Seismic retrofit of structural elements with FRCM prior to recent earthquakes in Italy: What happened to them?

Dr. G. Mantegazza
Technical and R.& D. Manager
RUREDIL Spa

PBO

CARBON

\+

Cementitiuos Matrix

=

FRCM

CARBON

\+

Epoxy Resin

=

FRP

Milan Soccer Stadium- Italy

Beams Shear reinforcement of first ring

2002

Cooling Towers

Thermal Power Plant (Germany)

FRCM Components

Carbon

+

Cement-based Adhesive

=

C- FRCM

FRCM Components

PoliparafenilenBenzobisOxazolo (PBO)

+

Cement-based Adhesive

=

PBO- FRCM

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

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 superior to carbon

Cement-based adhesive

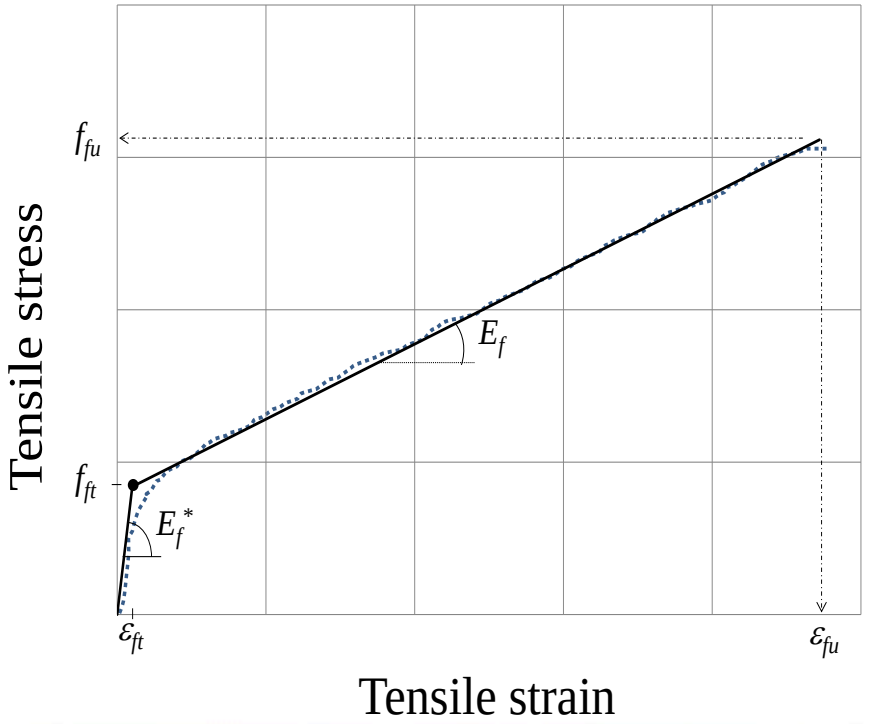
- Very low W/C ratio 0.30
- Very low heat of hydration
  - Compressive strength:
    - 4,900 psi at 28 days
  - Flexural Strength:
    - 580 psi at 28 days

AC434

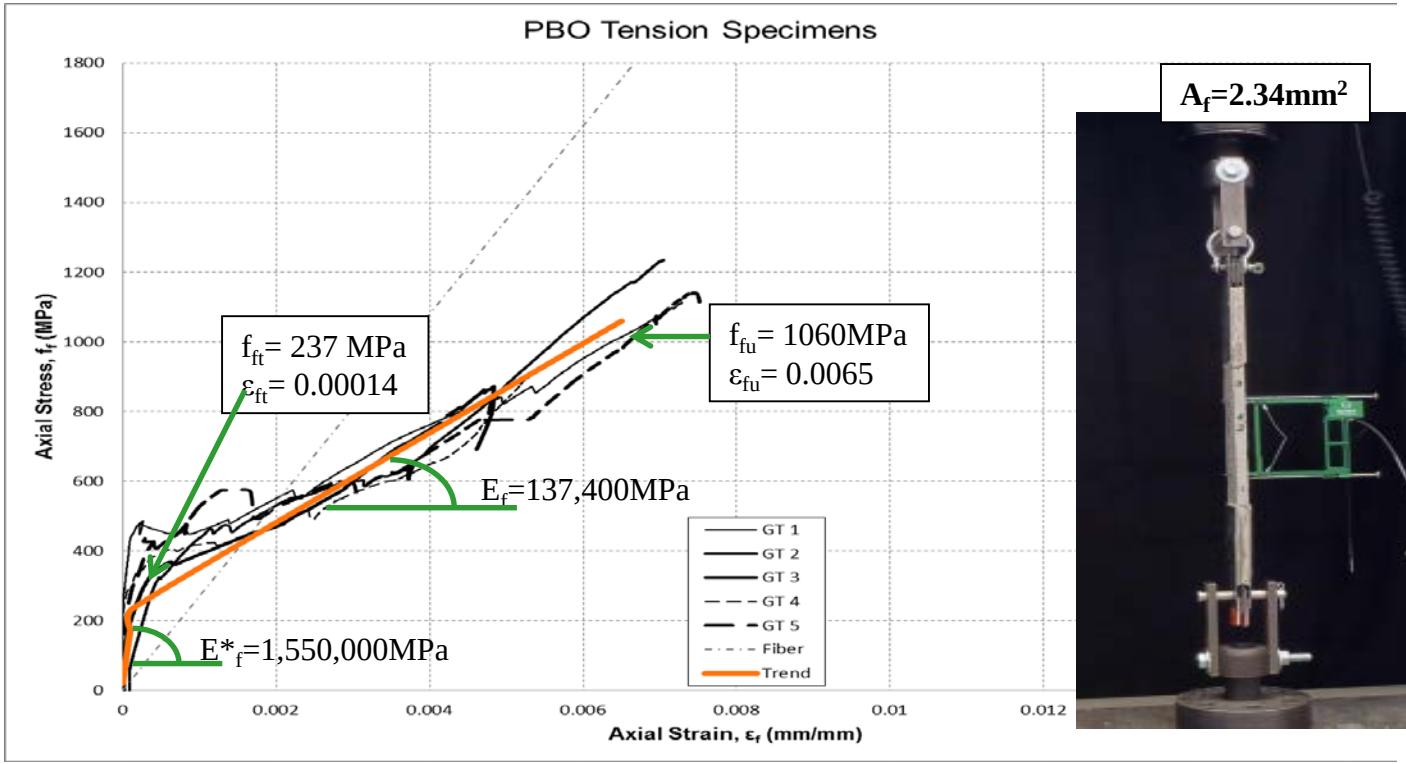
According to AC434, FRCM tensile properties evaluated include:

-Tensile modulus of elasticity of un-cracked specimen, **E_f^***
-Tensile modulus of elasticity of cracked specimen, E_f
-Ultimate tensile strain, ε_{fu}
-Ultimate tensile strength, f_{fu}
-Tensile strain corresponding to transition point, **ε_{ft}**
-Tensile stress corresponding to transition point, **f_{ft}**

Listed properties extracted from idealized graph resulting from experiment



Characterization – Typical Tensile Properties



Characterization – FRCM vs. FRP Failure Mode Comparison

FRCM failure is by pullout of the fibers

FRP failure is by breakage of the fibers

Material Characteristics of PBO FRCM Composite System

This strengthening system must be designed to meet specific project design requirements.
As design guide, follow ACI 549.4R-13 “Guide to Design and Construction of Externally Bonded Fabric-Reinforced Cementitious Matrix (FRCM) Systems for Repair and Strengthening Concrete and Masonry Structures”.

Performance characteristics of the composite were tested by ICC-ES accredited Lab in accordance to AC434 so as to satisfy ACI 549.4R-13 Design Guidelines

PROPERTY	SYMBOL	UNIT	MEAN	STD
Ultimate Tensile Strength	f_{fu}	ksi (MPa)	241.34 (1664)	11.17 (77)
Ultimate Tensile Strain	ε_{fu}	mm/mm	0,0176	0,0013
Modulus of Elasticity of Cracked specimen	E_f	msi (GPa)	18.51 (127,65)	2.22 (15,32)

Product Highlights

- ICC-ES ESR-2013 listed product.
- Level of reinforcement is **comparable to Fiber Reinforced Polymer** (FRP) that uses carbon fiber and epoxy resin as adhesive.
- Level of strengthening can be customized through the application of one or more plies of PBO Fabric.
- Once applied the composite does not alter the response to fire of steel reinforced concrete and therefore **fire protection is not required**, even for indoor applications.

Material Characteristics of carbon FRCM

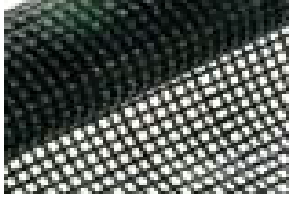
This strengthening system must be designed to meet specific project design requirements.

As design guide, follow ACI 549.4R-13 “Guide to Design and Construction of Externally Bonded Fabric-Reinforced Cementitious Matrix (FRCM) Systems for Repair and Strengthening Concrete and Masonry Structures”.

Performance characteristics of the composite were tested by ICC-ES accredited Lab in accordance to AC434 so as to satisfy ACI 549.4R-13 Design Guidelines.

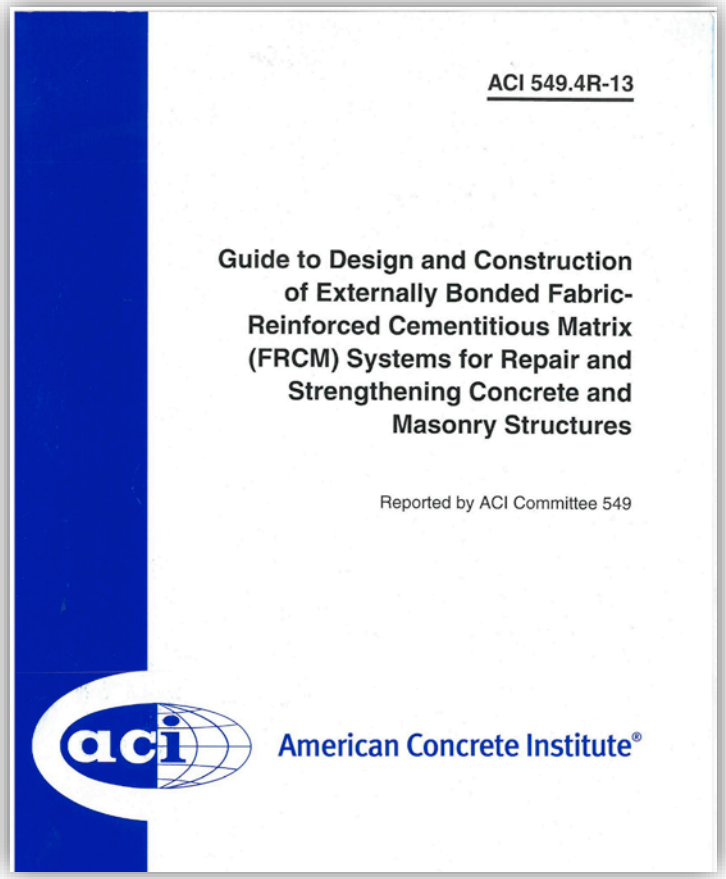
PROPERTY	SYMBOL	UNIT	MEAN	STD
Ultimate Tensile Strength	f_{fu}	ksi (MPa)	149.53 (1031)	7.83 (54)
Ultimate Tensile Strain	ε_{fu}	mm/mm	0,0100	0,0014
Modulus of Elasticity of Cracked specimen	E_f	msi (GPa)	11.56 (79,73)	2.67 (18,44)

Product Highlights



- ICC-ES ESR-2013 listed product.
- Level of strengthening can be customized throughthe **application of one or more plies of C-FRCM.**
- Once applied the system does **not alter the response to fire of masonry** construction and therefore fire **protection is not required**, even for indoor applications.

- **Durable** in conditions of **high ambient temperature** since the system is not characterized by glass transition temperature limitations.


ACI 549.4R-13
Guide to Design and Construction of Externally Bonded Fabric-Reinforced Cementitious Matrix (FRCM) Systems for Repair and Strengthening Concrete and Masonry Structures
Reported by ACI Committee 549
aci
American Concrete Institute®

AC 434

ICC EVALUATION SERVICE

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ACCEPTANCE CRITERIA FOR MASONRY AND CONCRETE STRENGTHENING USING FIBER-REINFORCED CEMENTITIOUS MATRIX (FRCM) AND STEEL REINFORCED GROUT(SRG) COMPOSITE SYSTEMS

AC434

Approved on June 2016

L’AQUILA EARTHQUAKE

April 6th 2009

Project: Church of Santa Maria di Centurelli –Caporciano (AQ) – ITALY

Amenities: The rural church was built in 1558. It is an ancient transit route for shepherds towards the city of L'Aquila, from the renaissance age. Geographical position, structure of the church, vaults.

Owner: Vatican City State Heritage

Contractor: Italian Artistic Heritage Autority

Consulting Engineering (Architecture): Franco De Vitis – Architect

Consulting Engineering (Structure): Carlo Grande – Engeneer

Year: 2003
Project area: 540.000 ft^2
Building area: 355.200 ft^2

Cost of the project: 700.

€

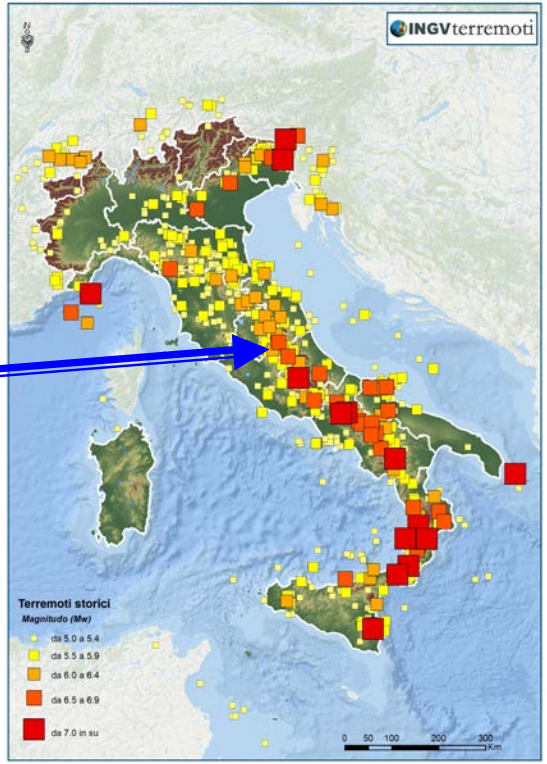
Strengthening Surface: 6500 ft^2 C-FRCM

Church of Santa Maria di Centurelli Caporciano (AQ)

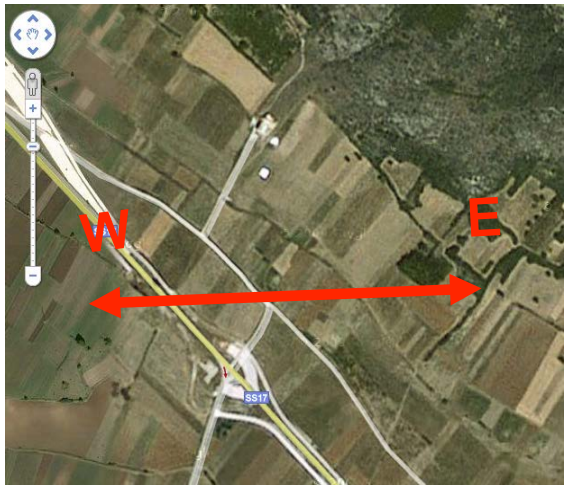
Seismic retrofitting of the vaults made with FRCM

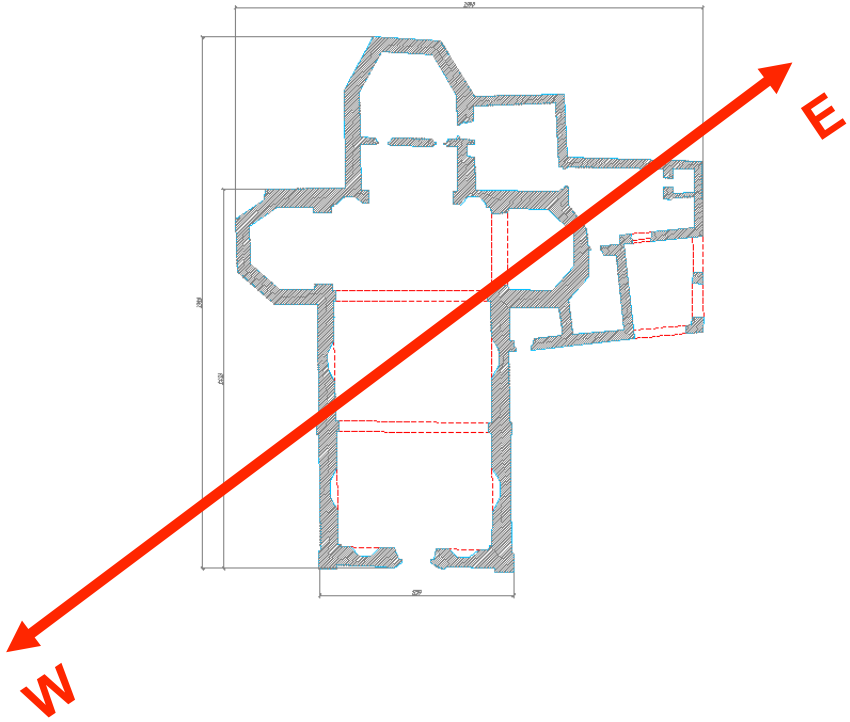
Church of Santa Maria di Centurelli
Caporciano (AQ)

Caporciano is located 12 mi from L'Aquila



Seismic wave direction





Damage due to earthquake

EMILIA ROMAGNA EARTHQUAKE
May 12th 2012

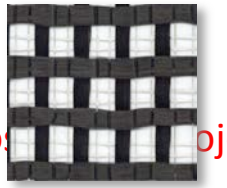
Project: Chapel of S. Francesco–ROLO (PC) – ITALY- Seismic retrofitting Oratory, Structure of the church and vaults.

Owner: Vatican City State Heritage

Contractor: Regional Christian Dept. Of Rolo - Italy

Consulting Engineering (Architecture): Eng. Poli –ESATECNA Consulting (Reggio Emilia)

Consulting Engineering (Structure): Eng. Poli –ESATECNA Consulting (Reggio Emilia)



Year: 2011

Project area: 43.100 ft^2

Building area: 3.300 ft^2

Cost of project: 100.000 €

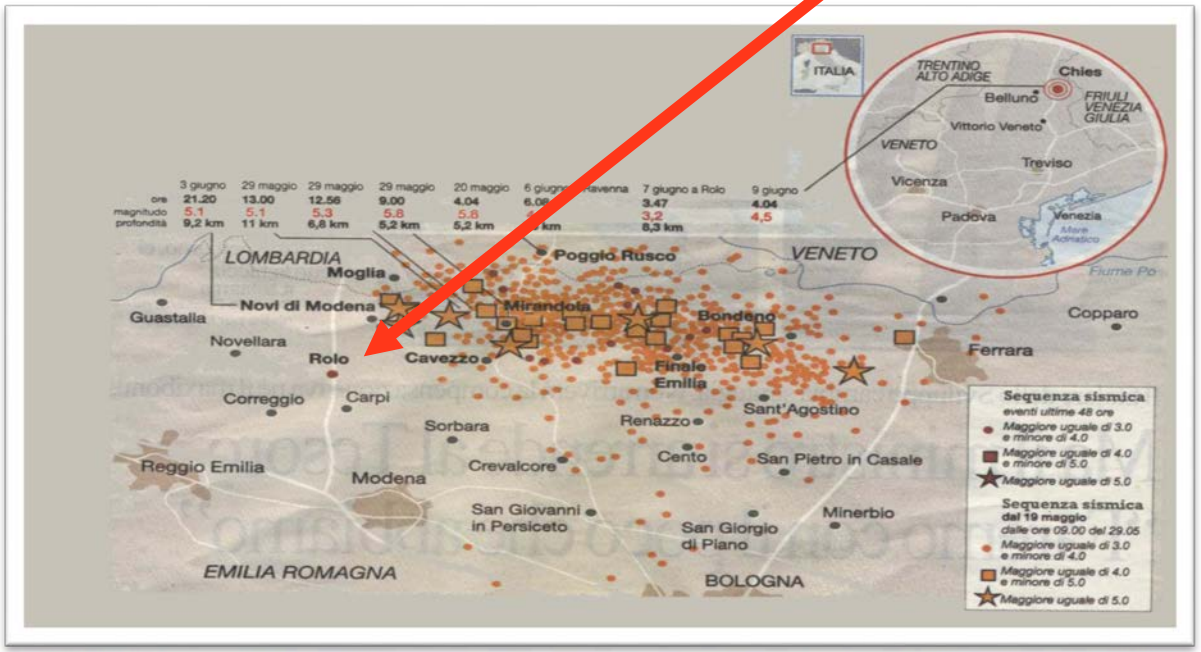
Strengthening Surface: 3.770 ft^2 C-FRCM

ORATORY CHAPEL ROLO (RE)

Seismic retrofitting of the vaults MADE WITH FRCM YEAR 2011

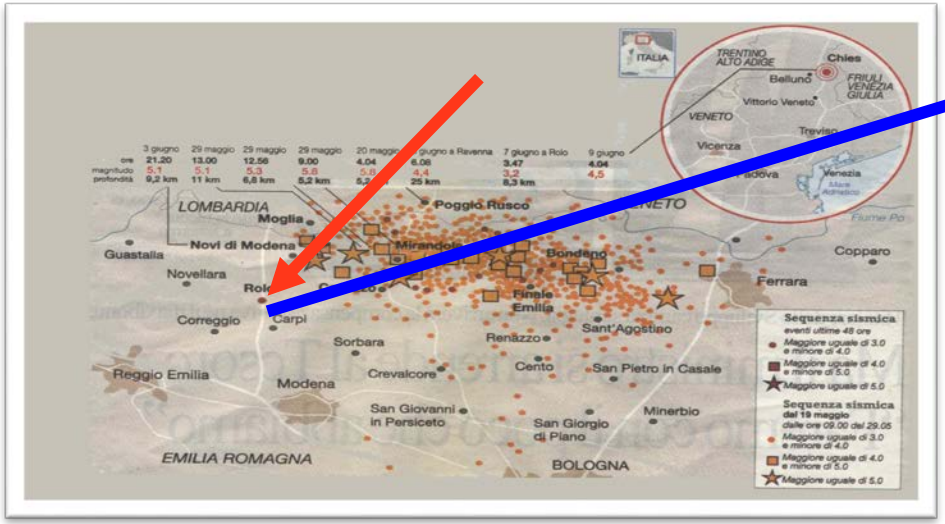
ORATORY CHAPEL - ROLO (RE)

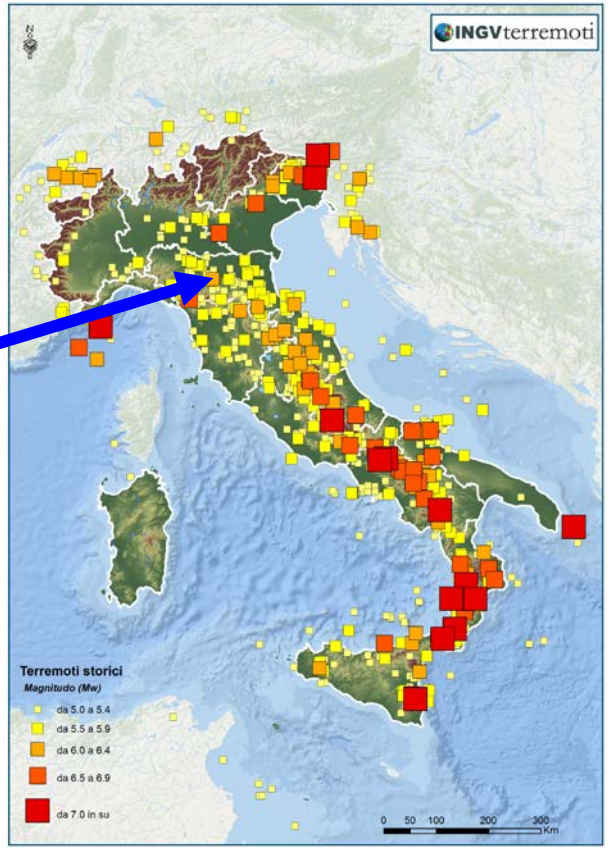
The Rolo municipality is located in the earthquake crater



ORATORY CHAPEL - ROLO (RE)

The Rolo municipality is located in the earthquake basin





The chapel is located in the red zone, a restricted area with a lot of collapsed buildings.

Absence of cracks on the vaults reinforced with FRCM

CENTER OF ITALY- EARTHQUAKE

August 24th 2016

Project: Regional State Highway Viaduct - Location Posta (Rieti)- Italy
Seismic retrofitting of colums and beams

Owner: ANAS ITALIAN NATIONAL HIGHWAY AUTHORITY

Contractor: ANAS ITALIAN NATIONAL HIGHWAY AUTHORITY

Consulting Engineering : Technical Office - Rieti's County

Year: 2015

Project area: 323.917 ft^2

: 269.097 ft^2

the project: 2.200.000 €

Strengthening Surface: 22.640 ft^2 PBO-FRCM

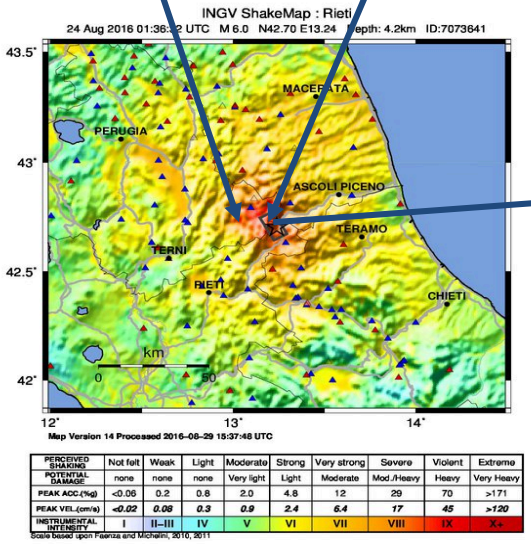
Viaduct 70° mile - Location Posta (Rieti)

Structural Repair with FRCM systems MADE IN 2015

Viaduct – 70 th Mile- Location Posta (Rieti)

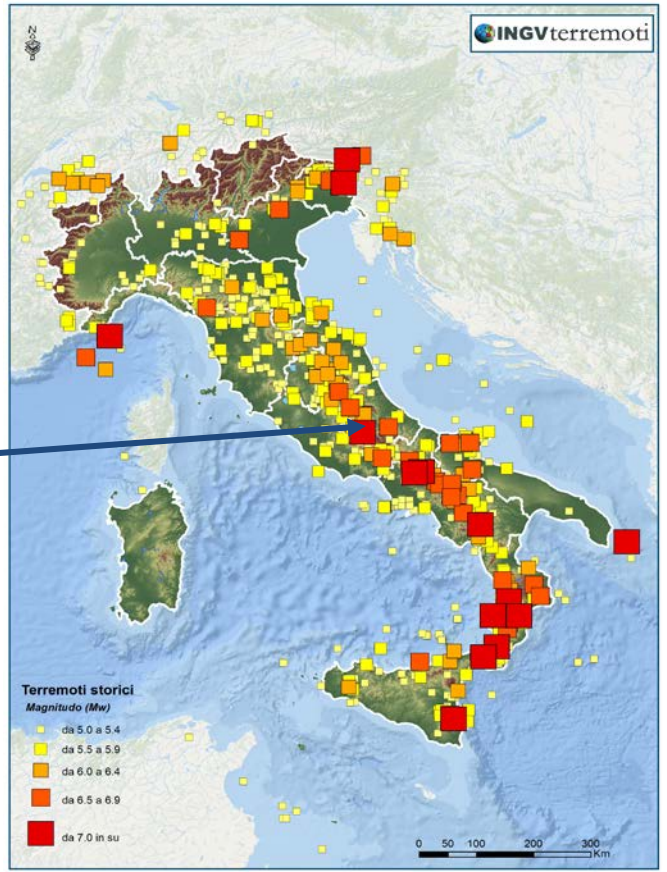
The viaduct is located in POSTA (Rieti)

17 mi distance from Amatrice



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.06	0.2	0.8	2.0	4.8	12	29	70	>171
PEAK VEL.(cm/s)	*<0.02*	*0.08*	*0.3*	*0.9*	*2.4*	*6.4*	*17*	*45*	*>120*
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Faenza and Michelini, 2010, 2011



ANAS ROMA – ITALIAN NATIONAL HIGHWAY AUTHORITY

They made a survey after the earthquake and they noted

NO DAMAGE NO CRACKS

AFTER THE EARTHQUAKE

NORCIA EARTHQUAKE

October 30th 2016

Project: Regional State Highway - Masonry bricks bridge
Location Abbazia di Fiastra Tolentino- Macerata Italy

Owner: ANAS ITALIAN NATIONAL HIGHWAY AUTHORITY

Contractor: ANAS ITALIAN NATIONAL HIGHWAY AUTHORITY

Consulting Engineering : Technical Office. Macerata's County

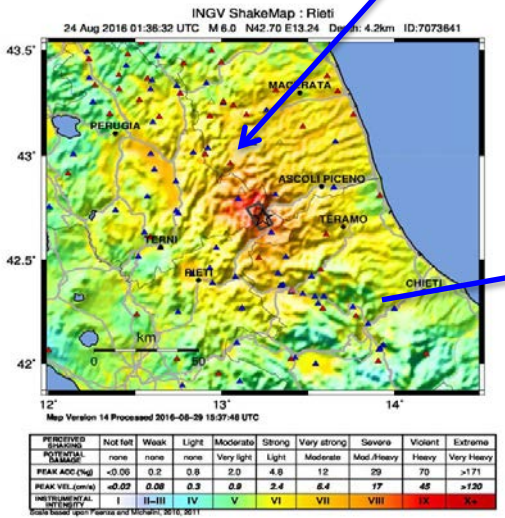
Year: March 2016
Project area: 215.278 ft^2
Building area: 161.458 ft^2

Cost of the project: 1.300.000 €
Strengthening Surface: 12.917 ft^2 C-FRCM

Masonry bricks bridge with arches on three span

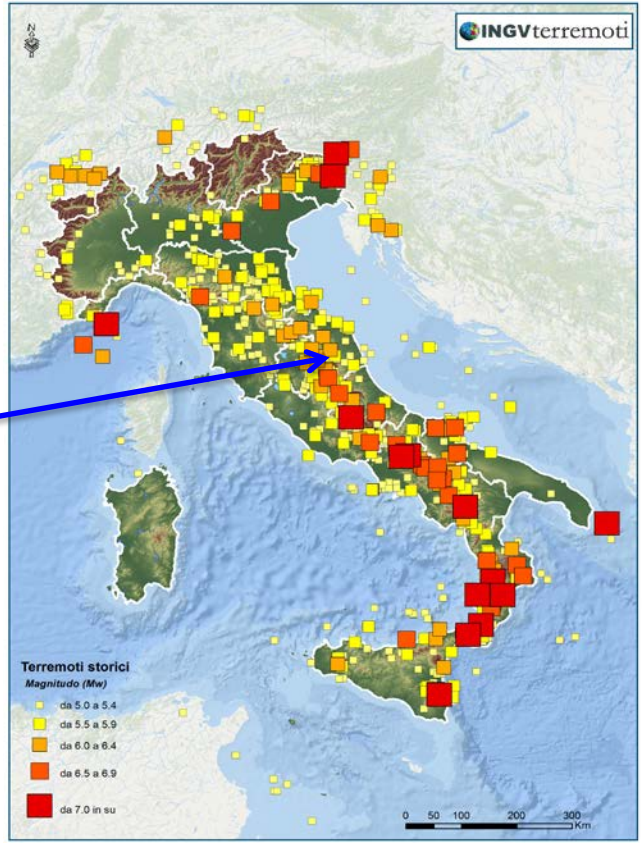
Location: Abbazia di Fiastra – Tolentino (Macerata)

Location Fiastra – Tolentino (Macerata)
About 40 miles from Norcia – Central earthquake location



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.2	0.8	2.0	4.8	12	29	70	>171
PEAK VEL.(cm/s)	<0.07	0.08	0.3	0.8	2.4	8.4	17	45	>120
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald and Worden, 2016, 2011



No damage, No cracks or other structural effets coming from the earthquake has been reported by Regional Highway Autority.


Thank you!

Questions