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Out of plane strengthening of masonry walls with inorganic composites

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❑ Introduction

Unreinforced masonry (URM) walls are prone to failure when subjected to in-plane and out-of-plane loads caused by earthquakes.

Partial or total collapses of existing masonry walls during earthquakes result in significant economic losses, severe injuries and loss of human lives.

Effective and sustainable strategies to enhance the safety of such existing assets are needed in order to have resilient structures.

❑ Introduction

Composite materials help in reducing the vulnerability of URM walls to in-plane and out-of-plane failures

- Externally bonded FRPs

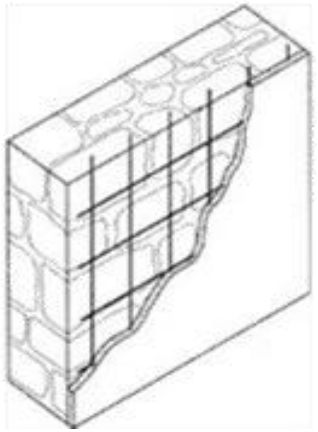
- FRCM/FRM

❑ Compatibility of resins with masonry support

❑ Special care during the application process

❑ Introduction

Different inorganic strengthening systems:



❖ Reinforced plaster (RP)

Steel Welded wire mesh
+
mortar (thick. 40-100mm)

❖ Fibre Reinforced Cementitious Mortar (FRCM)

Composite grid
+
mortar (thick. 10-30mm)

❖ Composite Reinforced Mortar (CRM)

Composite grid
+
mortar (thick. >30mm)

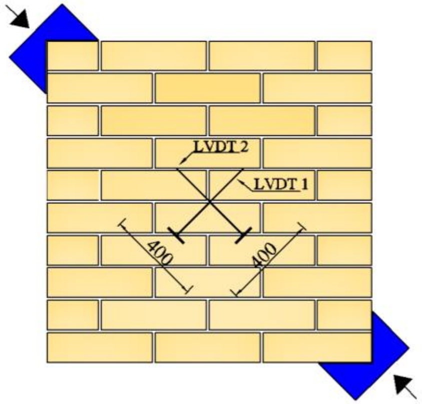
❖ Fibre Reinforced Mortar (FRM)

Short fibres
+
mortar (thick. 10-30mm)

❑ In-plane strengthening

In past years, 149 diagonal compression tests were performed at University of Naples Federico II, out of which:

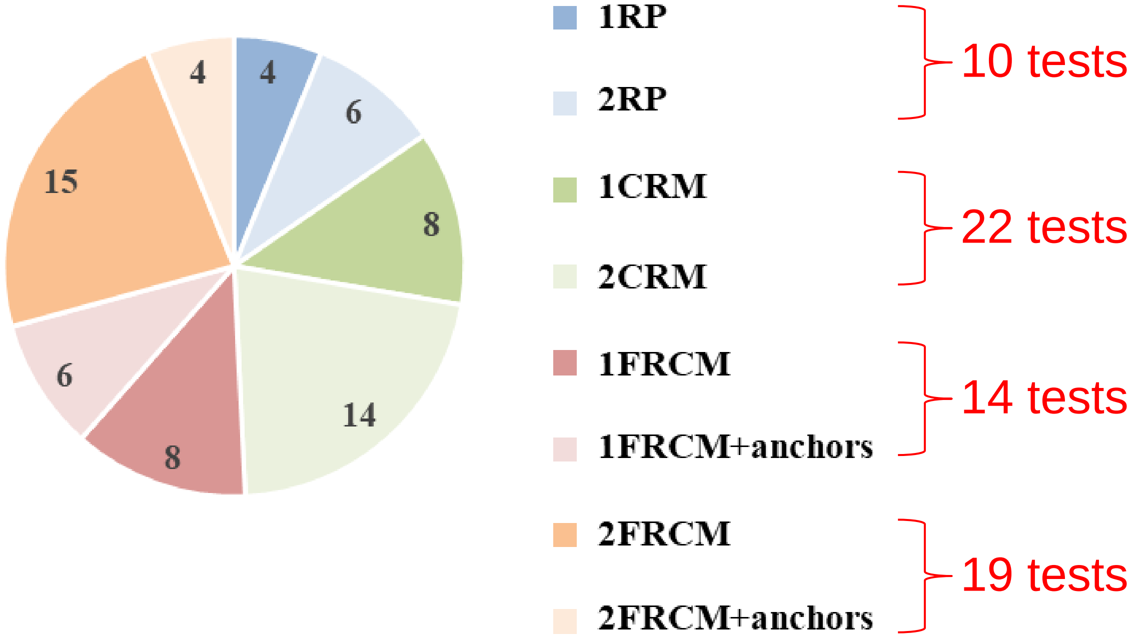
- ❖ 83 Tuff masonry panels (Neapolitan tuff)
- ❖ 30 clay brick masonry panels (Emilia-Romagna)
- ❖ 36 rubble stone masonry panels (L’aquila)



❑ In-plane strengthening

Different strengthening configurations have been investigated

Tuff strengthened panels:



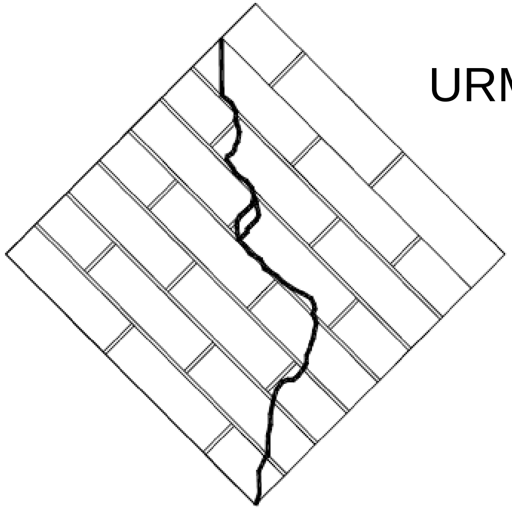
❑ In-plane strengthening

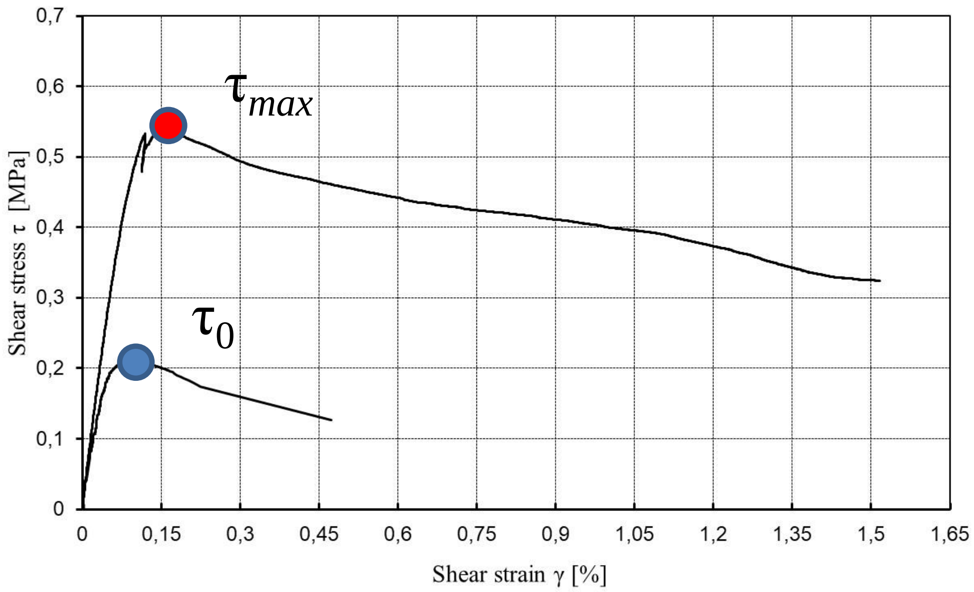
The effectiveness of different strengthening solutions fon enhancing the in-plane shear capacity of tuff masonry panels has been evaluated comparing the ratio

$$\tau_{max}/\tau_0$$

ASTM E 519

$$\tau = 0.707 \cdot \frac{P}{A_n}$$





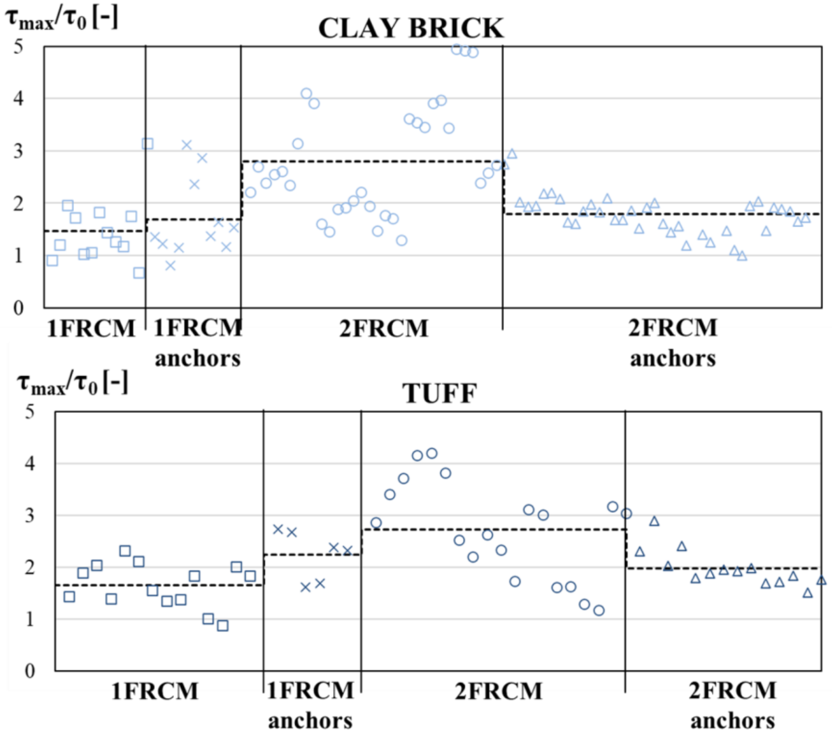
Where:

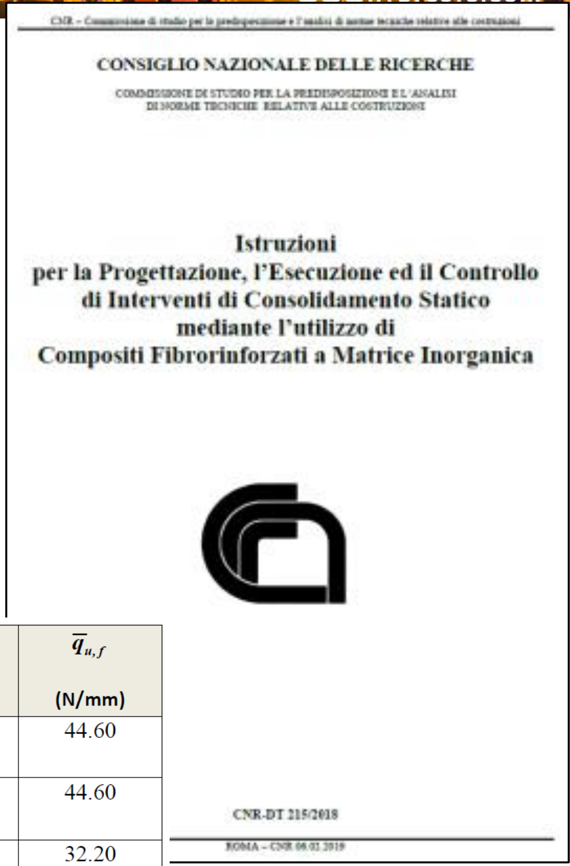
- ❖ τ_{max} the experimental peak shear stress computed for the reinforced panel
- ❖ τ_0 the average experimental peak shear stress of the corresponding URM panels

REINFORCED

❑ In-plane strengthening

Experimental data have been used to calibrate amplification factors for masonry shear capacity with different strengthening solutions:





CONSIGLIO NAZIONALE DELLE RICERCHE

COMMISSIONE DI STUDIO PER LA PREDISPOSIZIONE E L'ANALISI DI NORME TECNICHE RELATIVE ALLE COSTRUZIONI

Istruzioni
per la Progettazione, l'Esecuzione ed il Controllo
di Interventi di Consolidamento Statico
mediante l'utilizzo di
Compositi Fibrorinforzati a Matrice Inorganica

CNR-DT 215/2018

❖ **Italian guidelines**
CNR DT 215 - 2018

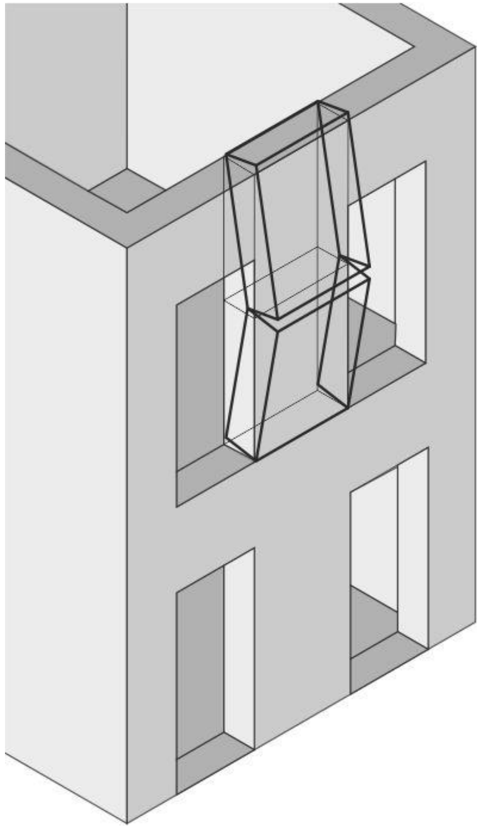
Tipo di muratura	Coefficiente correttivo	$\bar{q}_{u,f}$ (N/mm)
Muratura di pietrame disordinato (ciottoli, pietre erratiche e irregolari)	1.5	44.60
Muratura a conci sbozzati con paramenti di spessore disomogeneo	1.5	44.60
Muratura di pietre a spacco con buona tessitura	2.0	32.20
Muratura a conci di pietra tenera (tufo, calcarenite, ecc.)	2.0	44.60
Muratura a blocchi lapidei squadrati	1.2	44.60
Muratura di mattoni pieni e malta di calce	1.7	24.50
Muratura in mattoni semipieni con malta cementizia	1.3	44.60

In case of 1 side strengthening it is mandatory to use anchors!

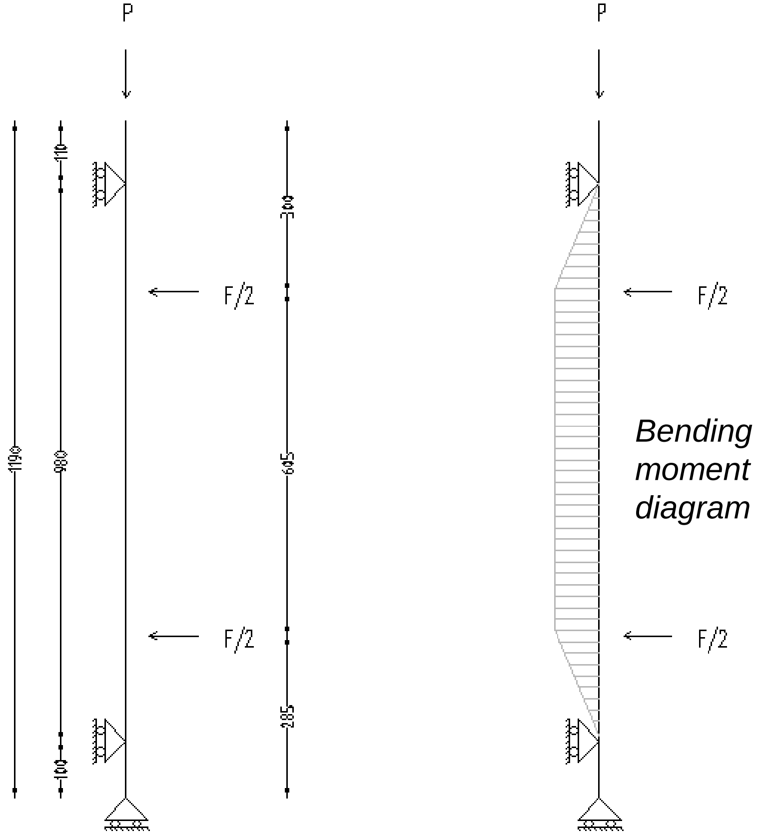
❑ Out-of-plane strengthening

Investigate the effectiveness of FRCM/FRM for the out-of-plane (OOP) strengthening of masonry walls through quasi-static testing

Selected failure mechanism

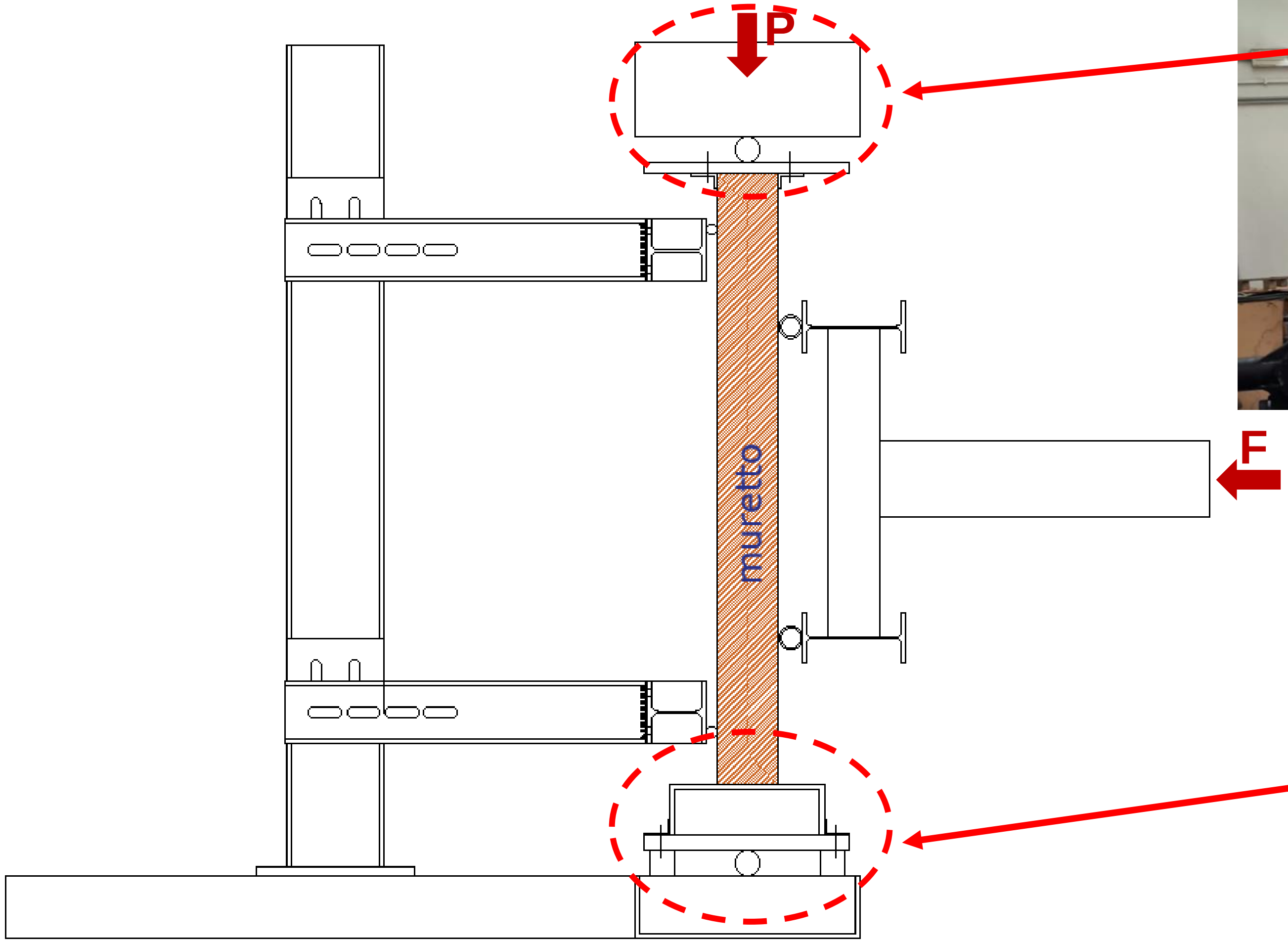


Simulated static scheme
(4 point bending test+compressive axial load)



❑ Experimental program

➢ Design of the set-up and boundary conditions

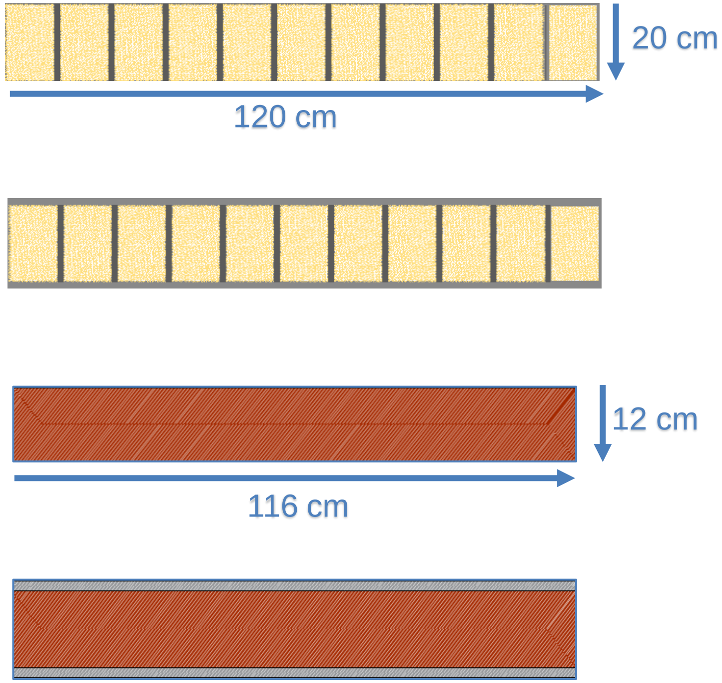


❑ Experimental program

➢ Two solid clay brick and two tuff masonry walls are presented:

TUFF
- T_URM — No strengthening
- T_FRM_2S — Strengthening on 2 sides with FRM

CLAY BRICK
- C_URM — No strengthening
- C_FRM_2S — Strengthening on 2 sides with FRM



FRM thickness = 15mm

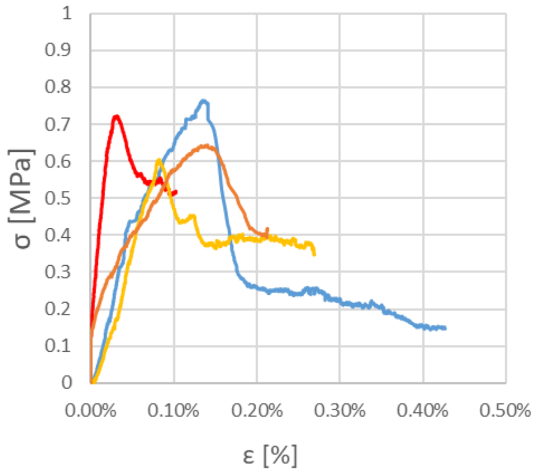
❑ Experimental program

- FRM: lime-based mortar with embedded short glass fibres (length 19mm, volumetric ratio less than 2%)

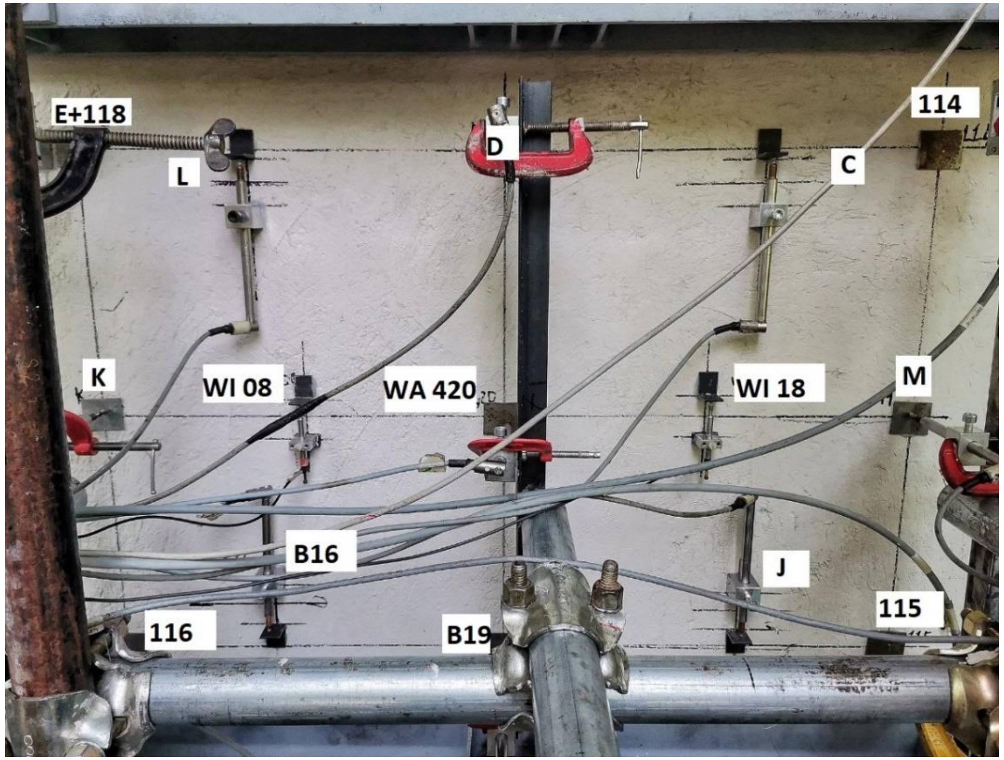
Mechanical properties

FRM mean compressive strength
23 MPa

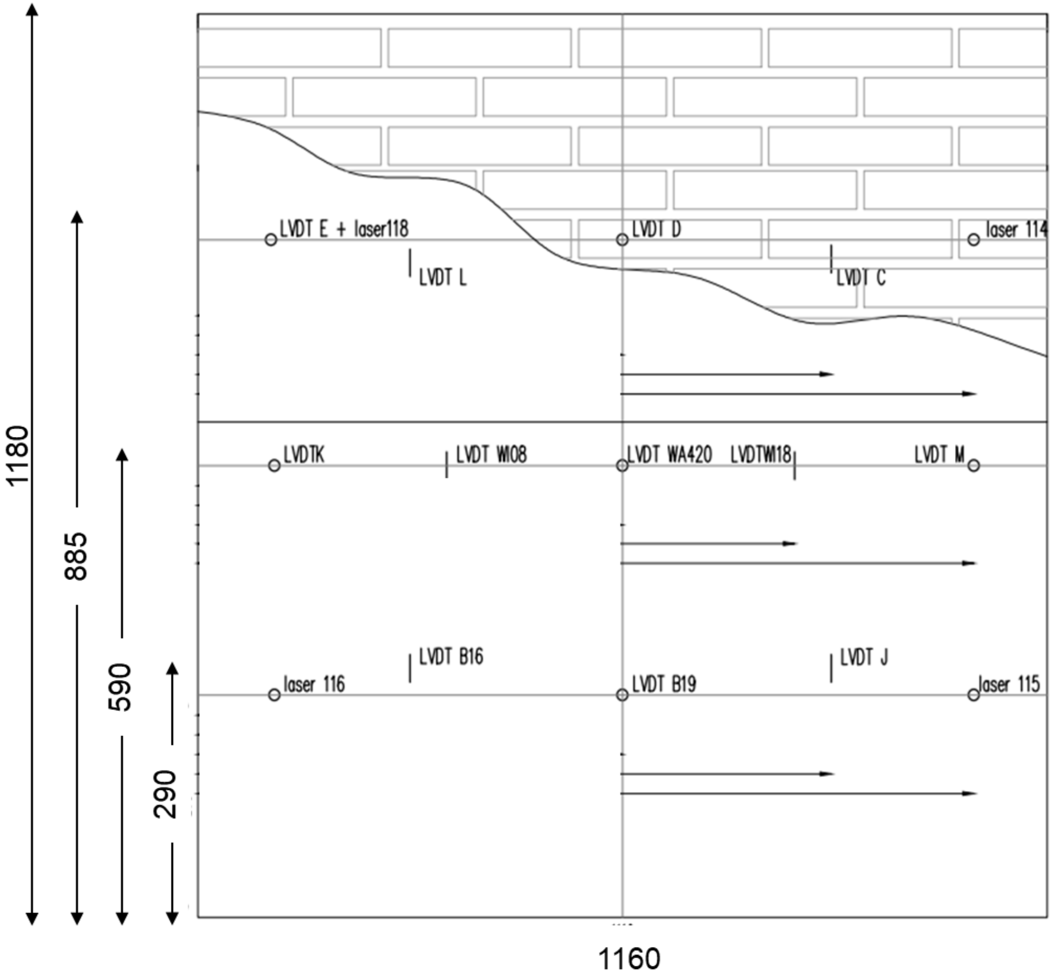
FRM mean tensile strength
0.7 MPa



❑ Experimental program



Instrumentation	
Laser	4
LVDT (perpendicular to the panel)	6
LVDT (parallel to the panel)	6



❑ Discussion of experimental results

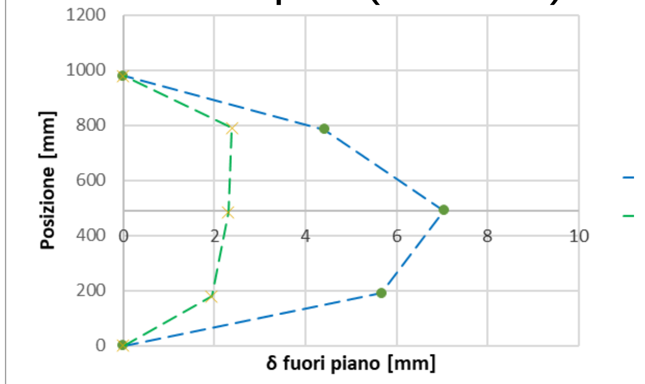
➢ Clay brick panels: failure mode

C_URM

C_FRM_2S

Bridging effect of the fibres

Deformed shapes (F=30kN)



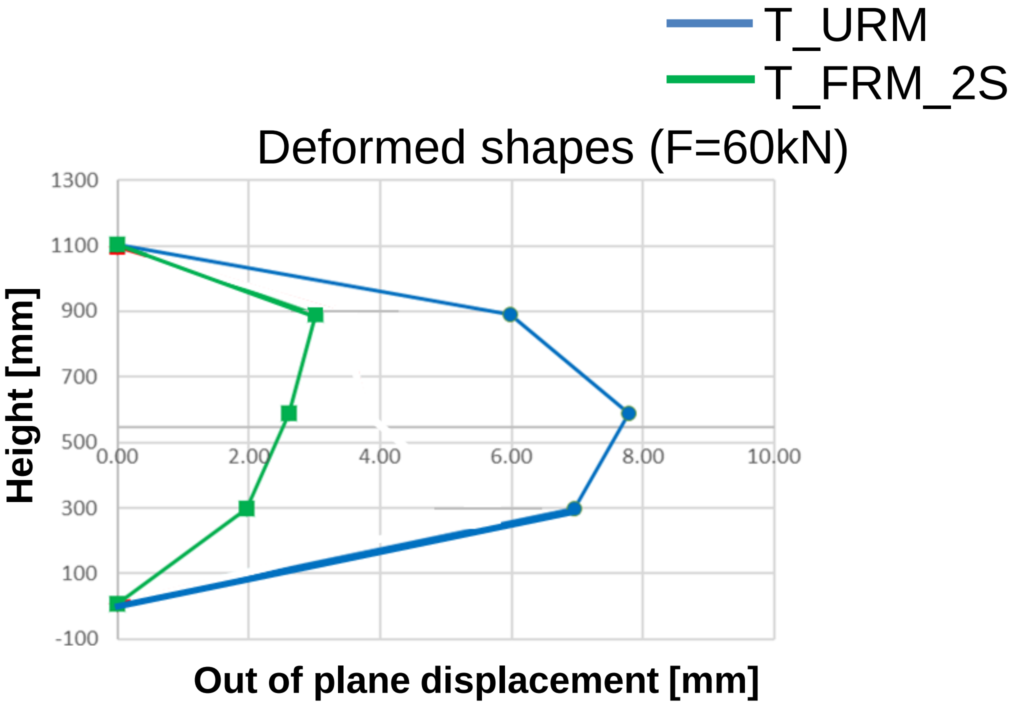
C_URM
C_FRM_2S

Discussion of experimental results

- Tuff panels: failure mode

T_URM

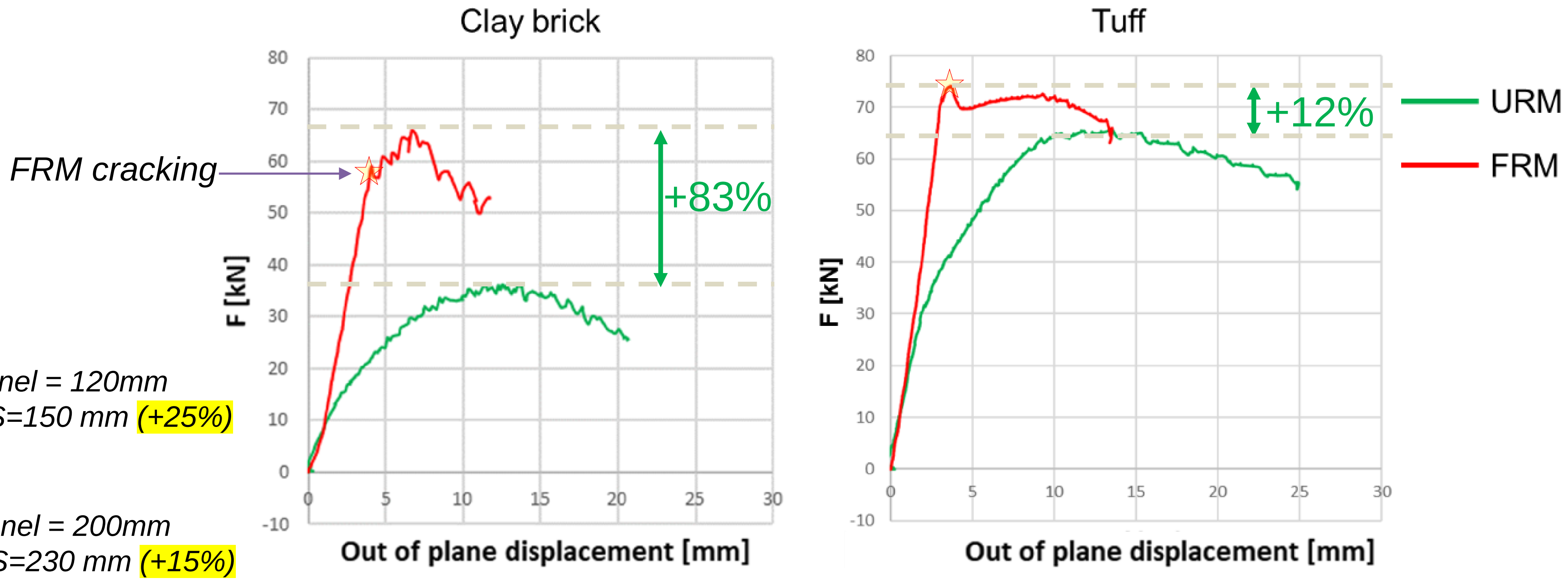
T_FRM_2S



Different activation of cracks

❑ Discussion of experimental results

➢ OOP capacity curves at the mid-span of the panels



Clay brick

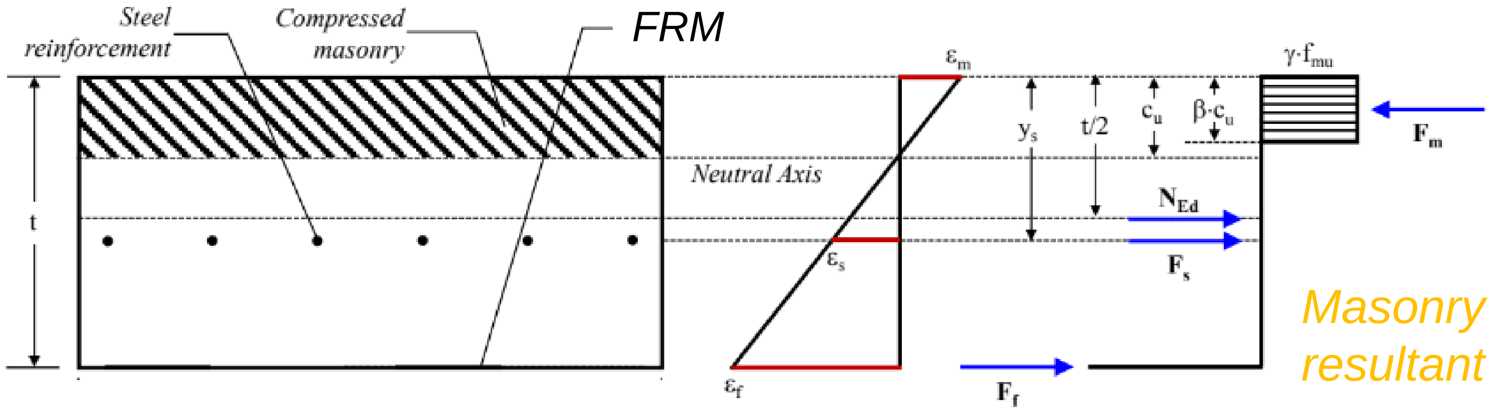
thickness of URM panel = 120mm
thickness of FRM_2S=150 mm (+25%)

Tuff

thickness of URM panel = 200mm
thickness of FRM_2S=230 mm (+15%)

❑ Proposal for analytical formulation

- Based on the approach currenlty adopted for FRCM (ACI 549)



Flexural capacity (no steel reinforcement):

$$Mn = Fm\left(\frac{t}{2} - \frac{\beta \cdot c_u}{2}\right) + Ff\,\frac{t}{2}$$

Equilibrium:

$$Fm - Ff = N_{Ed}$$

Masonry compressive resultant force

FRM tensile resultant force

$$Ff = tf \cdot Ef \cdot \varepsilon_f$$

Thickness of the FRM layer in tension

❑ Proposal for analytical formulation

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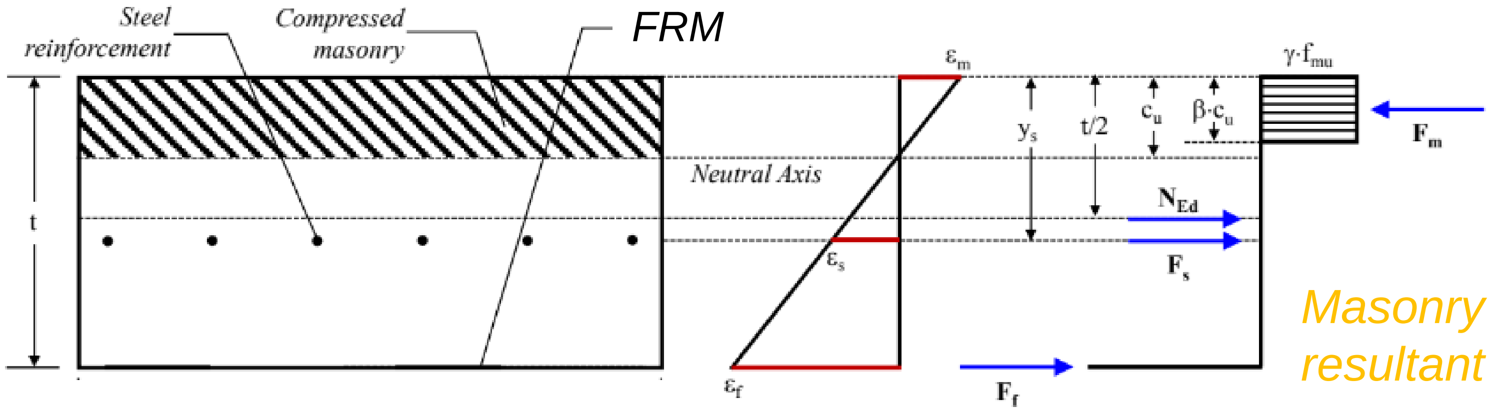

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Masonry compressive resultant force

FRM tensile resultant force

$$Ff = tf \cdot Ef \cdot \varepsilon_f$$

Peak tensile stress (f_f) of the FRM

FRM in compression Is not considered, as for FRCM

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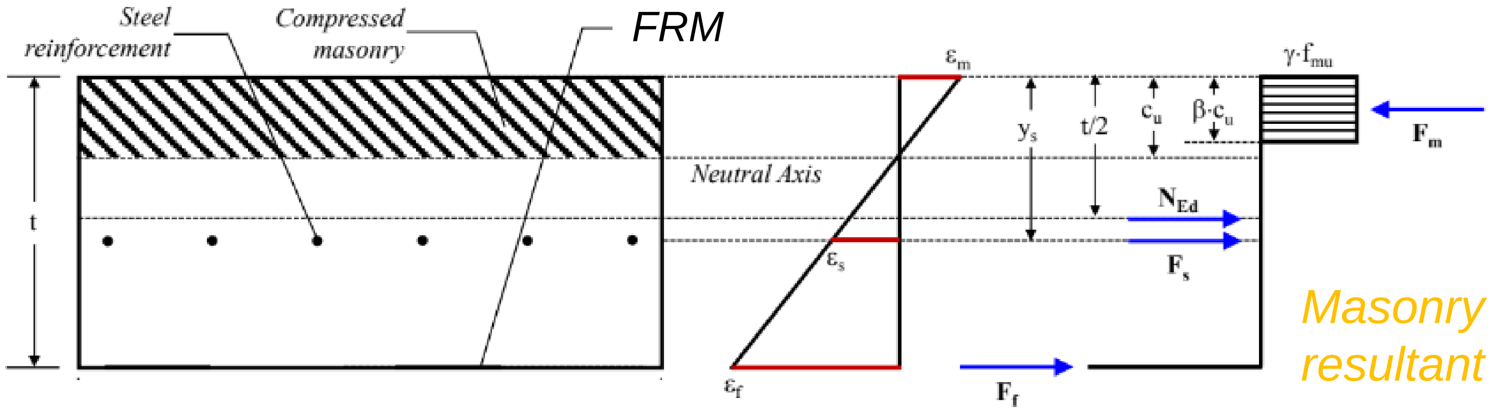

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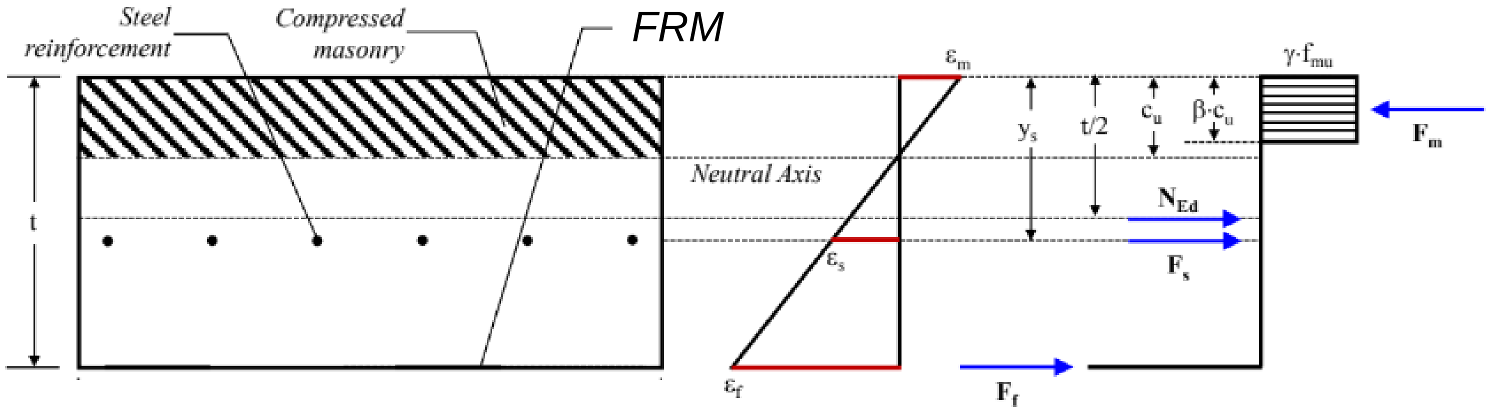


Flexural capacity (no steel reinforcement):

$$Mn = Fm\left(\frac{t}{2} - \frac{\beta \cdot c_u}{2}\right) + Ff\,\frac{t}{2}$$

Comparison:

	F theoretical	F max exp.	Δ
	kN	kN	-
C_FRM_2S	55.5	66.0	-16%
T_FRM_2S	61.6	74.0	-17%

The analytical calculation provides a safe estimation of the flexural capacity of FRM strengthened masonry panels

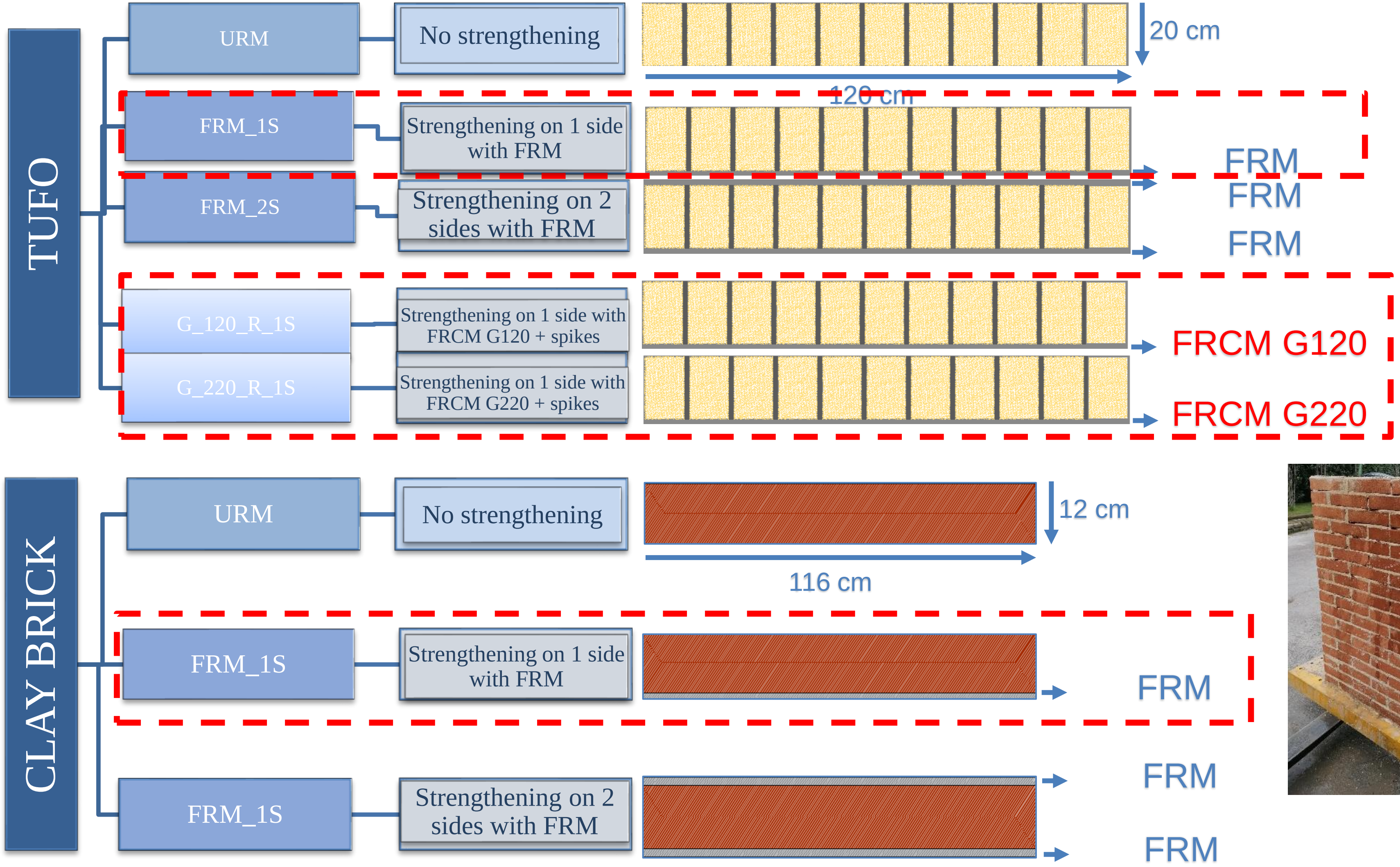
❑ Conclusive remarks

- The results of this preliminary experimental campaign showed that the failure mode of bare and strengthened specimens was quite similar, except for the tuff URM wall. In all cases, the failure was governed by flexure.
- The FRM increased the out-of-plane capacity and reduced the out-of-plane deformation of the panels. For the clay brick masonry walls the capacity was enhanced by 83% for the double-side configuration with respect to the bare wall. Conversely, for the tuff walls the capacity enhancement was about 12% due to the effect of the FRM.
- A proposal of analytical approach was used to compute the flexural capacity of FRM strengthened walls, providing an underestimation of the experimental data of 16-17%.
- From these preliminary results, the FRM appears a sound technique for the out-of-plane strengthening of masonry walls and further data are needed to validate design equations.

FUTURE DEVELOPMENTS

- Further experimental tests are needed; Comparison with FRCM strengthening solution is currently under investigation

❑ Ongoing research….



Thank you!

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