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Inspections and NDT for the Characterization of Historical Buildings after Seismic Events: Emilia Earthquake

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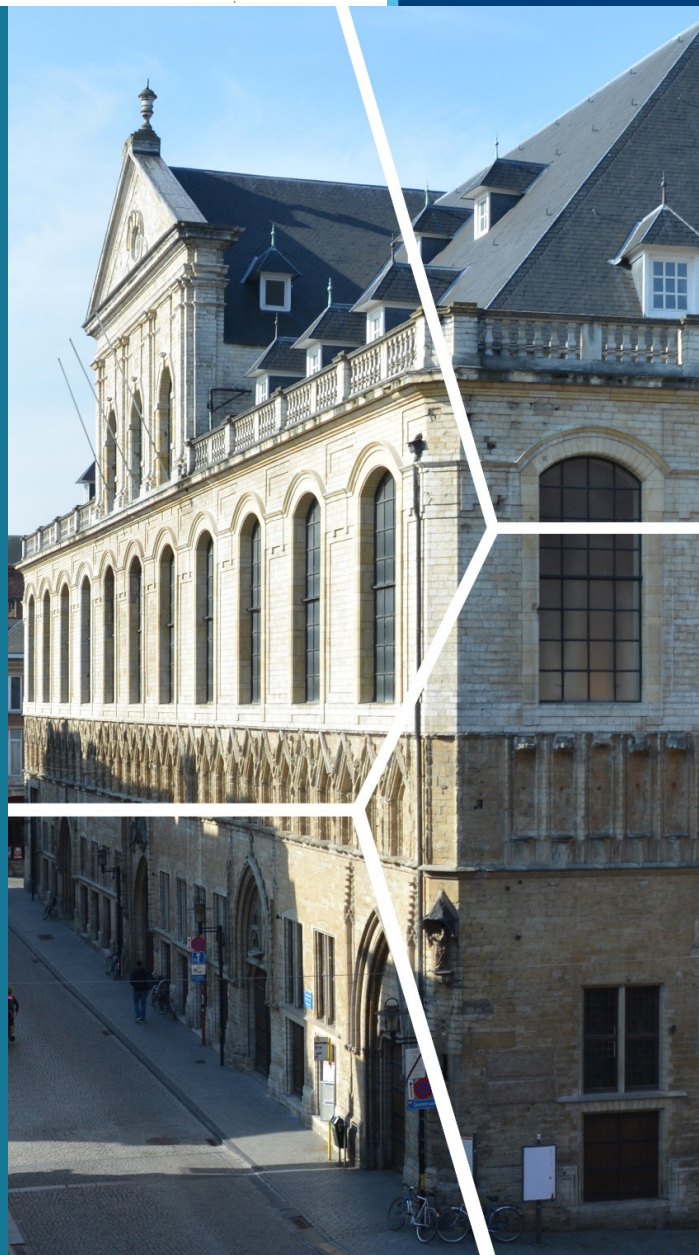


Outline

1. Introduction
2. Study Areas
3. Standard Test Methods
4. Compressive Properties of Masonry
5. Flat Jack-Shear Compression Test (FJ-SCT) – New Test Method
6. Shear Properties of Masonry
7. Conclusions

Napoli – S. Giovanni in Carbonara
Caracciolo del Sole Chapel
Leonardo da Besozzo (1421-1488)

1. Structural Safety of Existing Buildings

- Many seismic events have occurred in Italy over recent decades: Umbria (1997), Molise (2002), L'Aquila (2009), Emilia (2012) and Amatrice (2016).
- The assessment of structural safety of existing buildings is crucial, both because of the high vulnerability of the main part of the heritage, especially due to seismic loads, and because of the historical, architectural and artistic importance of these buildings.

S.Caterina church-Rovereto s/Secchia (MO)

1. Italian National Regulatory Framework

Chiarino Palace – L'Aquila (AQ)
S. Paolo church - Concordia (MO)

- 2008 Italian Seismic Code (D.M. 14/01/2008) currently under review.
- 2011 Guidelines concerning the Seismic Risk of the Cultural Heritage (D.P.C.M. 09/02/2011).

1. The Path of Knowledge

- The 2011 guidelines underline the fact that it is not possible to reach complete structural knowledge of a building.
  It is tracked a path of knowledge that can be developed with different levels of detail, depending on the accuracy of the preliminary analysis.

- This path is implemented over the following steps:

I. survey of the building, cracks and deformation patterns;

II. interpretation of the historical evolution of the construction;

III. structural identification of the building and of its construction details;

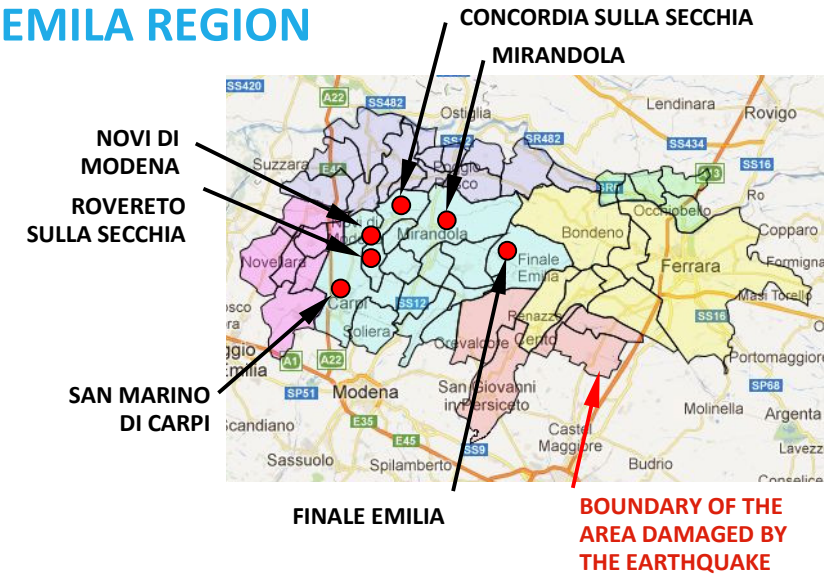
IV. evaluation of mechanical properties of materials and their deterioration;

V. evaluation of soil-foundation relationship.

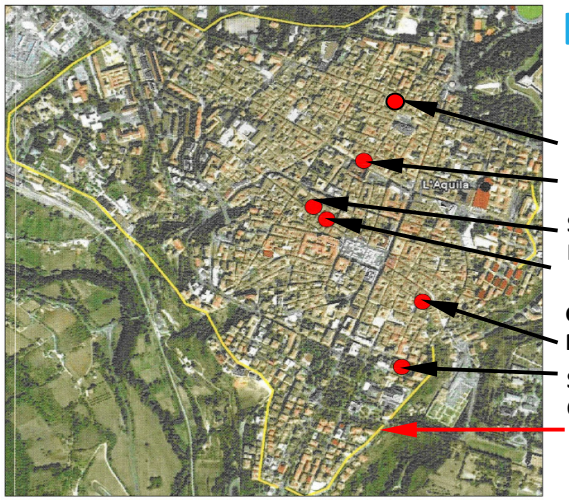
2. Study Areas

- After the 2012 earthquake **FMeA** analysed several buildings in the provinces of Modena and Reggio Emilia.
- These buildings feature differing typologies (churches, palaces, ancient farmhouses) but all have a significant uniformity of materials and construction techniques.
- In the same way after the 2009 earthquake **FMeA** tested a lot of structures located in the historical centre of L'Aquila.

EMILA REGION



L'AQUILA



2. Study Areas – Masonries Typologies

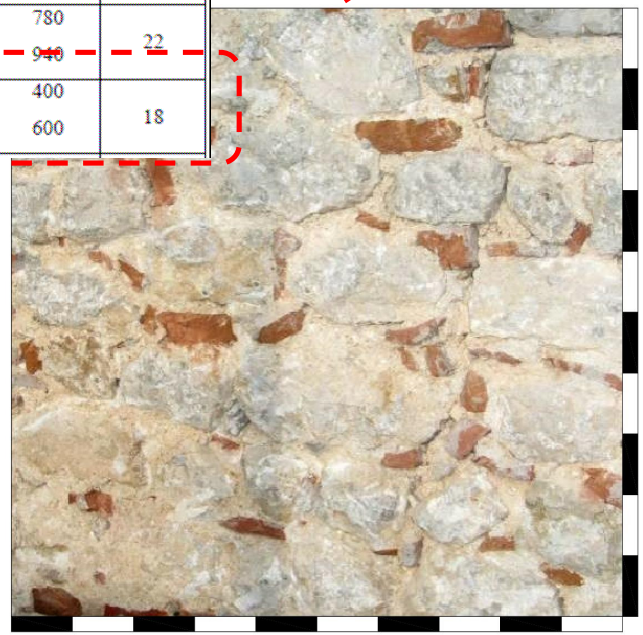
D.M. 2008

Tab. C8A.2.1

Tipologia di muratura	f_m (N/cm^2)	τ_0 (N/cm^2)	E (N/mm^2)	G (N/mm^2)	w (kN/m^3)
	Min-max	min-max	min-max	min-max	
Muratura in pietrame disordinata (ciottoli, pietre erratiche e irregolari)	100 180	2,0 3,2	690 1050	230 350	19
~~Muratura a conci sbozzati, con paramento di limitato~~ spessore e nucleo interno	~~200~~ 300	~~3,5~~ 5,1	~~1020~~ 1440	~~340~~ 480	20
Muratura in pietre a spacco con buona tessitura	260 380	5,6 7,4	1500 1980	500 660	21
Muratura a conci di pietra tenera (tufo, calcarenite, ecc.)	140 240	2,8 4,2	900 1260	300 420	16
Muratura a blocchi lapidei squadrati	600 ~~800~~	9,0 ~~12,0~~	2400 ~~3200~~	780 ~~940~~	22
Muratura in mattoni pieni e malta di calce	240 400	6,0 9,2	1200 1800	400 600	18

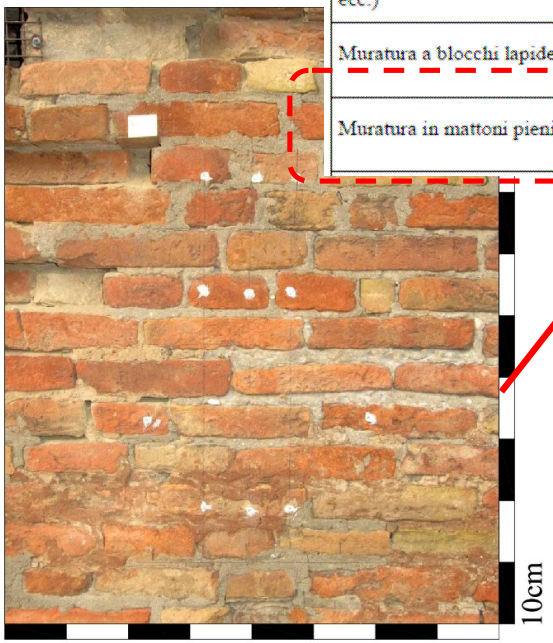
L'AQUILA

disordered masonry made with rubble stone

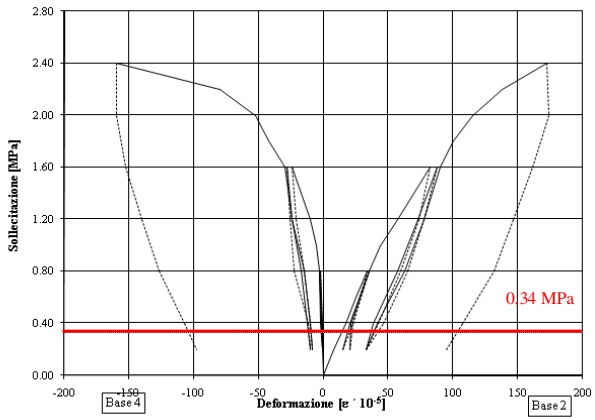


EMILA REGION

solid brick masonry made with lime mortar

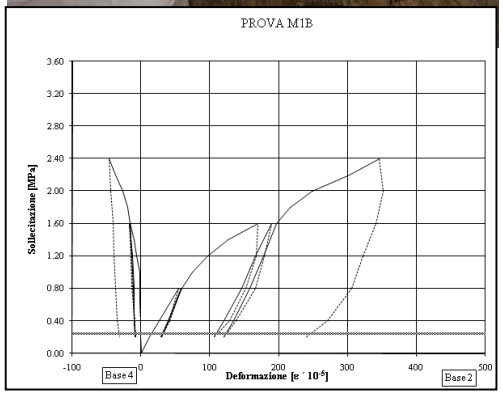


3. Test methods – flat jacks

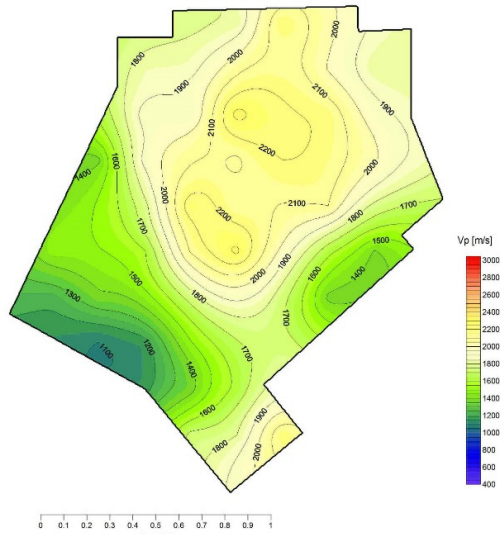


- The compressive stress within masonry was estimated using flat jack measurements (ASTM C 1196-09) -coefficient of variation as great as 20%.
- The deformability properties were measured with two flat jacks (ASTM C 1197-09) - variations between tests as great as 24%.
- This last test also allows to measure the maximum compressive strength - overestimation up to 15%.

3. Test methods – SDT vs NDT

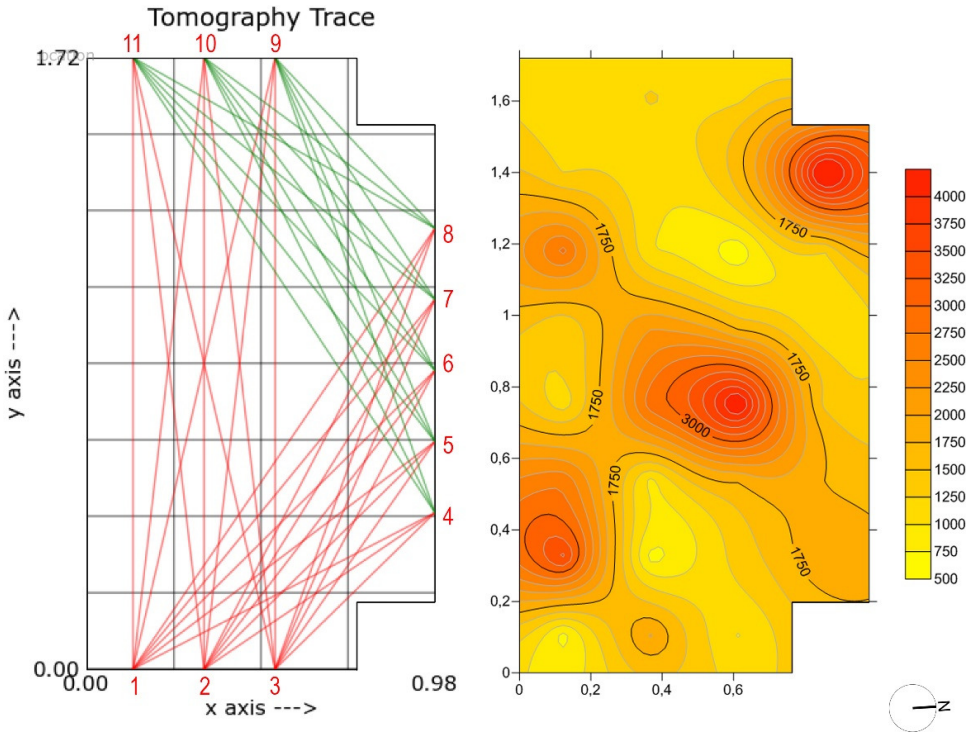


The 2011 Italian guidelines (cap. 4.1.7) state that: "**Non Destructive diagnostic Techniques of indirect type**, such as sonic and ultrasonic tests, **assess the homogeneity of the mechanical parameters** … but they **do not provide a reliable quantitative estimation of their values** … Therefore, **the direct measurement of the mechanical parameters** … in particular those relating to resistance, **can be performed only through Slightly Destructive or Destructive Tests**, even if applied to limited portions. **Calibrations of Non Destructive Tests with Destructive Tests can be used to reduce the invasiveness of the investigation campaign**."



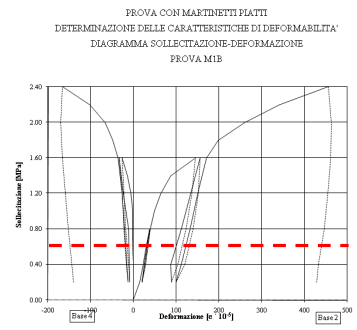
3. Test methods – determination of sonic/ultrasonic pulse velocity

- The number and the invasiveness of the SDT investigations were reduced by correlating the results of the flat jack tests with the measurements of the sonic/ultrasonic pulse velocity in accordance with UNI EN 12504-4.
- Some of the tests were also processed using tomographic methods in order to evaluate the homogeneity of the masonry.

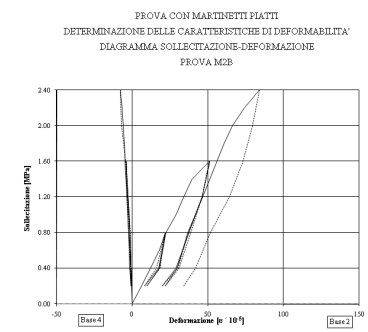


4. Compressive Properties of Masonry - Emilia Region

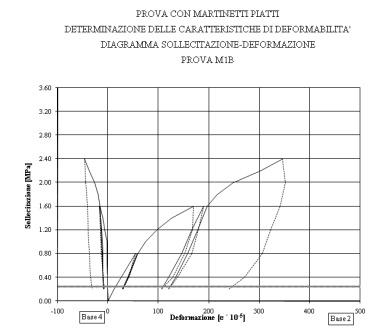
S.MARIA ASSUNTA CHURCH FABBRICO (RE)



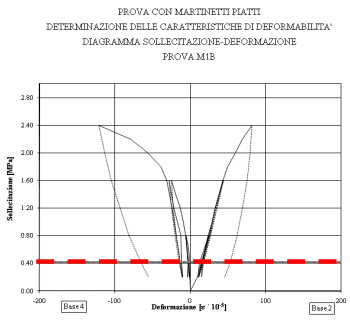
S.BIAGIO CHURCH CARPI (MO)



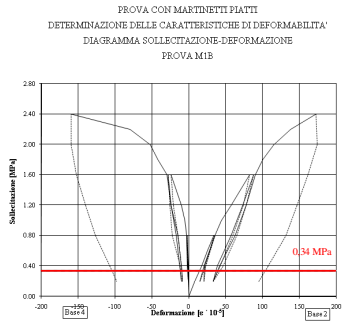
BONASI BENUCCI MANOR STUFFIONE DI RAVARINO (MO)



LA BERTUSA MANOR S. ANTONIO MERCAND. (MO)



TIRELLI VINEGAR FACTORY ROVERETO SULLA SECCHIA (MO)

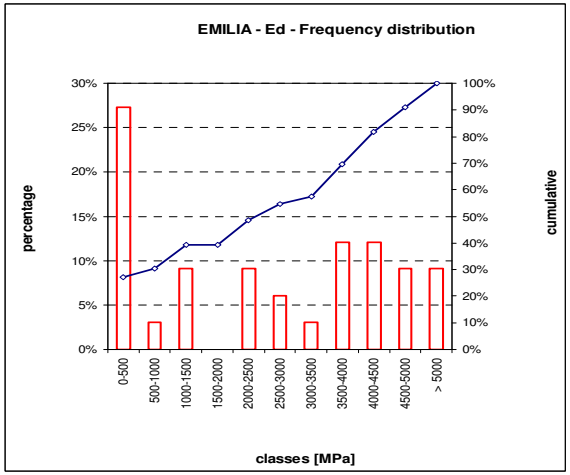


4. Compressive Properties of Masonry

EMILA REGION

$E_{d\,av}$ = 2672 [MPa]

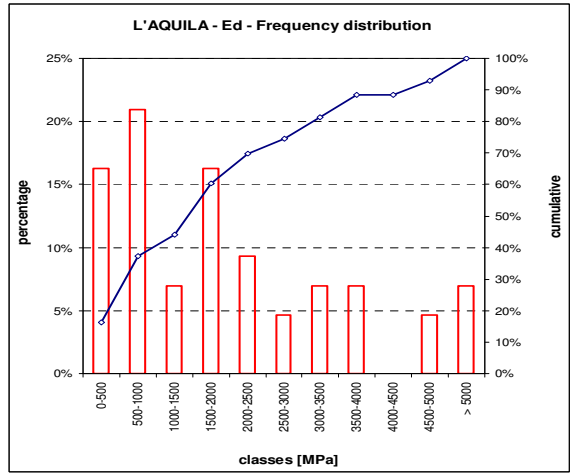
E_d vs f_m R^2 = 0,78

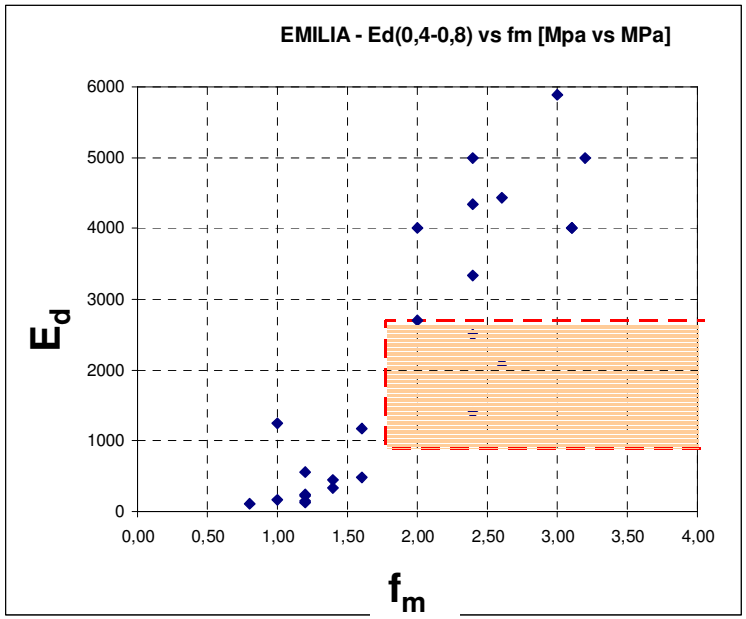


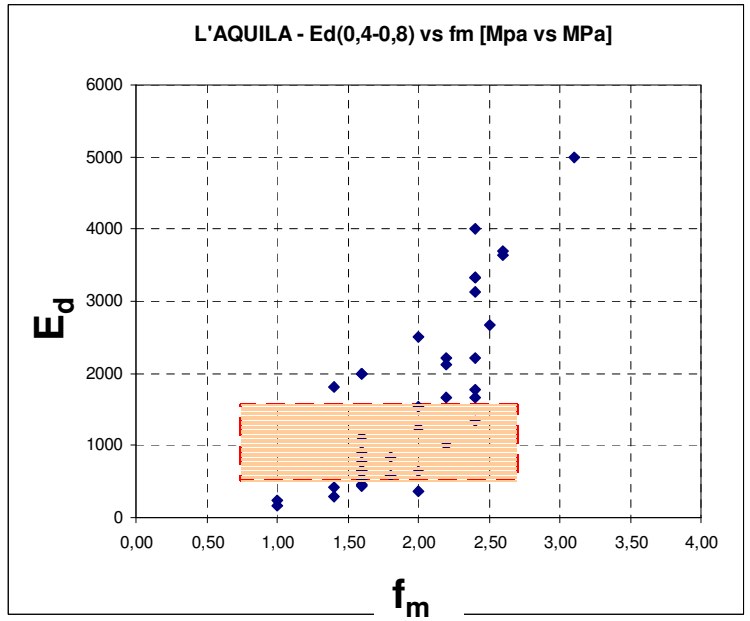
L'AQUILA

$E_{d\,av}$ = 2248 [MPa]

E_d vs f_m R^2 = 0,45







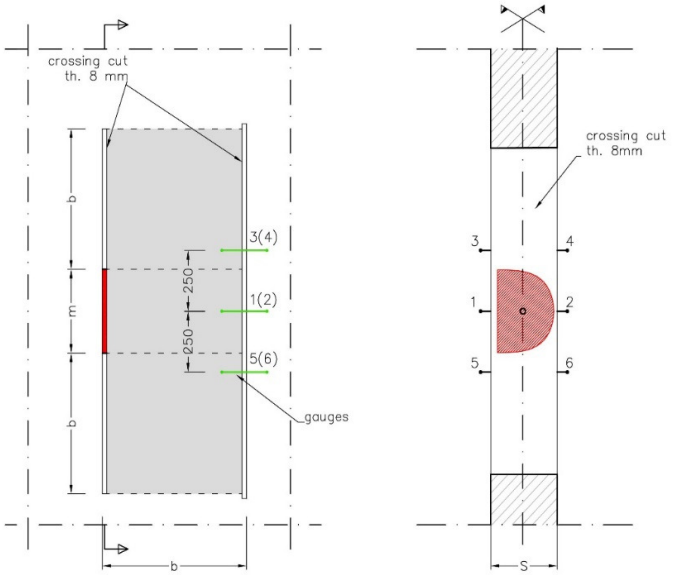
5. Standard Shear Test

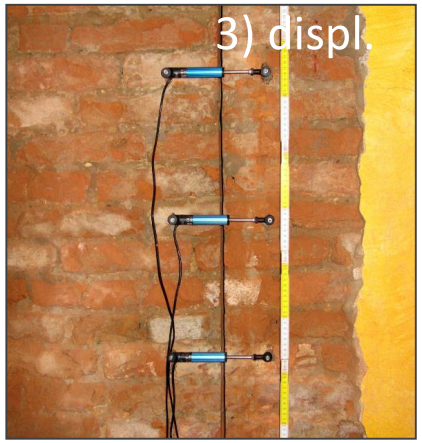
- The in situ tests currently applied can be classified according to three methodologies:

1. diagonal compression test (ASTM E519-81)
2. shear compression test
3. on site shove tests (RILEM TC 127 MS B.4)

- These are Highly Destructive Tests, so as to be unsuitable in use for existing buildings

5. Flat Jack-Shear Compression Test (FJ-SCT) – Procedure





5. Flat Jack-Shear Compression Test – Laboratory Calibration

- The calibration of the **FJ-SCT** technique was performed in **FMeA** laboratory on real scale brick masonry panels.
- The panels were built with new bricks with low nominal resistance, mortar with poor quantity of lime and mortar joints of considerable thickness in order to obtain walls with poor mechanical properties, similar the buildings in the Italian Pianura Padana (Emilia region) 1,0 MPa< fm <2,0 MPa.
- Bricks, mortar and sand were sampled during the construction and they were analysed with ultrasonic, compression and indirect traction tests.

5. Flat Jack-Shear Compression Test – Laboratory Calibration

a) On 4 small panels diagonal compression standard tests test (ASTM E519-81) were performed to determine the shear strength.

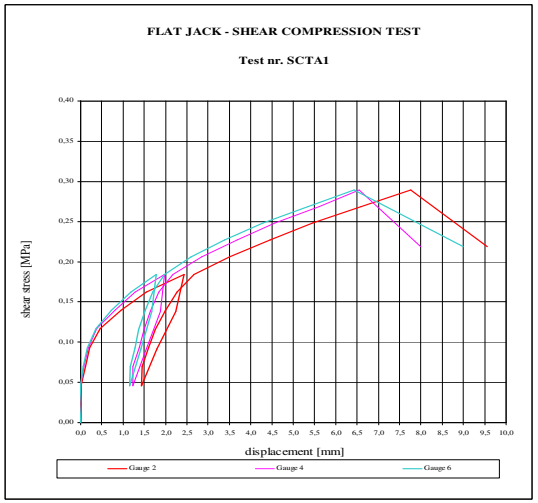
b) On 8 large panels vertical compression tests were performed to evaluate the masonry vertical deformability properties.

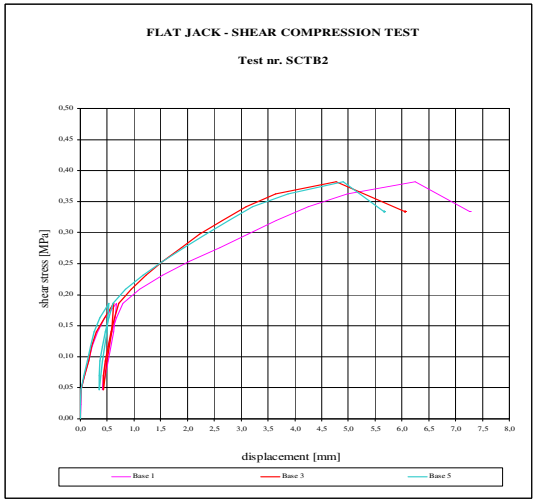
c) Then the pressure in the top flat jack was fixed to a predetermined level and the **FJ-SCT** shear compression test was performed:

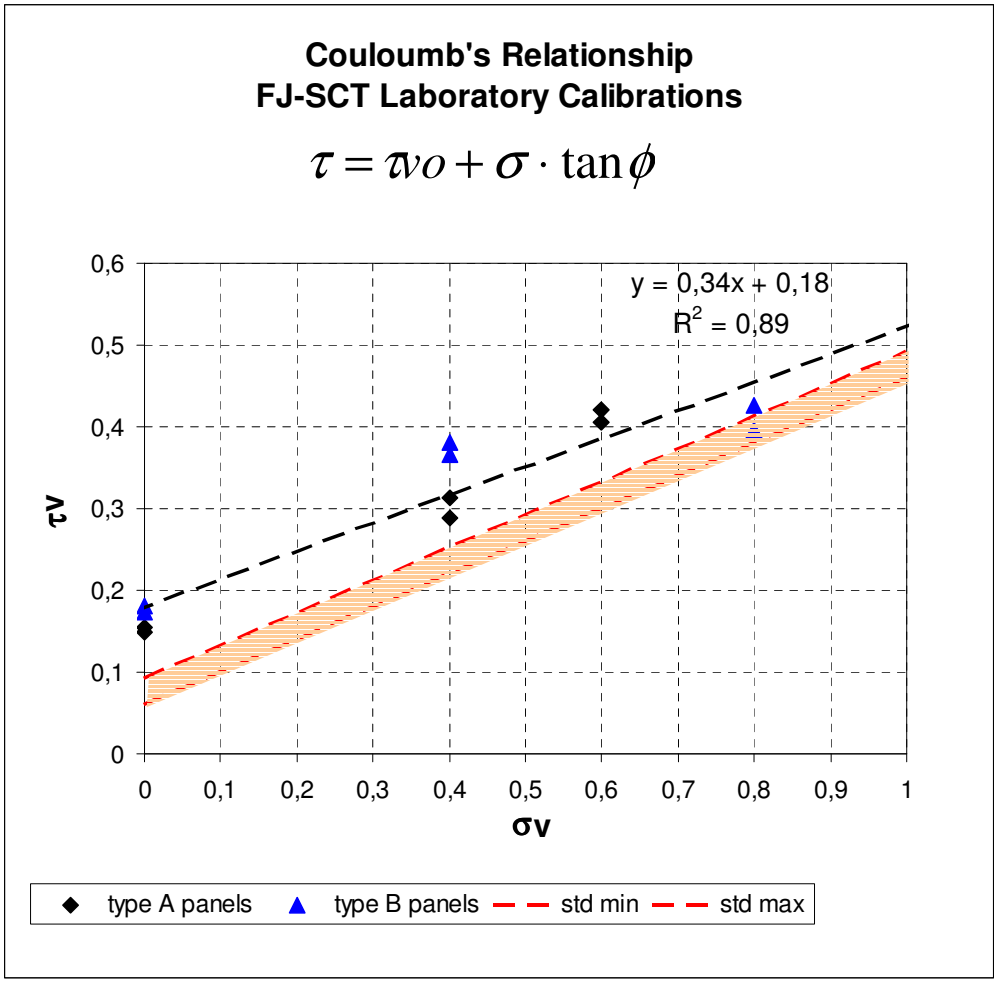
d) A vertically positioned flat-jack was inserted and its pressure was increased until the diagonal cracking of the panel was reached.

CONTRAST FRAME USED FOR THE CALIBRATION

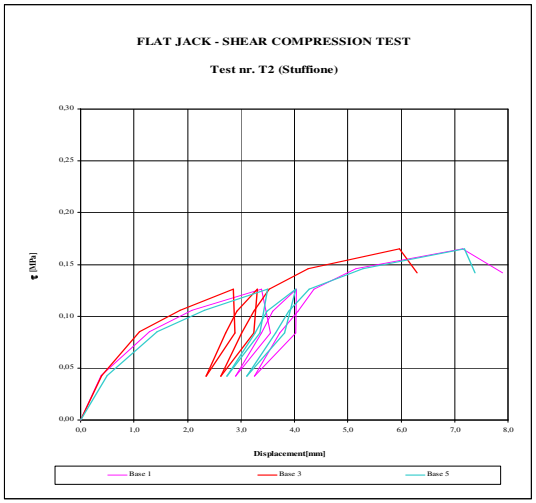
6. Shear Properties of Masonry – Laboratory Calibration Results

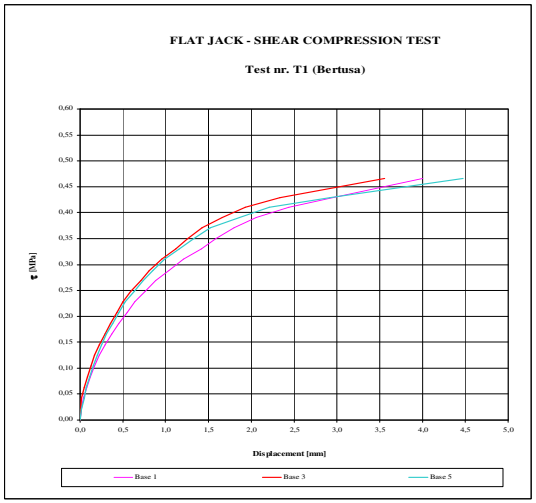


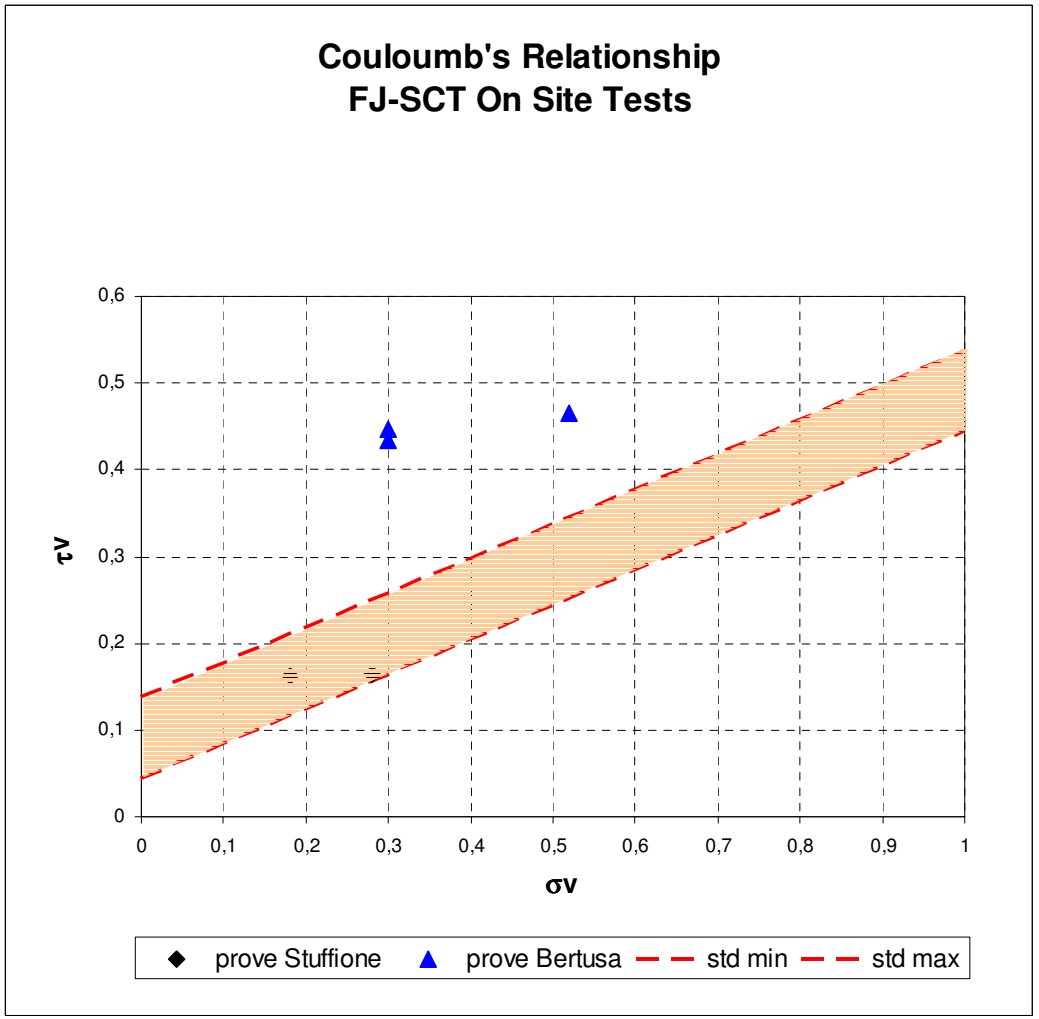




6. Shear Properties of Masonry – On Site Results







7. Conclusions

- The comparison of the data related to L'Aquila stonework masonry and those related to Emilia solid brick masonry is significant.
- **The Italian code** adequately captures the mechanical characteristics of the rubble stonework masonry, but **does not appear sufficiently accurate in defining the mechanical properties of solid brick masonry**.
- The current standard divides stonework masonry in many typologies, depending on the texture, while ranks the brick masonry in a single typology, presumably because, there are not evident differences in the texture of these walls.
- **The mechanical properties of brick masonry are strongly influenced by the quality of the mortar and by the joint thickness**: this variability should be taken into account by the seismic code to obtain a classification closer to the real characteristics of the masonry.

Thank you for your attention

"there are more things in heaven and earth, Horatio, than are dreamt of in your philosophy“

(Hamlet 1.5.167-8)