REPAIRING AND STRENGTHENING BRIDGES USING FRP

PRESENTED BY:

ERI VOKSHI, P.E.
SIKA CORPORATION, LYNDHURST, NJ

BUILDING TRUST

KEY LEARNING OBJECTIVES

01 **DETERMINE CAUSES BEHIND STRUCTURAL DETERIORATION IN BRIDGES AND TYPICAL STRENGTHENING TECHNIQUES**

02 **DESIGN AND SPECIFICATION CONSIDERATIONS FOR FRP, ALONG WITH AVAILABLE INDUSTRY GUIDELINES, FOR SUCCESSFUL USE OF MATERIALS**

03 **HIGHLIGHT MATERIALS THAT BE USED IN STRUCTURAL STRENGTHENING ALONG WITH THEIR ADVANTAGES AND DISADVANTAGES**

WHAT WE DO – BUILDING TRUST

Sika is a specialty chemicals company with a leading position in the development and production of systems and products for bonding, sealing, damping, reinforcing and protecting in the building sector and motor vehicle industry.

SIKA AT A GLANCE

+25,000	EMPLOYEES
100	COUNTRIES
300+	PLANTS WORLDWIDE
108	NEW PATENTS IN 2023
2	ACQUISITION IN 2023
11.24 BN	NET SALES IN 2023 (IN CHF)

WE ARE THERE

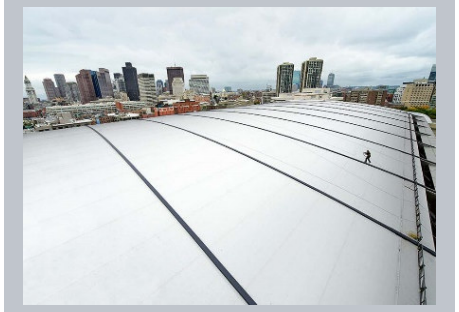
Our products might not always be visible but the results they achieve bring clear added value to customers and society.

FOCUS ON ATTRACTIVE MARKETS:
CROSS-SELLING, LIFE-CYCLE MANAGEMENT, ONE STRONG BRAND

Concrete

Waterproofing

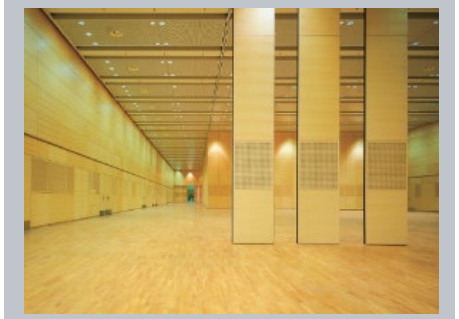
Roofing



Building Finishing

Flooring & Coating

Sealing & Bonding



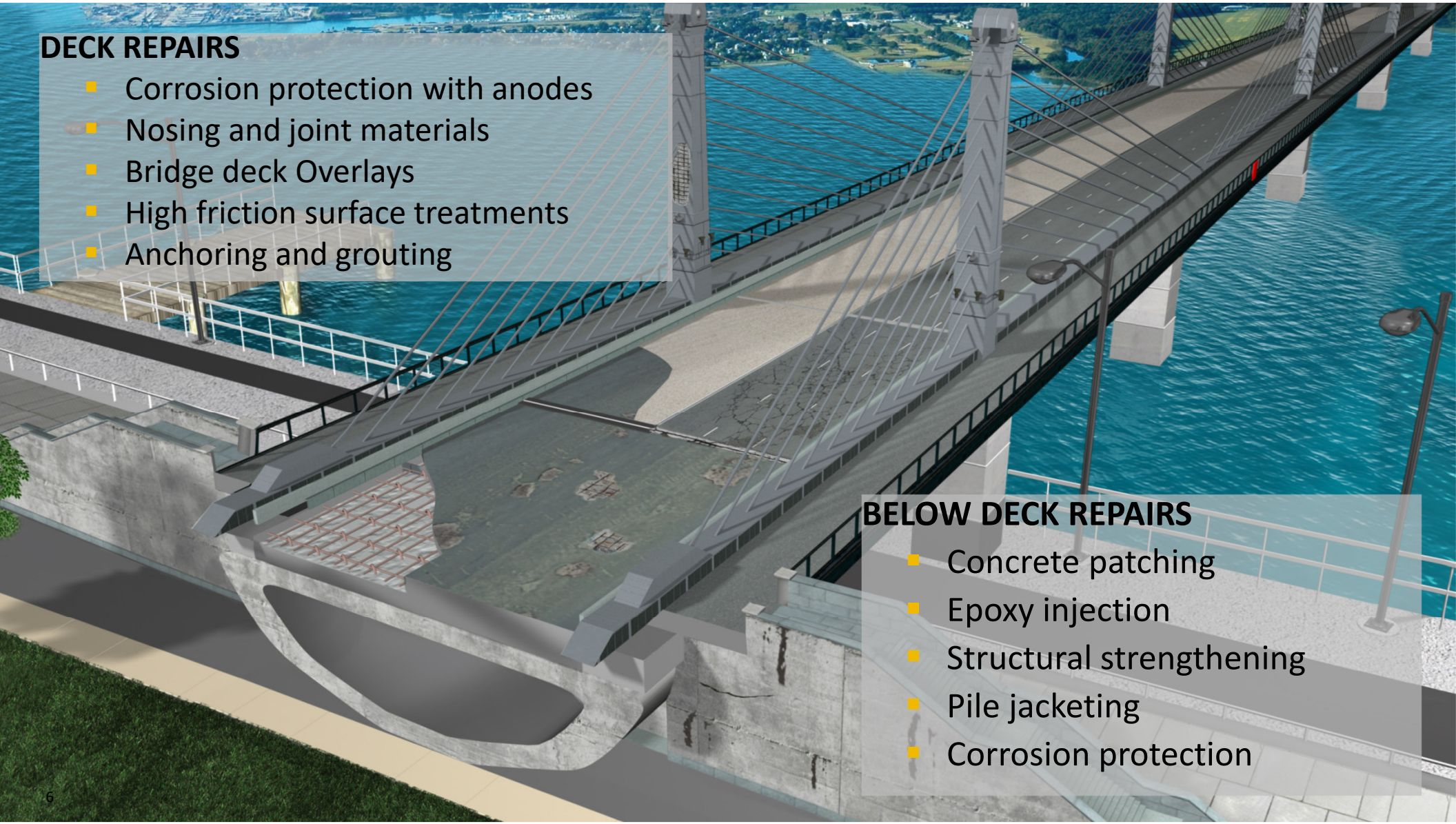
Refurbishment

Industry

CONCRETE REPAIR & PROTECTION

Repairing, protecting, and maintaining structures of all types is a necessary and worthwhile investment to extend a structure's usable service life.

Products	Product Families
Bonding Agents	Sika® Armatec®, Sikadur®, SikaLiquid® Weld
Coating & Water Repellents	Sikalastic®, Sikagard®
Concrete Fibers	Fibermesh®, Enduro®, Novomesh®
Corrosion Protection	Sika® FerroGard®, Sika Armatec®
Crack Injection	Sikadur®, SikaFix®, Sika® Inject
Expansion Joints	Emseal® Grouts Sikadur®, SikaGrout® Mortars SikaTop®, SikaQuick®, SikaCrete®, SikaRepair® Multipurpose Epoxies Sikadur® Structural Strengthening Sika Carbodur®, SikaWrap® Traffic Coatings Sikalastic® Deckpro
Grouts	Sikadur®, SikaGrout®
Mortars	SikaTop®, SikaQuick®, SikaCrete®, SikaRepair®
Multipurpose Epoxies	Sikadur®
Structural Strengthening	Sika® Carbodur®, SikaWrap®
Traffic Coatings	Sikalastic® Deckpro

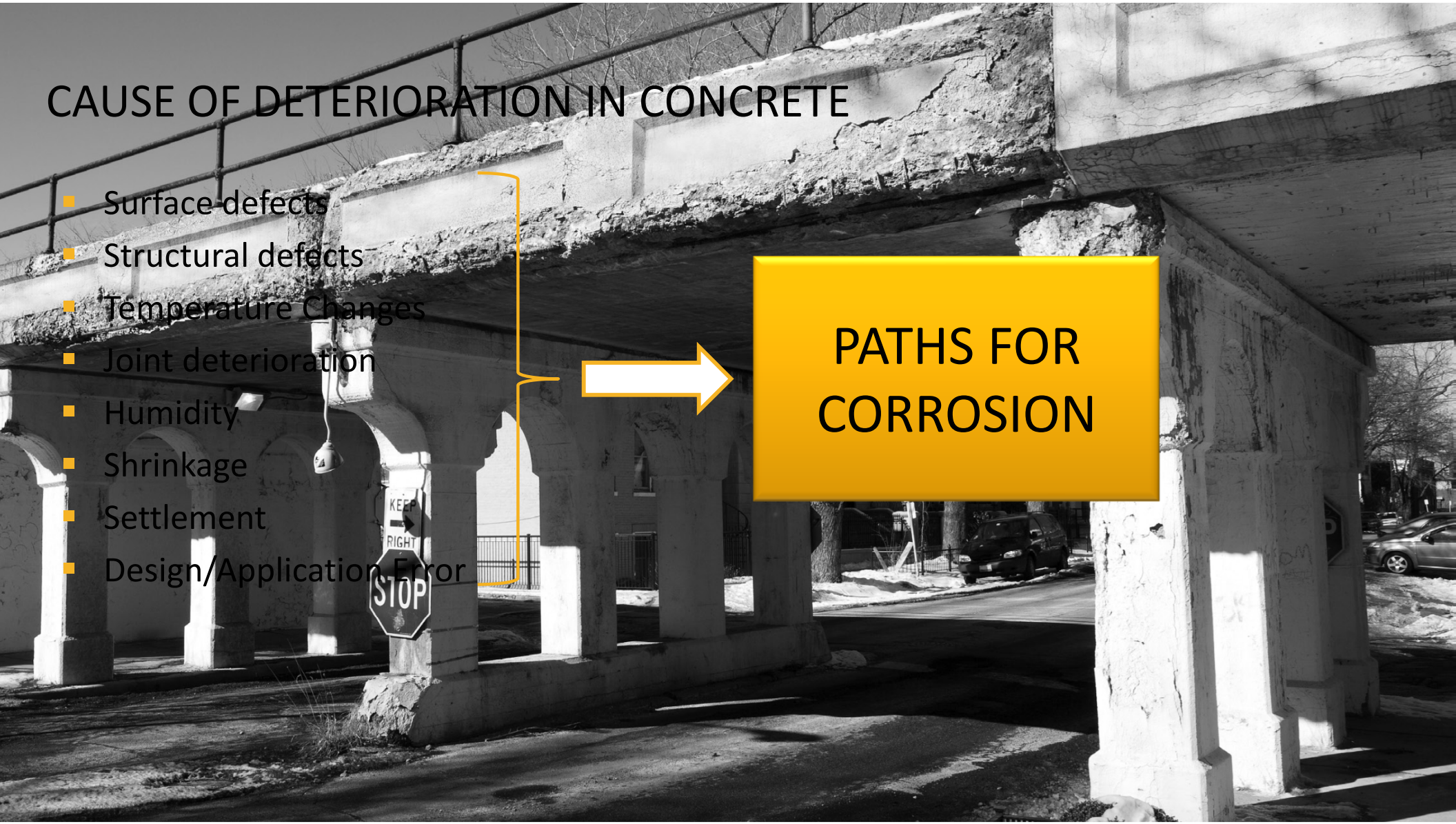

DECK REPAIRS
Corrosion protection with anodes
Nosing and joint materials
Bridge deck Overlays
High friction surface treatments
Anchoring and grouting
BELOW DECK REPAIRS
Concrete patching
Epoxy injection
Structural strengthening
Pile jacketing
Corrosion protection

U.S. INFRASTRUCTURE STATE

- American Society of Structural Engineers – Report Card
- Overall grade: C-
- Over 600,000 bridges in U.S.
- 231,000 bridges need repair
- 4 in 10 bridges are 50 years or older
- Total infrastructure needs: $5.94 TRILLION over 10 years

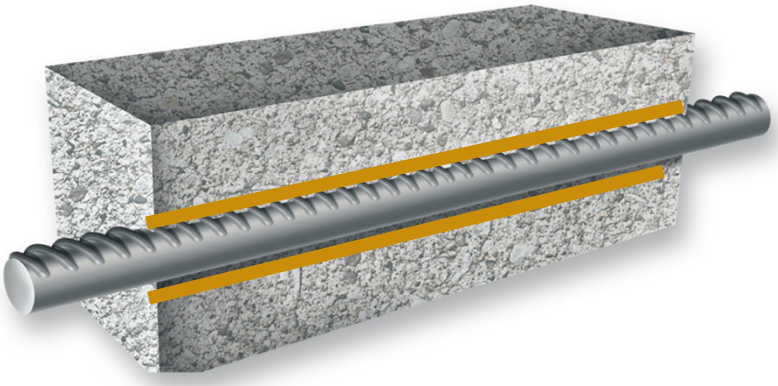
CAUSE OF DETERIORATION IN CONCRETE

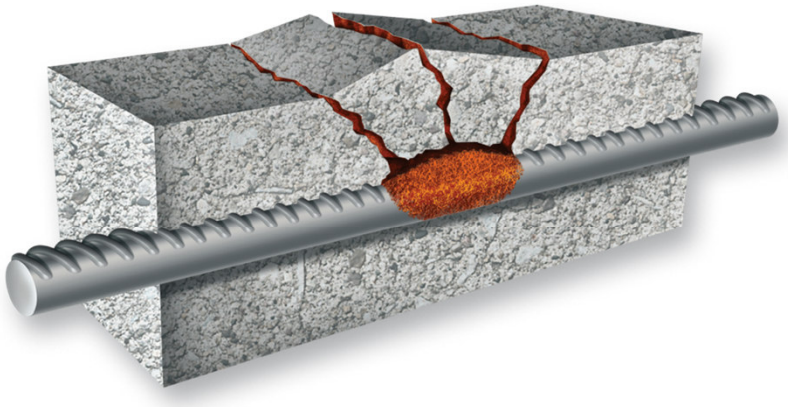
- Surface defects
- Structural defects
- Temperature Changes
- Joint deterioration
- Humidity
- Shrinkage
- Settlement
- Design/Application Error



PATHS FOR CORROSION

CORROSION CELL





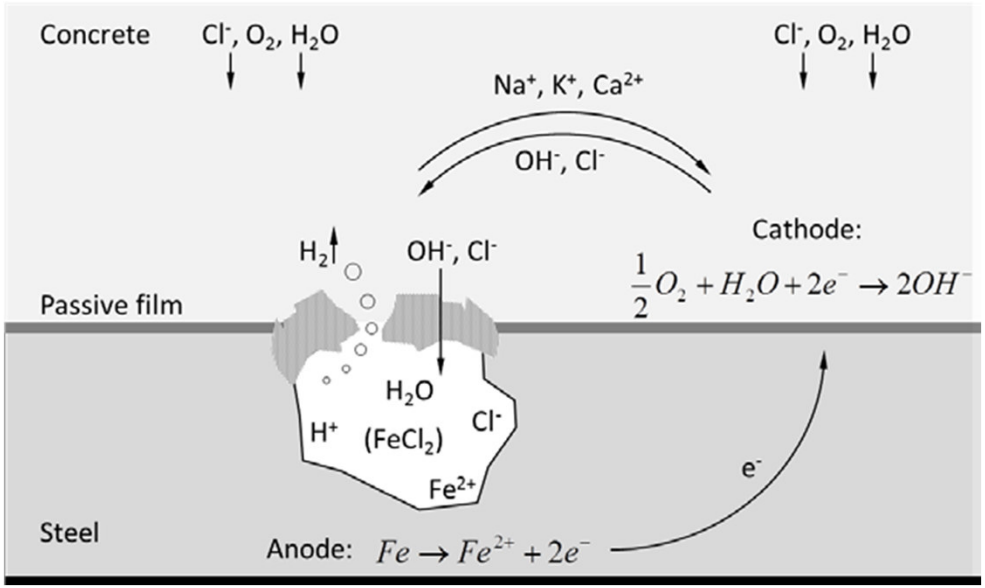
BUILDING TRUST

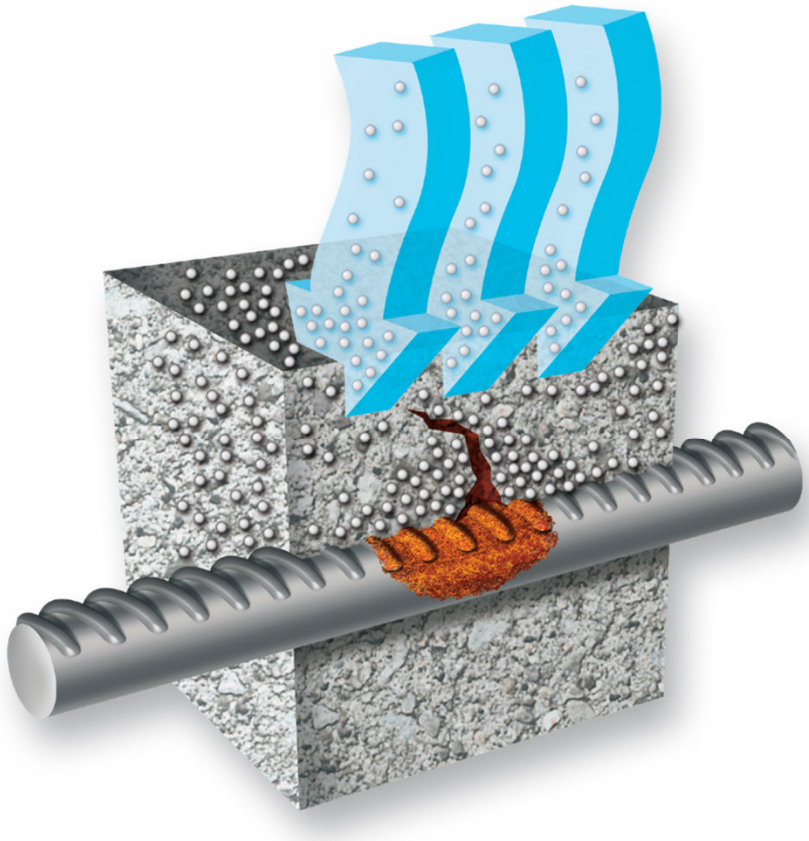
GIVEN SOME HELP……

BUILDING TRUST

CORROSION IS EVERYWHERE WE LOOK….

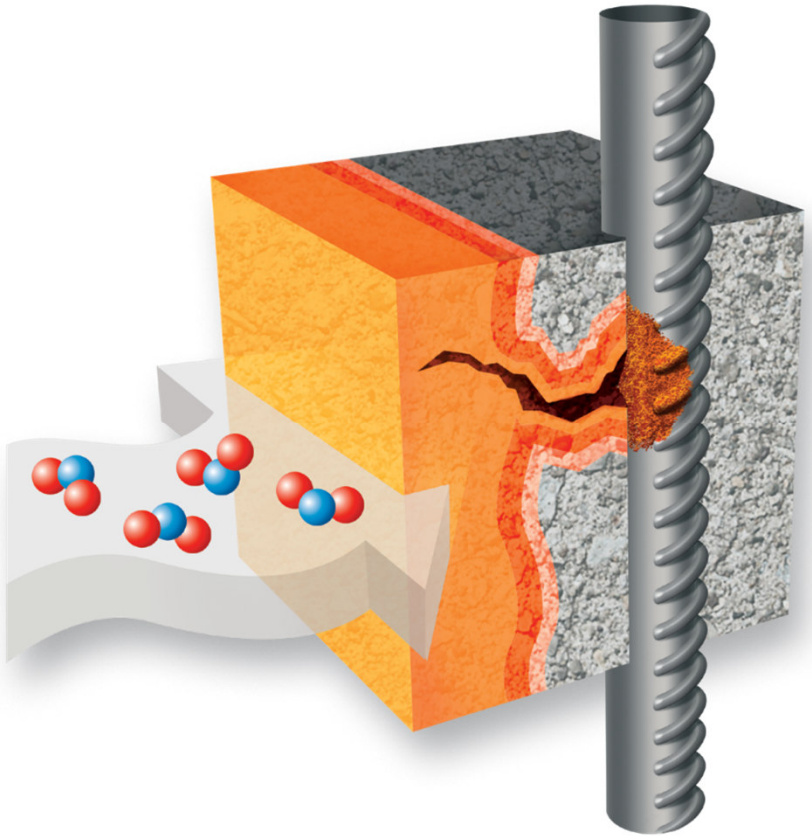
CHLORIDE INDUCED CORROSION

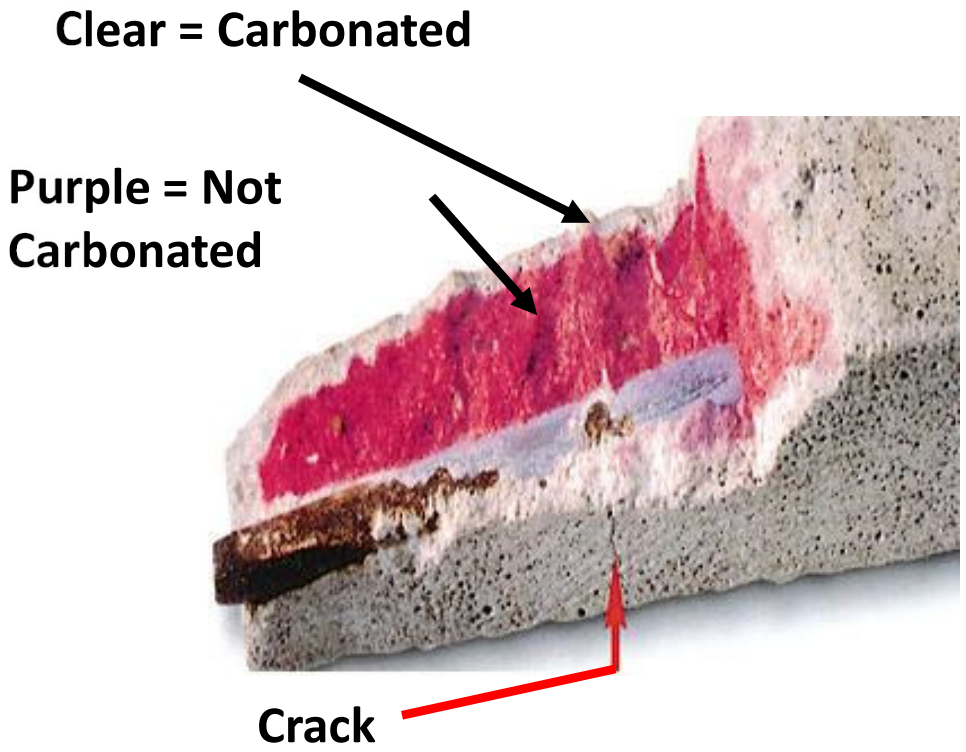




BUILDING TRUST

CARBONATION INDUCED CORROSION





TYPICAL CONCRETE DEFECTS

- Voids

- Honey Comb

TYPICAL CONCRETE DEFECTS

- Bug Holes

- Spalling

TYPICAL CONCRETE DEFECTS

- Cracks
  - Plastic Shrinkage

  - Scaling

TYPICAL STRUCTURAL DEFECTS

- Shear Cracks

- Major Spalling and rebar loss

EXTENDING SERVICE LIFE OF STRUCTURES
REPAIR, PROTECTION, AND STRENGTHENING PHILOSOPHY

Repair – Identify the root cause of issue and fix visible damage such as spalls, rough surface, cracks and joints

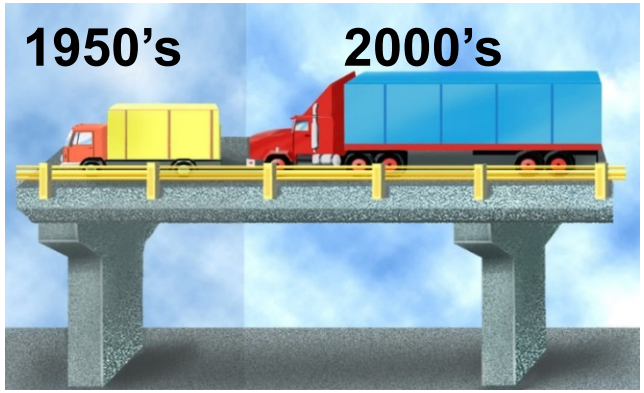
Protect - ACTIVELY mitigate corrosion on steel

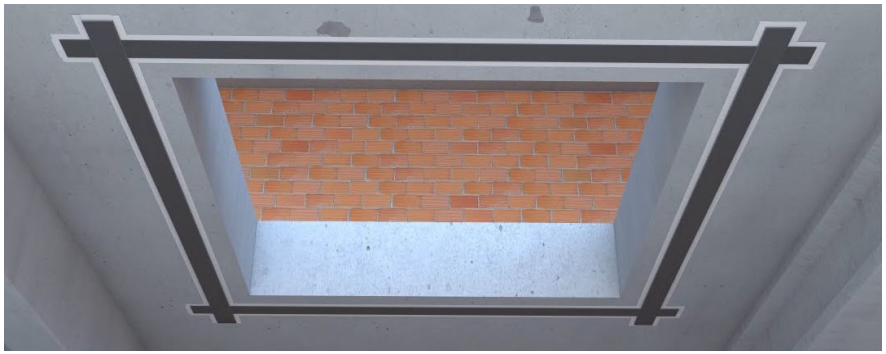
- Prevent further ingress of chemicals
- Monitor health of structure

Strengthen - Add lost or missing capacity to members that are deficient

WHY DO STRUCTURES NEED STRENGTHENING?

- Insufficient reinforcement
- Corrosion damage
- Change in use
- Structural damage
- Seismic upgrade





BUILDING TRUST

HOW ARE STRUCTURES STRENGTHENED
TYPICAL STRENGTHENING METHODS

EXTERNALLY BONDED FRP OR STEEL

Traditionally done with steel, most bonded strengthening is nowdays done with FRP

SECTION ENLARGEMENT

Used frequently, this method is intrusive to the structure, adds a lot of weight, and takes longer to implement

EXTERNAL POST-TENSIONING

For cases where high-capacity contribution is required, external PT is great solution. Traditionally done with steel, PT strengthening can also be done with FRP

SUPPLEMENTAL SUPPORTS

Supplemental supports are a great solution, though they take headspace and can be tricky to install.

WHAT ARE FRP SYSTEMS?

FABRIC

Fabrics are made from glass or carbon fiber.

RESIN

Most used resins to saturate the fabrics are epoxy and more recently PU.

REINFORCED CONCRETE

Reinforced concrete is a composite. Bonding FRP to it creates a complex system. Understanding how to design with it properly is critical for successful strengthening.

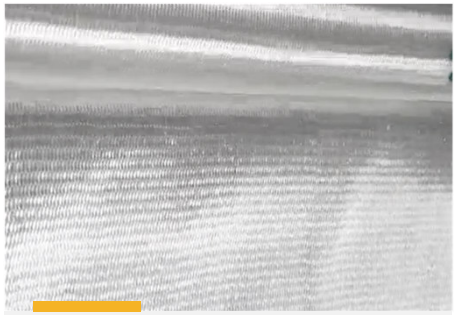
MOST COMMON FRP MATERIALS
GLASS VS CARBON

Carbon Systems (CFRP)

- Damp/wet conditions
- Stiffness driven
- Extreme alkaline conditions

Stronger, stiffer, more durable

CFRP



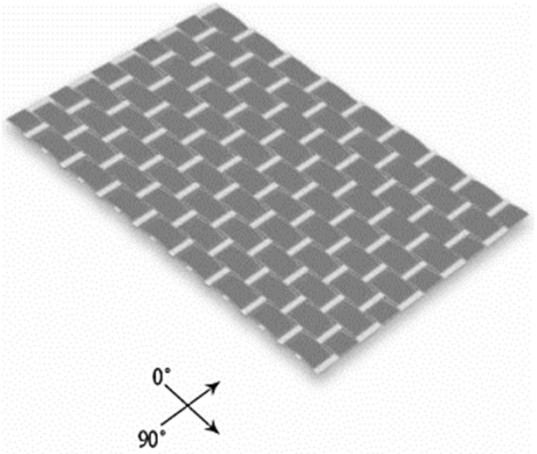
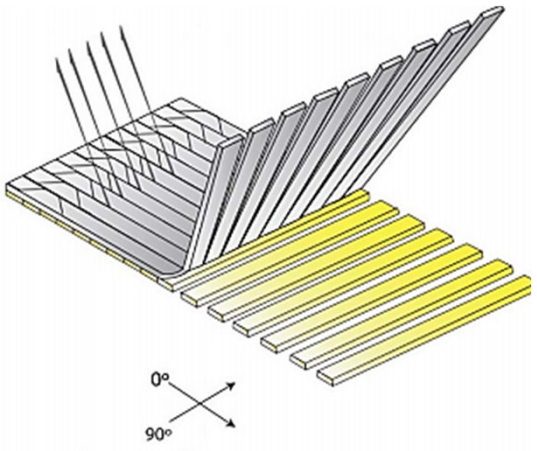
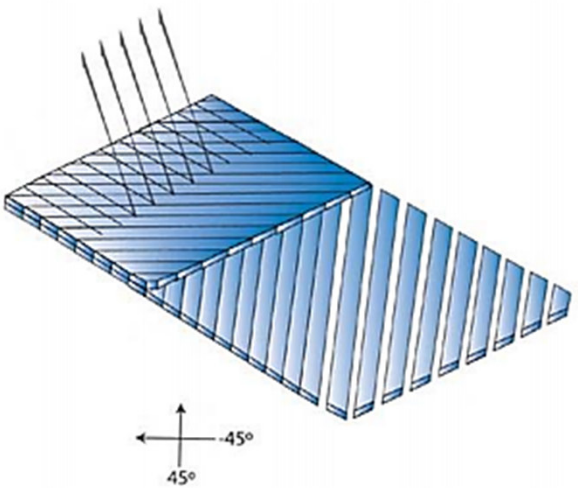
Glass Systems (GFRP)

- Seismic strengthening
- Dry conditions
- Extreme acidic conditions
- Economical

Economical, used commonly for seismic retrofit

GFRP

FRP FABRIC TYPES

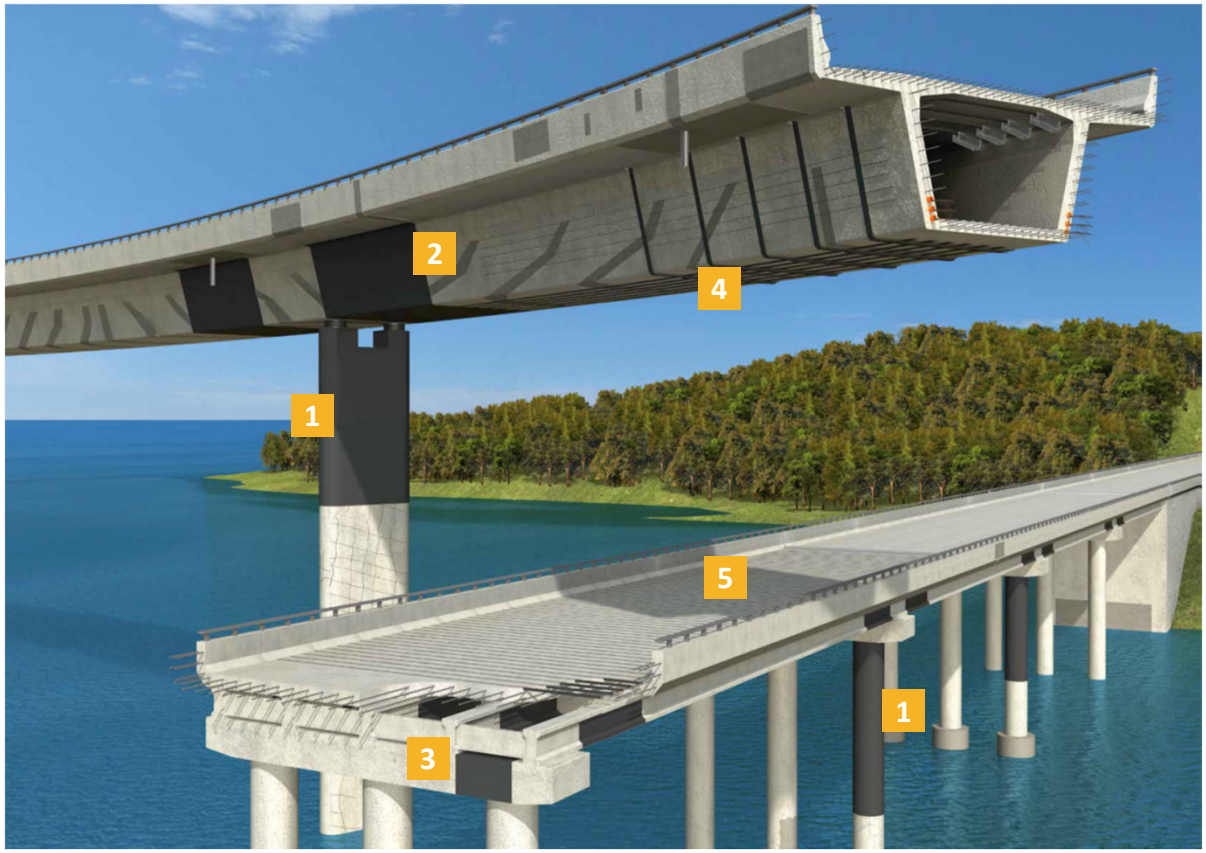
Uniaxial Fabrics	Biaxial Fabrics	+/-45d Fabrics
		

ADVANTAGES OF FRP REPAIRS

- Cost/scheduling benefits
- Reduced maintenance costs
- Light weight materials puts less strain on the structure
- Non-corrosive, designed for long-term performance

TYPICAL APPLICATIONS

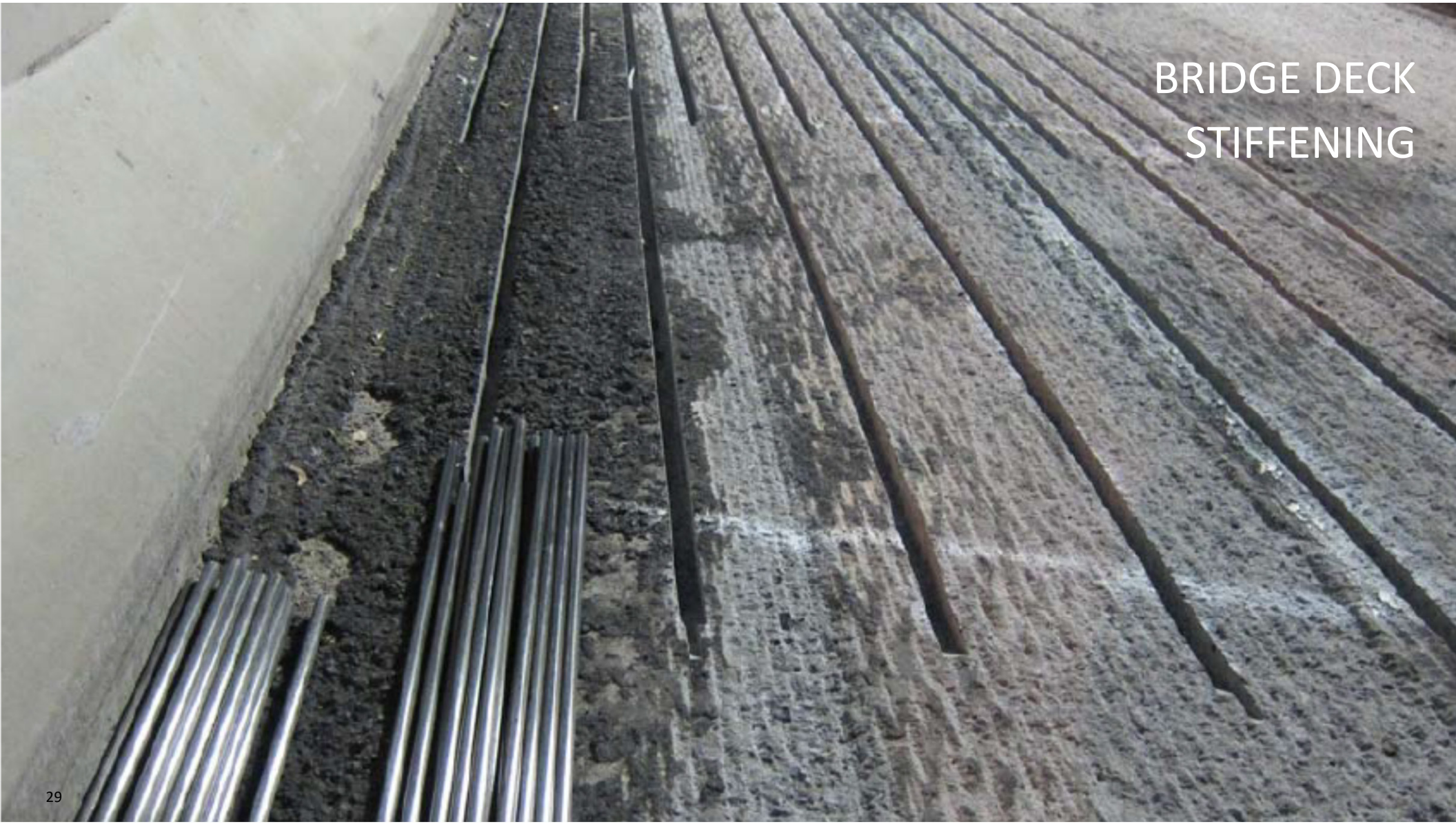
TYPICAL USE
BRIDGE APPLICATIONS



1. **Pier confinement**
2. **Shear strengthening of girders**
3. **Shear strengthening of pier caps**
4. **Flexural strengthening of girders**
5. **Deck Stiffening**

PIER CONFINEMENT AND PIER CAP SHEAR STRENGTHENING

GIRDER FLEXURAL STRENGTHENING


BRIDGE DECK
STIFFENING

TYPICAL APPLICATIONS

Building and Parking Structures

- Shear Strengthening
- Corrosion Damage
- Column strengthening
- Modifications (wall or slab openings)
- Change in use
- Seismic upgrades

DESIGN GUIDES AND PRINCIPALS

BUILDING TRUST

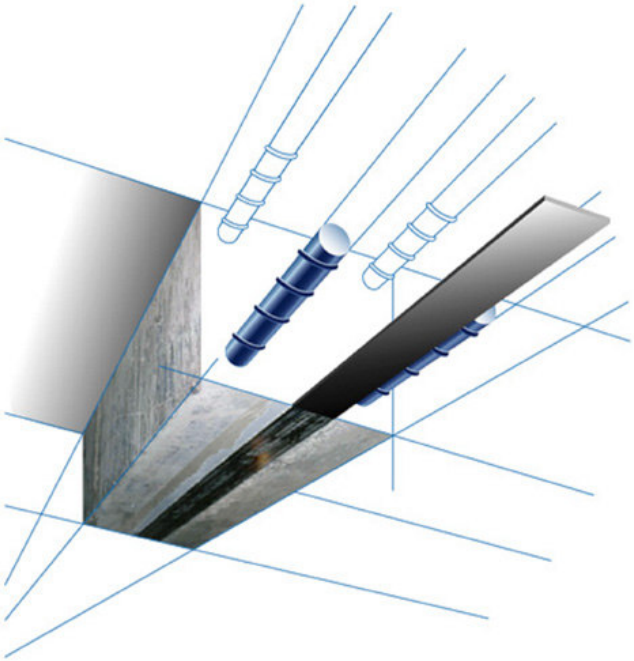
CODES AND STANDARDS

- AASHTO Guide 2nd Ed
  - Guide Specification for Design of Bonded FRP Systems for Repair of Strengthening Concrete Bridge Elements

- ACI 440.2R-17
  - Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures

DESIGNING WITH FRP

- Provides secondary reinforcement



FRP Limitations

"SUPPLEMENTAL REINFORCEMENT"

AASHTO STRENGTHENING LIMIT

$$R_r \geq \eta_i\left[(DC+DW)+(LL+IM)\right] \qquad (1.4.4\text{-}1)$$

ACI 440 STRENGTHENING LIMIT

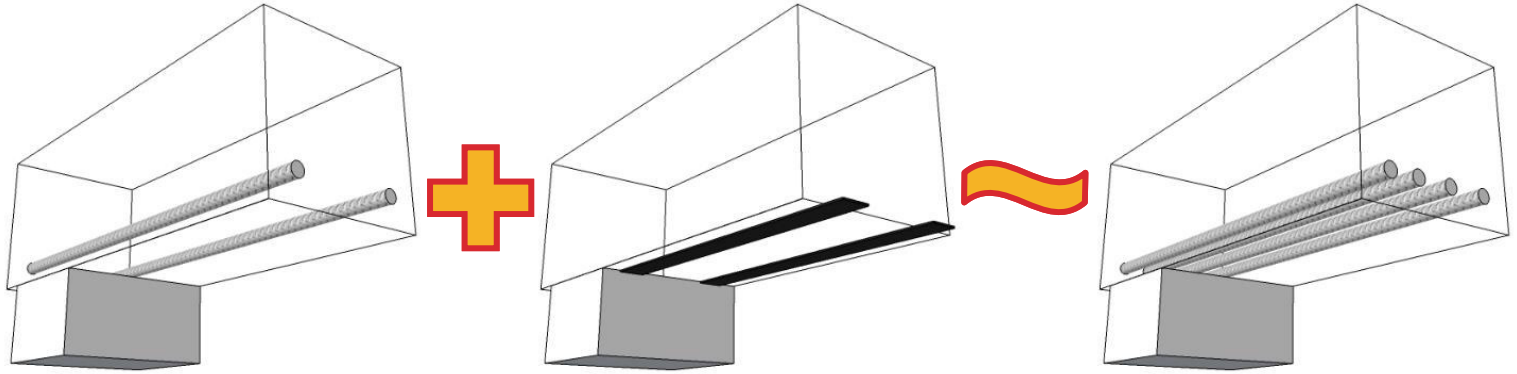
$$(\phi R_n)_{existing} \geq (1.1S_{DL} + 0.75S_{LL})_{new}$$

Existing Capacity ≥ Load demand:
1.1DL + .75LL

BUILDING TRUST

HOW DOES CFRP AFFECTS A REINFORCED BEAM?

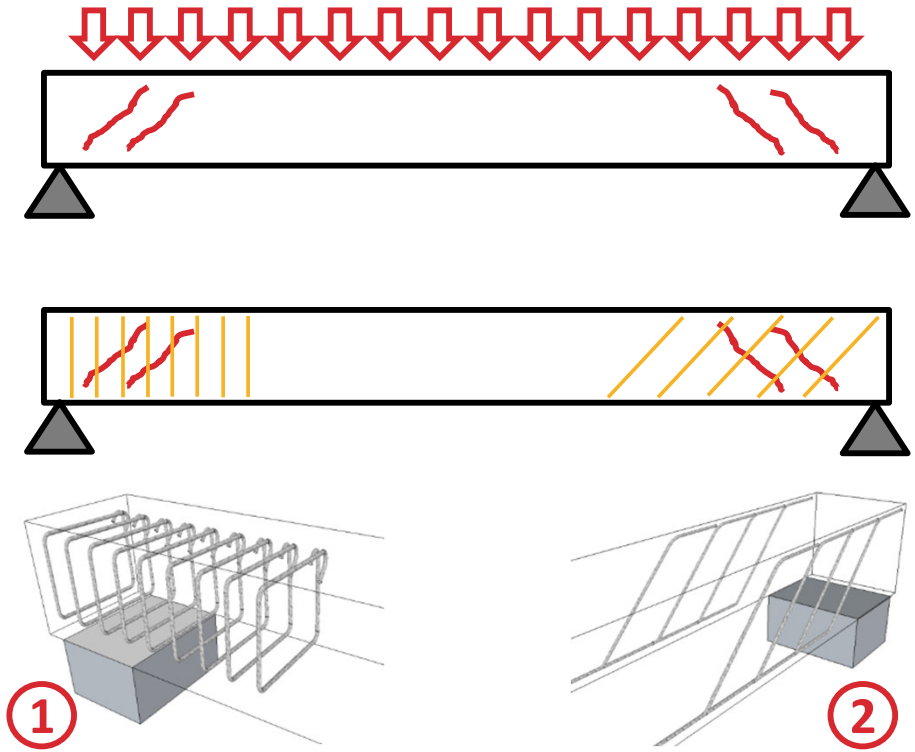
FLEXURAL STRENGTHENING



BUILDING TRUST

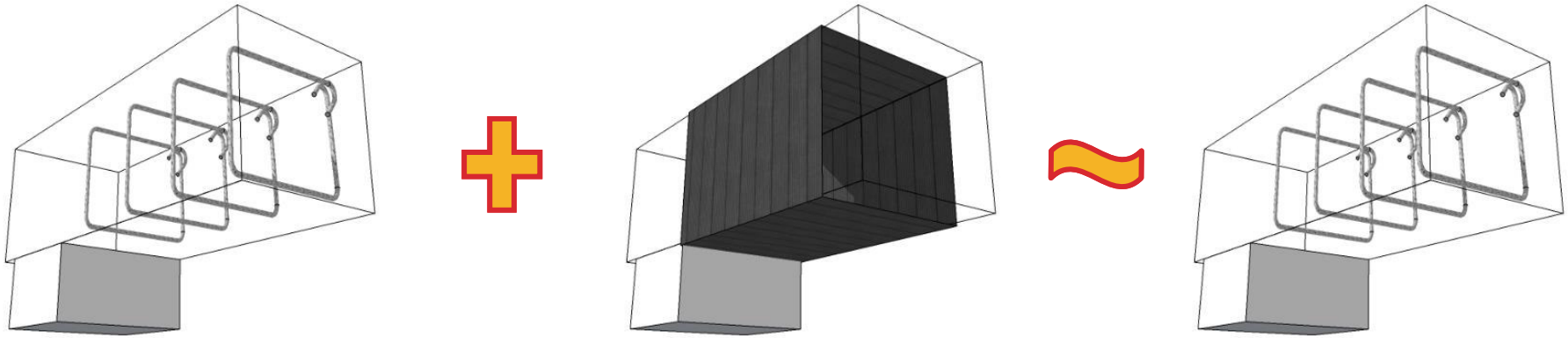
MAIN TYPES OF STRENGTHENING

SHEAR



BUILDING TRUST

HOW DOES CFRP AFFECTS A REINFORCED BEAM?
SHEAR STRENGTHENING



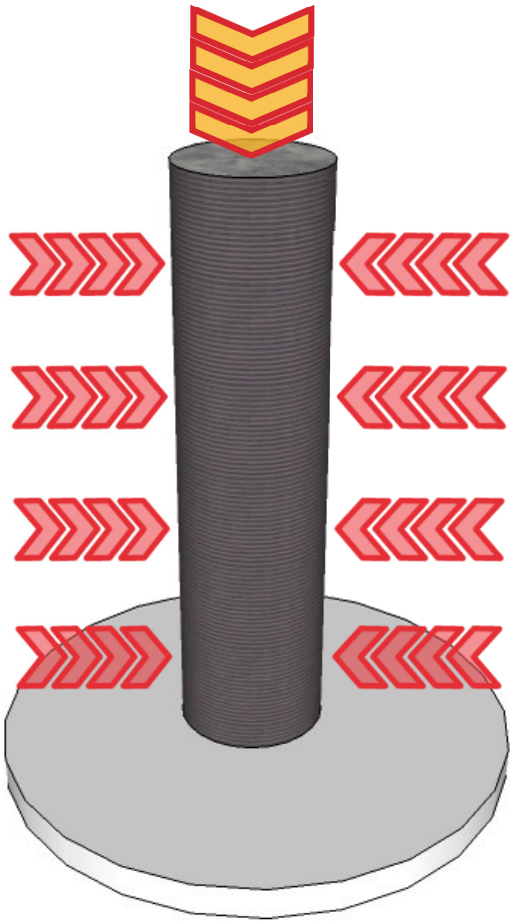
BUILDING TRUST

SHEAR STRENGTHENING

TYPES OF STRENGTHENING

CONFINEMENT

To avoid the lateral expansion, its necessary to ensure a confinement around the element using a rigid material with a high strength such as FRPs.



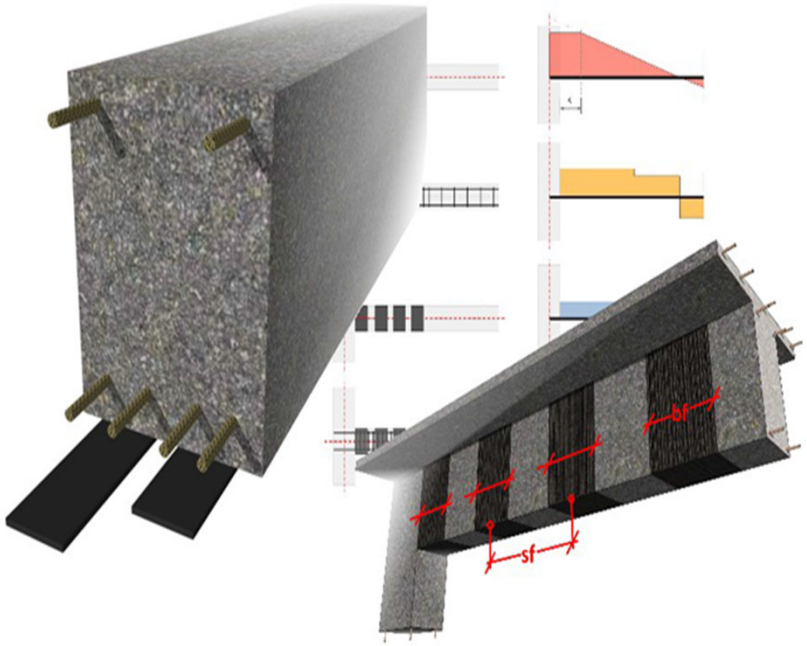
CFRP strengthening

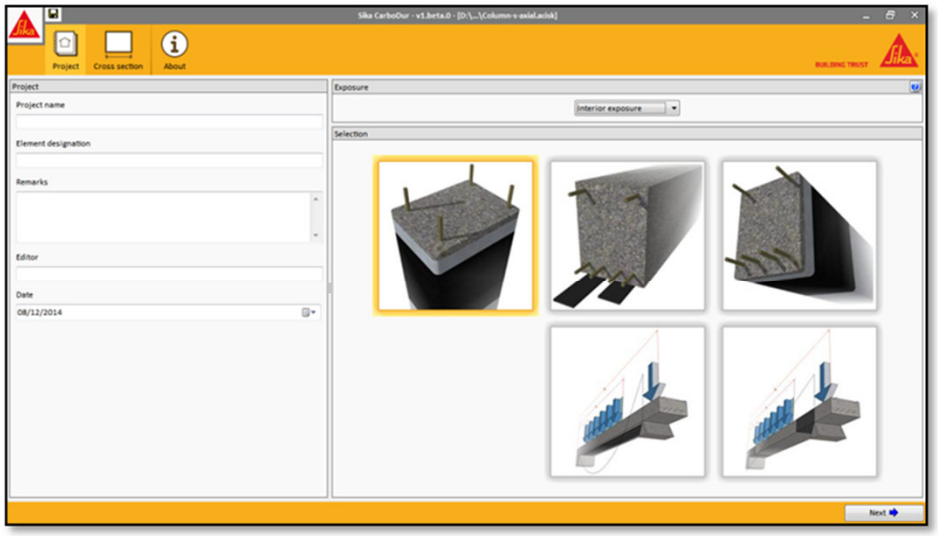
- Increase in both axial and flexural strength
- Commonly used for seismic retrofitting
- Most efficient reinforcement in circular columns

PIER STRENGTHENING

CONFINEMENT

FRP DESIGN SOFTWARE



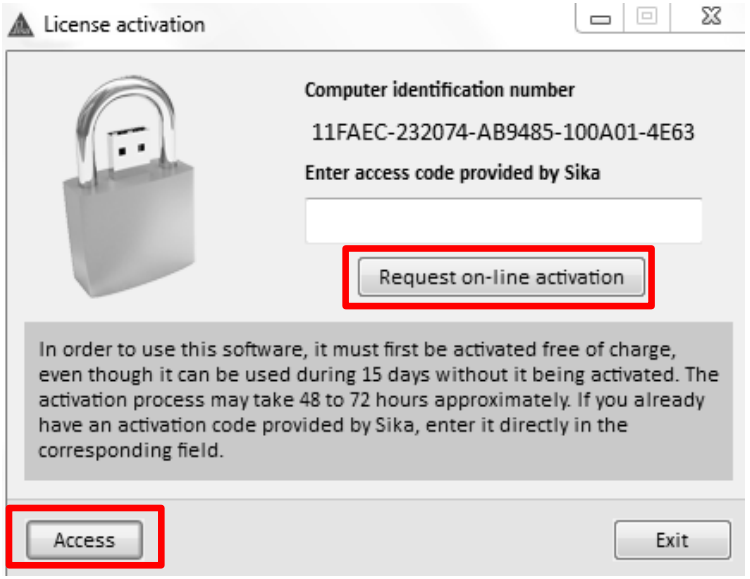


BUILDING TRUST

SIKA® CARBODUR® SOFTWARE

- Sika® CarboDur® Software one of the most complete and powerful FRP strengthening software available.

- Free download from http://www.sika.com. Within 15 days from installation is necessary to require the activation of a **FREE** license

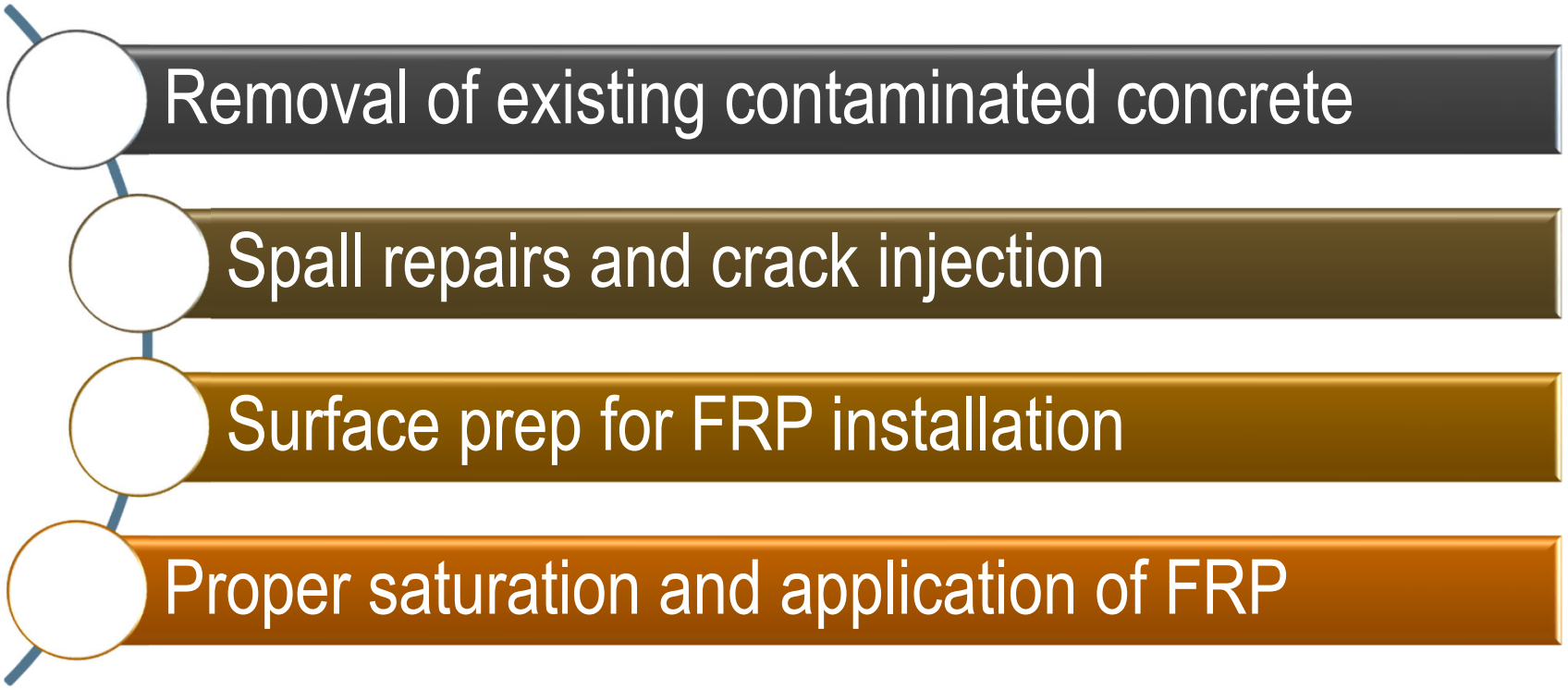


BUILDING TRUST

CONCRETE REPAIR PROCESS FOR FRP INSTALLATION

BUILDING TRUST

FRP REPAIR AND INSTALLATION REQUIREMENTS



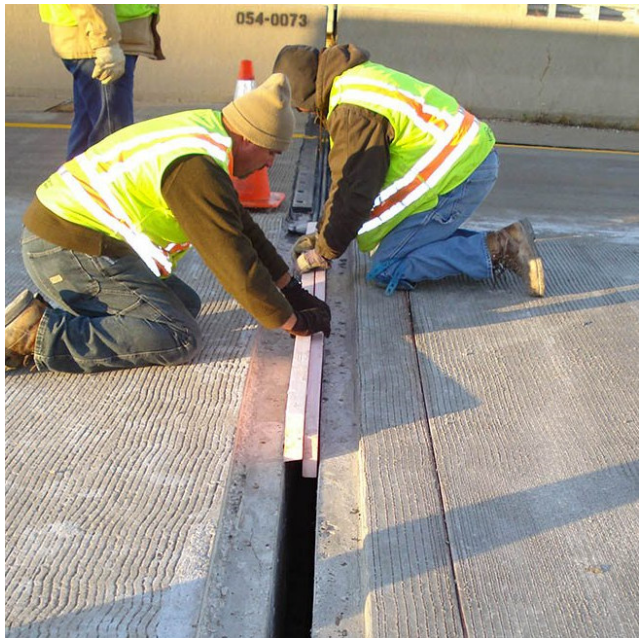
SELECTION OF PROPER REPAIR MATERIAL

- Repair and size of patch
- Depth of repair
- Speed of cure
- Shrinkage sensitivity
- Built-in corrosion inhibitor






PROTECTION



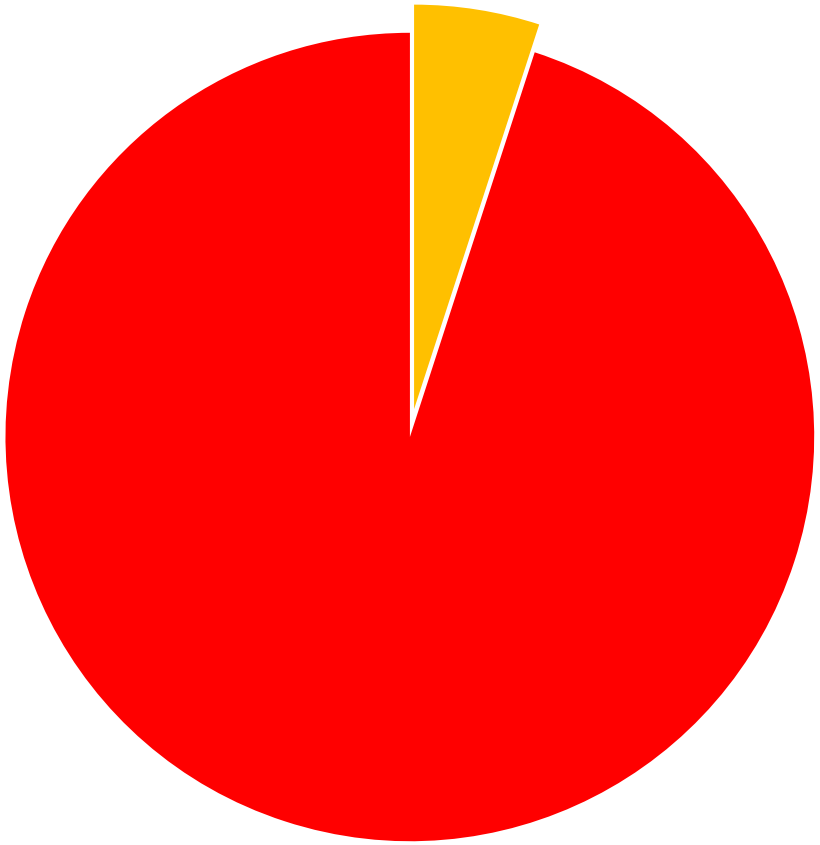
BUILDING TRUST

CRACK REPAIR: BASICS

- Structural crack repair - need to use epoxy resin
- Used for static cracks
- Can repair horizontal, vertical and overhead cracks
- If substrate is dynamic, crack will reopen or translate elsewhere in the member

REPAIR BASICS
SURFACE PREPARATION

2 Key Factors for Repair Success



Material

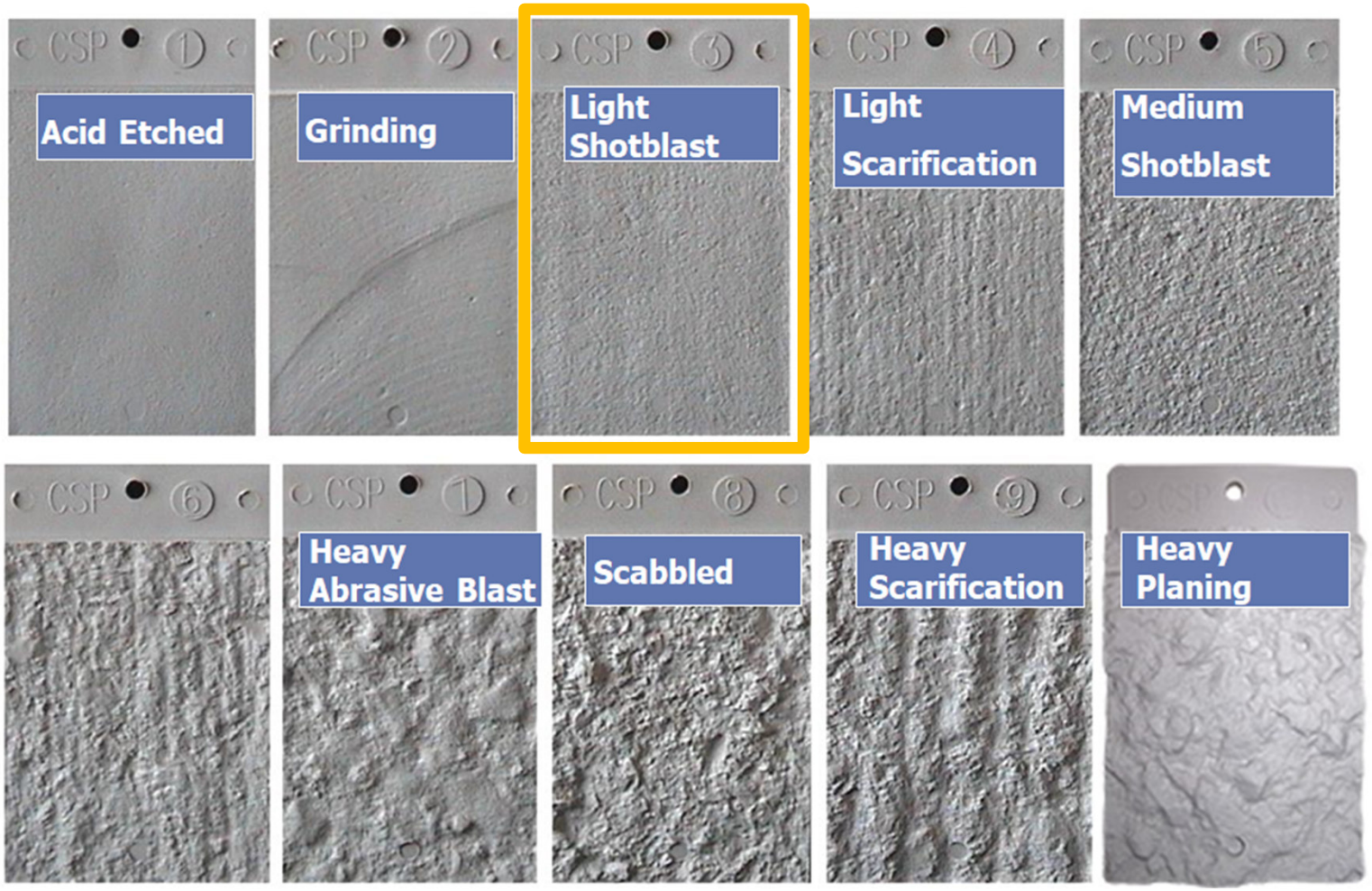
Surface Prep.

SURFACE PREP PRIOR TO FRP INSTALLATION

- Concrete prepared by sandblasting or grinding
- Surface is smooth and level
- Remove laitance
- Corners rounded to ½” min
- Open pores

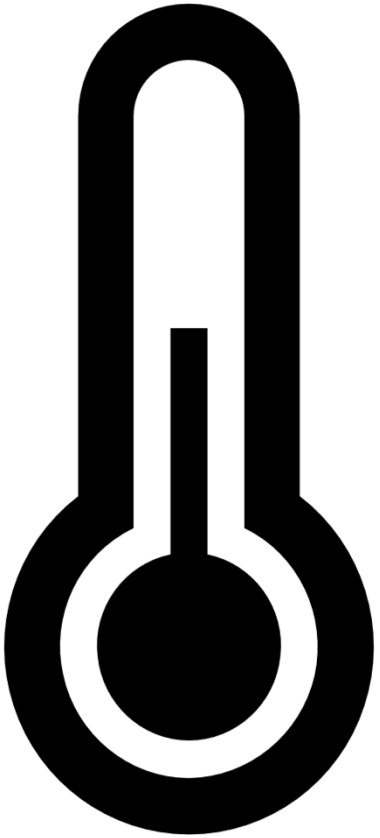
BUILDING TRUST

MECHANICAL PREPARATION



SURFACE PREP – SITE CONDITIONS

- 40 F minimum, and rising!
  - Warm material
- 95 F maximum
  - Need hot weather protocol
    - Avoid direct sunlight
    - Cool material
- Substrate moisture - <4% via Tramex
- Concrete must be 21-28 days old



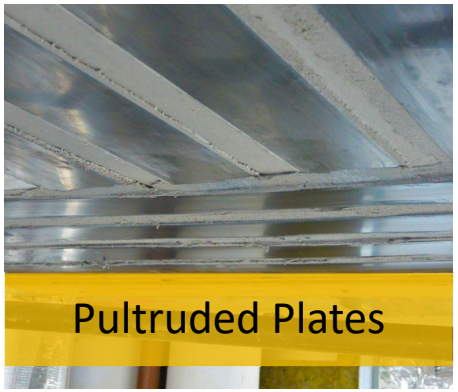
INSTALLATION OF FRP MATERIALS

AVAILABLE FRPS SYSTEMS

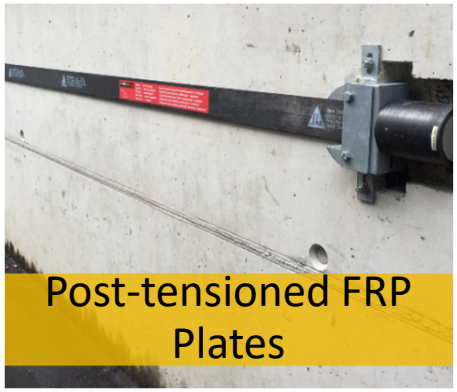

Epoxy Wet Lay-up Systems


Dry Lay-up Systems


Pre-saturated Wet Lay-up Systems


Pultruded Plates


NSM Rods


Post-tensioned FRP Plates


FRCM System


Anchorage FRP System

INSTALLATION TOOLS

PRIMER APPLICATION FOR FRP SYSTEMS

- Mix & Apply Epoxy Primer





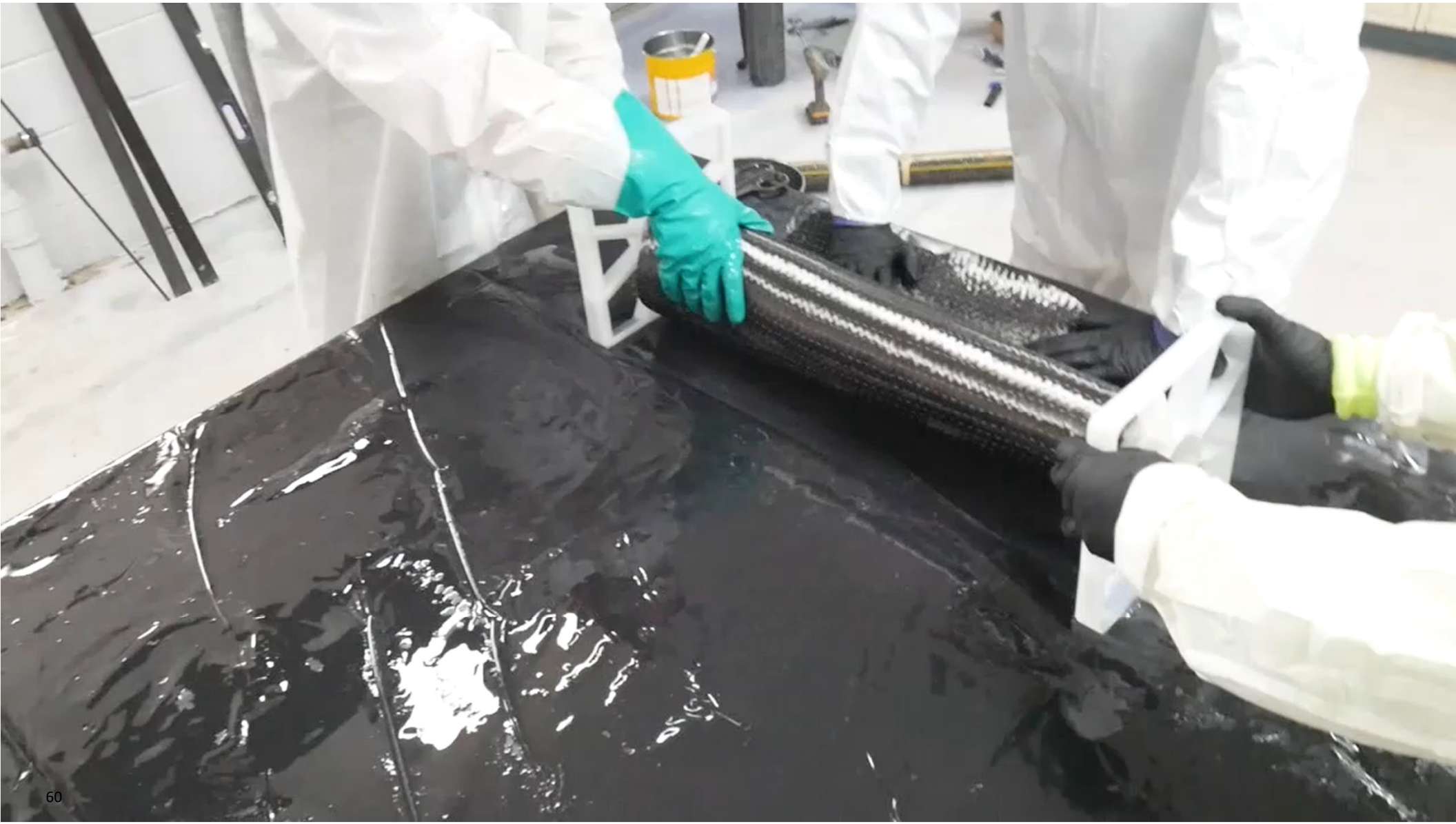
Sika
A
1 COMP. OF 2
Sikadur®
330 US
High-modulus, high-strength, impregnating resin
~1.25 US gal
Sika
B
1 COMP. OF 2
Sikadur®
330 US
High-modulus, high-strength, impregnating resin
~0.35 US gal

FIELD SATURATED FRP SYSTEMS

- Saturate Fabric with Resin – Table or Saturator

BUILDING TRUST


Sikadur®
Hex 300
High-modulus, high-strength, impregnating resin
- 2.8 US gal
WARNING
ÁVISO
UN 2735
Sikadur®
Hex 300
High-modulus, high-strength, impregnating resin
- 1.2 US gal



DRY LAY-UP INSTALLATION METHOD

- A simplified wet lay-up application method
- Applicable for very thin carbon or glass fabric systems (< 11oz/yd^2)
- Reduction in labor
- Application efficiency

FRP PLATES AND NSM SYSTEM

BUILDING TRUST

CFRP PLATES

Clean the CFRP strips

Cut the laminate to size

Apply even amount of epoxy to the laminate

Apply and roll the CFRP strip onto concrete

FRP RODS – NSM REINFORCEMENT

Cut and clean grooves

Place rods in the groove

NSM REINFORCEMENT

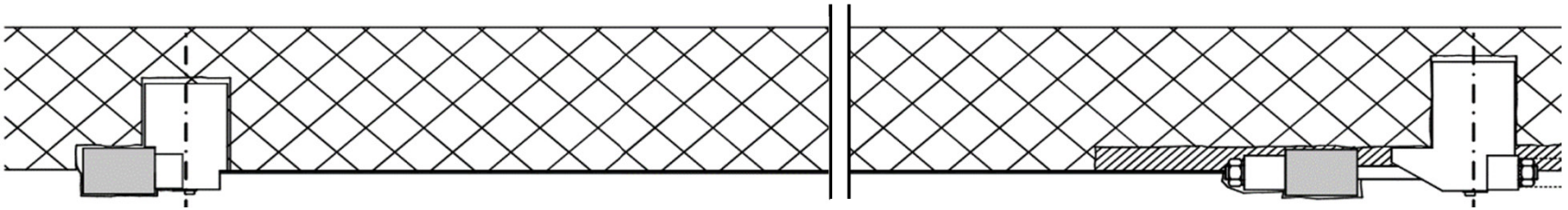
- Fill the groove with epoxy

POST-TENSION FRP PLATES

SYSTEM

- Standard anchor Type III

P_0 = 50 kips

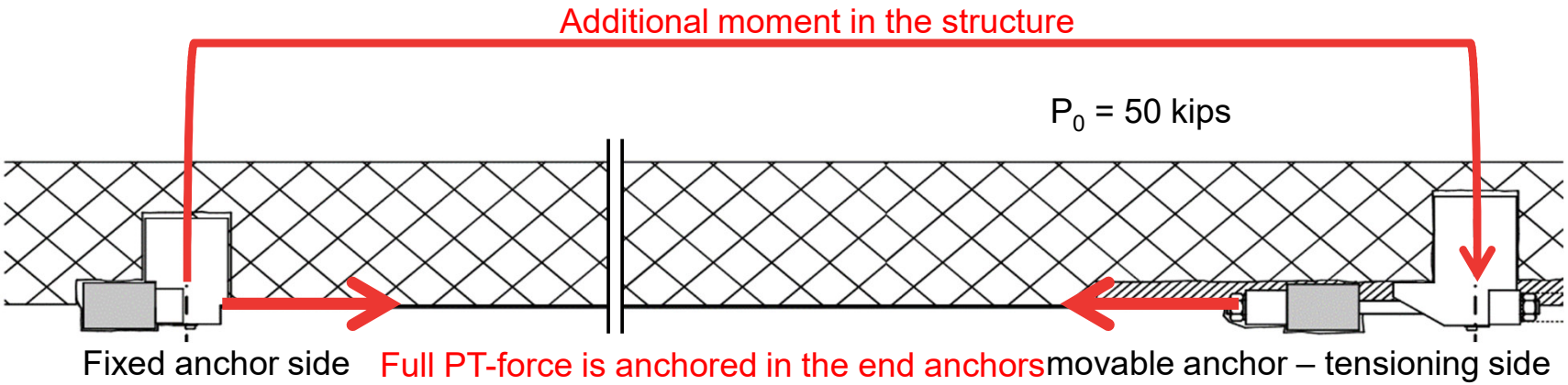


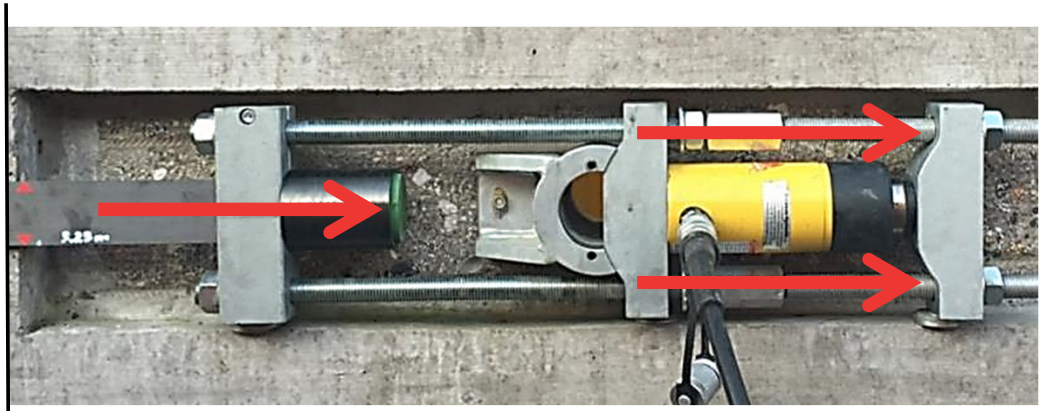
Fixed anchor side

movable anchor – tensioning side

BUILDING TRUST

SYSTEM





BUILDING TRUST

EXTERNAL POST-TENSIONING

- Attached to existing members at discrete locations
- Requires special anchor design
- Tendons/ FRP plates are post-tensioned in the field to desired force

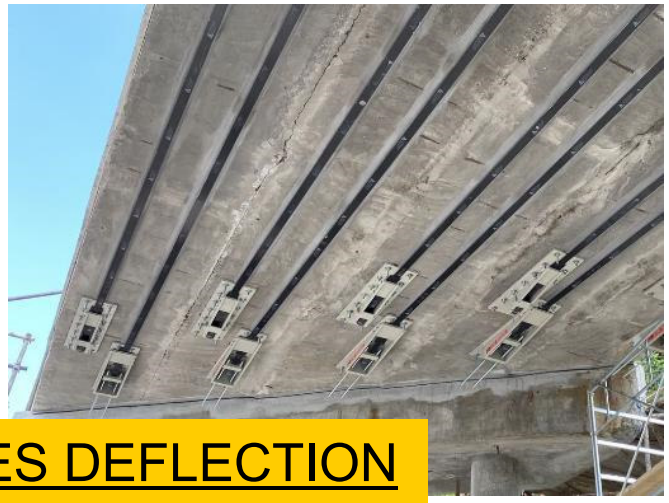
PASSIVE VS. ACTIVE STRENGTHENING

Externally FRP systems

- **Passive Strengthening**

External PT FRP system

- **Active Strengthening**



PT SYSTEM ADDRESSES DEFLECTION AND PROVIDES MUCH HIGHER CAPACITY, COMPARED TO EXTERNAL FRP

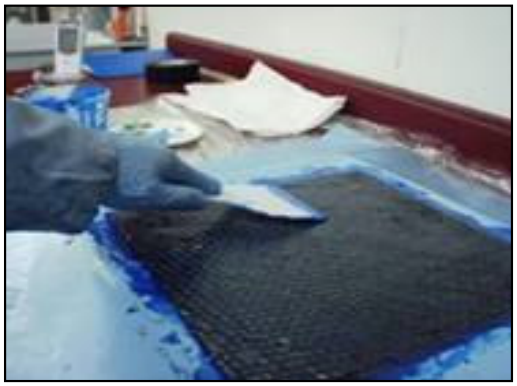
PROJECT COMPLETION

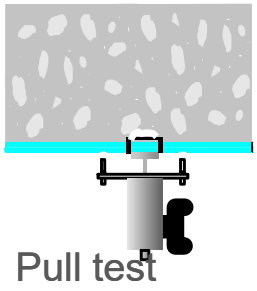
BUILDING TRUST

PROTECTIVE COATINGS

QC ACCEPTANCE CRITERIA

- Delamination
  - Limited to ensure proper bond
- Bond
  - Pull off tests to determine bond strength to concrete
  - Minimum 200 psi (1.4 MPa)
- Laminate tensile Testing
  - Panel making is an art-form
  - Panels must be flat and have smooth finish





CONCLUSIONS

- FRP's are cost and time effective solutions for reinforcement of infrastructure
- Typical FRP strengthening applications in RC include flexural, shear, confinement, and seismic strengthening
- Specifying FRP properly will prevent delays, headaches, and RFI's on projects.
- Proper repair and application is critical to ensure successful and long-lasting reinforcement
- Sika has many resources and tools, including the very powerful design software, to help you with the design and specification process

THANK YOU FOR YOUR ATTENTION

Eri Vokshi, PE
Technical Sales Manager– CFRP and
Corrosion Products
Vokshi.eri@us.sika.com

Mobile: (561) 254 - 8472

BUILDING TRUST