ICRI 2015 Fall Convention:

"Design Flexibility of FRCM (Fiber Reinforced Cement Matrix) Strengthening: Worldwide Applications"

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Ruredil
Construction chemicals and building technologies

“Modern Trends”

- Compatibility with original structure:
  - Integration of restoration material with the material of the structure in need of repair
  - Restoration material that responds to stress and strain consistently with the original structure
- Easy application:
  - Non-specialized crews
  - Extended weather conditions
- Safety:
  - Materials that are safe for applicators, users and the environment

FRCM Solution

FRCM: Fiber Reinforced Cement Matrix

A composite system for structural strengthening:

- High strength mesh works as continuous reinforcement
- Cement-based adhesive anchors the mesh to the concrete support
- One or more sheets of mesh are used so as to reach the requested load increase

FRCM Components

PoliparafenilenBenzobisOxazolo (PBO)

+

Cement-based Adhesive

=

FRCM

Components At-A-Glance

PBO fiber mesh reinforcement

Type of Fiber	Ultimate Tensile Strength ksi (MPa)	Tensile Modulus Elasticity ksi (Gpa)	Ultimate Elongation %
PBO	840 (5,800)	40,000 (270)	2.5
Carbon	550 - 700 (3,500 - 4,800)	35,000 - 55,000 (230 - 375)	0.9 - 2.1
Aramidic (Hi-Mod)	290 - 400 (2,000 - 2,800)	15,000 - 17,000 (109 - 120)	1.7 - 2.4
Glass	220 - 500 (1,500 - 3,500)	4,500 – 11,500 (30 - 80)	2.1 - 4.5

PBO performance characteristics are equal, if not superior, to carbon

Cement-based adhesive

- Very low W/C ratio 0.30
- Very low heat of hydration
- Contains microfibers

- Compressive strength:
  - 4,900 psi at 28 days
- Flexural Strength:
  - 580 psi at 28 days

FRCM Vs “Modern Trends”

- Compatibility with concrete substrate
  - Same response to fire as concrete
  - Aesthetics, same gray color as concrete
- Easy to manage in the job site
  - Lightweight material for vertical and overhead applications
  - Works on damp substrates
  - Does not required a highly specialized crew
- Non toxic components
  - Safe for applicators and environment
  - Minimal respirator requirements

And Also…

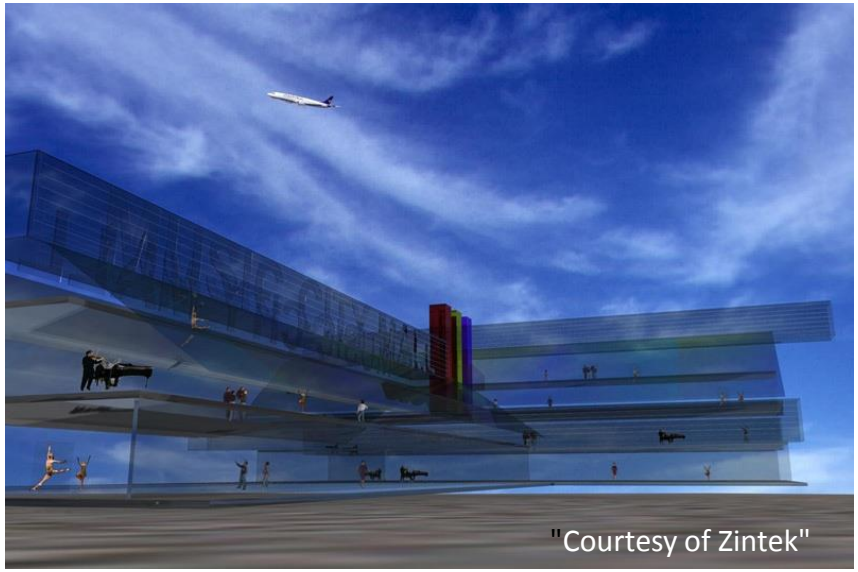
- Structural Upgrade
  - Increases flexural, shear and compressive strength of structural elements
  - Supplements, or replaces, cross sectional loss of corroded reinforcing steel
  - Seismic retrofit
- Durability
  - Not affected by high service temperature
  - Not affected by UV rays
  - Does not corrode
- Visual Prediction of Failure
  - Slippage of fibers after multiple cracking

Case Studies

- Music City Mall, Porto Marghera, Venice, Italy
  - "Industrial archeology"
- Gravel Square Bridge, Parma, Italy
  - Urban bridge in a unique setting
- Cooling Tower, Bergheim, Germany
  - Cooling tower application

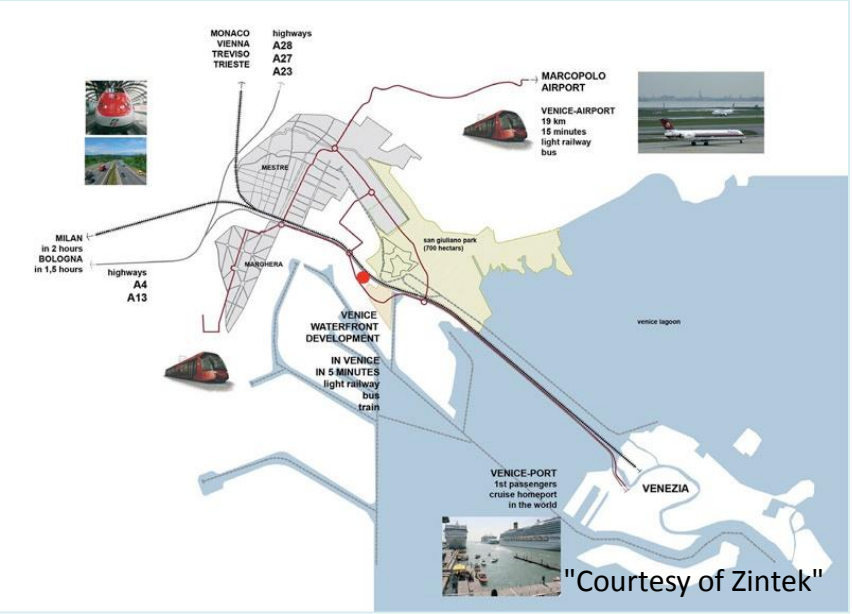
- Railway Viaduct, Roma-Formia, Italy
  - Under-arch reinforcement
- Bridge Footings, Novosibirsk, Siberia, Russia
  - Preventative maintenance

Music City Mall
Porto Marghera, Venice, Italy



Conversion of an industrial building into a multi-use center for musical training, musical production, shows and entertainment

The Venice Lagoon



"Courtesy of Zintek"


"Courtesy of Zintek"

Industrial area of Porto Marghera: built after WWII facing the Venice lagoon

Recent years conversion: from production of fertilizers and oil refinement to the creation of the Venice Lifestyle Center, a cultural and commercial center that supports the economic model of Venice

Project Profile

- **Project:** Music City Mall at Porto Marghera, Italy
- **Amenities:** a theatre sitting 1,500 people, ballroom, music hall, shops, restaurants, fitness center
- **Owner:** Nova Marghera Spa (private)
- **Contractor**: Guaraldo S.p.A.
- **Consulting Engineer (Architecture):** prof. Armando Dal Fabbro
- **Consulting Engineer (Structure):** Favero & Milan
- **Year:** 2008- 2012
- **Project area:** 122,780 ft^2
- **Building area:** 53,410 ft^2
- **Cost of the Project:** € 25 M
- **Strengthening Surface:** 80,000 ft^2

Damaged Structure

Rehabilitation of the Agrimont fertilizer warehouse, built in the 1940s
Concrete compressive strength: 20-25 MPa
Loss of cross section of steel bars, especially the external columns

Challenges

Loss of cross section of corroded reinforcing steel bars:

→ Recover load bearing capacity of the structural elements

Consistency with current Italian standards for commercial buildings:

→ Reinforce the structure in accordance with seismic code requirements

Maintain size and shape of original concrete structural elements:

→ Use a strengthening system that does not add thickness to the concrete elements.

Concrete Vaults

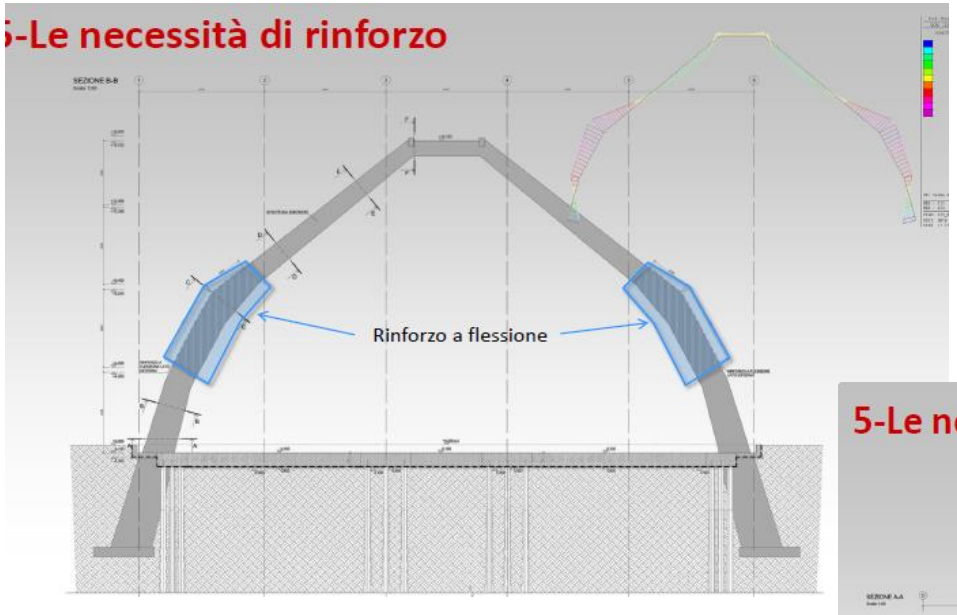
To comply with Italian RC 120 code for fire protection, FRP system would have required encapsulation with gypsum boards plus insulating plaster. This would have added more than 3 in. thickness to the concrete beam vaults

Vault Repair and Strengthening

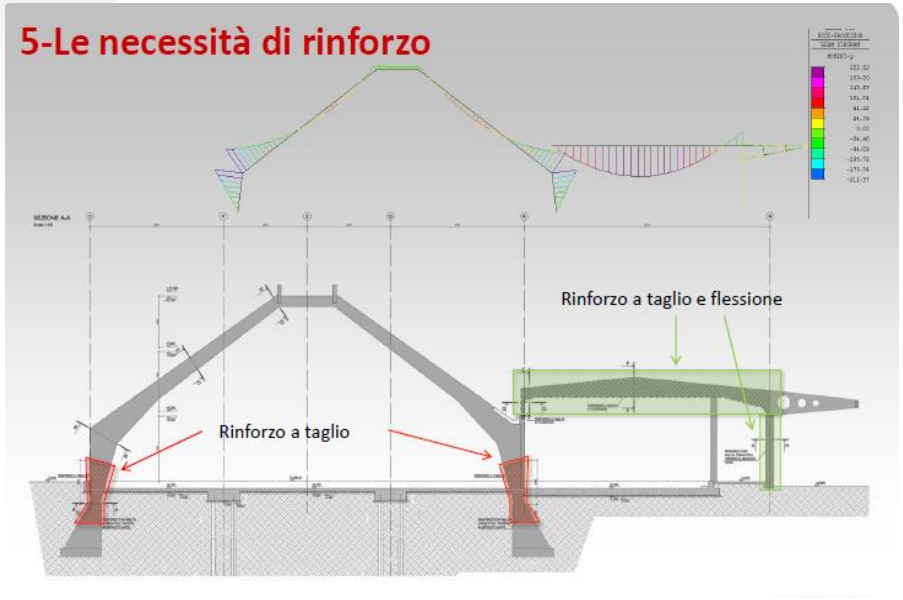
2 platform lifts
3 people on each platform
2 people on the ground

Adhesive was raised up in large containers of 65 -110 lbs

Flexural and Shear Reinforcement



Flexural reinforcement: 2 FRCM layers

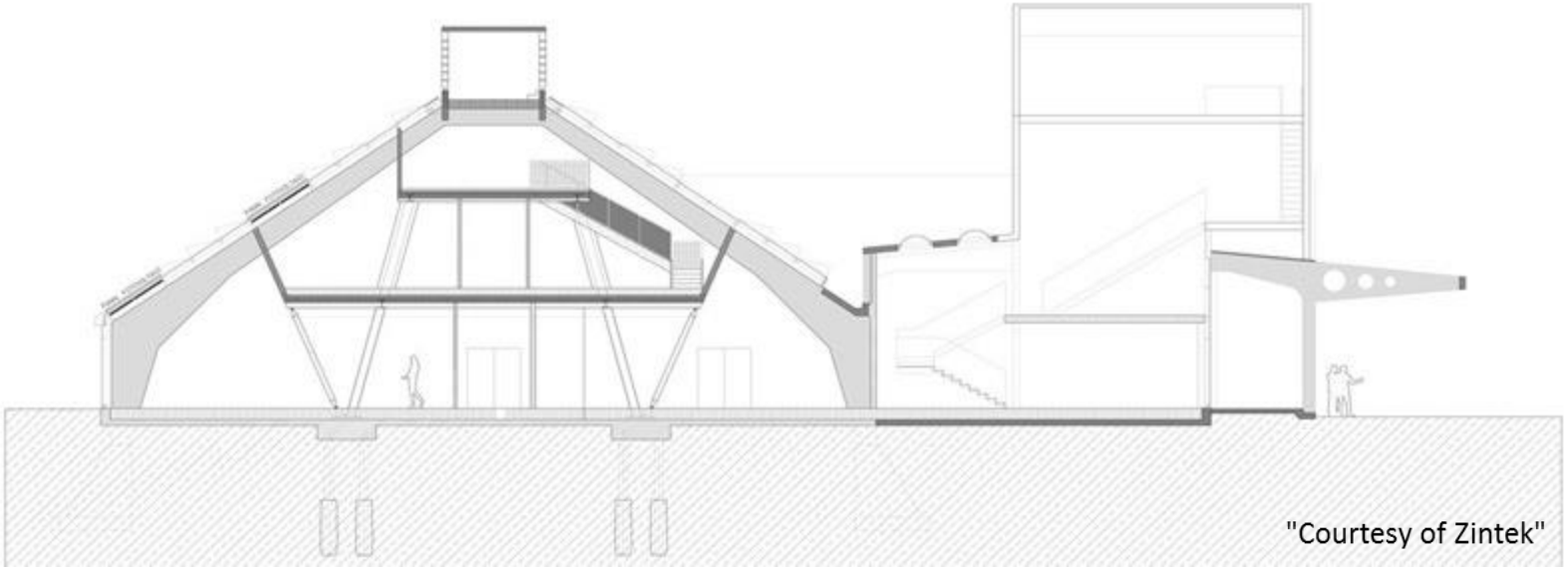


Shear reinforcement: 2 FRCM layers

Strengthening Application

Total thickness of the two layers: 1/3 in.

Completed Project: the Inside



A free standing steel structure was inserted inside the vaulted space. It provides three levels and connecting paths

Completed Project: the Outside

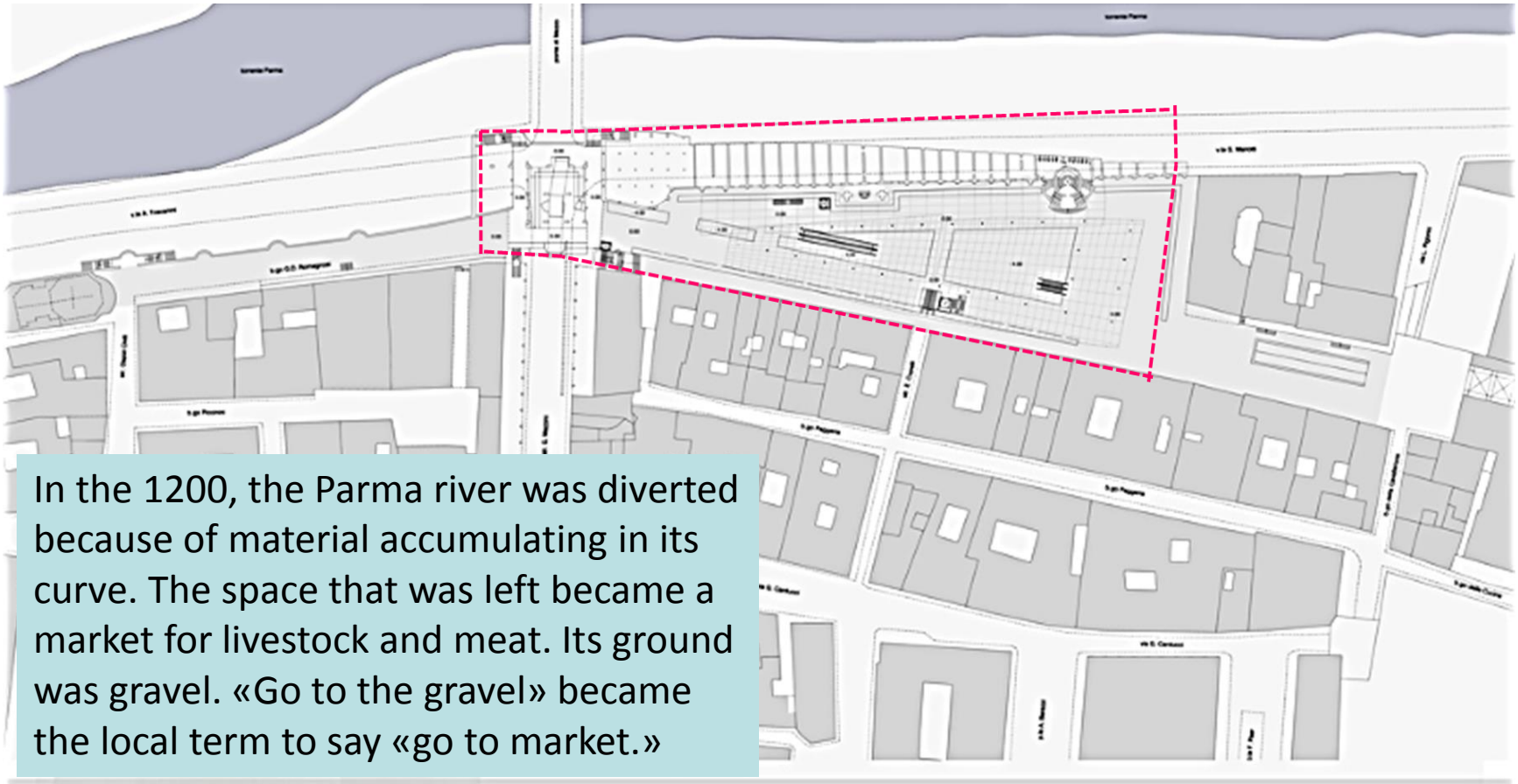
Completed project, a glass oriental-type pagoda

Two teams of 5 people applied 80,000 ft^2 of FRCM in 45 days
Daily productivity: 180 ft^2 per person

Urban Underground Bridge
Piazza della Ghiaia ("Gravel Square"), Italy

“Gravel Square” in Parma

“Go to the Gravel”



In the 1200, the Parma river was diverted because of material accumulating in its curve. The space that was left became a market for livestock and meat. Its ground was gravel. «Go to the gravel» became the local term to say «go to market.»

Overall Project

Renovation of buildings and market spaces in the historic Mariotti Street
Creation of a new market square covered by a lightweight steel and glass structure
Creation of 3 underground floors of mixed use: indoor market, food stores and garages

Total area (open air and underground): 175,000 ft^2
Project cost: € 30 M

Roman Arches

Two arches are the remaining of the roman bridge built in 180 BC during the age of Emperor Augustus. The original bridge had 11 arches spanning over the Parma river

Over the years the underground area of Gravel Square bridge became very degraded. A major refurbishment was needed

Project Profile

- **Project:** Restoration and strengthening of THE underground bridge at Della Ghiaia Square, Parma, Italy
- **Owner:** City of Parma
- **Contractor**: Bonatti
- **Sub-contractor:** Comandatore Emanuele
- **Consulting Engineer (Architecture):** Francesco Asti, Andrea Mombriani
- **Consulting Engineer (Structure):** Paolo Sorba - Studio A.I. erre engineering S.r.l.
- **Year:** 2007- 2012
- **Cost of the Project:** € 30 M
- **Strengthening Surface:** 15,000 ft^2

Challenges

Heavily damp environment: a creek is running under the bridge, 3 sides are closed by commercial buildings, water is leaking from a containment wall:

→ Use a material compatible with damp environment and damp substrate

Avoid spillage of construction material in the creek and any form of contamination of the Roman arches:

→ Apply a system with no risk of spillage and contamination

Loss of cross section of corroded reinforcing steel bars:

→ Recover the original load bearing capacity of the bridge

Bridge Deterioration

Old bridge (> 50 yrs) over heavily trafficked via Emilia

Water leaking from the deck, which is not waterproofed

Use of deicing salts in winter

Concrete spallings and steel corrosion of bridge superstructure

Concrete Repair

Rebar rust was brushed off, bars were treated with a cement-based anti-corrosion primer

Additional reinforcing bars were applied on the girders (more than 50% bending moment was lost)

Form-and-pour application system for the repair of the girders

Strengthening Application

PBO mesh, one sheet, was applied on the underside of the deck

PBO mesh, one sheet, was then applied on the bottom and vertical side of the beams (U shape) for their entire length

Mesh overlap between beams and deck: 8 in.

Cement-based finishing layer provides aesthetical finishing

Final Project

Working crew: 3 people: 1 mixing, 2 for adhesive and mesh application
Strengthening surface: 15,000 ft^2 Project completion: 40 days
Daily productivity: 130 ft^2 per person

Cooling Tower
Bergheim (Germany)

Project Profile

- **Project:** Strengthening of cooling tower
- **Setting:** Coal power plant
- **Location:** Bergheim, Germany
- **Owner:** RWE (Rhine-Westfalia Power Plant)
- **Contractor**: Stromberg
- **Consulting Engineer:** LAW Ingenieure GmbH
- **Year:** 2012
- **Cost of the project**: € 600,000
- **Strengthening Surface:** 18,000 ft^2

Challenges

Loss of steel bar cross section at the inside section of the wall

→ To recover the original capacity of the tower, EN codes

Continued cooling tower operations during strengthening:

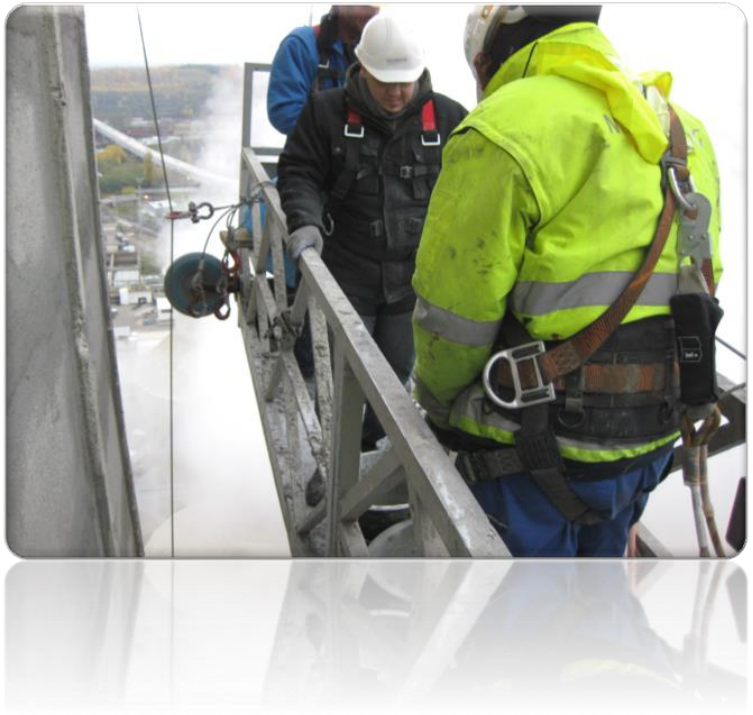
→ Application at 85 °F + concrete substrate temperature

Surface Preparation

- Loose cement paste was removed and aggregate exposed to achieve concrete surface profile
- Pressure washing prior to application
- Minor defects were treated with a cement-based mortar, not latex modified

Application Crew

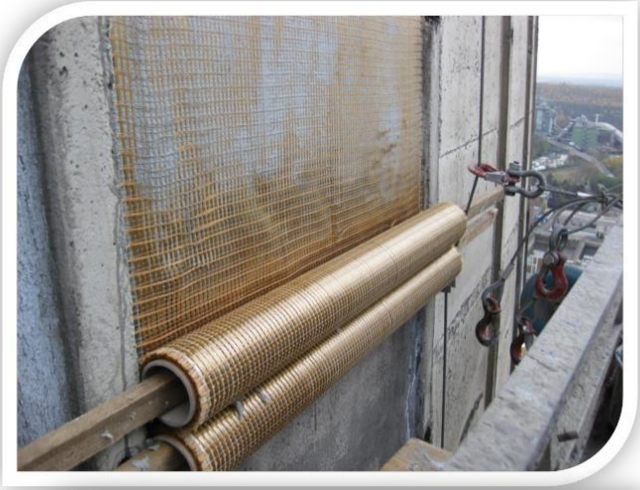
- A crew of 3 people worked on the platform lift
- Two people continuosly applied adhesive and PBO mesh
- Adhesive was mixed on the lift in a pail with a paddle mixer
- Water was carried from the ground through a flexible hose

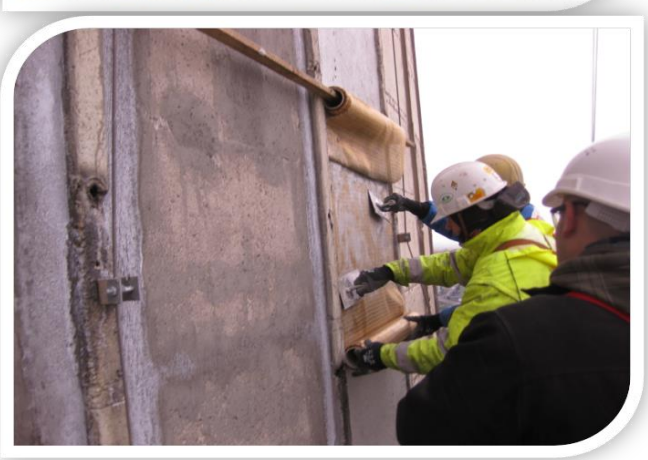


Application Sequence

20 ft. length moving from top to bottom

- Trowel application of first layer of adhesive, 1/8 in. + thick
- First sheet of PBO mesh over the adhesive pressing the mesh into the cement-based matrix
- Application of a second layer of adhesive 1/8 in. thick
- Second, final sheet of PBO mesh and concurrent application of adhesive top layer





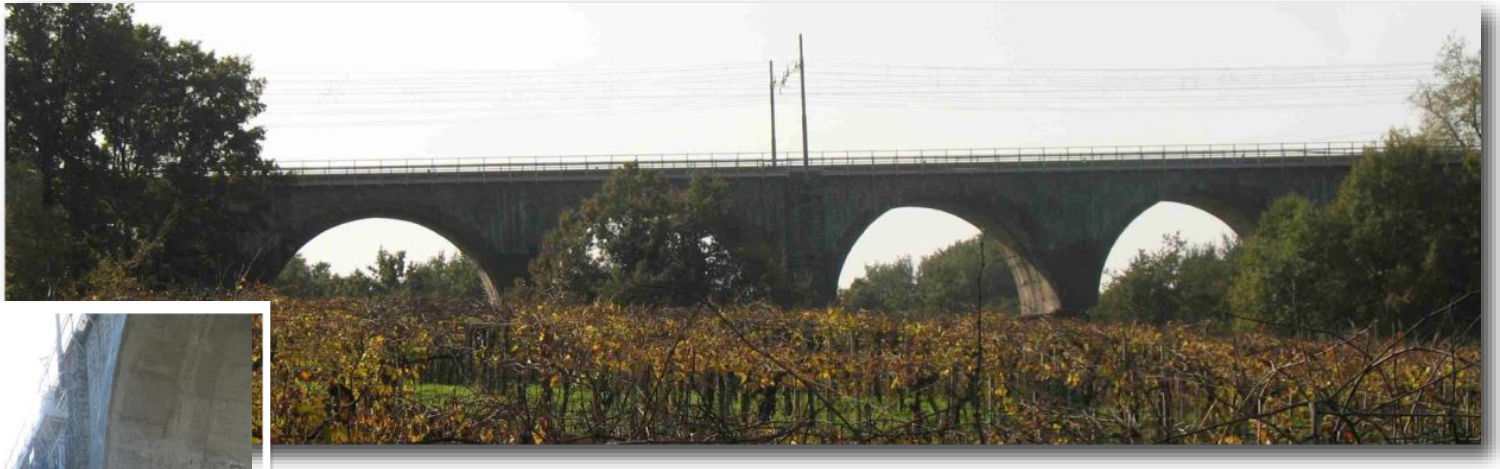
Final Project

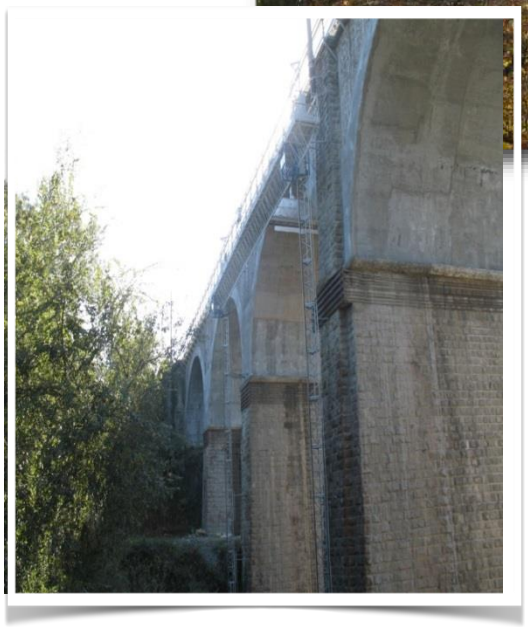
Initial 1,500 ft^2 were applied in November 2011, remaining 16,500 ft^2 were applied in Spring 2012. Strengthened surface: 5% of the total

Project was completed by a crew of 3 people in 36 days

Daily productivity: 170 ft^2 per person

Railway Viaduct
Roma-Formia-Naples, Italy





Rome–Naples Direttissima in Italian ("most direct")

Six semicircular reinforced concrete vaults supported by masonry abutments made of blocks of tuff, a local stone

Built in 1950, it was obsolete for high speed trains

Project Requirements

Owner: Italian Railway Company
Year: 2010-2011
Strengthening Surface: 15,000 ft^2

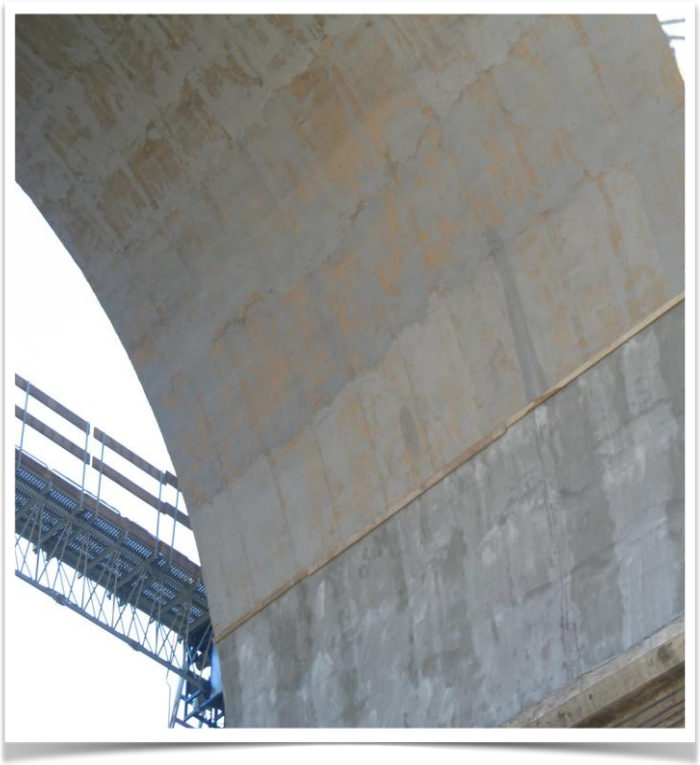
Requirements:

- Repair deteriorated concrete
- Bring the bridge up to current Italian Railway Company standards
- Do not interrupt railway traffic during strengthening application

Strengthening Application

1. Trowel application first layer of adhesive over 50 ft length
2. First sheet of PBO mesh over the freshly applied adhesive (45 mins working time)
3. Second, thinner layer of adhesive
4. Second, final sheet of PBO mesh and cement-based top layer

Final Project



A crew of 3 people applied FRCM in 15 days

Daily productivity: 300 ft^2 per person

Bridge Footings
Novosibirsk, Russia

Repair, strengthening and waterproofing of concrete footings

Ob River concrete bridge in Siberia

Project Requirements

Owner: Novosibirsk County
Year: 2007
Strengthening Surface: 6,000 ft^2

Strengthening Requirements:

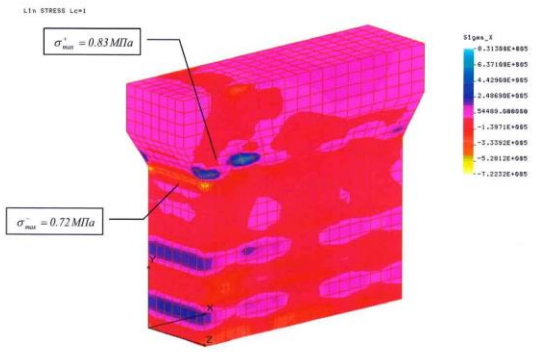
- Avoid further deterioration
  - Bridge constructed in 1958, cast-in-situ concrete
  - 1991: cracks were filled with an epoxy compound
  - 1997: cracks appeared again
- Work in cold temperatures

Repair, Strengthening & Waterproofing

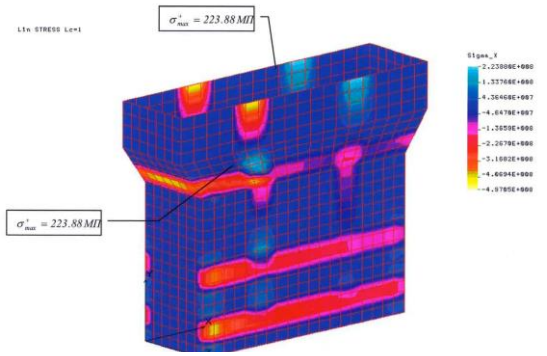
- Crack injection with epoxy
- Concrete repair and resurfacing with cement-based mortar
- Application PBO-FRCM composite
- Waterproofing with a polymer-modified, cementitious protective layer

Concrete-Composite Teamwork

X axis

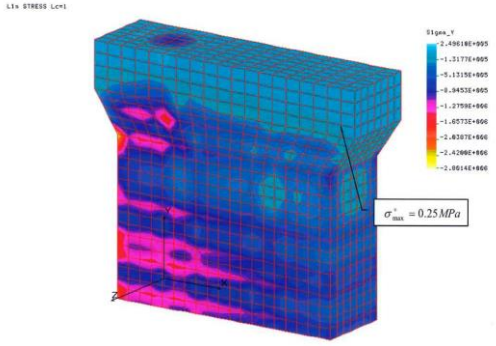


Concrete

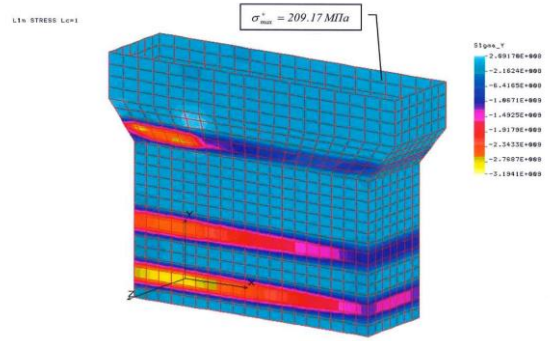


Composite

Y axis



Concrete

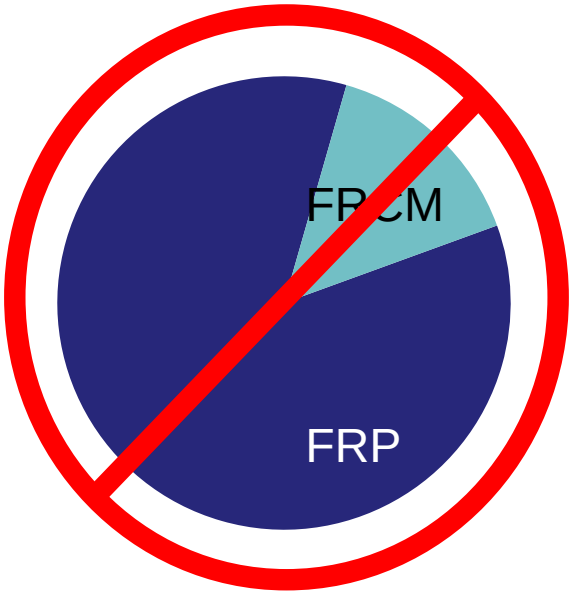


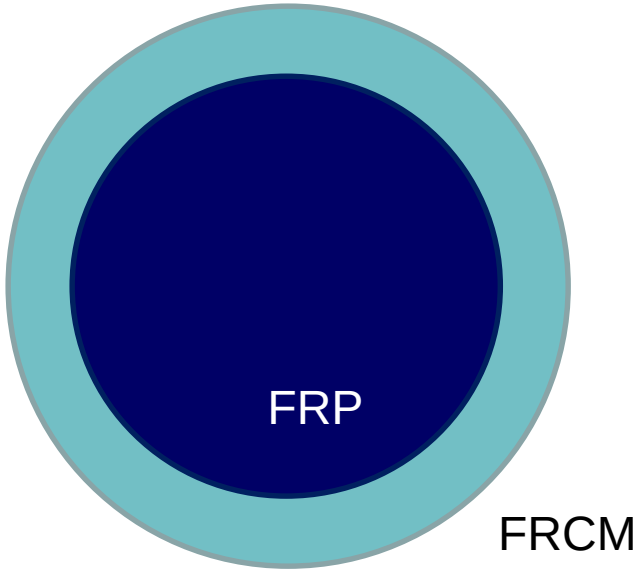
Composite

- "Composite reinforcement system actively teamworks with concrete for normal tensile stresses, direction of axis X and Y"
- "Reinforcement system keeps the integrity of concrete footings and protects the structure from the further crack propagation"

Source: Novosibirsk Railway University

FRP & FRCM





FRCM allows unique strengthening applications
FRCM enlarges the fiber-based strengthening market based on FRP with epoxy adhesive

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