

Use Of CFRP Rebars As Retrofitting System For Masonry Panels

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THE WORLD'S GATHERING PLACE FOR ADVANCING CONCRETE



Motivation and objective

- **Seismic vulnerability** of masonry
- Possibility of using **high-performance materials**, such as Fiber Reinforced Polymers (**FRP**) for the strengthening of masonry elements

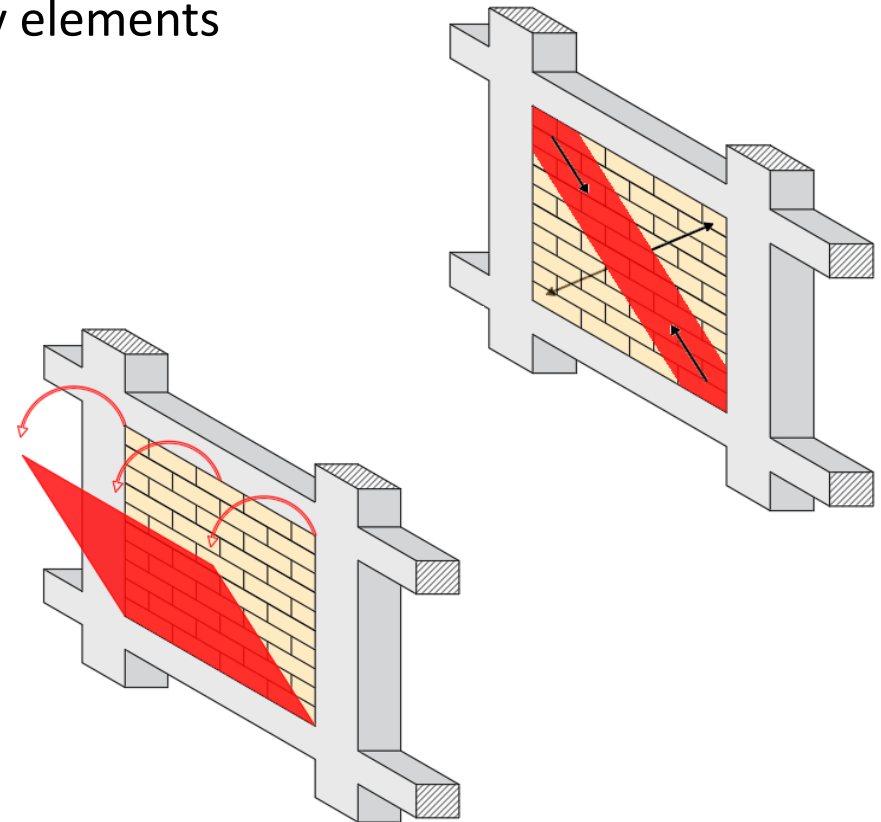


INNOVATIVE STRENGTHENING SYSTEM

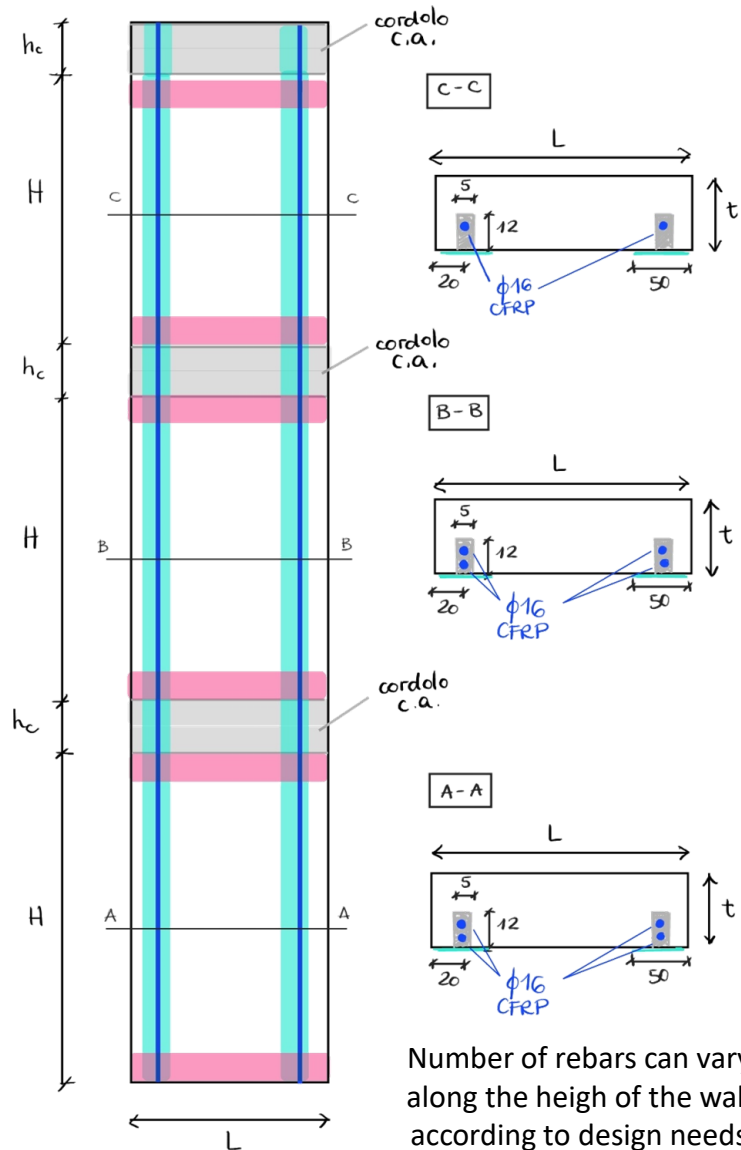
- Applicable to load-bearing elements and infills
- Improvement of in-plane and out-of-plane behavior
- Interventions executed from the outside (no interruption of use)



Study on the **efficiency** in improving the **shear behaviour** (sliding and diagonal cracking) of **single-leaf masonry** elements

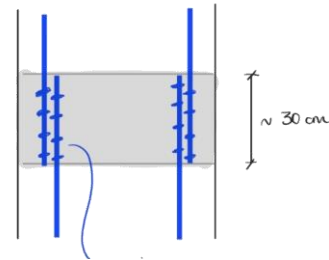


Description of the strengthening system



Number of rebars can vary along the height of the wall according to design needs

RC corbel
Detail of overlapping of rebars



- RC corbel
- FRP rebars
- Multi-axial FRP sheets
- Biaxial FRP sheets



Experimental campaign

Masonry

- Clay-brick single-leaf masonry panels:
 - Bricks: UNI 12×25×6 cm³
 - Cementitious mortar



Material	f_c [MPa]	f_{fl} [MPa]
Mortar	4.35	2.36
Brick UNI 12×25×6	42.60	/

Strengthening system

- Carbon FRP rebars ($\phi 16$)
- High-performance cementitious mortar
- Multi-axial carbon FRP sheet (400 g/m²)

Material	f_c [MPa]	f_{fl} [MPa]	f_t [MPa]	f_s [MPa]	E [GPa]	ϵ [%]
Mortar	18.78	7.66	-	-	-	-
CFRP rebars	-	-	845	262	135	-
CFRP sheets	-	-	4030	-	359	1.44

- f_c : compressive strength
- f_{fl} : flexural strength
- f_t : tensile strength
- f_s : shear strength
- E : elastic modulus
- ϵ : ultimate deformation

Test typologies on wall panels

- Direct shear test
- Diagonal compression test

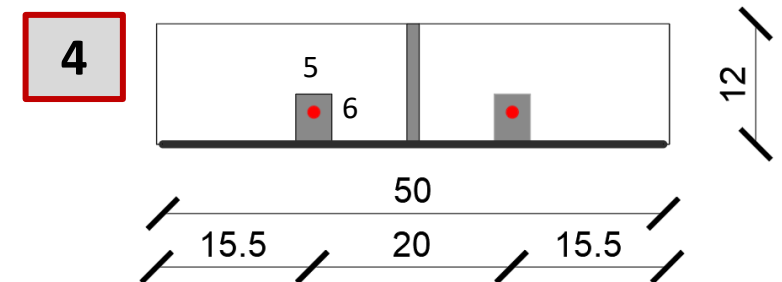
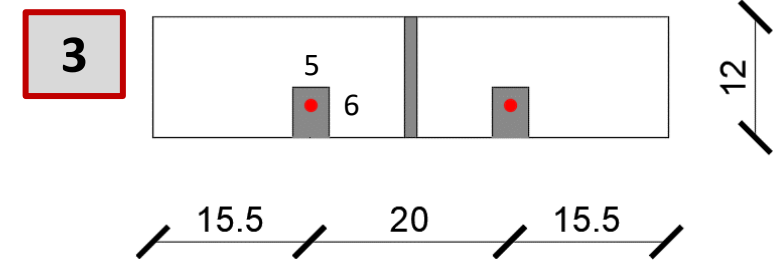
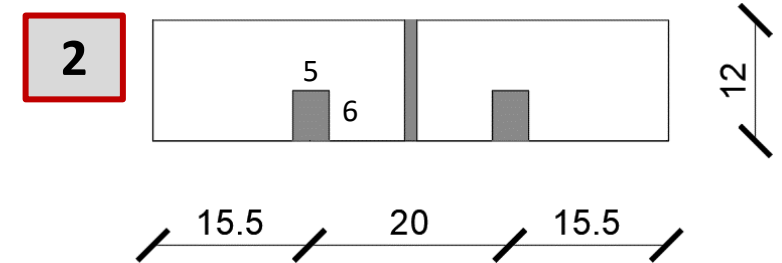
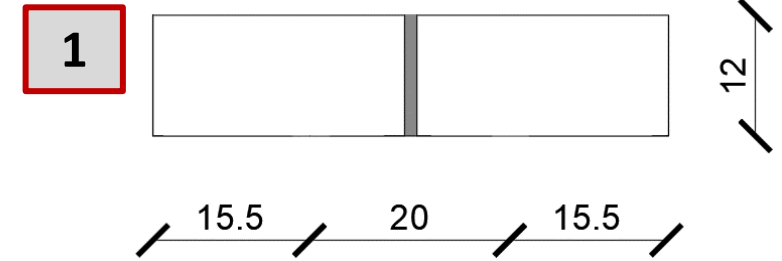
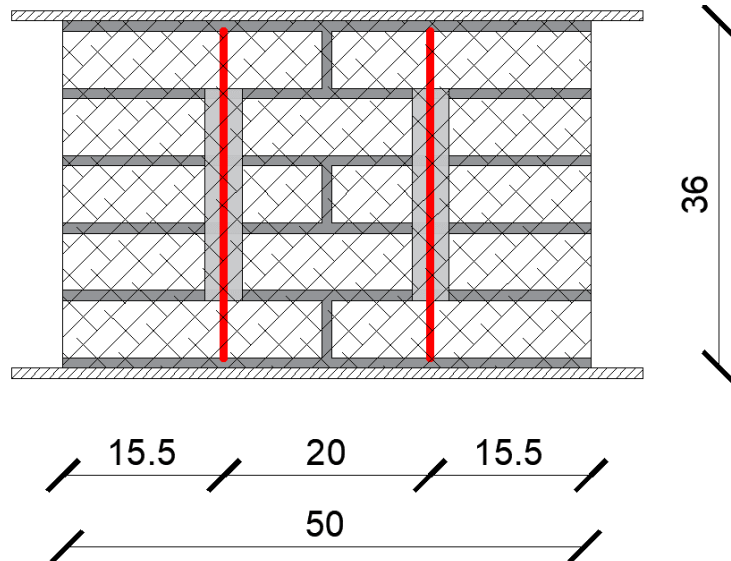


Direct shear tests

Description of tested samples

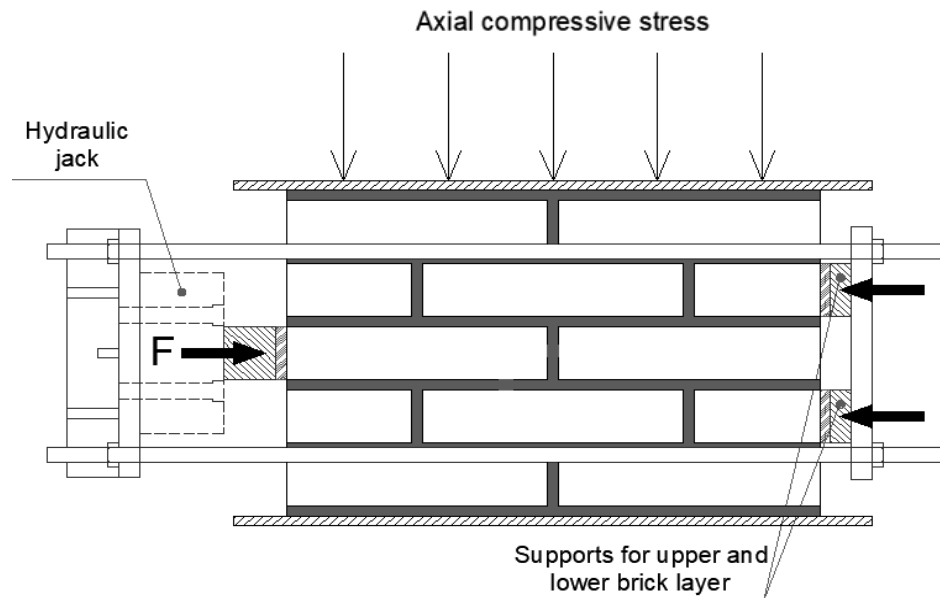
Strengthening layouts:

1. n.2 unreinforced (URM) samples
2. n.2 samples reinforced only with mortar into the grooves
3. n.2 samples reinforced with mortar and rebar into the grooves
4. n.1 sample with the complete reinforcing layout (CFRP rebar + mortar + CFRP sheet)



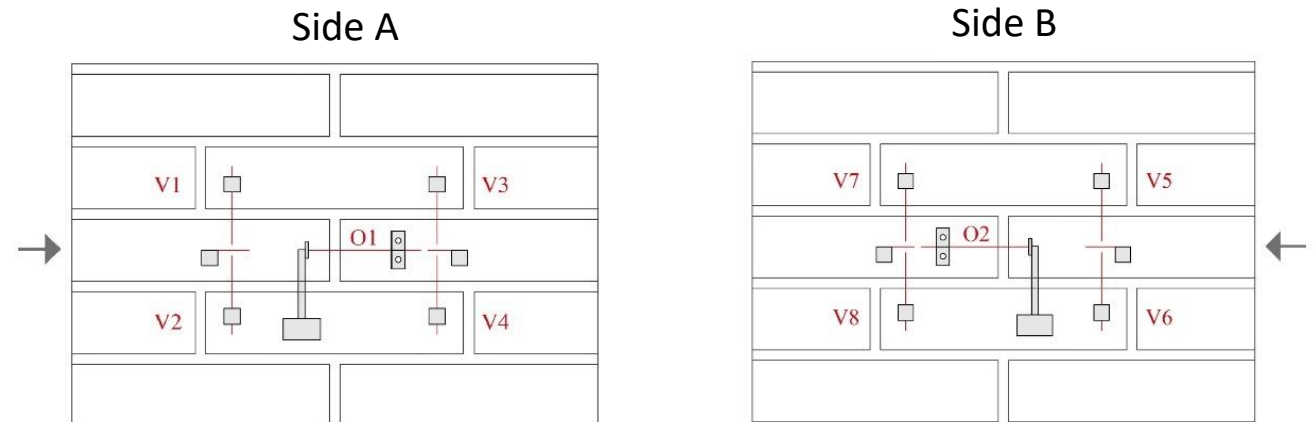
Direct shear test

Setup



Test protocol

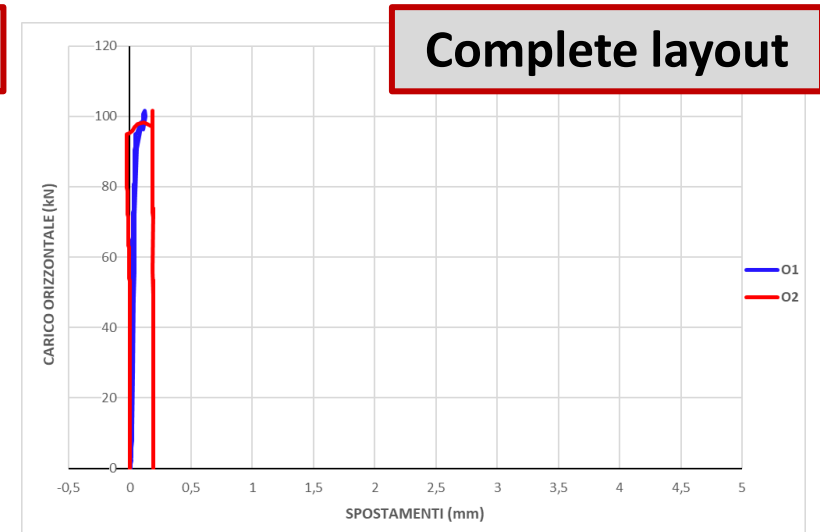
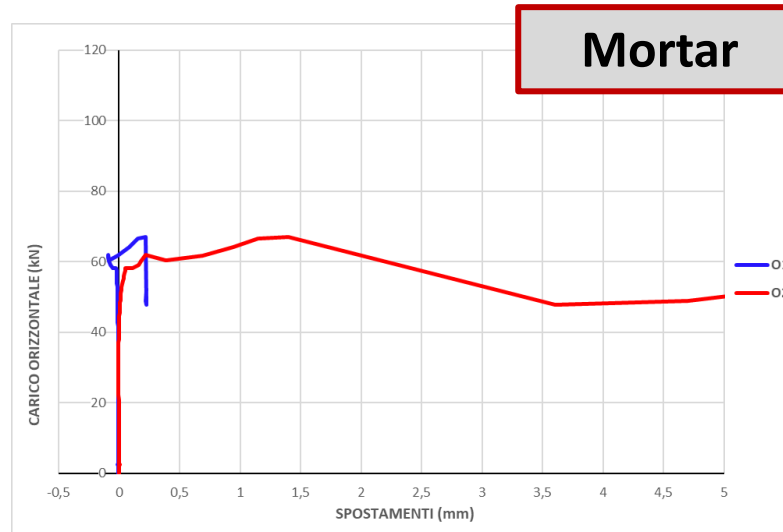
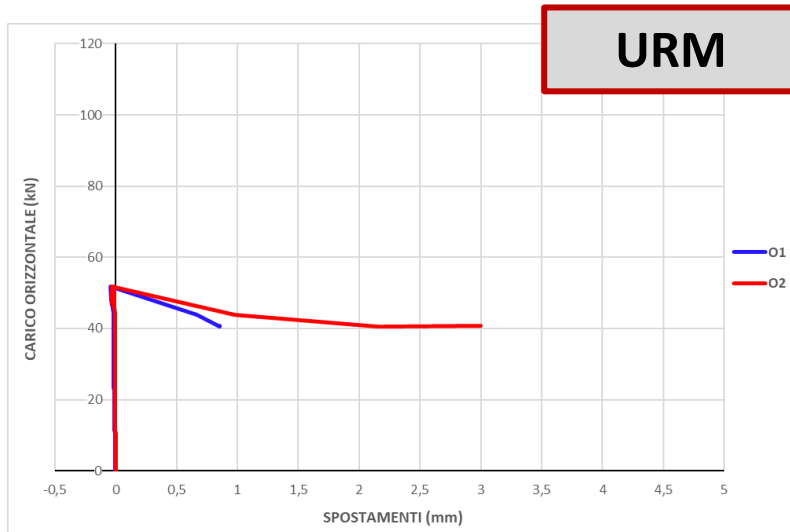
1. Application of vertical stress \rightarrow 0.20 MPa
2. Application of the horizontal load
3. Sliding failure
4. Increment of vertical stress \rightarrow 0.4 – 0.6 MPa
5. Application of the horizontal load



Direct shear test

Results

Force vs displacement graphs – vertical stress: 0.2 MPa



Sample code	σ [MPa]	F_{max} [kN]	Increment [%]	f_v [MPa]	$F_{max,residual}$ [kN]	$f_{v,residual}$ [MPa]
URM_1	0.2	50.7	-	0.42	-	-
	0.6	-	-	-	78.7	0.65
URM_2	0.2	51.8	-	0.43	-	-
	0.4	-	-	-	85.3	0.71
	0.6	-	-	-	89.2	0.74
Mortar_1	0.2	50.6	-	0.42	-	-
Mortar_2	0.2	67.0	31	0.56	-	-
Mortar+Rebar_1	0.2	78.7	54	-	-	-
		77.4				
Mortar+Rebar_2	0.2		54	-	-	-
Complete layout	0.2	101.6	98	-	-	-

$$f_v = \frac{F_{max}}{2A_{joint}}$$

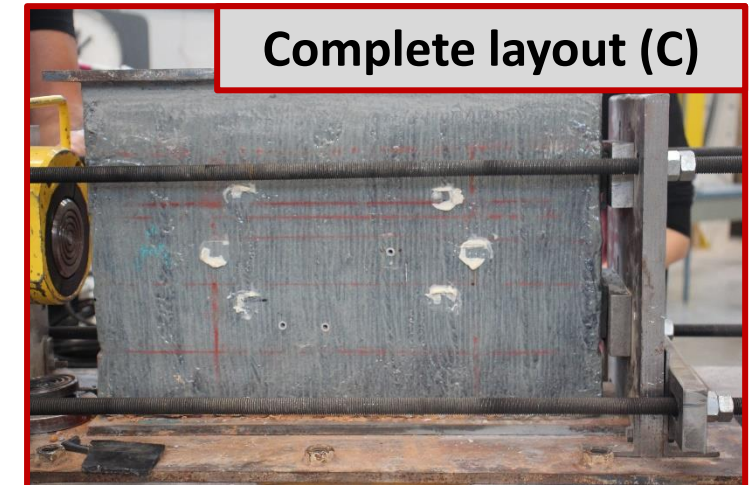
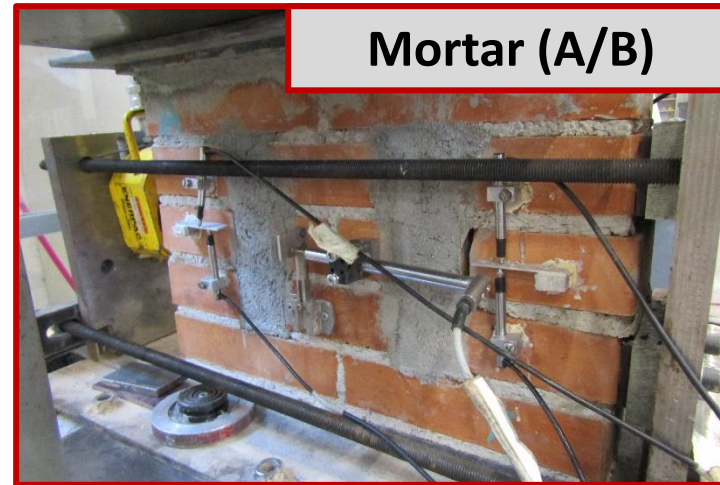
- Strength increment obtained
- Shift in failure mode
(see next slide)



Direct shear tests

Failure modes

- Failure Mode A: sliding
- Failure Mode B: out-of-plane rotation of loaded brick
- Failure Mode C: like B + splitting failure of loaded brick

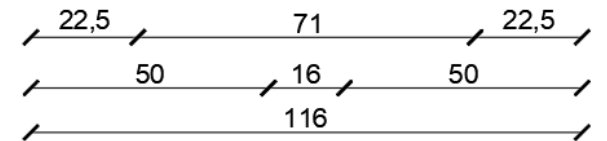
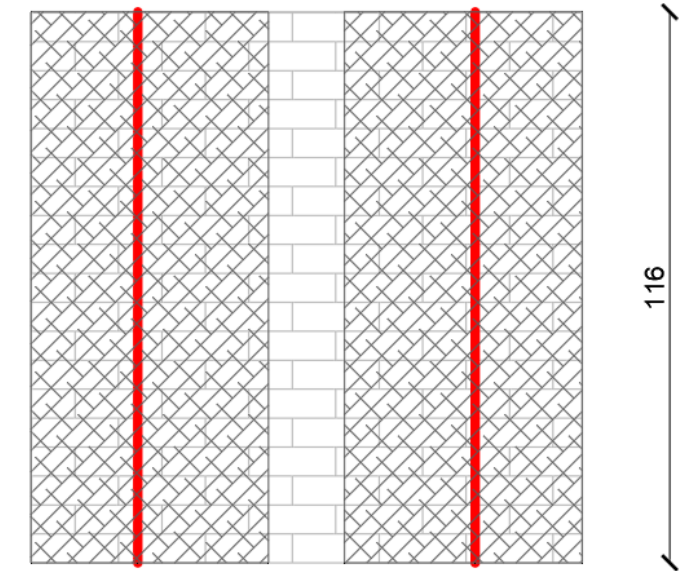
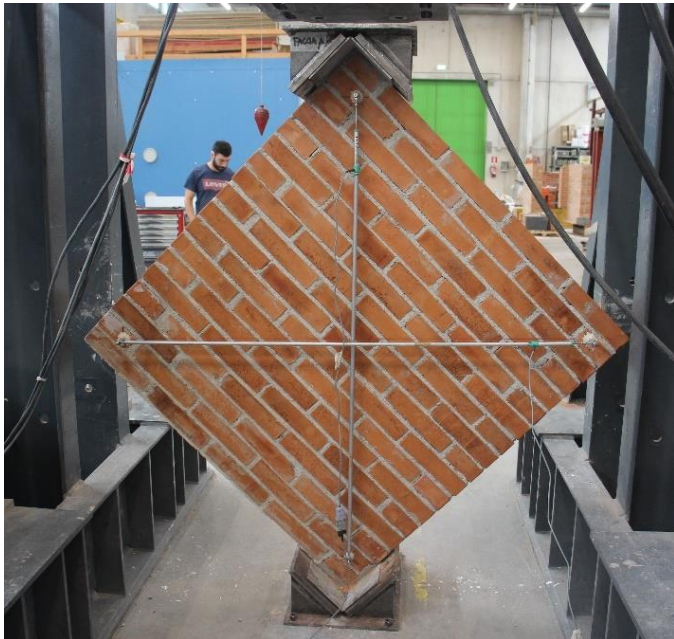


Diagonal compression tests

Description of tested samples

Strengthening layouts:

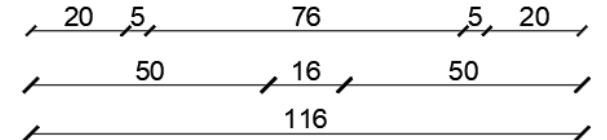
- n.2 unreinforced (URM) samples;
- n.2 samples strengthened with the complete layout (CFRP rebar + mortar + CFRP sheet)



Side B



Side A



Diagonal compression tests

Strengthening procedure



1. Construction of the wall panels
(bricks already cut to prevent undesired failure during the realization of grooves due to slenderness of the panels)
2. CFRP rebars insertion
3. High-performance mortar application
4. Closing of grooves with mortar
5. Primer application
6. Multi-axial CFRP sheets application



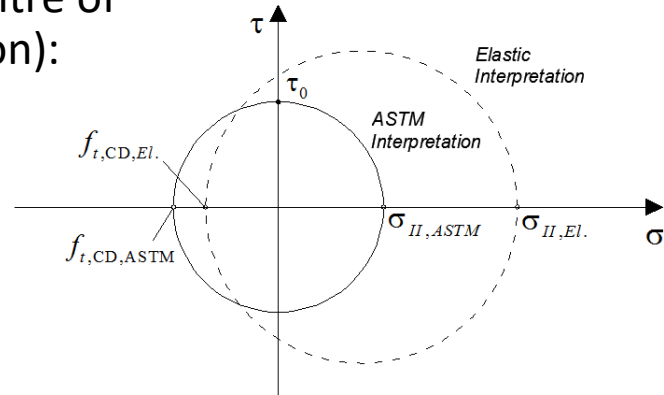
Diagonal compression tests

Setup

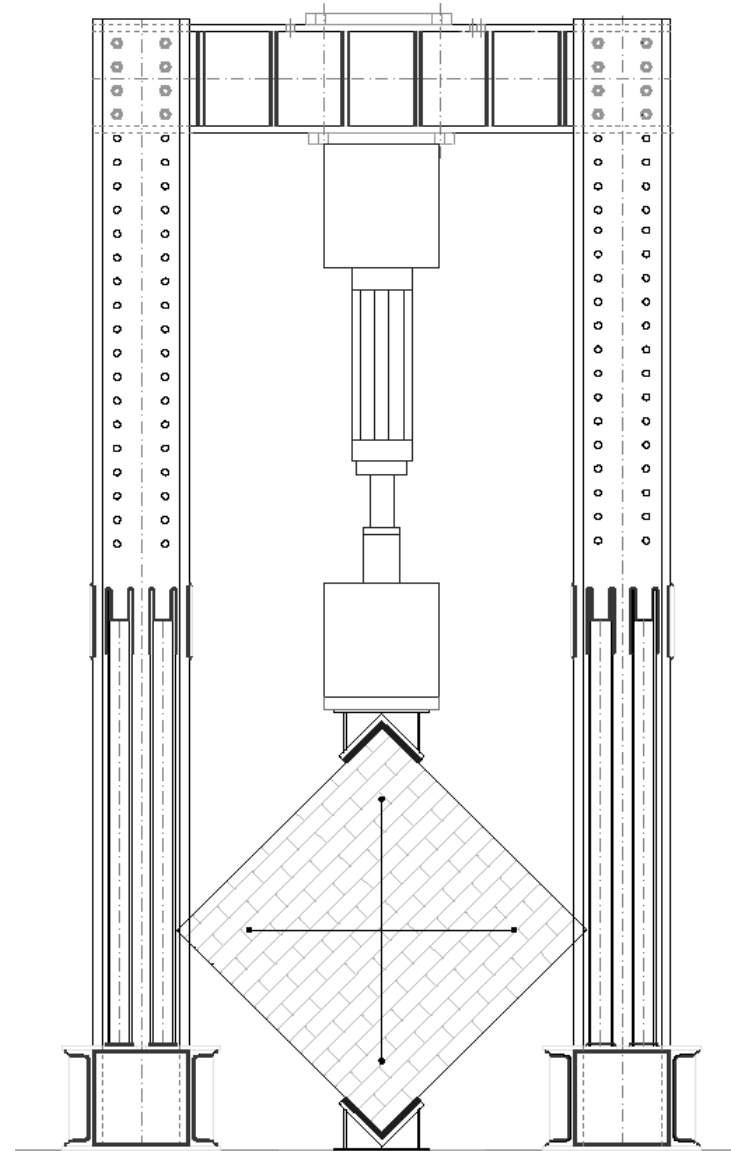
- Displacement-controlled apparatus (capacity of 500 kN)
- Imposed displacement rate: 0.02 mm/s
- Diagonal displacements measured using linear potentiometers (50 mm stroke)
- Digital Image Correlation

State of stress in the centre of the panel (elastic solution):

$$\sigma = 0.56 \frac{F}{A_n}$$
$$\tau = 1.05 \frac{F}{A_n}$$

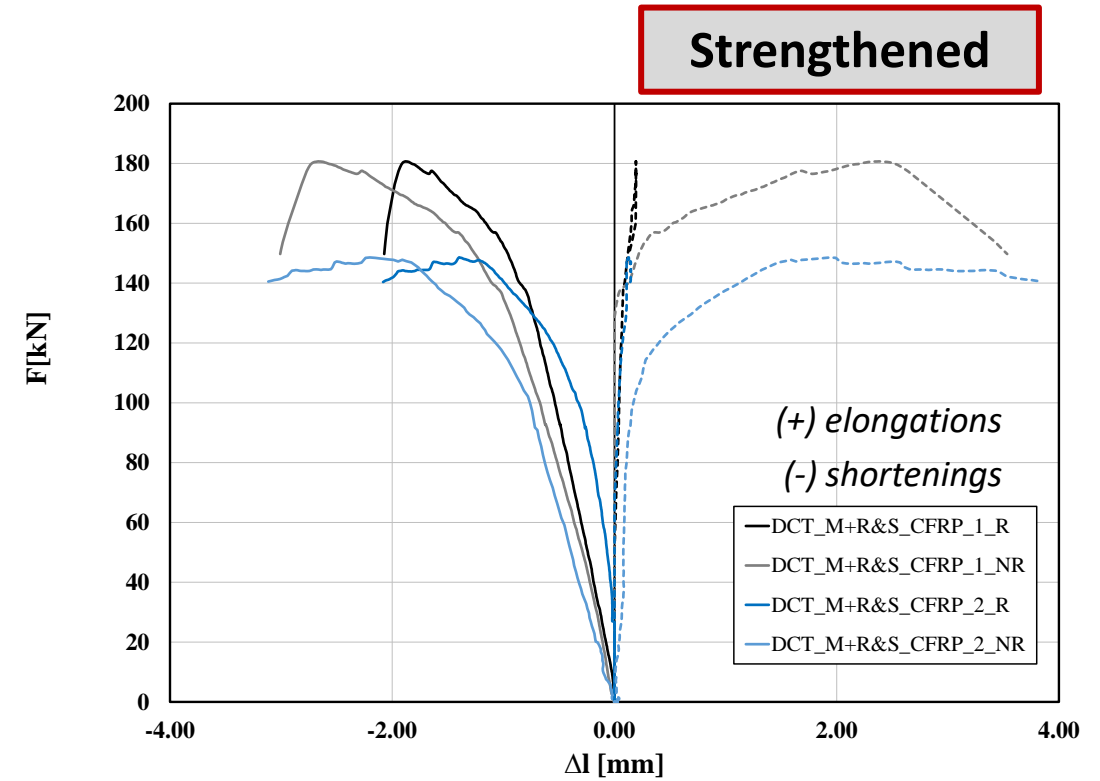
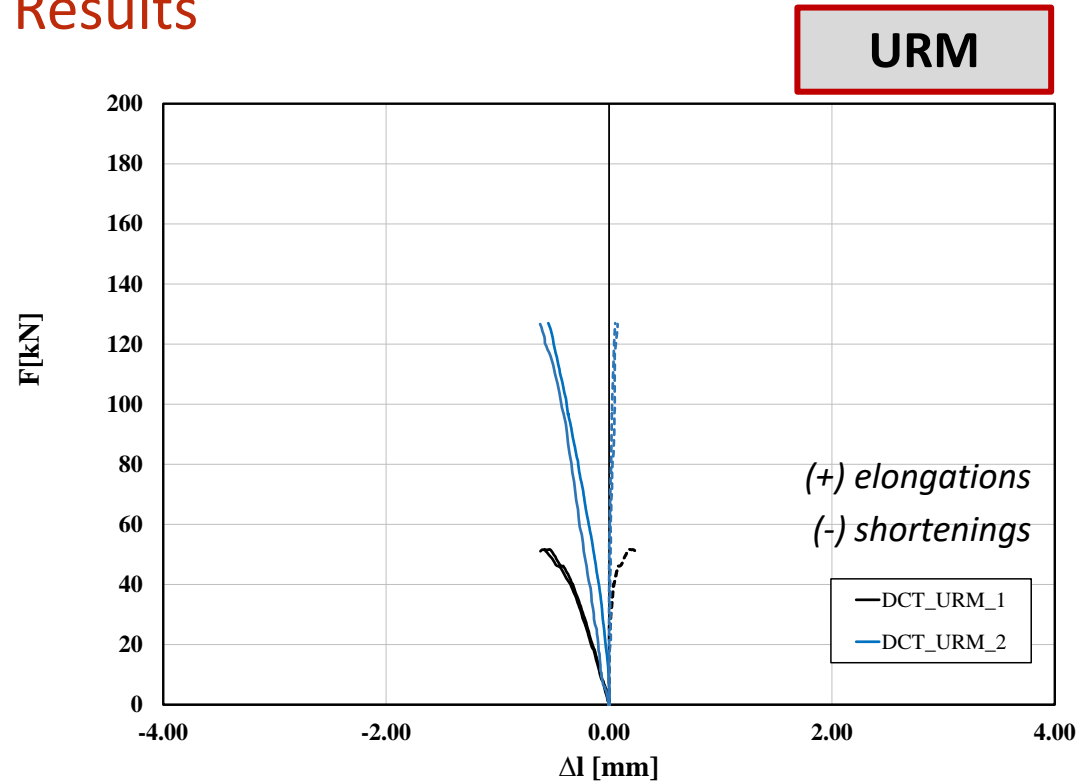


Principal stresses: $\sigma_I = f_{t,M} = 0.5 \frac{F_u}{A_n}$; $\sigma_{II} = 1.62 \frac{F_u}{A_n}$



Diagonal compression tests

Results



Sample code	F_u [kN]	Increment [%]	f_t [MPa]	τ_{el} [MPa]	γ_{max} [-]	G [MPa]
URM_1	51.7	-	0.19	0.39	0.0005	1335
URM_2	126.7	-	0.46	0.96	0.0005	2890
Strengthened_1	180.7	103	0.65	1.38	0.0032	1758
Strengthened_2	148.6	67	0.54	1.13	0.0033	2005



Diagonal compression tests

Failure modes



Stair-stepped crack (sliding phenomenon)

URM



Strengthened panels

Multiple cracks

Local debonding of CFRP sheets

No damage to CFRP rebars



Diagonal cracking (very fragile)

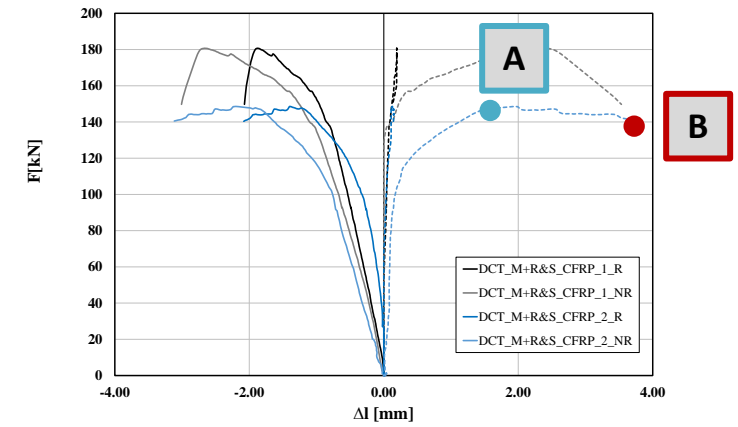
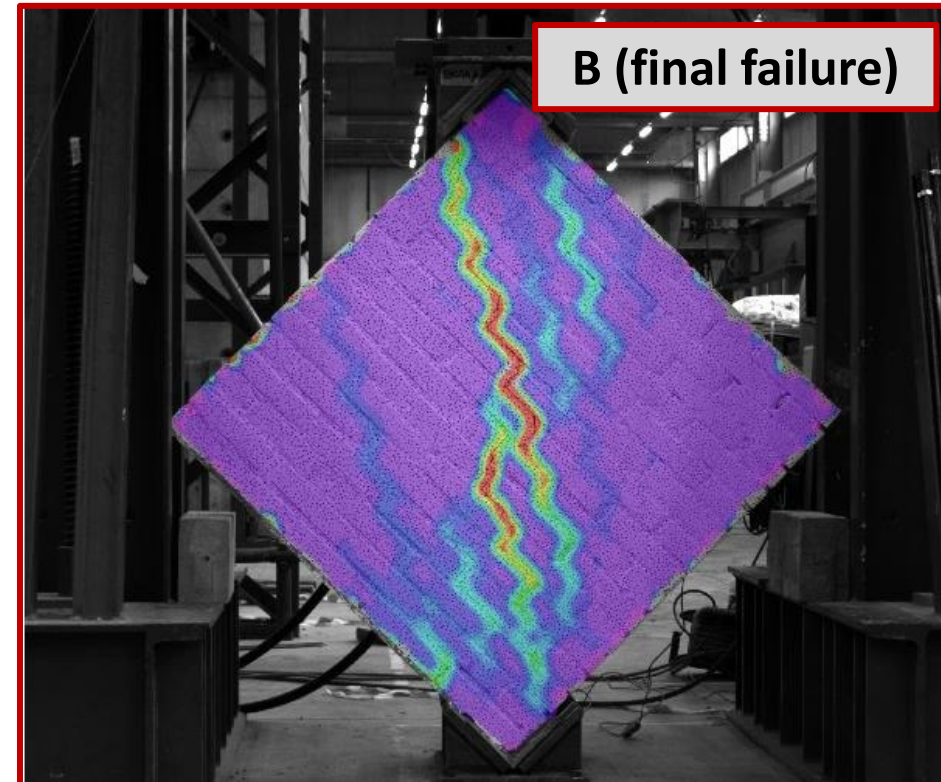
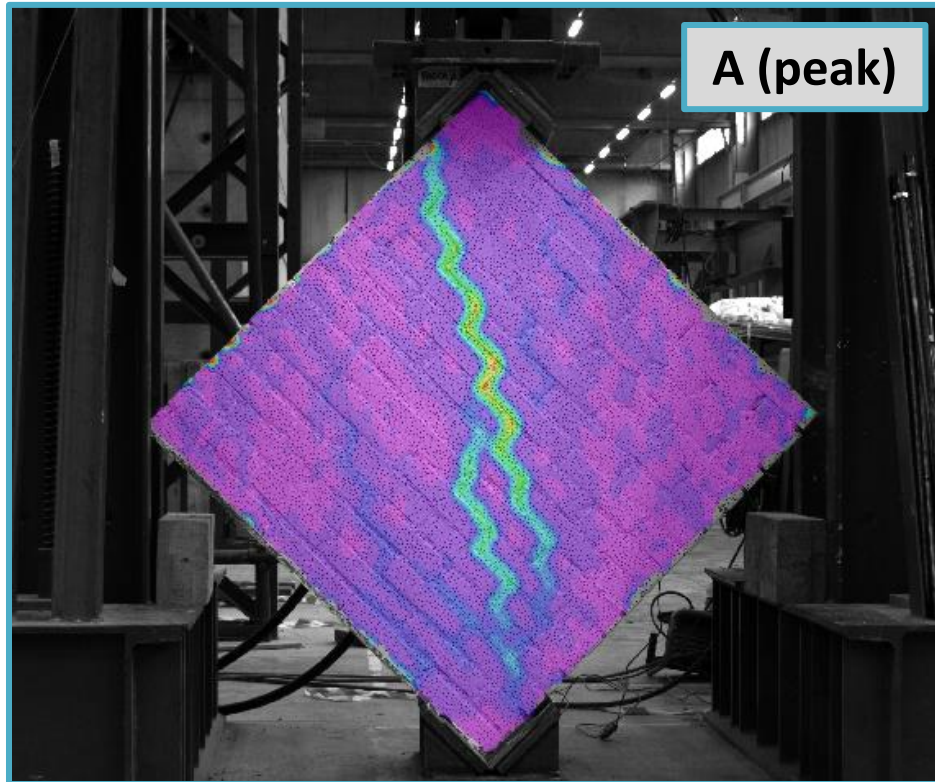
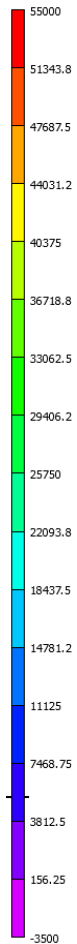


Diagonal compression tests

Digital Image Correlation

Strengthened sample:

DIC technique applied on the unreinforced side



Conclusions

- **Innovative strengthening technique:** use of CFRP rebars and high-strength mortar (into grooves) and CFRP sheets (on the surface)
- Investigation of the **shear behaviour** of strengthened masonry elements → direct shear and diagonal compression tests
- **Strength improvement** and **change in failure modes** obtained (sliding failure prevented)



Future works

Tests on **full-scale walls** with different geometries to verify the effectiveness against **flexural and shear failure** (work in progress..)



THANK YOU FOR THE ATTENTION



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