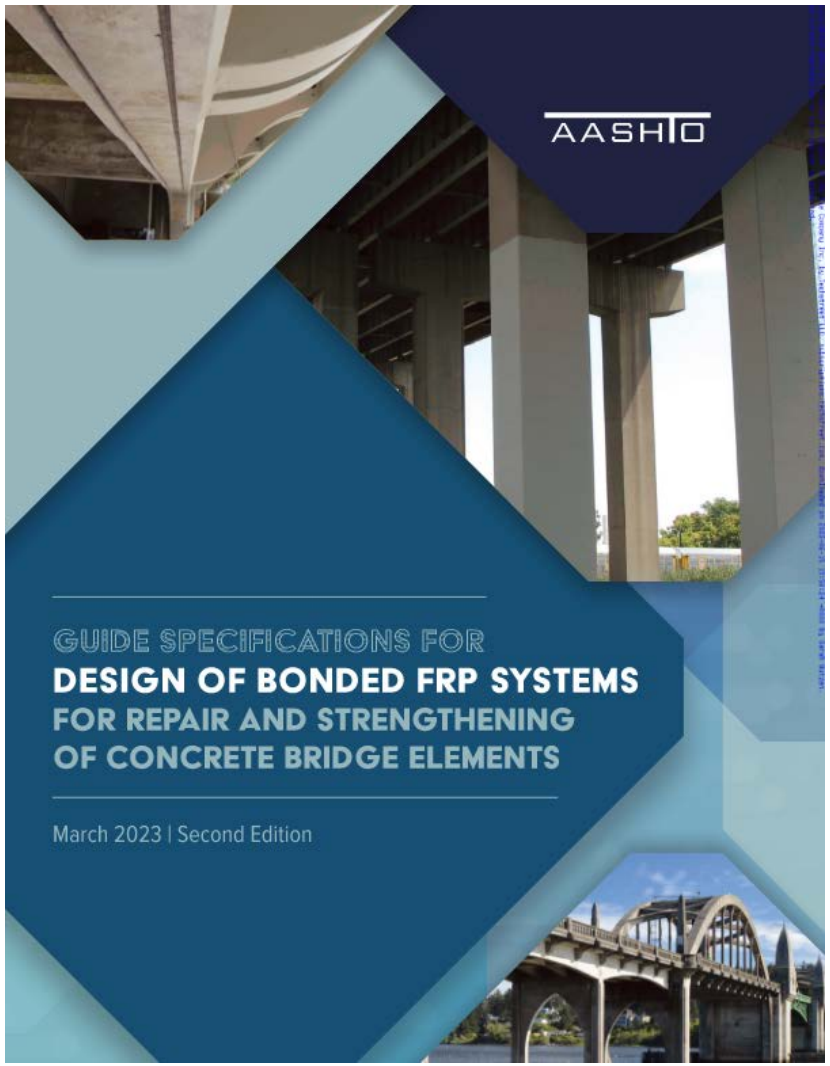
Where does the composite go?



Typical Placement – Externally Bonded FRP

How Do We Design FRP for Transportation Structures?





The Benefits of Strengthening with FRP

To make structures safer

- Retrofit older and possibly degrading bridges and other transportation structures

To make structures last longer

- FRP composites are protective as well as strengthening
- High performance coatings over FRP add durability

To make structures stronger

- Design Trucks load rating upgrades
- Barrier detailing changes impact effects on road surfaces and bridge decks

QA/QC for FRP Fabric: Ensuring Specified Performance

ASTM D3039 – Tension

- Send witness panels to independent lab
- Verify tensile modulus, strength, & strain

ASTM D4541 – Adhesion

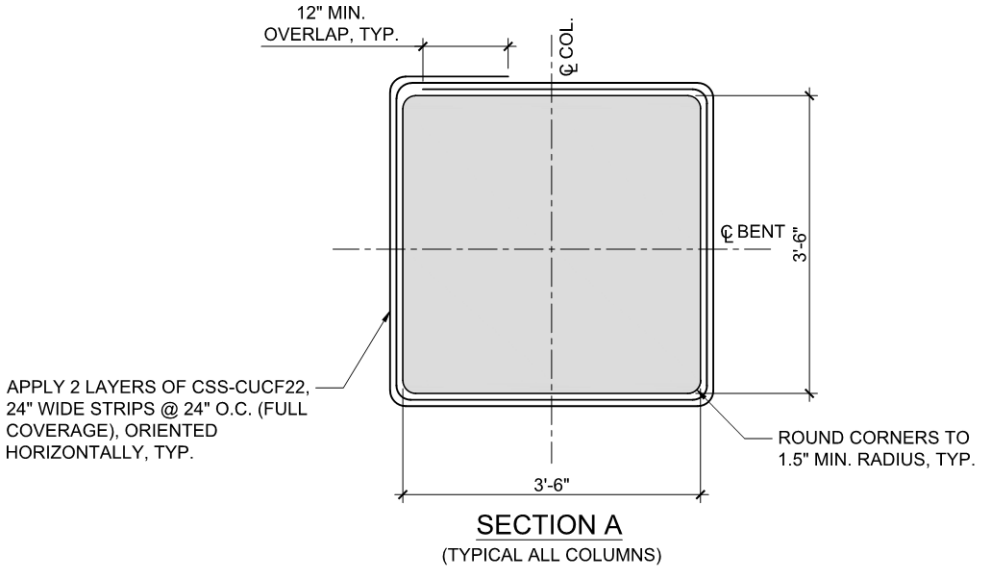
- Before and after installation
- > 200 psi
- Perform in low stress areas or representative mockups

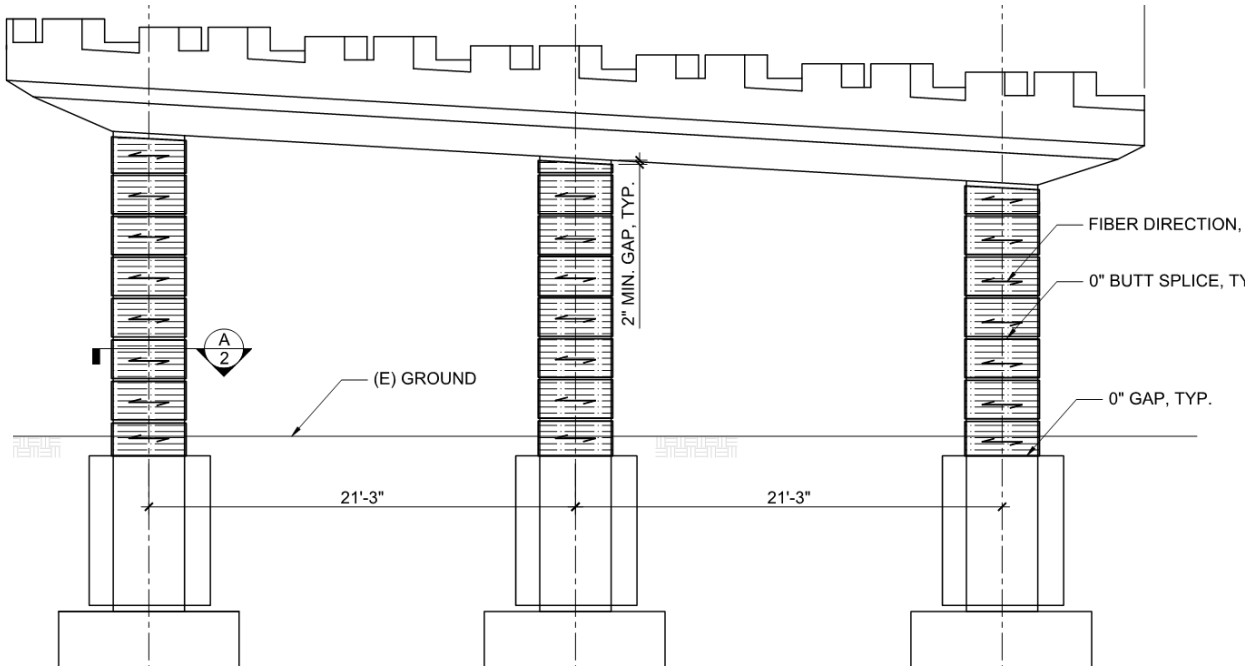
WHY FRP?

Next, a few sample project images to share the benefits and features of using FRP for transportation repair and retrofit.

I-80 Seismic Column Strengthening

- Seismic Strengthening
- General Scope of FRP – Shear strengthening of Columns

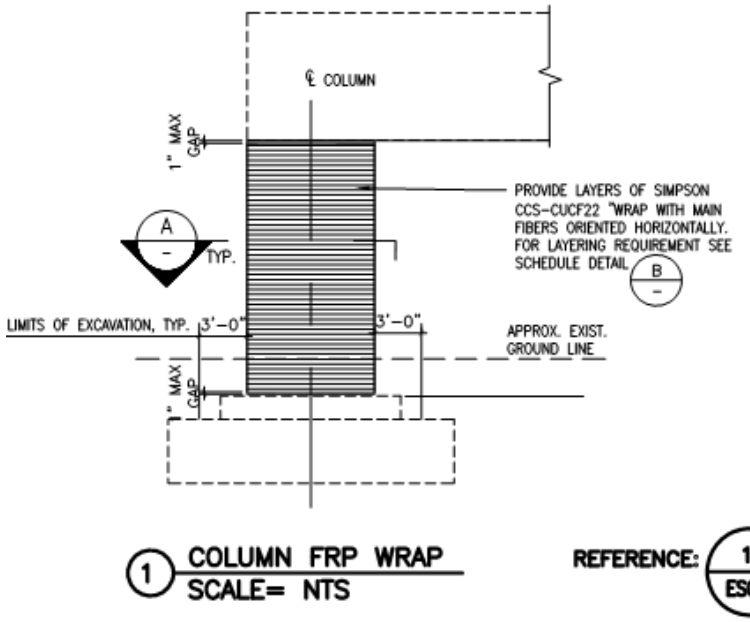


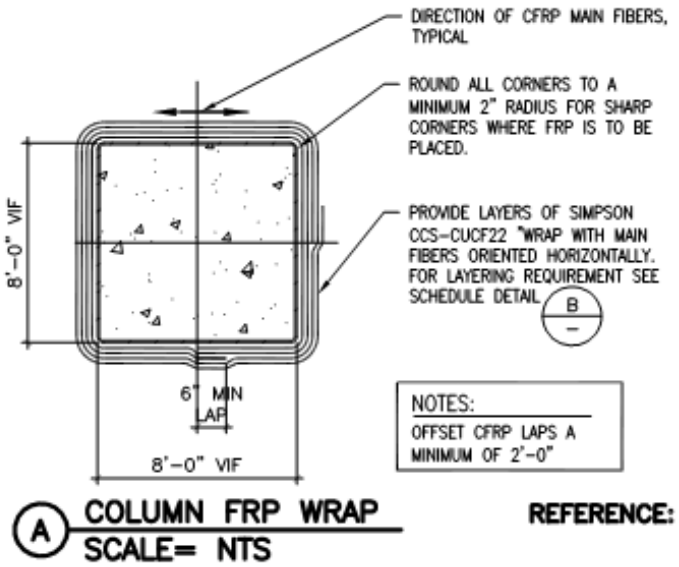


I-80 Seismic Column Strengthening

I-90 Seismic Retrofit, Multiple Locations

- Seismic Retrofit of Bridge
- General Scope of FRP – Shear strengthening of existing columns
- Several locations featured unique geometry

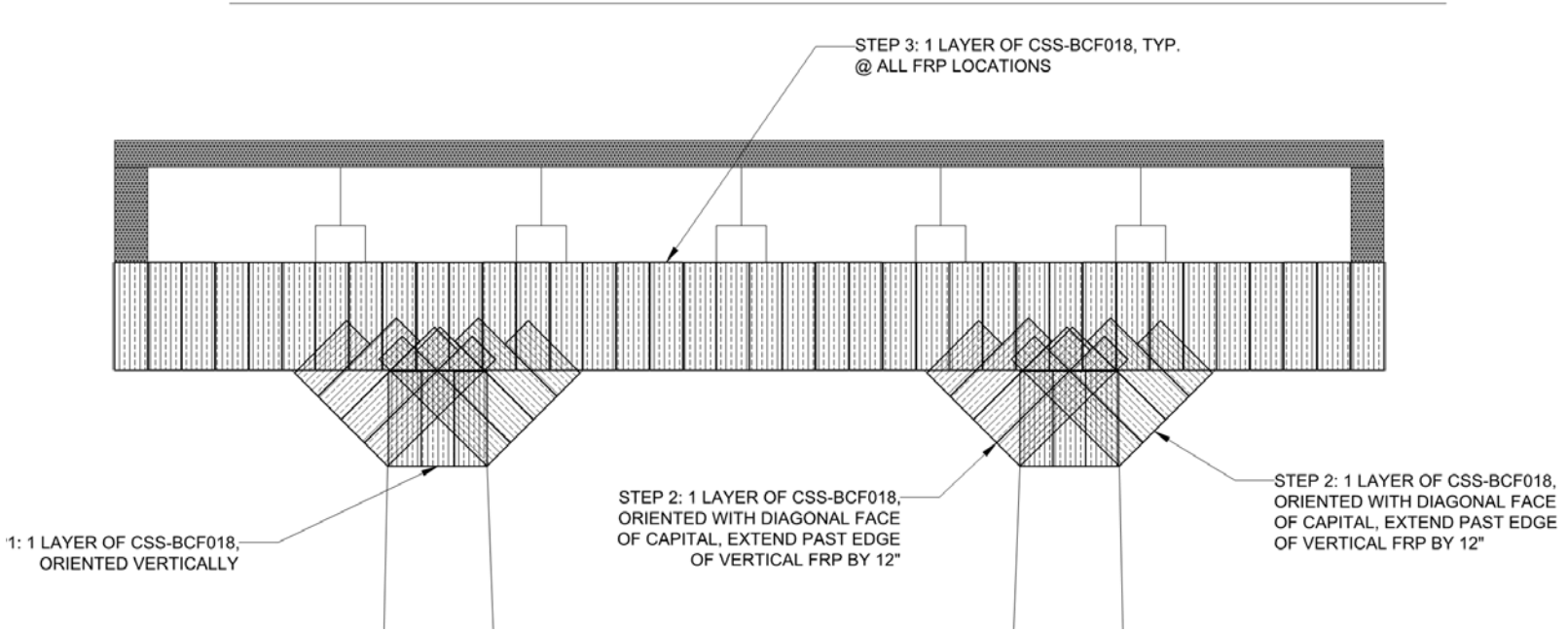




I-90 Seismic Retrofit: East Channel Bridge

I-25 Gravity Strengthening of Bridge Girders

- Gravity Strengthening of Bridge
- General Scope of FRP – Shear and flexural strengthening of existing girders
- Due to load rating upgrade



I-25 Gravity Strengthening of Bridge Girders

CASE STUDY: US50

FRP as a value-engineered alternative to steel jackets at concrete bridge columns.

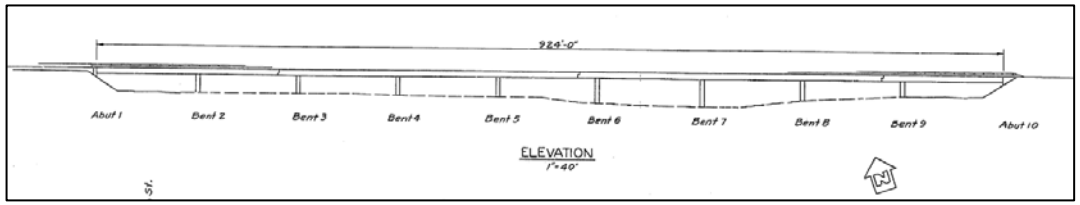
Project Background

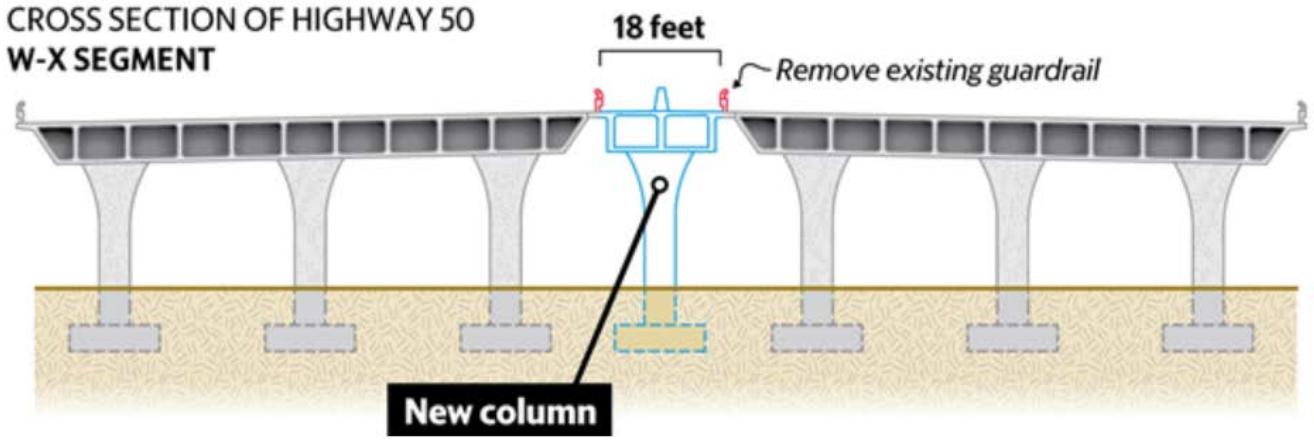
- Highway constructed in mid 1960's in Sacramento County, CA
- Enhance Sacramento's multimodal corridor network near downtown
  - Widen 11 bridges and seismic upgrades
  - 7 miles of carpool lanes
  - Replace all lanes pavements & asphalts
- Delivery: Design/Build (D/B)
- Construction
  - Summer 2020 – Spring 2024

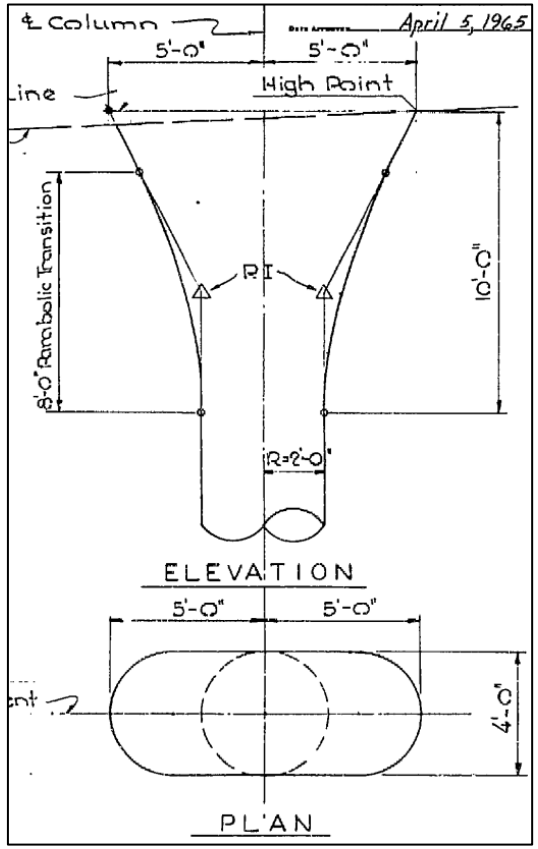
Project Location

Structure: Southside Park Viaduct (15/16th Street similar)

- Superstructure: CIP box girder
- Substructure: Columns supported by footings piles
- 48 Columns: 8 bents x 6 columns per bent (support)
- 4’ diameter columns with hyperbolic flare to 10’

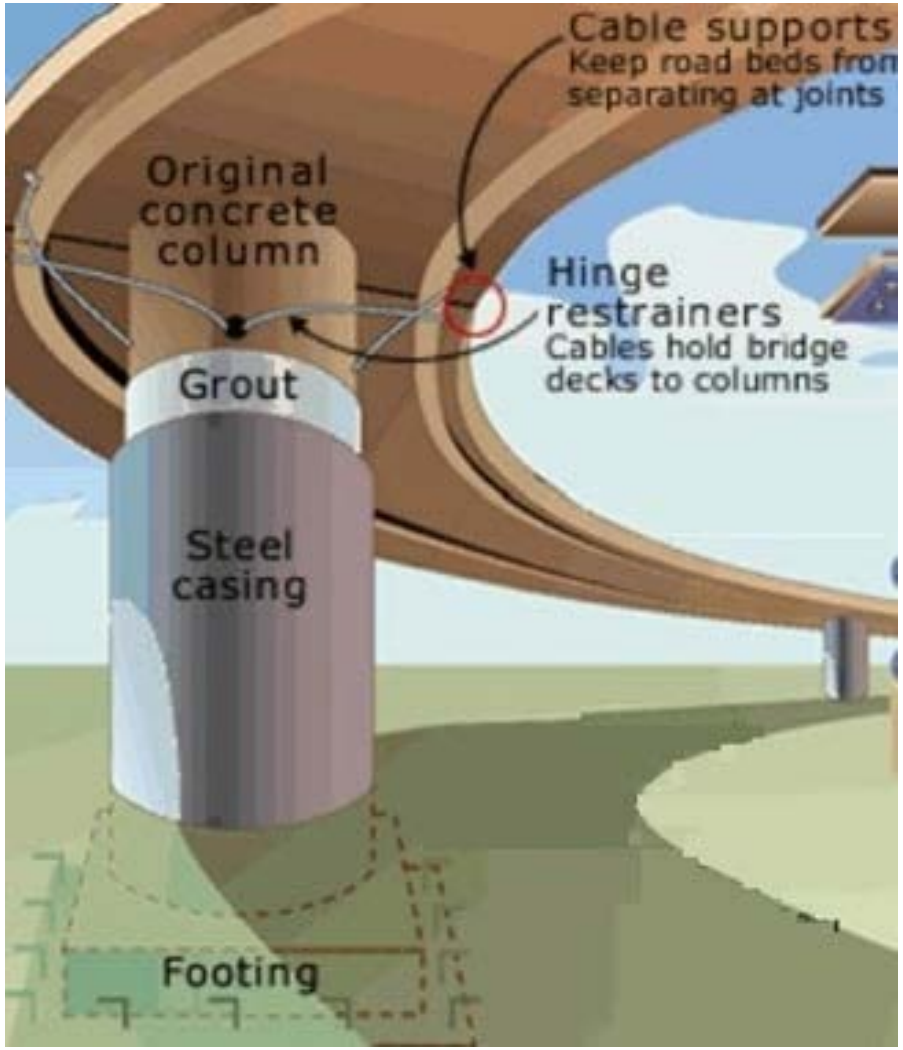






Original Solution: Column Steel Jacketing

- Steel casing fabricated in 2 halves welded together onsite with horizontal and vertical joints
- Thin layer of concrete grout fills in gap between steel casing and column
- Steel Jacket Design: ½” thick steel casing top of the foundation to the top of the column flare



Challenges

- Complexity: geometry with column flare adds significant lead time for material fabrication
- Lead time 12-16 weeks
- Pricing
- Fit up / Alignment / Weight
- Required Inspection
- Corrosion Concerns

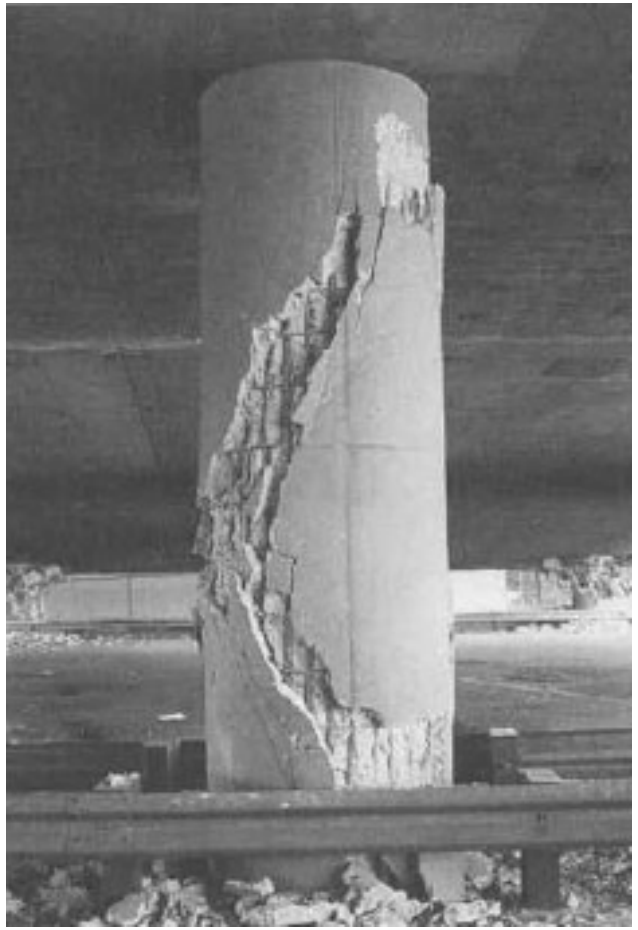
Original Solution: Column Steel Jacketing

- Column lack adequate confining steel that holds the column together during earthquakes
- Susceptible to Lap Splice, Confinement and Shear Failure.

<u>Steel Jacket Design</u>

- ½” thick steel casing **top of the foundation to the top of the column flare**

Typical Column Failure Modes



Shear

USGS

Confinement

Kenneth J. Elwood

Lap Splice

FRP Value Engineered (VE) Option – Benefits to D/B Team

Benefits

- Lightweight and much easier to install
- Eliminates welding
- Access issues / concerns are addressed
- Schedule and cost advantage (10-15% cheaper)
- Installed without cranes (Safety)
- Flexible installation of FRP on columns with complex geometry
- Long Term Durability: FRP does not corrode / degrade and may be finished with protective coating, offers an improved service life over steel

Value Engineering with D/B Delivery

- **Design / Build** delivery allows for creativity and optimization through a collaborative effort with all stake holders
- Contractors approached the project looking for technology that would set them apart from the competition while providing a cost advantage
- Conversations with Caltrans was positive when asking their appetite for alternative solutions
- FRP wrapping of columns was born from these conversations with the next steps being to evaluate the cost-benefits of an **ATC (Alternative Technical Concept)**

FRP Design Criteria

Design Approaches:

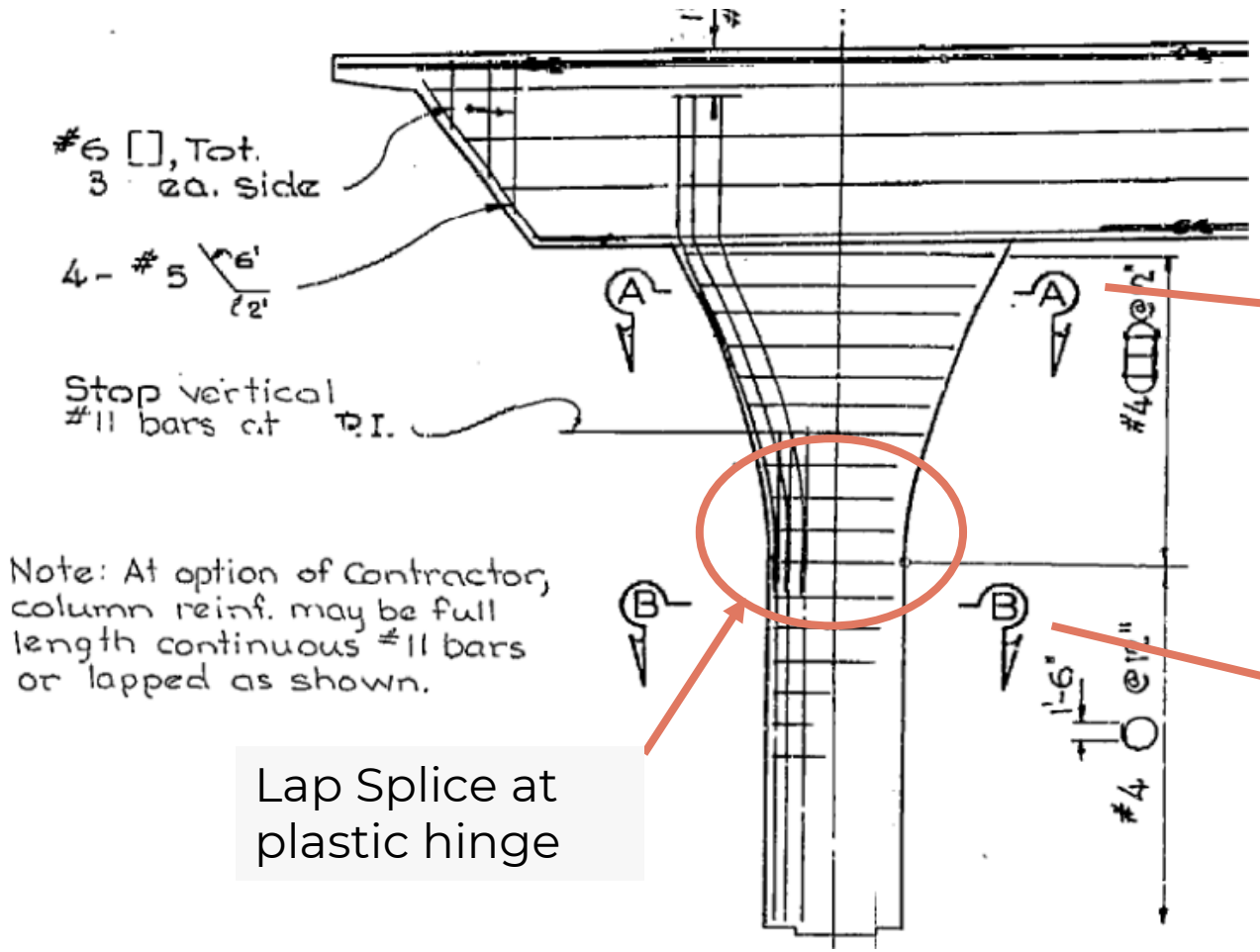
- *Option 1: Steel Equivalency (1/2")*
- *Option 2: Performance Criteria*

Performance Criteria provided by SEOR

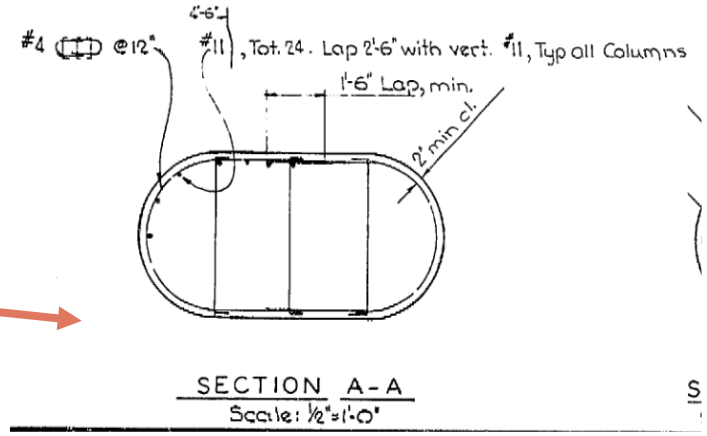
- Drift in Longitudinal Direction: 6.5 in.
- Drift in Transverse Direction: 5.0 in.
- Column Axial Force: 1100 kips
- Required Shear Strength: 1.2Vp
- Column fixed at the top and pinned at the bottom

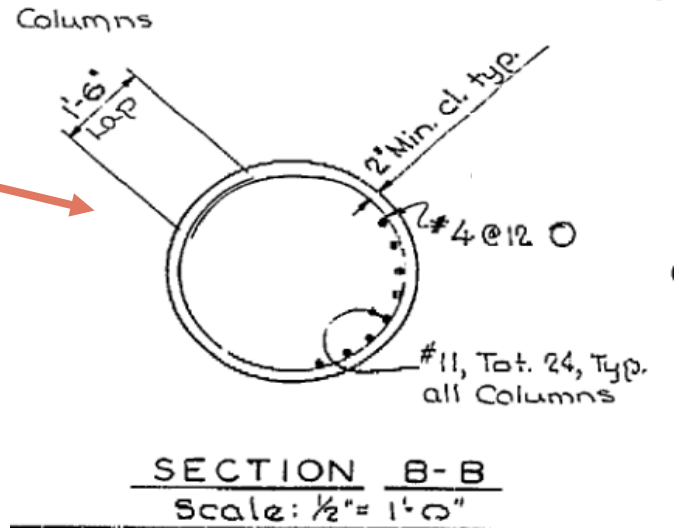
Performance Based Design

Existing Columns



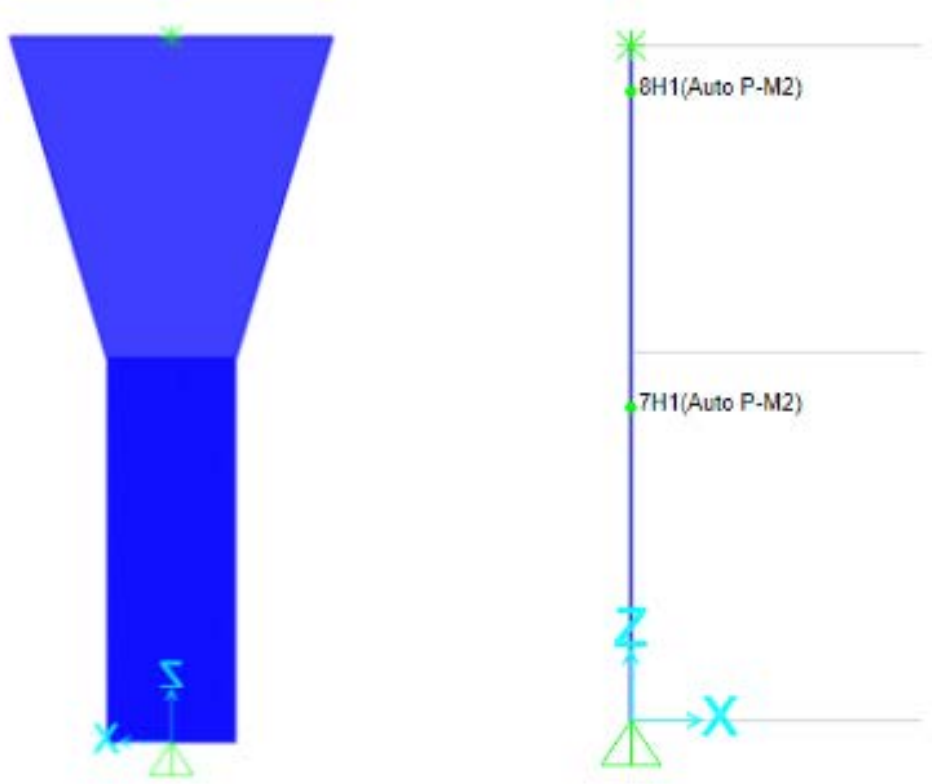
Lap Splice at plastic hinge

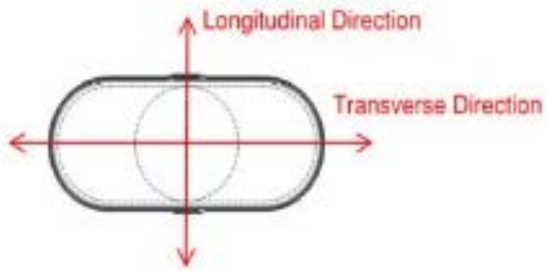




Plastic Hinge Confinement

Non-linear Modeling

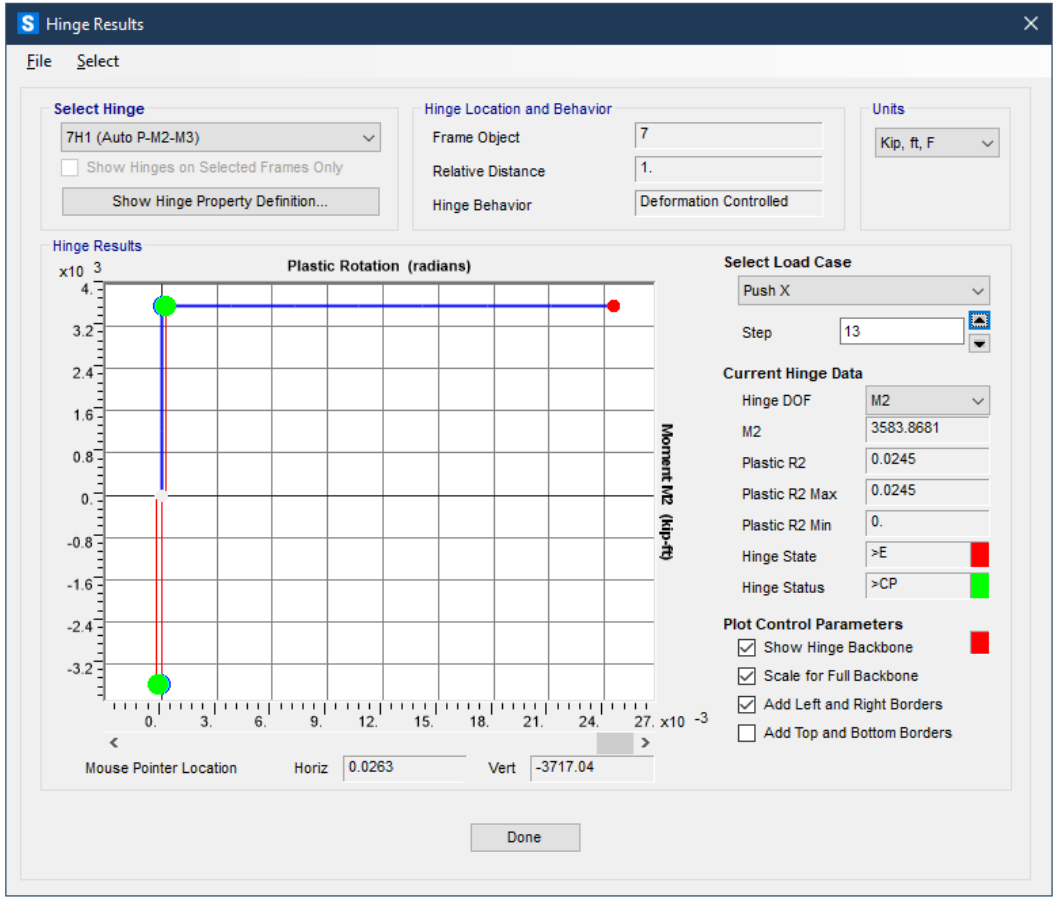




Modeling of columns in SAP 2000

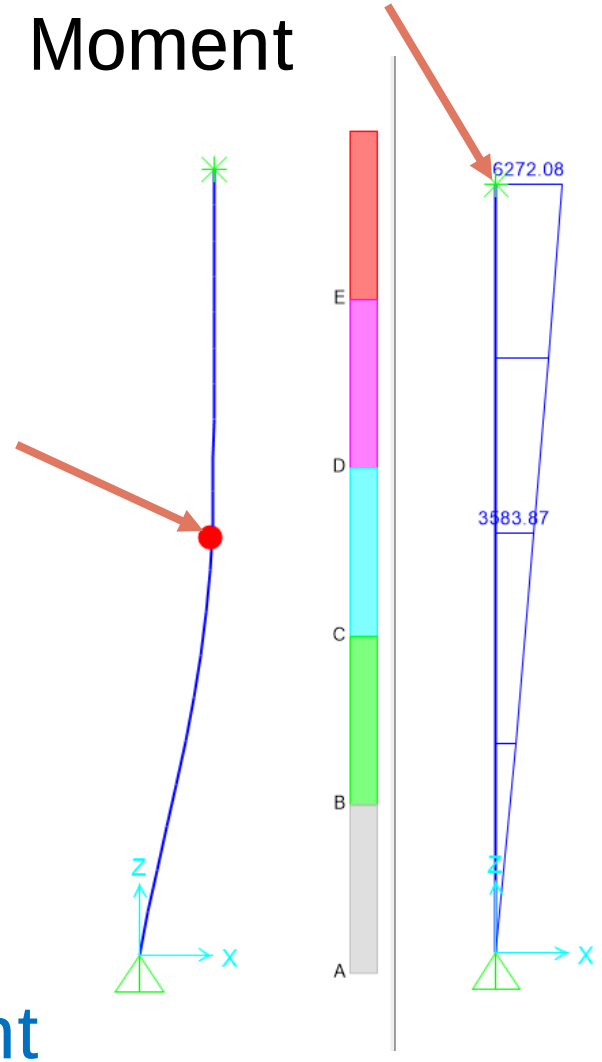
Plastic Hinge Confinement

Plastic Hinge Rotation



Max. Moment

Plastic Hinge



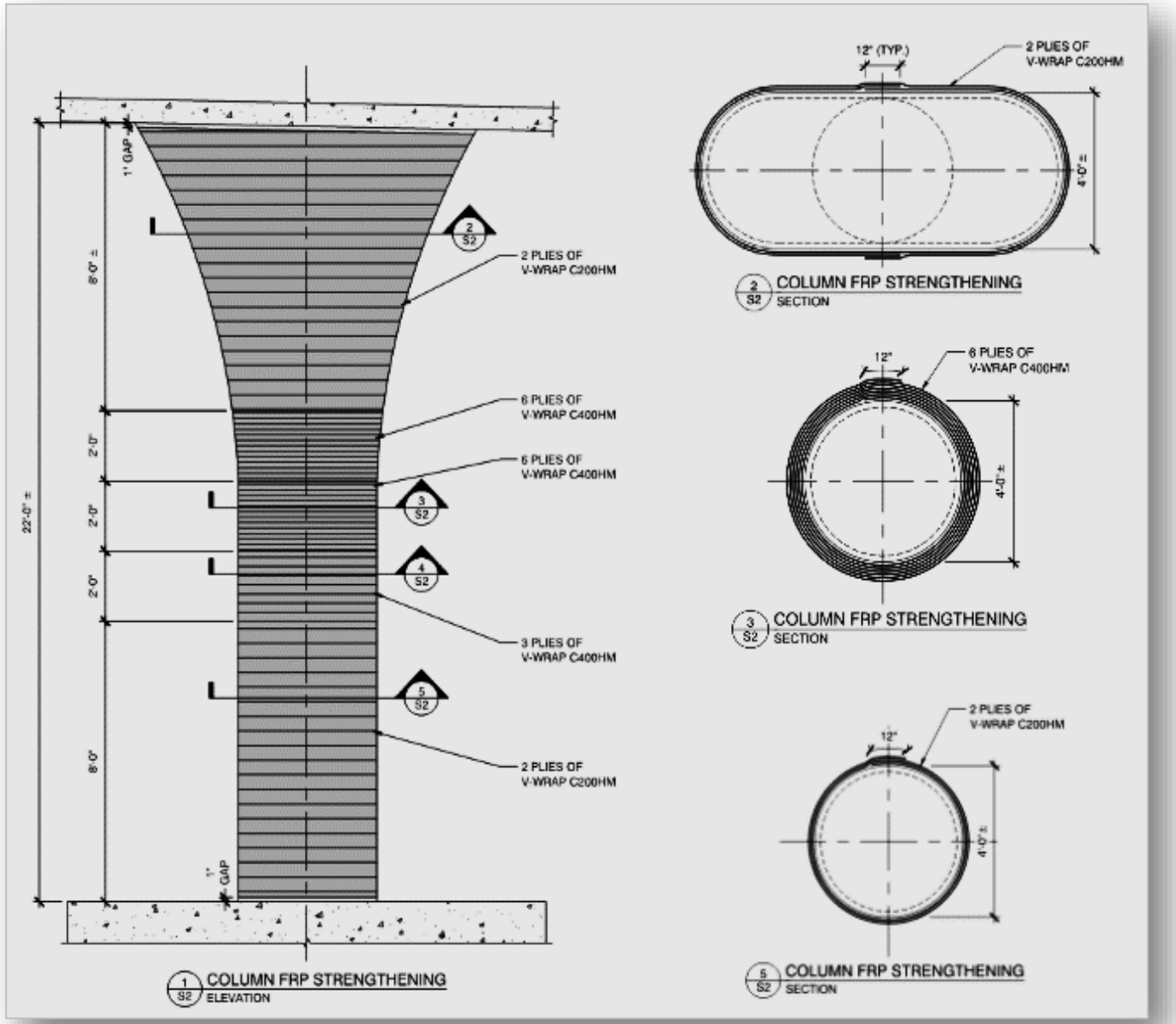
Plastic hinge **does not** occur at max. moment

Backbone Curve of FRP Confined Hinge

FRP Design Summary

Item	Existing Capacity	Demand	FRP Layout	FRP Strengthened	M_p Exist. (k-ft)	M_p FRP (k-ft)	Δ_{yi} (in)	Δ_D (in)	μ_D
Plastic Rotation at Bottom of Flare (Transverse)	0 rad	0.024 rad	6 Plies C400HM	0.034 rad	3791	4134	1.48	5	3.4
Plastic Rotation at the Top of Flare (Longitudinal)	0.026 rad	0.016 rad	2 Plies C200HM	0.03 rad	4952	4973	2.31	6.5	2.8
Shear Strength	301 kip	413 kip	2 Plies C200HM	558 kip					
Bar Lap Splice Capacity	36 ksi	48 ksi	5 Plies C400HM	48 ksi					

FRP Jacket: Final Design Detailing



FRP Installation Process – Substrate Preparation

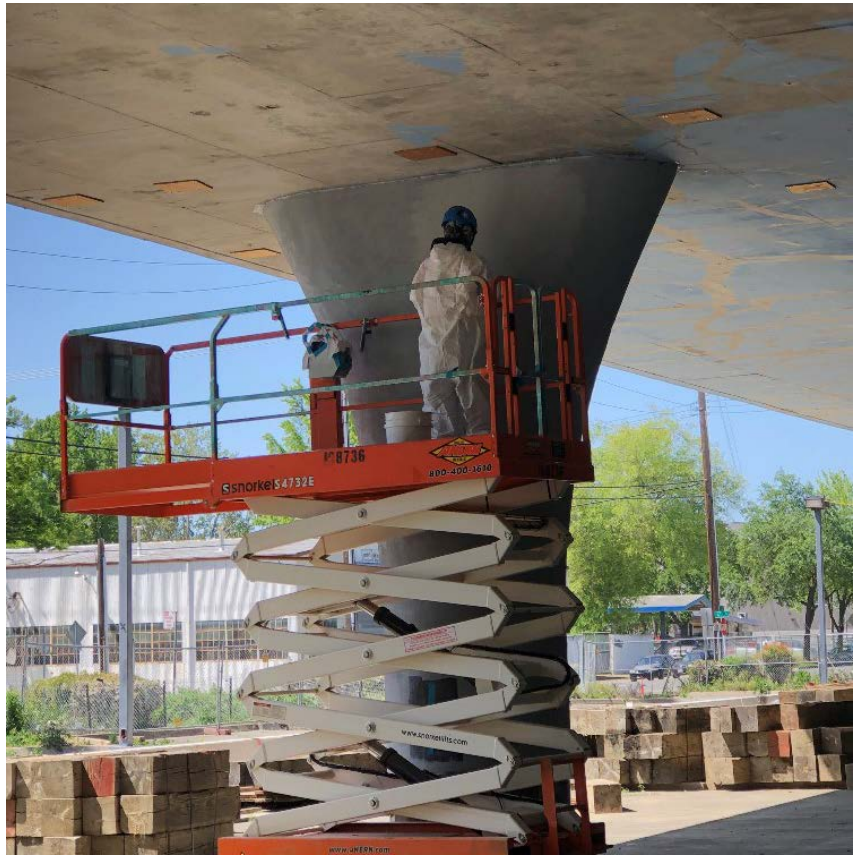
- Use mechanical grinder to open concrete pores and grind any concrete form lines
- Required surface profile, CSP3

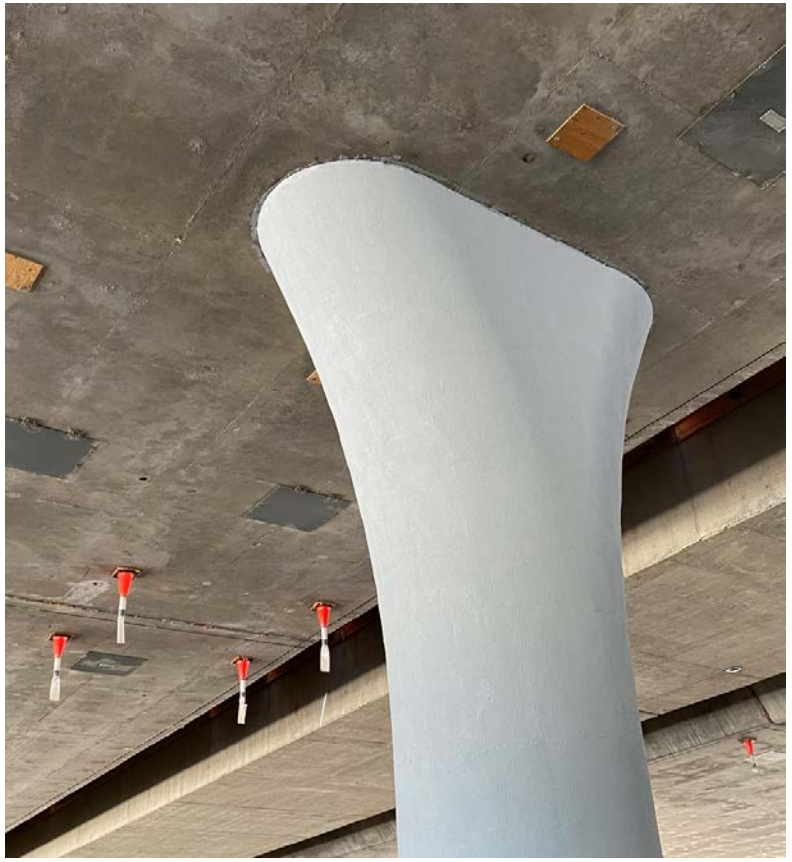
FRP Installation Process: Wrapping with FRP




- Excavate to top of footing
- Repeat steps for FRP installation

FRP Installation Process: Finishes





- Complete FRP wrapping
- Apply topcoat for long term protection

Summary

- Worked collaboratively with D/B team to explain FRP proof of concept & initial design for owner approval
- Provided input for FRP optimization and specifications
- Supplied/installed a carbon fiber strengthening system

Performance Factors	Steel Jacket	FRP Wrapping
Installed Cost (includes labor)	Base Price	Saved over $3,000 / col x 72 columns
Quality Assurance	Verify Welds ($$)	Direct Tension Tests ($)
Durability	Periodic maintenance	Corrosion resistant
Flexibility for Odd Shapes	Moderate	High
Materials Lead Time	12 – 16 weeks	2 – 3 weeks

QUESTIONS?

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