COST Action C26 Urban Habitat
Constructions under Catastrophic Events

MALTA, 23rd – 25th October 2008

FEM modeling masonry shear walls strengthened with metal sheeting

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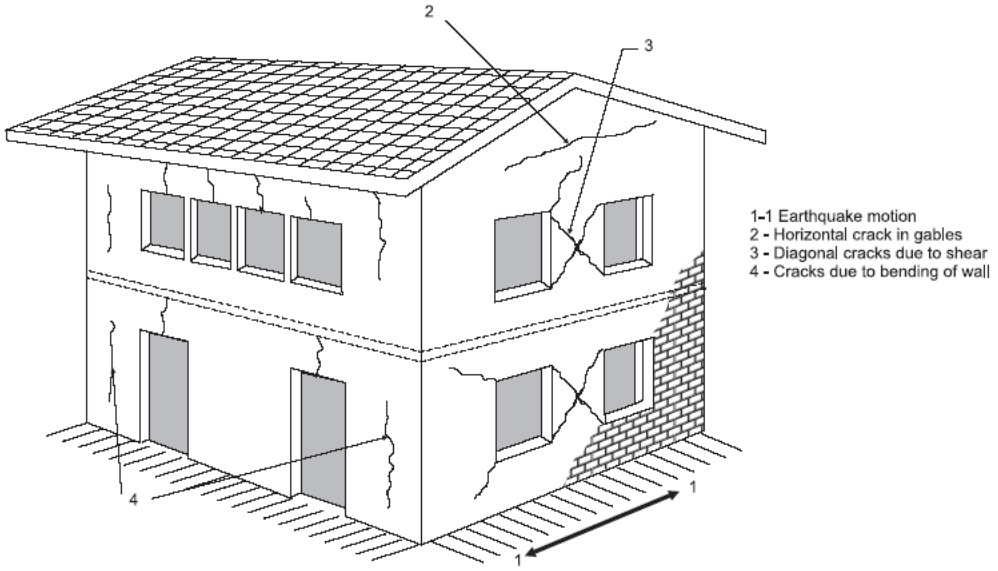
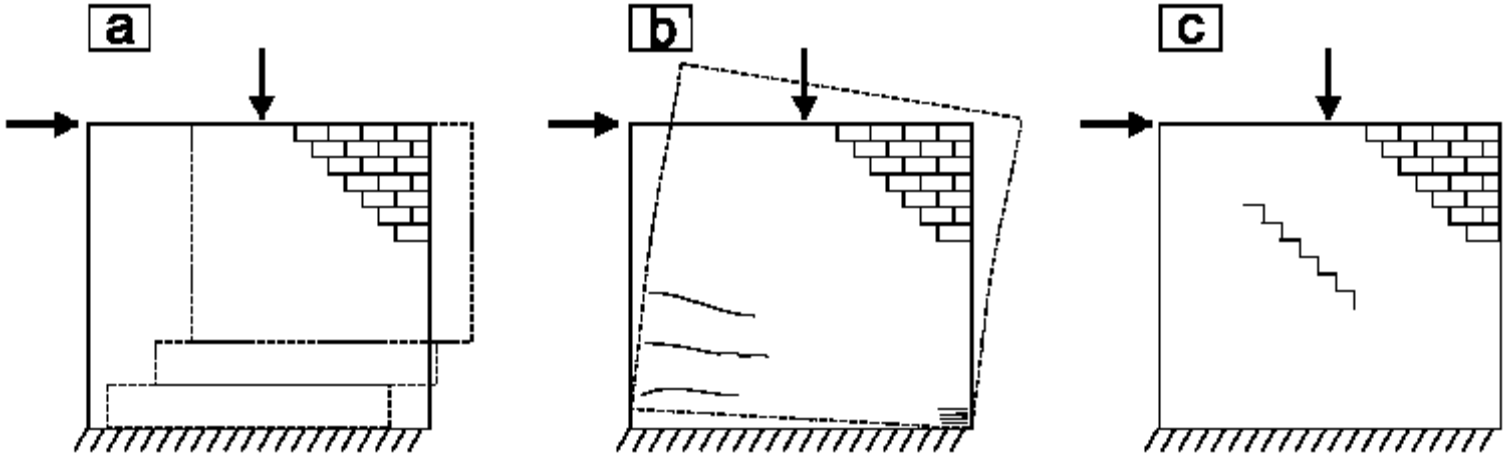
Masonry behavior structure vs. panel



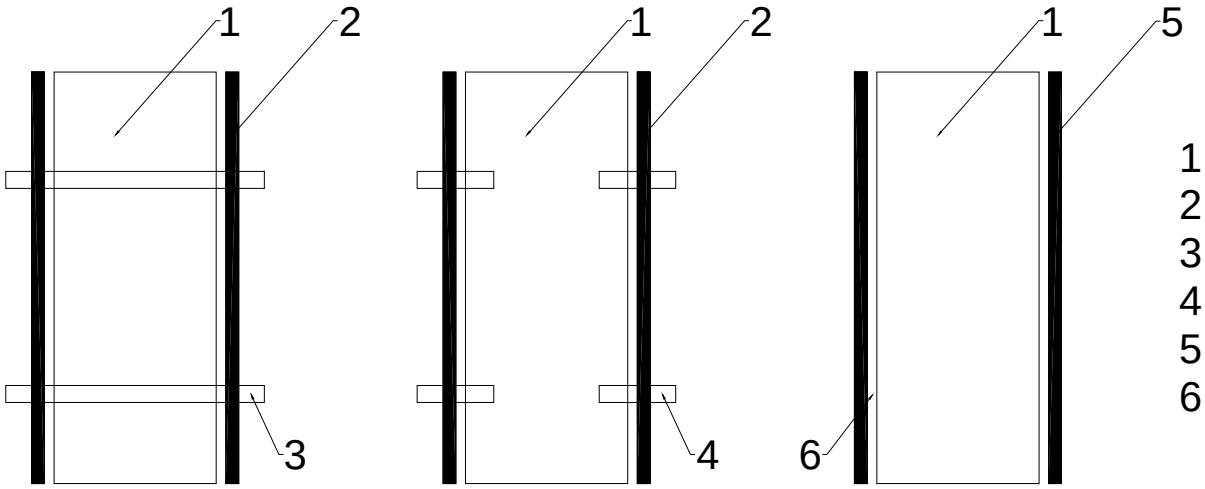
IN PLANE failure modes

- Sliding failure (a)
- Flexural failure (b)
- Shear failure (c)



Retrofitting techniques

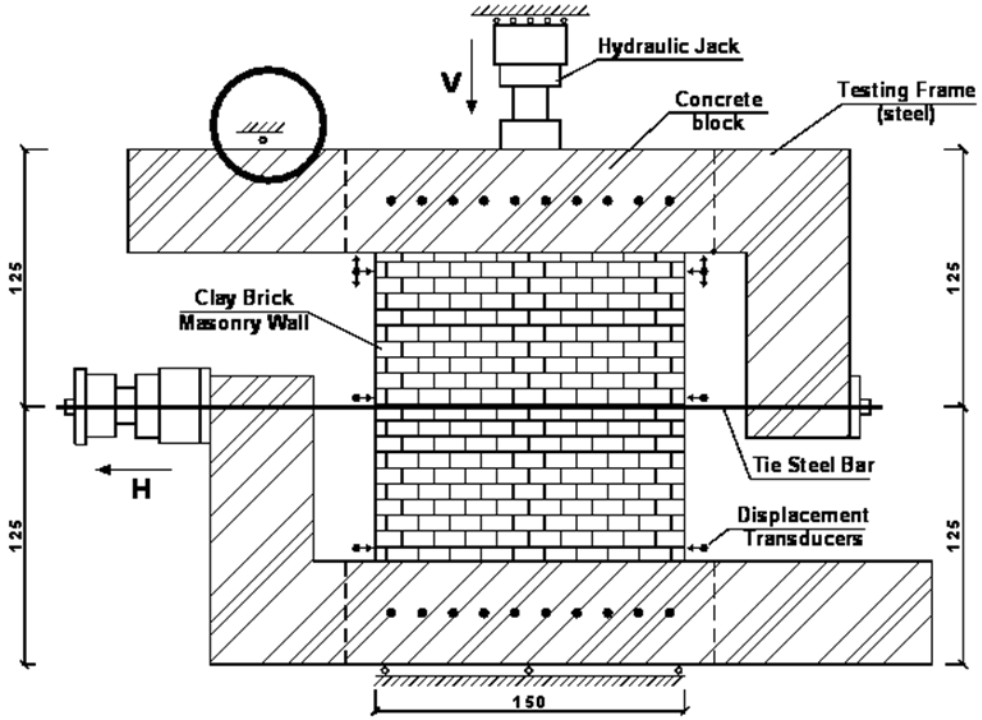
- First one consists in sheathing some steel (SSP) or aluminium plates (ASP) either on both sides or on one side of the masonry wall. Metallic plates are fastened either by prestressed steel ties (PT), or chemical anchors (CA).
- The second one is derived from the FRP technology, but in stead of FRP material, applies a steel wire mesh (SWM) bonded with epoxy resin to the masonry wall

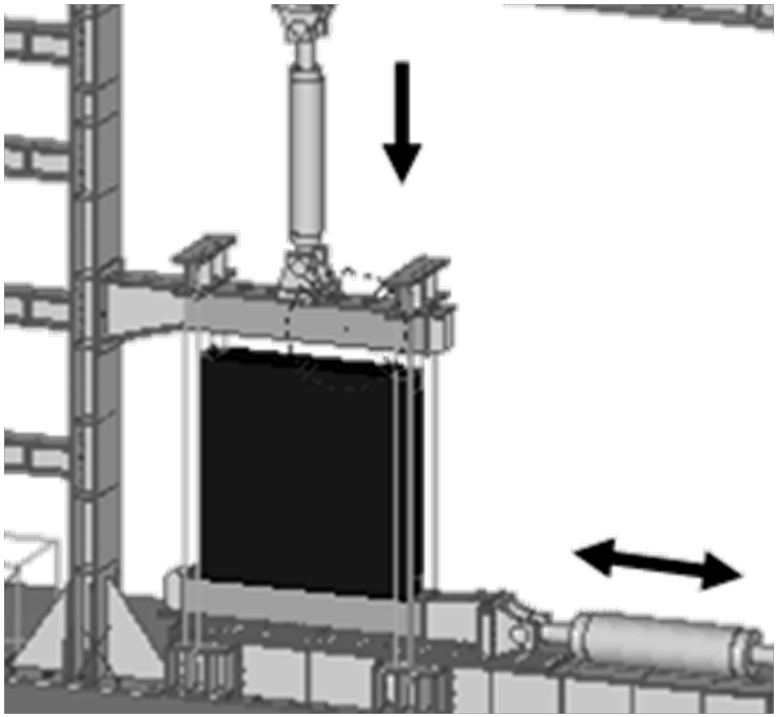


1. Masonry wall
2. Metallic plates
3. Prestress ties
4. Chemical anchors
5. Steel wire mesh
6. Epoxy resin

Experimental program

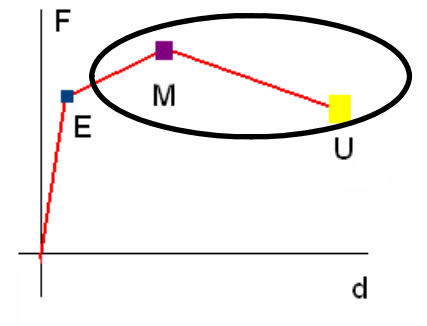
- **The entire experimental work include:**
  - material tests (on steel wire, aluminium, masonry component)
  - preliminary tests on 500 x 500 mm specimens (diagonal tensile test)
  - full scale shear tests on 1500 x 1500 mm specimens, both under monotonic and cyclic loading

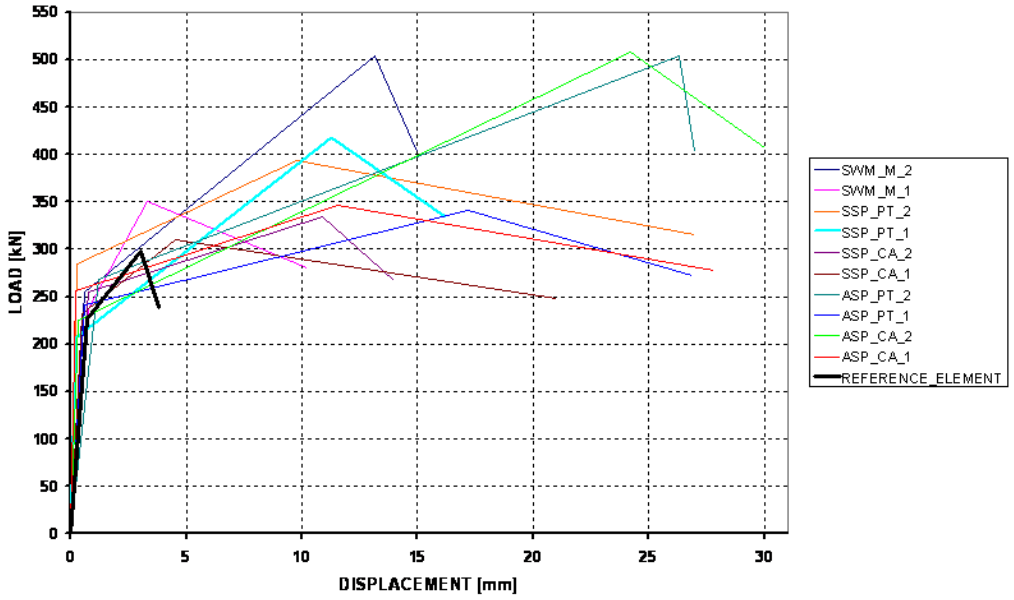


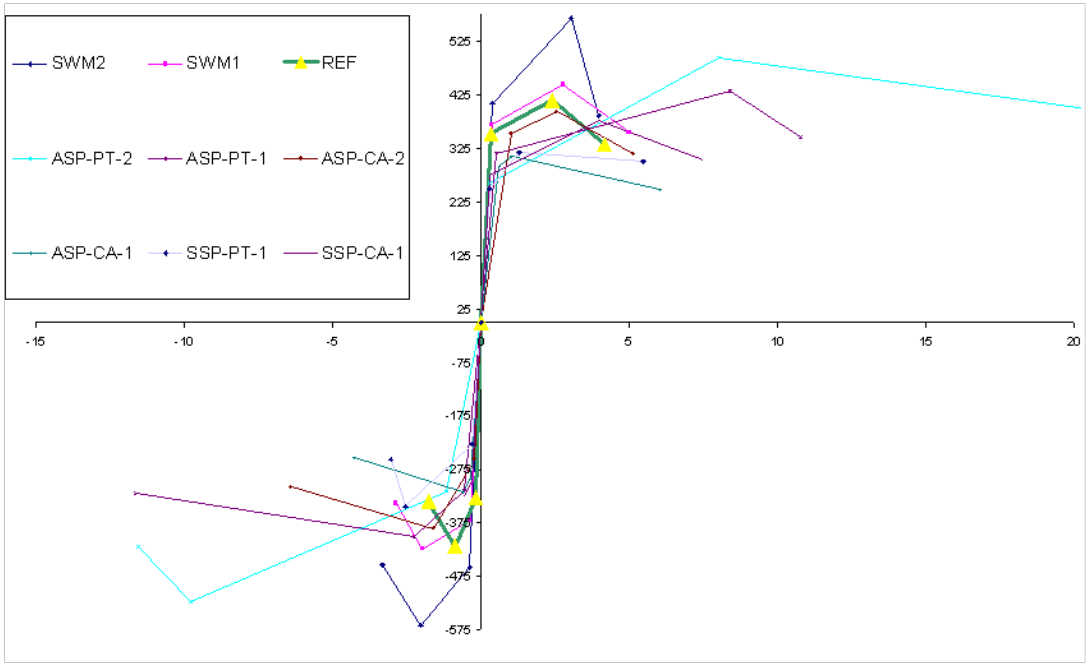


Summary of experimental results

- **The proposed strengthening systems were confirmed:**
  - **gain in strengthening – 15-75%;**
  - **gain in ductility – 400%;**
  - **not much change in stiffness.**
- **The proposed techniques are suitable to apply for seismic upgrading of masonry walls by means of a PBD Methodology aiming to improve performance in the [live safe – near collapse] range**

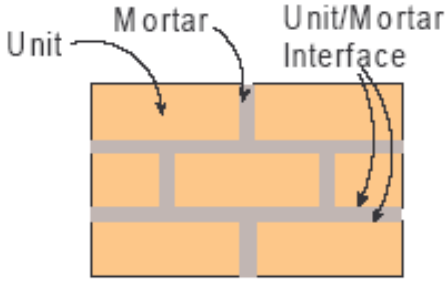




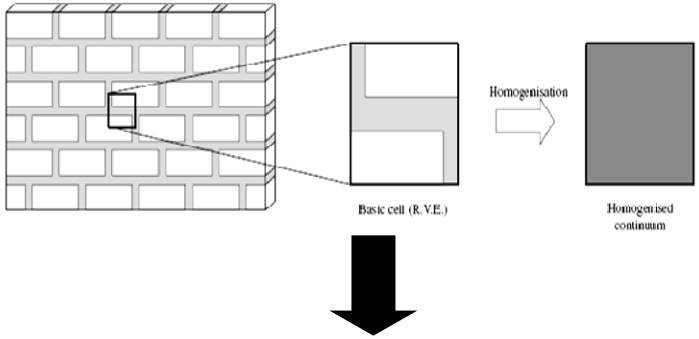


Numerical models

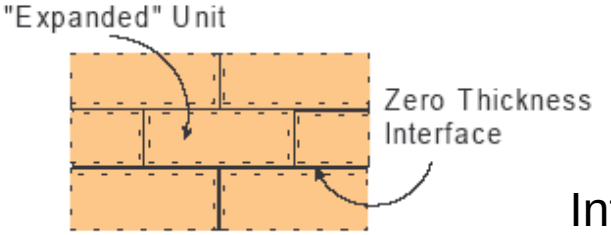
- **Advances numerical models**
  - **Micro-model**
    - **Simplified – interface model**
    - **Detailed – layer model**
  - **Macro-model – homogenization**
    - **Continuum model**



Two-phase materials where the brick and mortar are considered separately

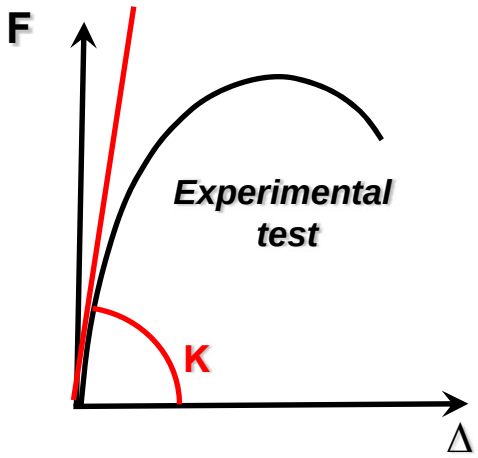


One-phase material – masonry as an ideal homogeneous material with constitutive equation different from those of the component



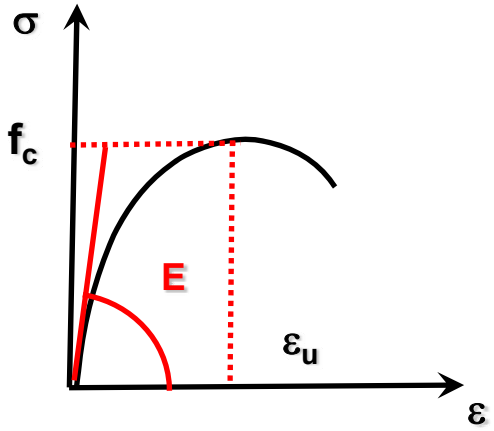
Interface model

Global behavior – Material behavior



Global behavior

Constitutive law



Material behavior

$$K = \frac{1}{\frac{h^3}{12EI} + \frac{h}{\lambda GA}} \quad \Longrightarrow \quad E = ? \quad \Longrightarrow \quad f_c = \frac{E\varepsilon_u}{2}$$

$$G = \frac{E}{2(1+\nu)}$$

$$\varepsilon_u = 0.2 - 0.25\%$$

Material behavior - Uniaxial solicitation

- **In scientific papers and standards are propose different empirical determined equation as constitutive laws for masonry elements as a homogenous material.**

- Turnsek-Cacovic (1970):

$$\frac{\sigma}{\sigma_k} = 6.4\left(\frac{\varepsilon}{\varepsilon_k}\right) - 5.4\left(\frac{\varepsilon}{\varepsilon_k}\right)^{1.17}$$

- Sawko (1982) based on Powell-Hodgkinson experimental test:

$$\frac{\sigma}{\sigma_k} = 2\left(\frac{\varepsilon}{\varepsilon_k}\right) - \left(\frac{\varepsilon}{\varepsilon_k}\right)^{2}$$

- ANDIL (Italian Association of Clay Brick Producers):

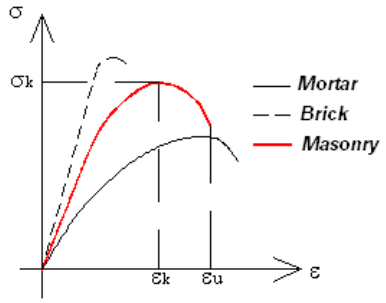
$$\frac{\sigma}{\sigma_k} = 3.4142 * \left[1 - \left(1 + \frac{\varepsilon}{\varepsilon_k}\right)^{0.5}\right]$$

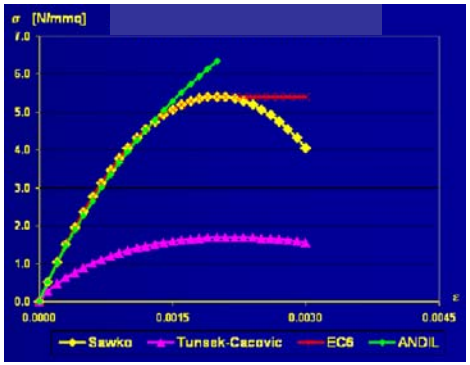
- EC 6 propose :

$$\frac{\sigma}{\sigma_k} = 2\left(\frac{\varepsilon}{\varepsilon_k}\right) - \left(\frac{\varepsilon}{\varepsilon_k}\right)^{2} \qquad for\ 0 \le \varepsilon \le \varepsilon_k$$

$$\frac{\sigma}{\sigma_k} = 1 \qquad for\ \varepsilon_k \le \varepsilon \le \varepsilon_u$$

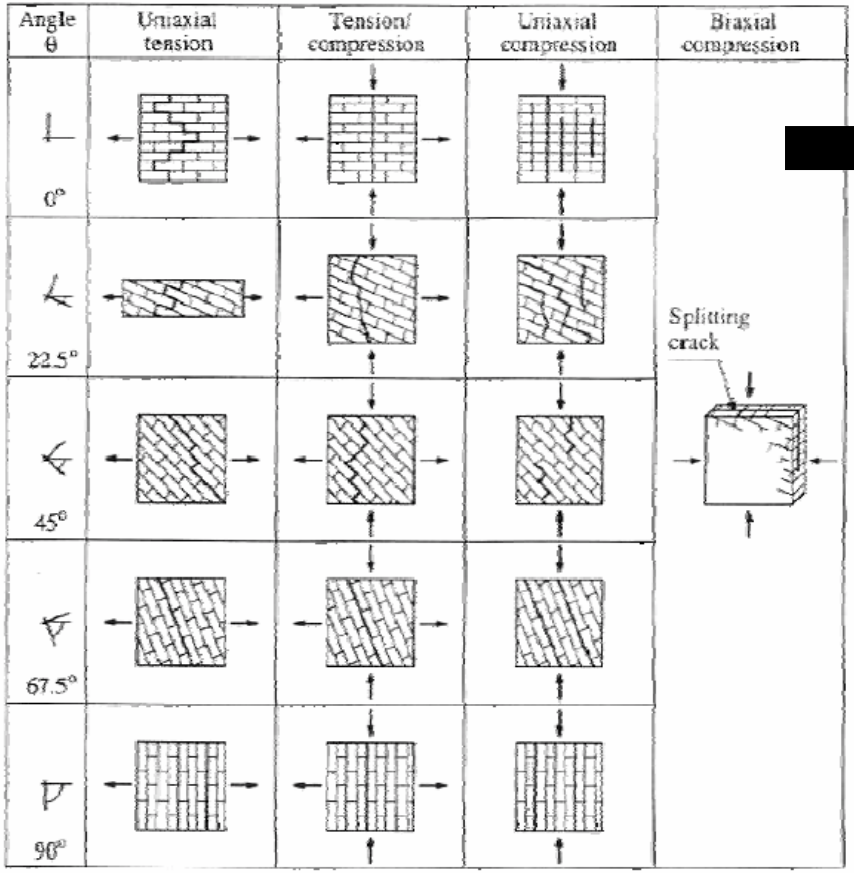
Legend:
σ_k = maximum allow compression strength
$\varepsilon_k = 0.002$ (characteristic strain correspondent σ_k)
$\varepsilon_u = 0.003 \div 0.0045$ (ultimate strain)

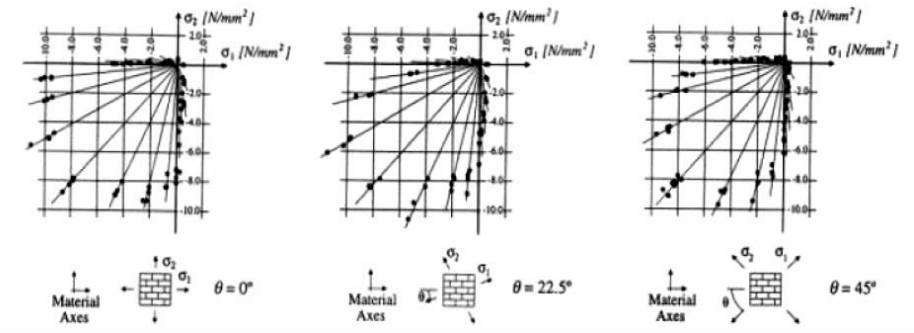


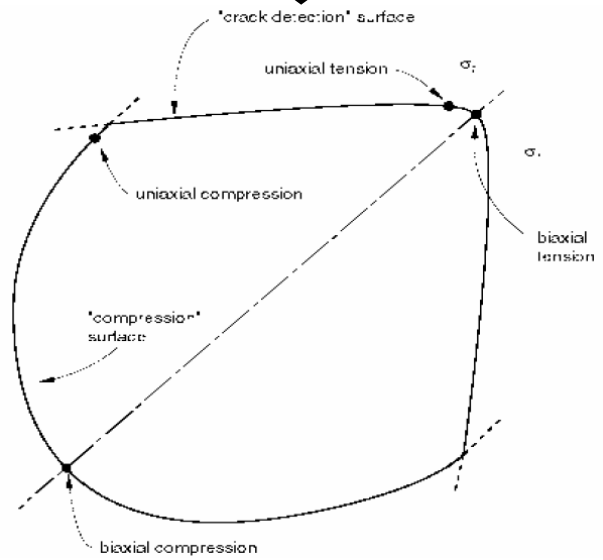


Material behavior - Biaxial solicitation

- **Biaxial behavior –masonry has a very different behavior referring at the direction of the applied load**



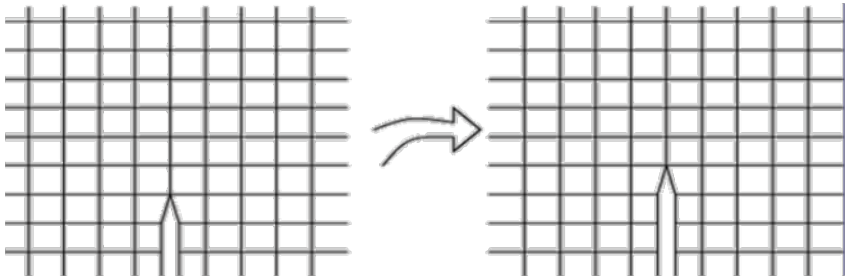




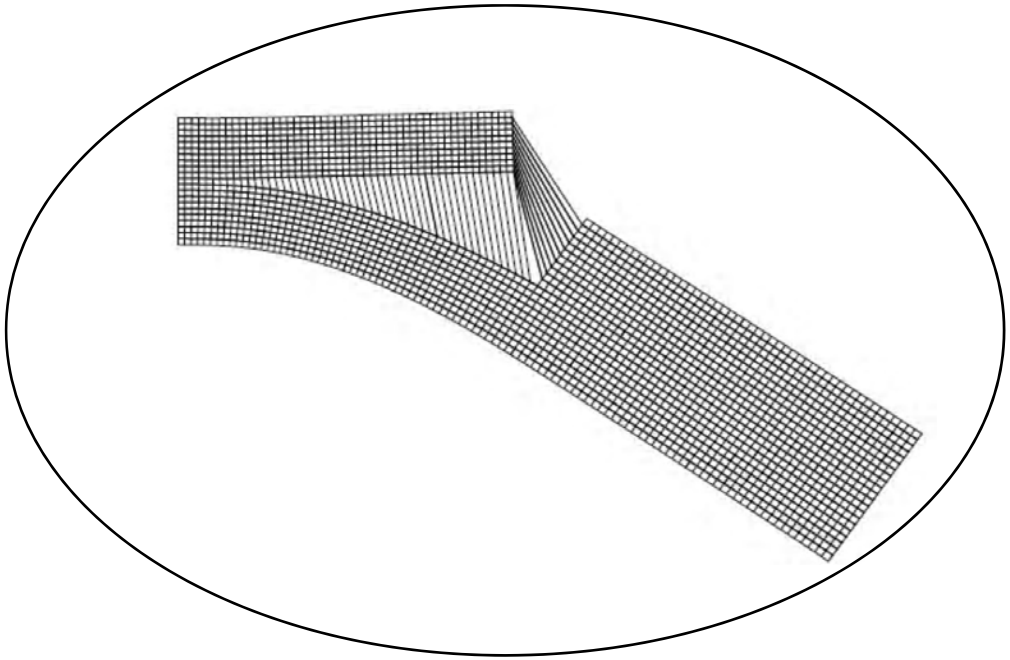
failure domain

Discontinuous modeling of masonry approaches

- **Discrete crack**



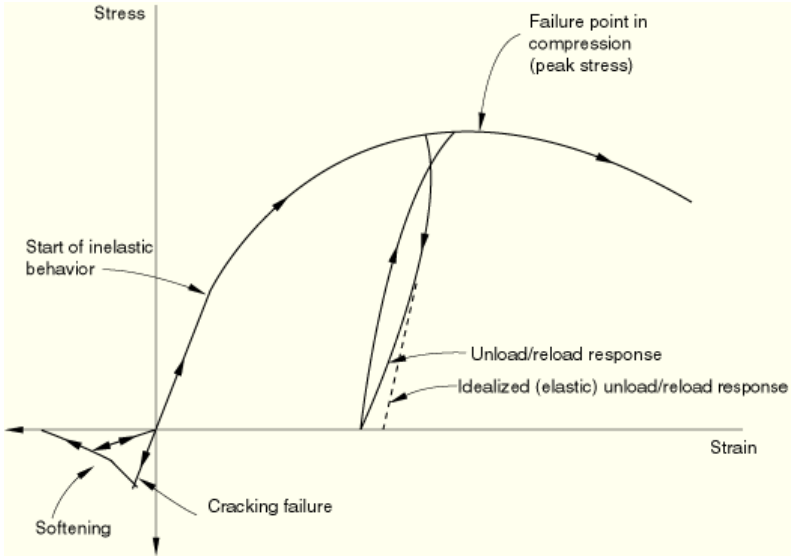
- **Smeared crack**



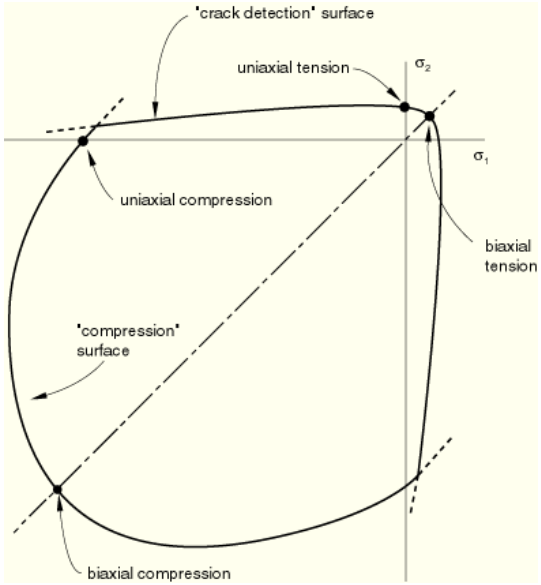
- **Interface smeared crack**
- **Use of joint elements**

CONCRETE SMEARED CRACKED

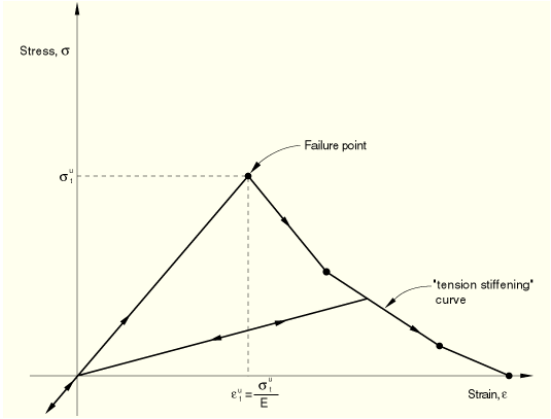
- **Parameters**
  - Concrete – uniaxial behavior (a)
  - Failure ratios – biaxial behavior (b)
  - Tension stiffening (c)
  - Shear retention (d)



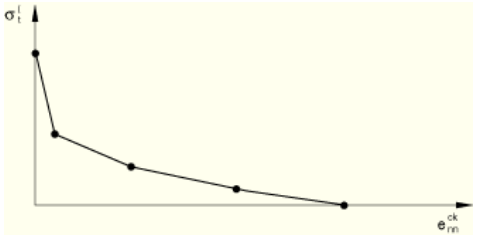
(a)



(b)



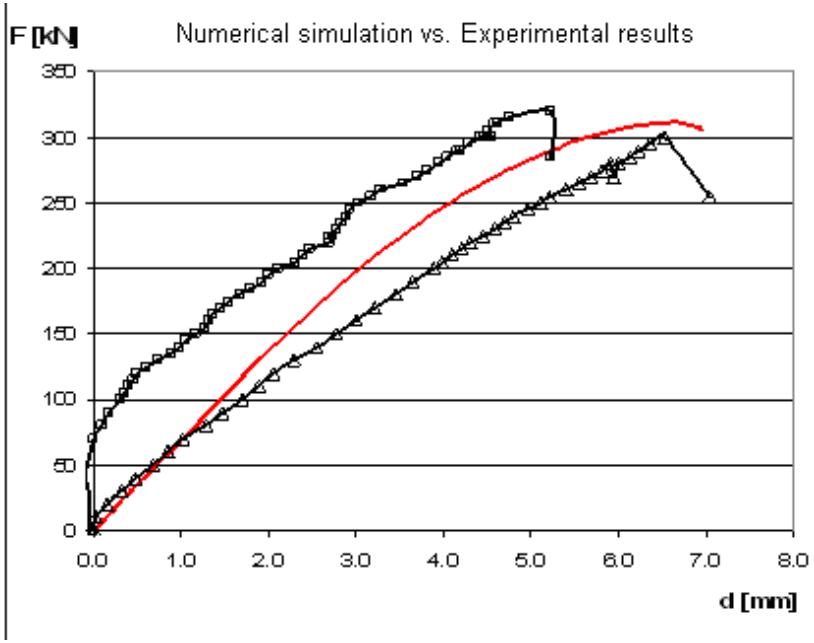
(c)

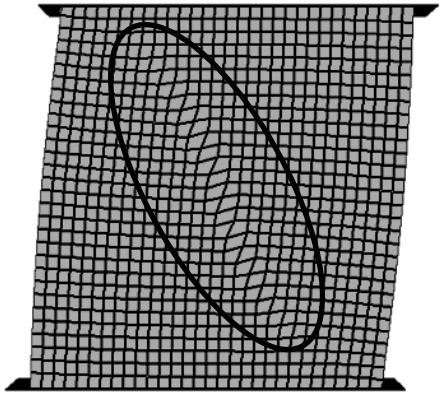


(d)

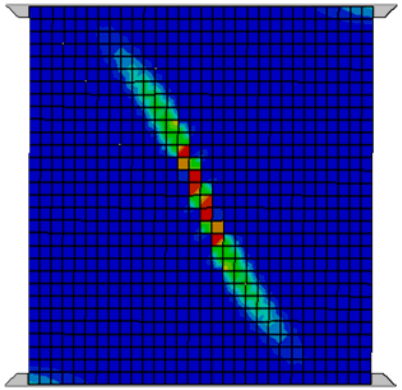
FEM Results for unreinforced panel

- **By calibration of material model parameters a very good behaviour in terms of global behaviour and failure mode was obtain for masonry panel.**

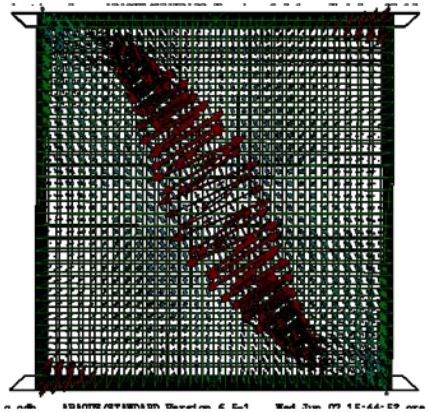




Deformed shape



The logarithmic strain along principal tensile stresses



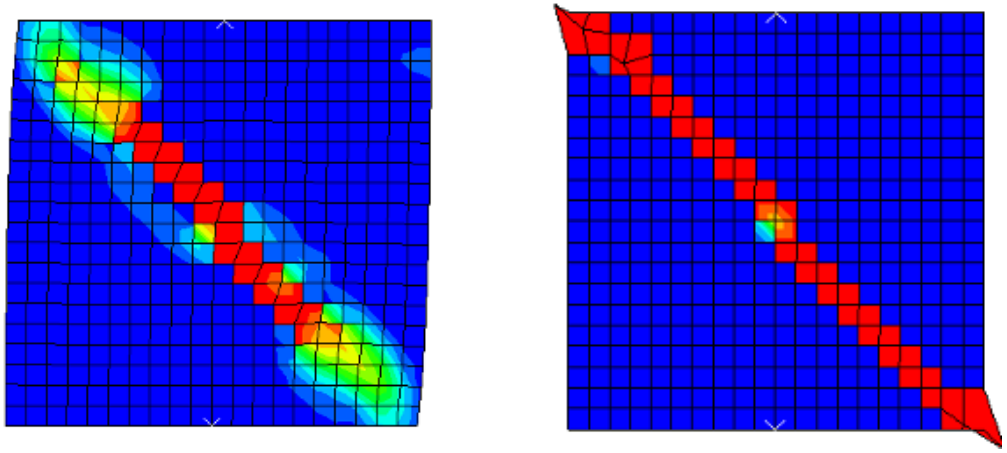
The principal tensile test (tension)

FEM Results for reinforced panel

- **The model used is not capable to develop large ultimate displacements. Therefore even if the experimental results have showed an increase of the ultimate displacement of 3-5 times in case of retrofitted elements, the contribution of confining effect by sheathing plates cannot be replicate by the applied numerical model used.**

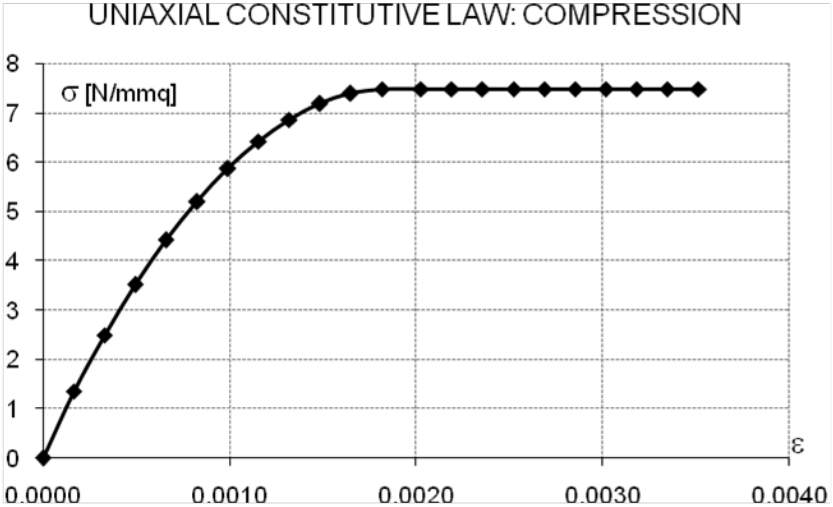
BRITTLE CRACKING MODEL

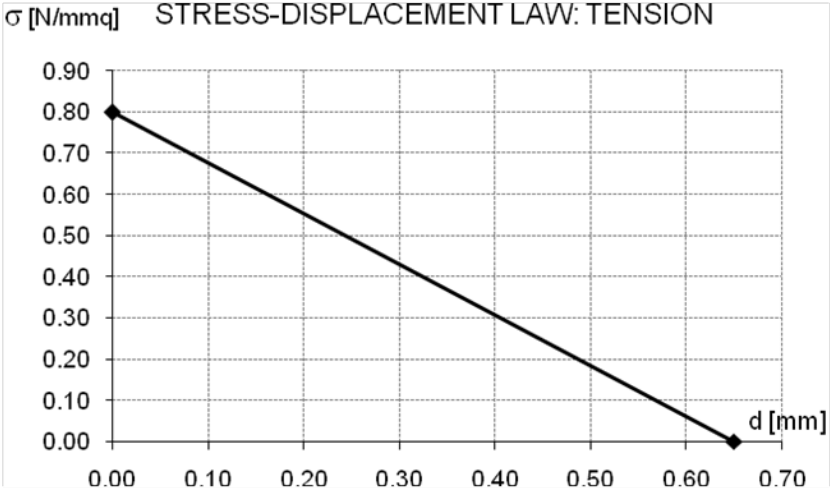
- Is suitable for evaluation of the brittle behavior of materials, i.e. masonry.
- The failure criterion is introduced only in the tension range. The model neglects any compressive ultimate stress/deformation considering infinite compressive strength.
- Mesh instability occurs and a high energy unbalance appears in the post cracking state of the model



CONCRETE DAMAGE PLASTICITY

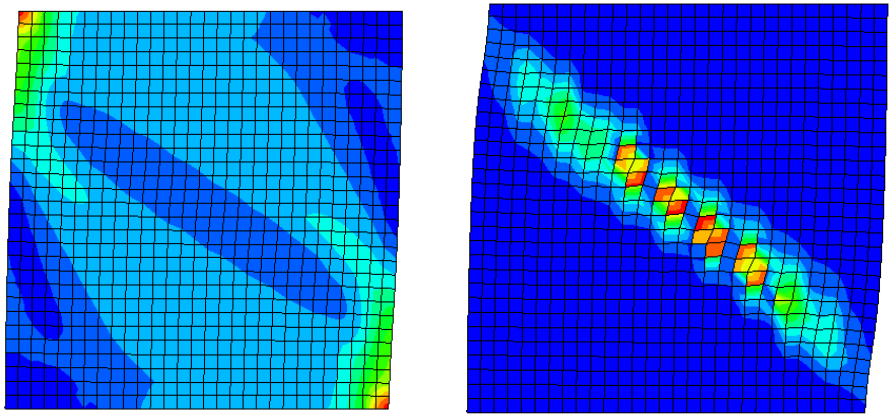
- Is oriented for analyses of concrete elements. Even so the brittle behaviour of masonry, together with the cracks development, can be simulated with a good accuracy.
- The material model provides both crushing (compression) and cracking (tension) failure modes, but does not introduce shear retention assumptions.





FEM Results for unreinforced panel

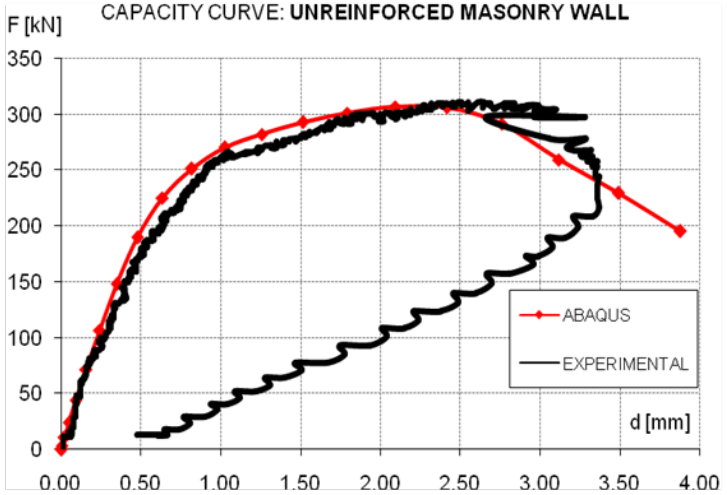
- **A quasi-static analysis with an explicit solution has been performed**



(a) (b)

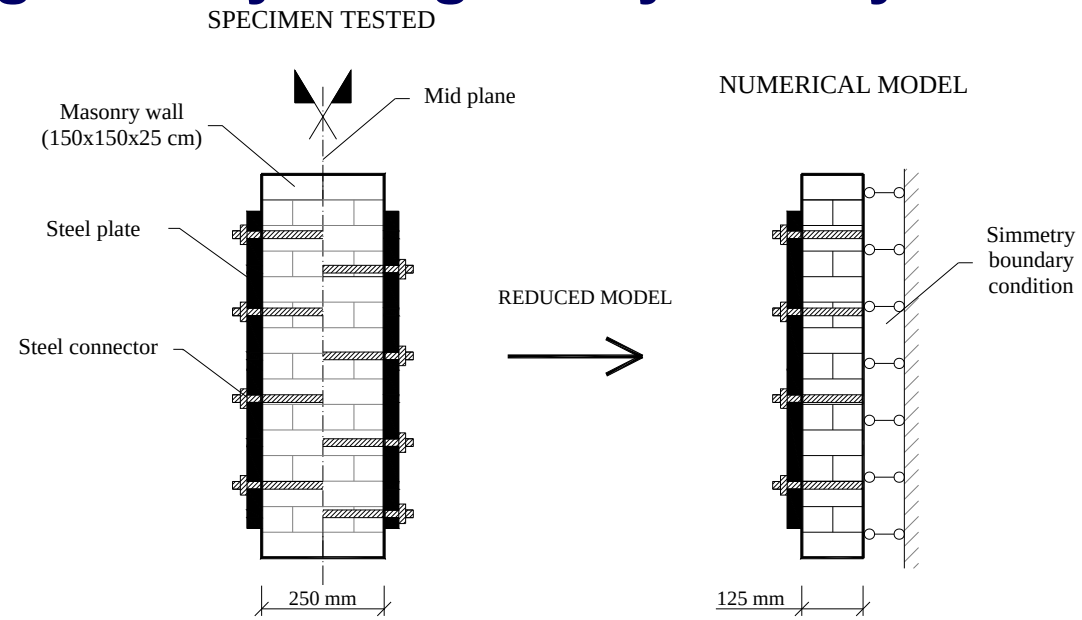
Masonry panel
Von Misses stress (a)
Distribution of cracks (b)
at failure

- **The URM numerical model is enabled to reach very large ultimate displacement and from this point of view can be suitable to our purpose, moreover the failure mode of the masonry wall reflects the observed physical shear failure, i.e. diagonal tensile cracking.**



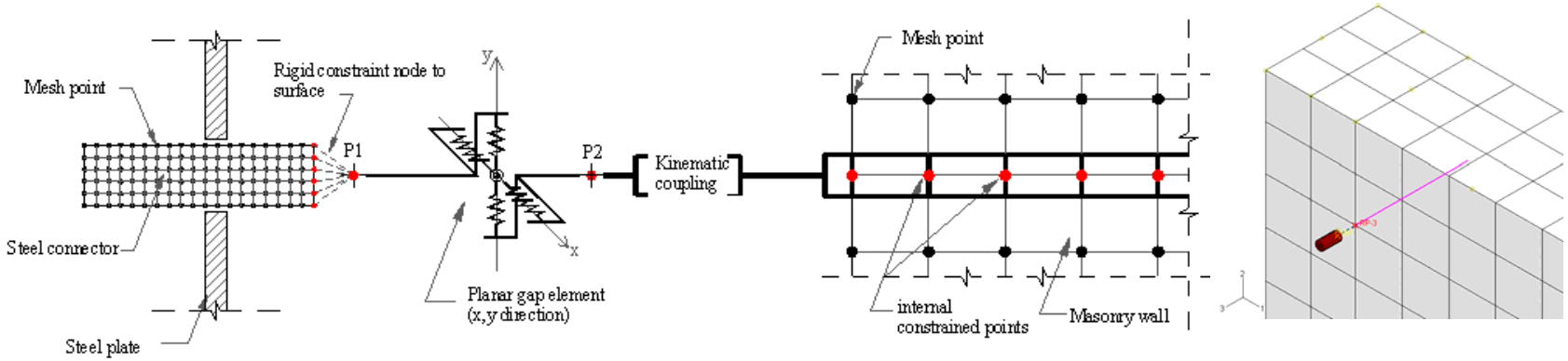
FE Model for retrofitted panel

- Assuming CDP for the retrofitted masonry panel model has been developed.
- This model was built referring to the real geometry of the system (1.5x1.5x0.25 m masonry wall, 2 mm thickness of the steel plate applied on both side anchored with steel connectors chemically infilled in masonry).
- Reduced geometry using the symmetry of the system

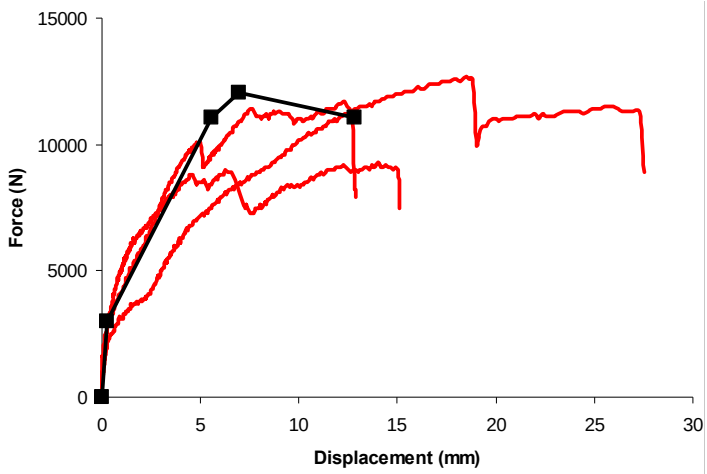


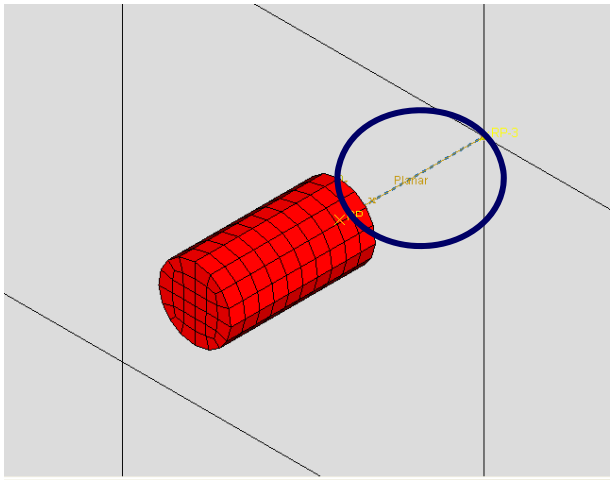
FE Model for retrofitted panel

- **The link between connector and masonry was simplified in sequence of node to node internal constraints and by using gap elements.**



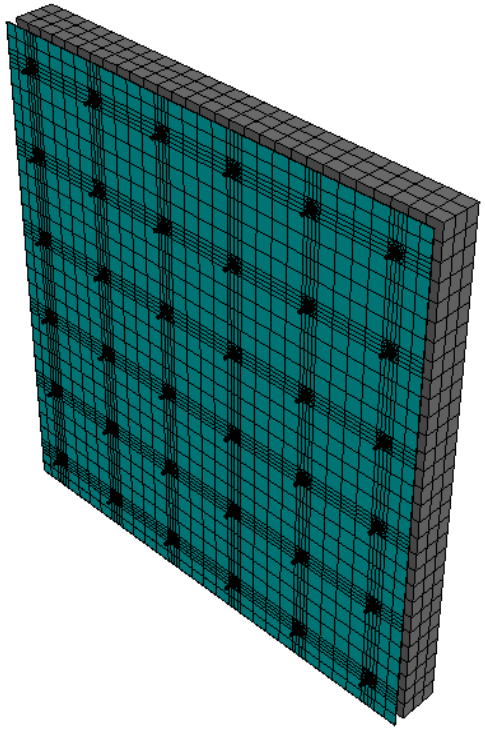
- **The constitutive law of the springs has been directly derived from experimental tests made on the same steel connectors loaded in shear.**

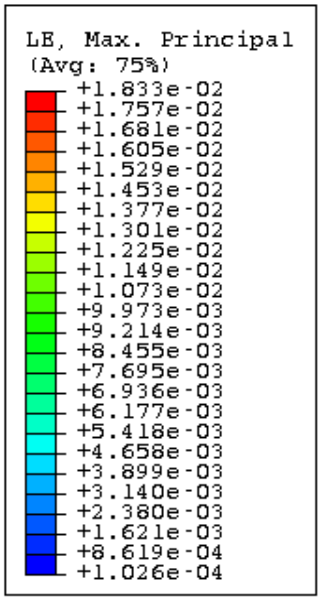


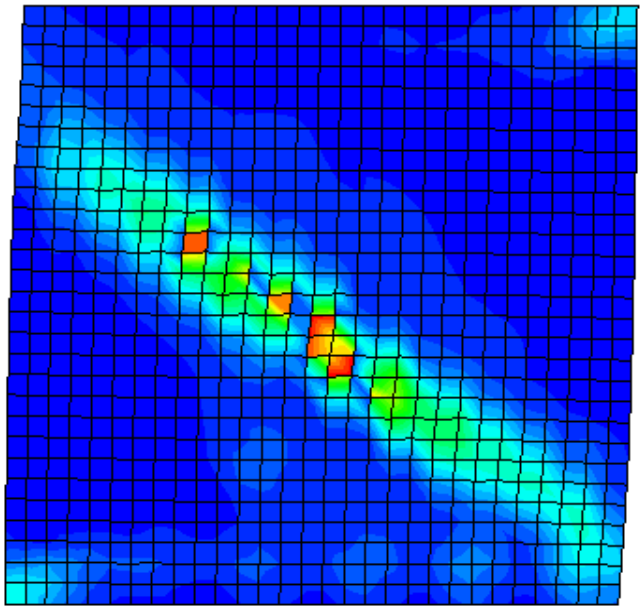


FEM Results for reinforced panel

- **The failure mode of confined masonry remains diagonal cracking similarly to what was observed in the unreinforced model and in the experimental tests.**



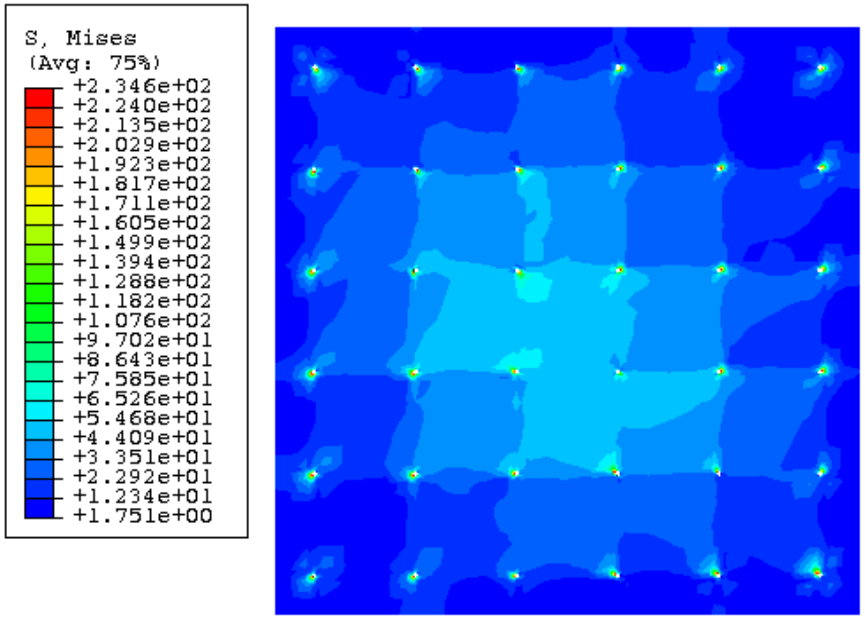




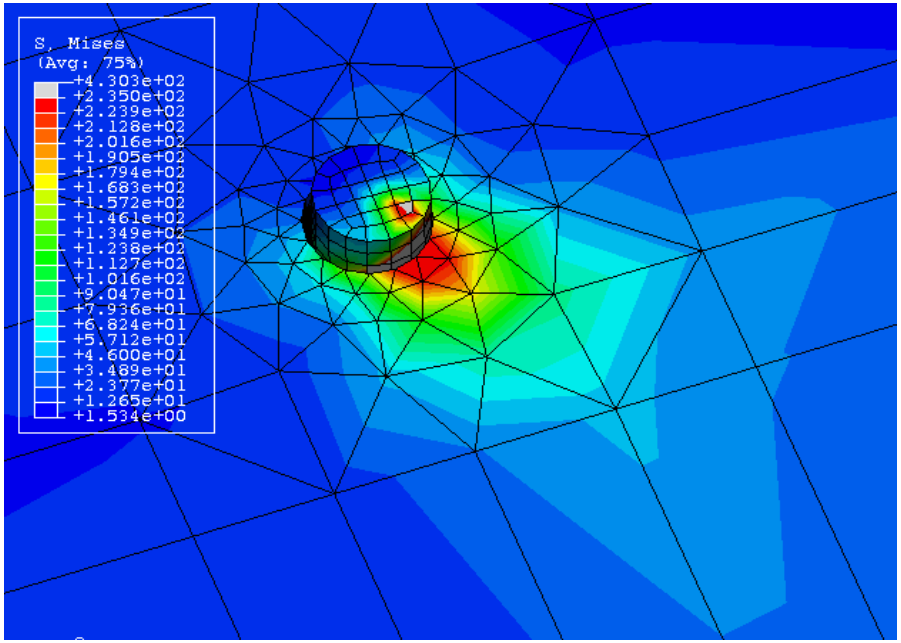
Logarithmic strain in masonry panel at 4.0 mm displacement

FEM Results for reinforced panel

- **The steel plate works with low values of stresses except in the strictly areas around the steel connectors, in which, because of the contact, yielding stress is reached.**



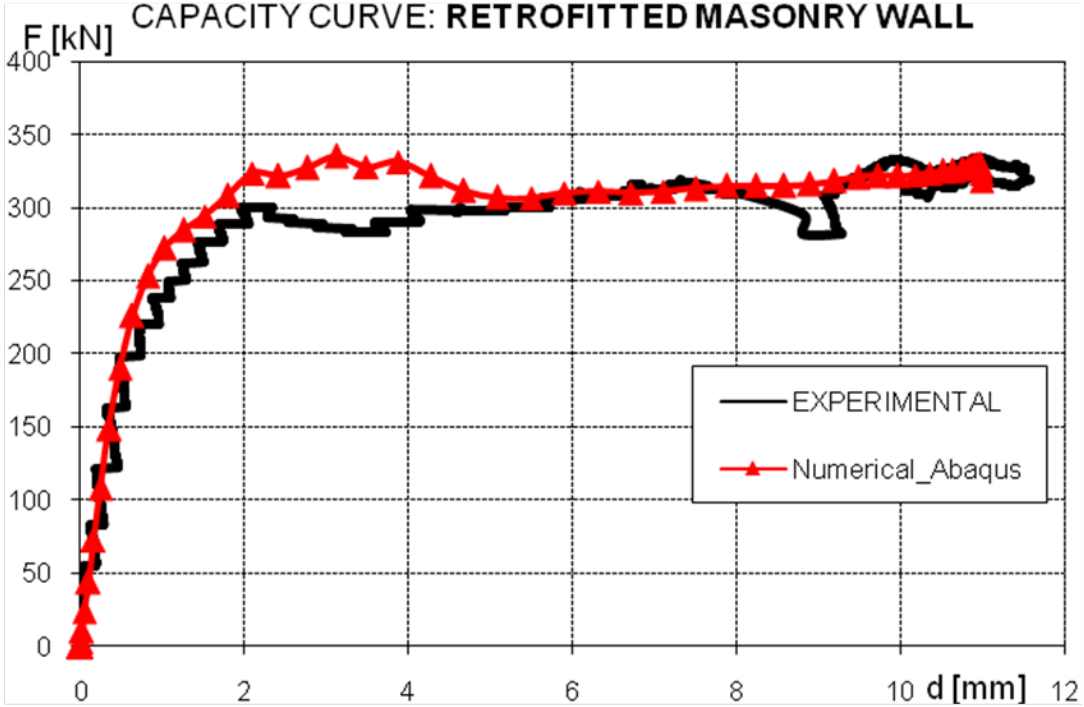
Von Misses stress in the steel plate at ultimate displacement



Von Misses stress in the connector-steel plate contact interface

FEM Results for reinforced panel

- **The adopted modelling strategy for the retrofitted model has revealed the same global response measured in the experimental test.**



- **The reinforcing system increase the global ductility of the system, while the carried ultimate shear force remains substantially equal to the unreinforced masonry wall.**

CONCLUSIN

- **The model was calibrated on 1.5 x 1.5 m, but can be extended for an entire wall, real geometry, or building façade – making possible determination of the wall capacity in compare with the seismic demand**

$$E_{s,i,j} < R_{s,i,j}$$

$$R_{s,i,j} = R_k \cdot L_{i,j}$$

- **Thank you for attention !**