National Commission for Culture and the Arts
National Museum, Philippines
Bakas Pilipinas
ICOMOS Philippines
University of Santo Tomas - Center for Conservation of Cultural Property and Environment in the Tropics

JANUARY 13 – 14, 2016

First Session: CONTEXT

Global Seismic Responses of Unreinforced Heritage Masonry Construction

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CONTENTS

- Masonry typologies and masonry quality
- Damages and failure mechanisms: in-plane and out-of-plane behavior
- Building typologies:
  - churches
  - towers
- Damages connected to unappropriated retrofitting strategies/technologies

CONTENTS

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  - churches
  - towers
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What is masonry?

- Mortar

(binder + aggregate + water + ev. additives)

Hydraulic lime

Pozzolana

Clinker (cement)

- Natural/artificial “units”

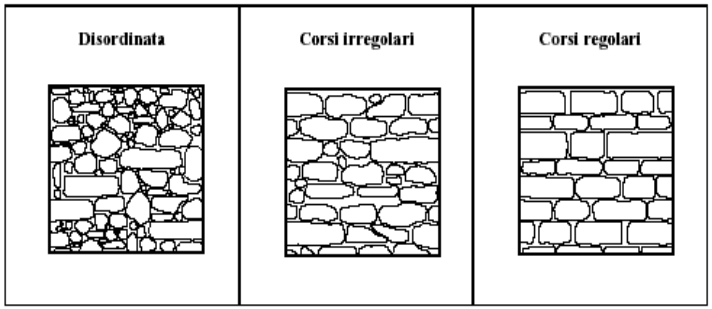
Calcareous stone

Brick elements

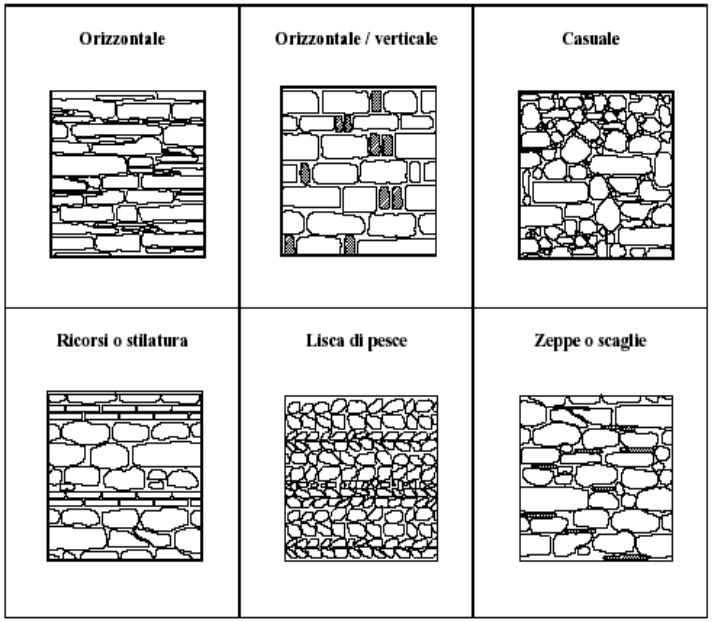
Masonry typologies

STONE MASONRY

APPARECCHIATURA

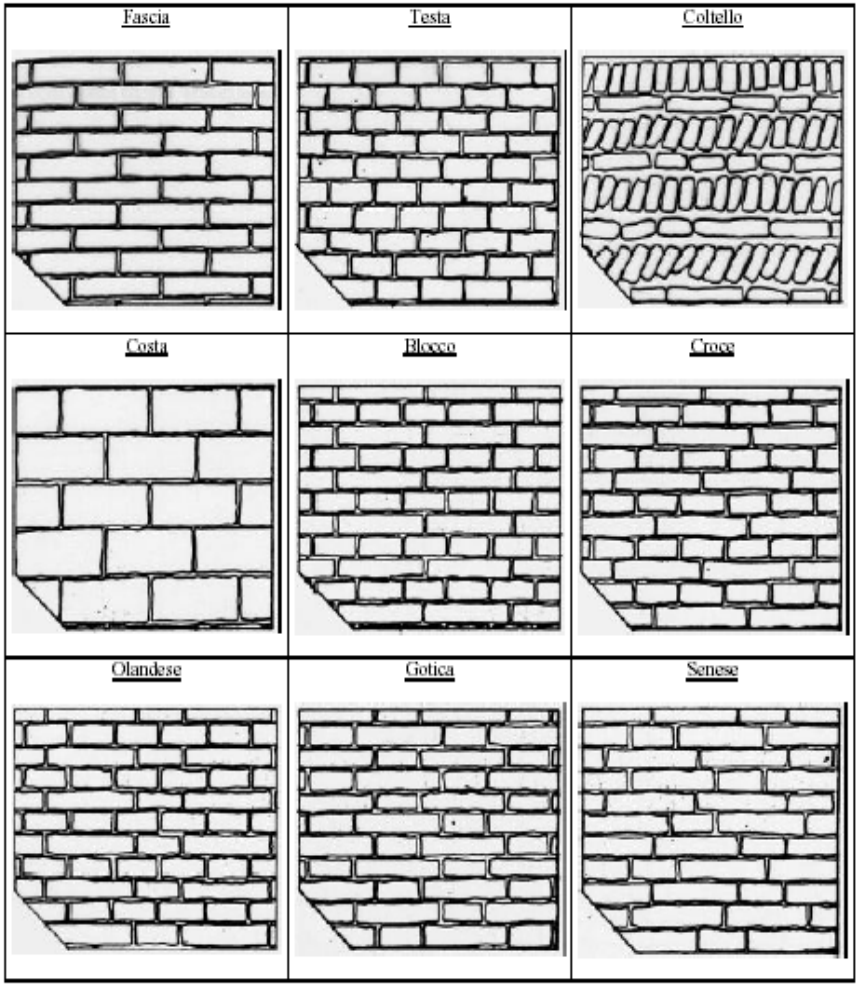


POSA DEGLI ELEMENTI



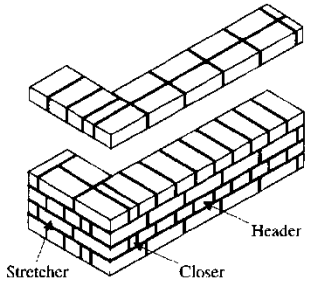
BRICK MASONRY

BRICKS LAYER

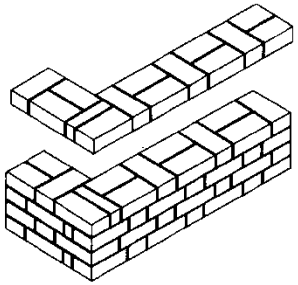


Masonry abacus – Università di Genova

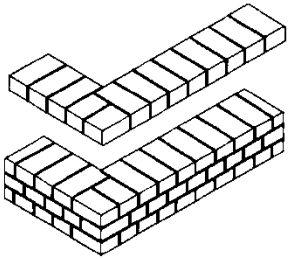
Masonry typologies



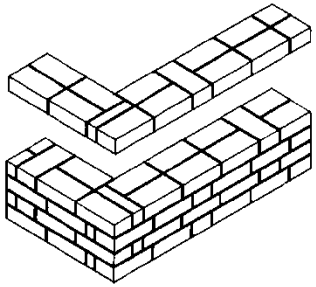
(a) English



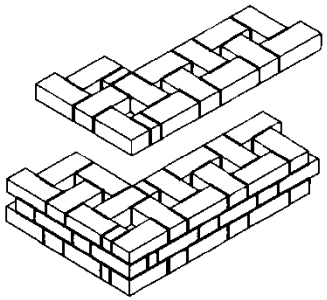
(b) Flemish



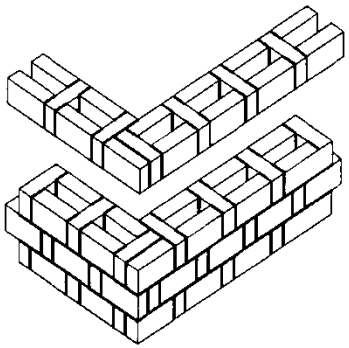
(c) Heading



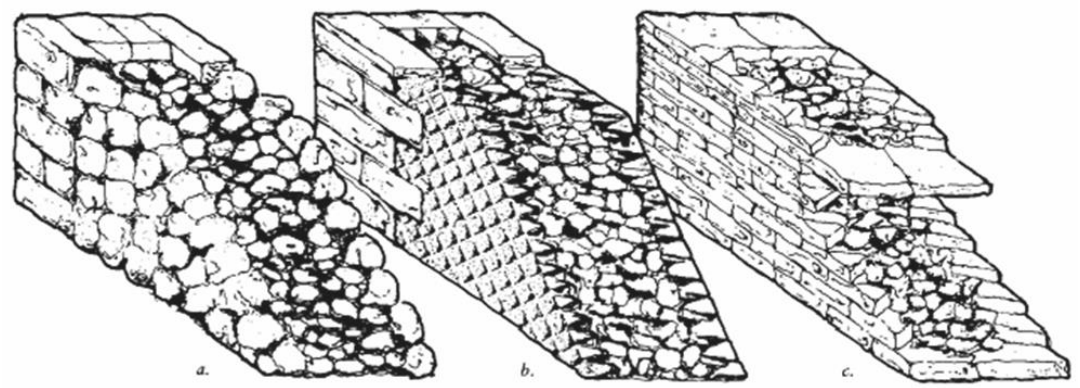
(d) Flemish garden wall

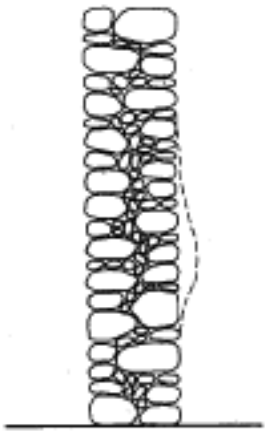


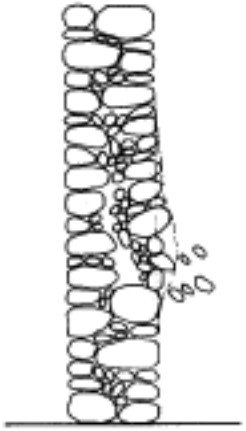
(e) Quetta (reinforcement not shown)



(f) Rat-trap

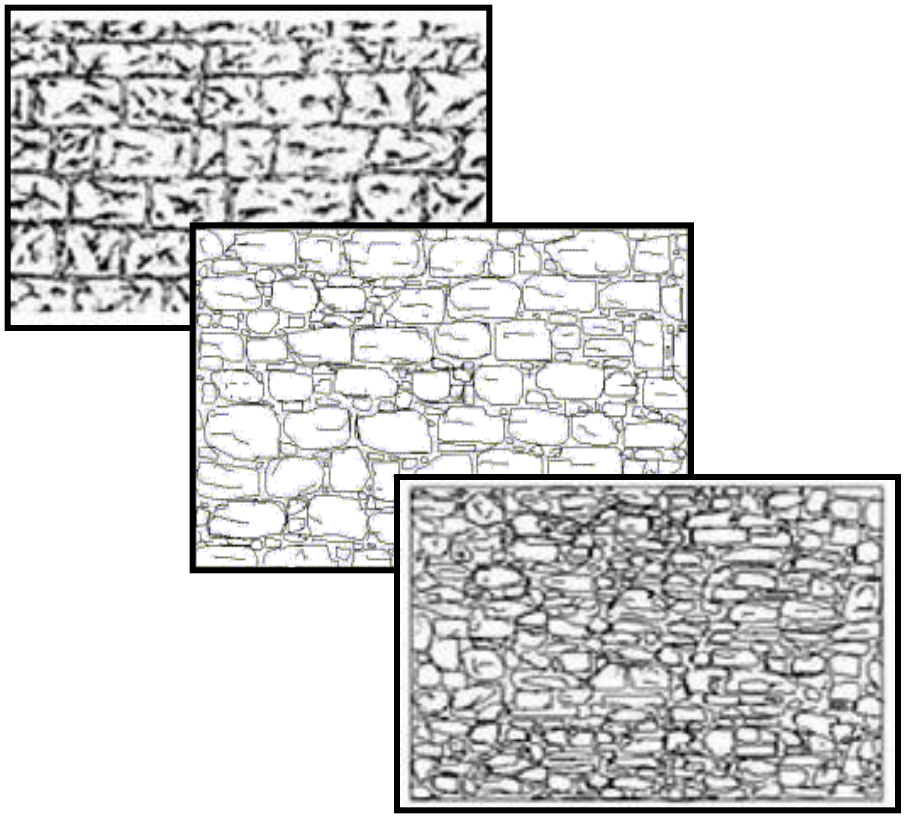






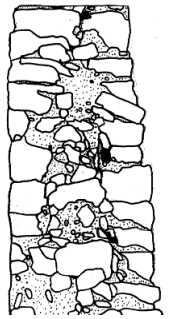
Stone masonry

• **Stone walls with mortar between stones:** walls are characterized by selected pieces of stone, which are spaced out by mortar. **Bondstones** are fundamental in order to improve the wall behavior



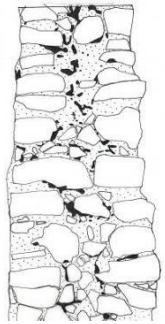
Regular texture





Partially regular texture

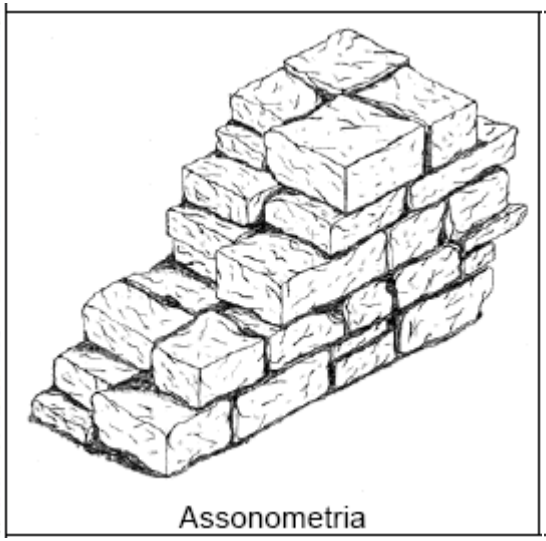


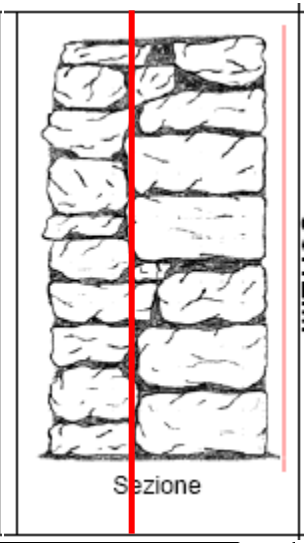


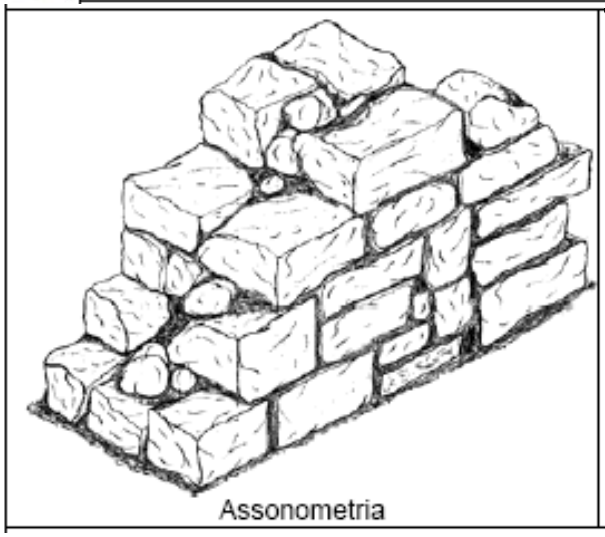
Irregular texture

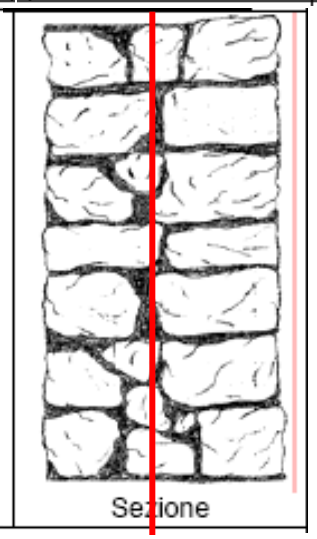


MORPHOLOGY : TWO LEAVES WALL

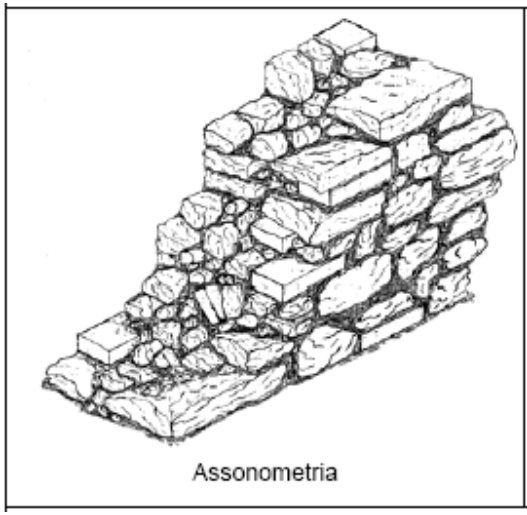


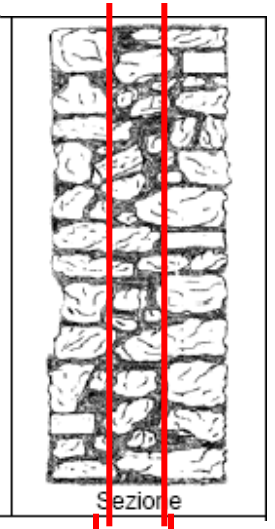


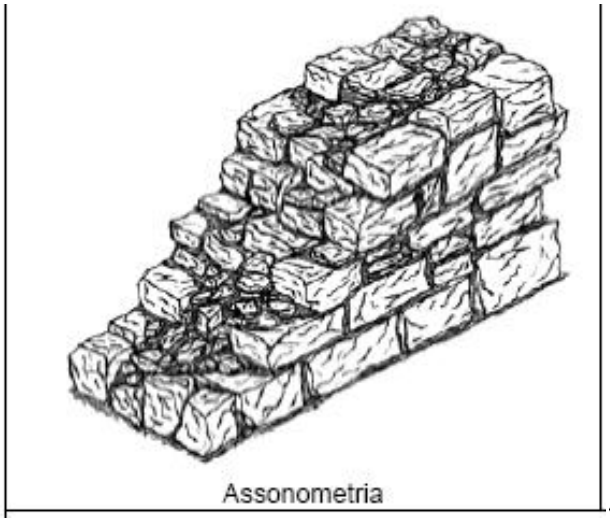


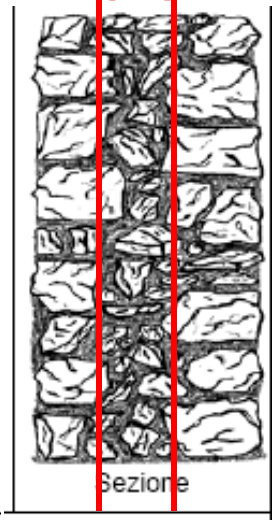


MORPHOLOGY : THREE LEAVES WALL



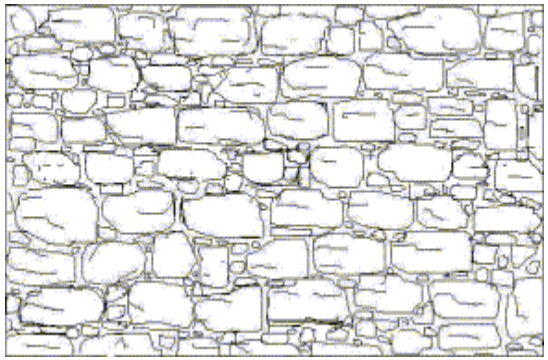
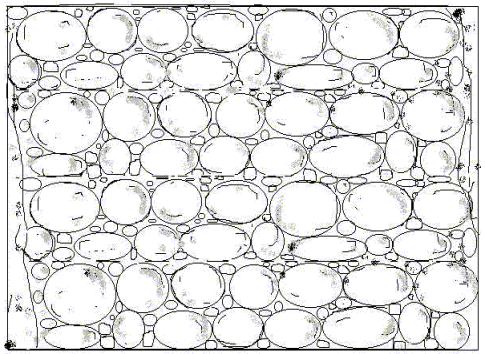




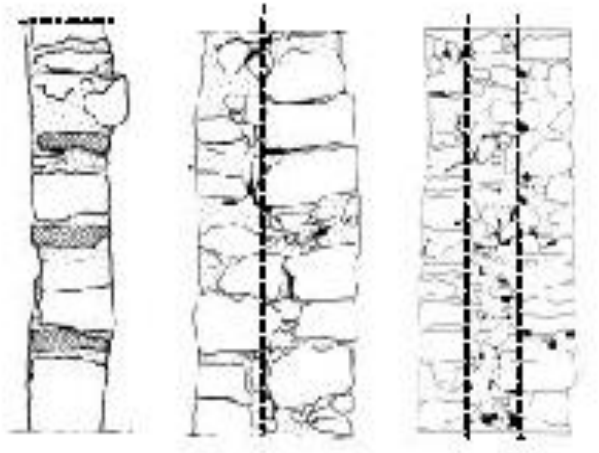


Stone masonry

- **Irregular texture**


- **Irregular sections**



- **Heterogeneous material**

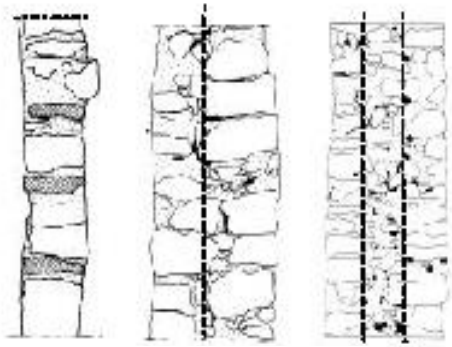
- **Different types of stones**
- **Bricks**
- **Different types of mortar**
- **Sand**
- **Clay, soil**
- **Presence of voids**

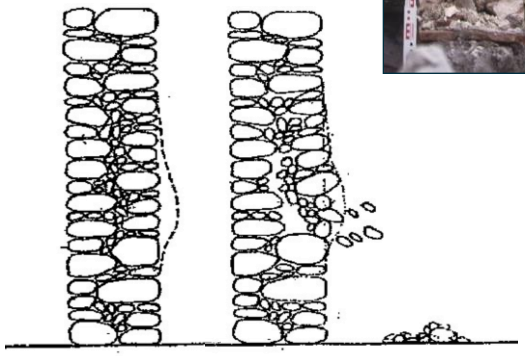
These elements influence:
- structural behavior
- intervention choice

Stone masonry

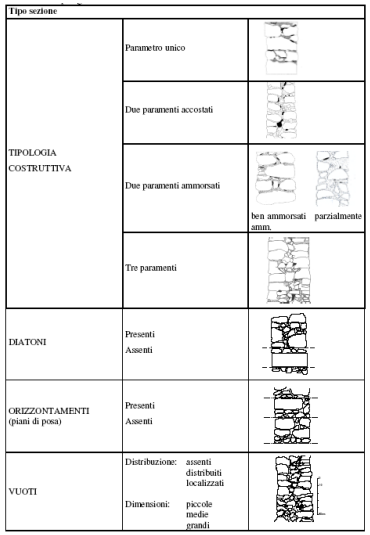
It Is possible to refer to abaci for the evaluation of the quality and bearing capacity of **masonry typologies**

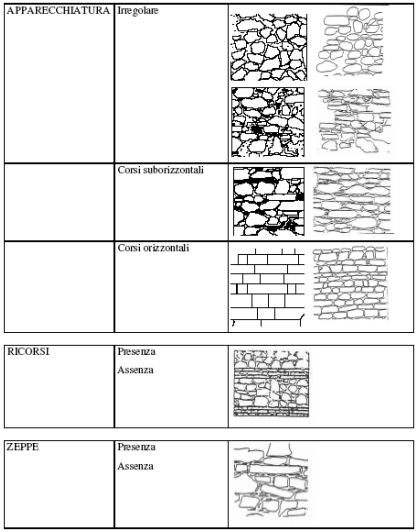
Heterogeneous masonry built up with poor materials, presence of voids, irregularities, multi-leaf sections, absence of connections

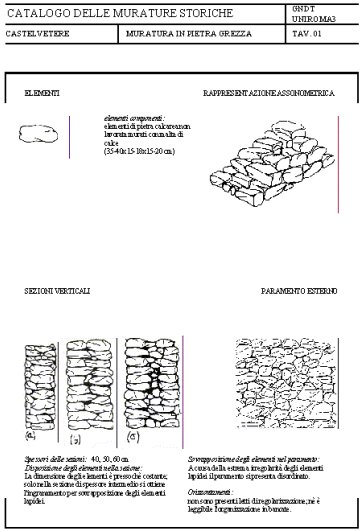


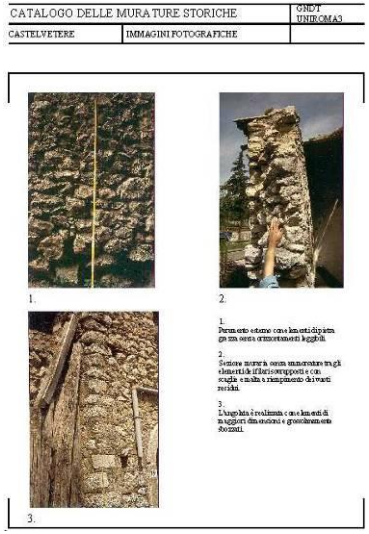


Out-of-plane brittle collapses





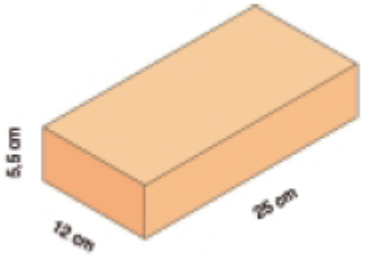




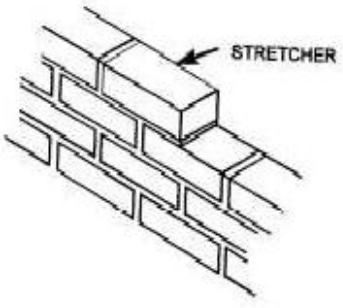
Survey forms: frequent local masonry typologies

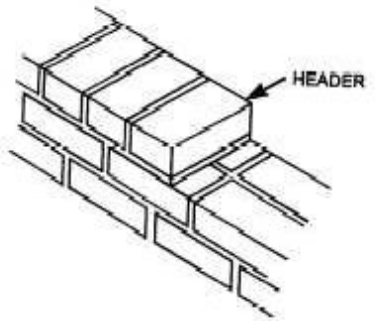
Brick masonry

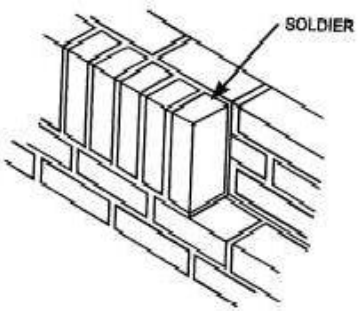
Bricks can be used as an alternative to stone. Stone is less workable.
Benefits: fire resistance; humidity resistance; workability and manageability, geometrical modularity, reuse.

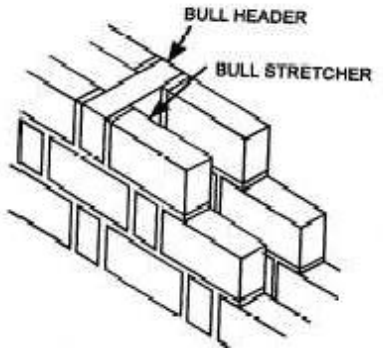


Denominazioni dei materiali	Lunghezza mm	Larghezza mm	Grossezza mm	Volumi m^3	Pesi kg
Mattone ordinario	279	140	37	0,001445	2,390
Mattone zoccolo	279	140	74	0,002890	4,780
Mattone grosso	335	168	47	0,002645	4,375
Pianella	317	158	28	0,001402	2,319
Quadruccio	261	102	41	0,001092	1,806
Mattone quadro	223	223	28	0,001392	2,302
Tegola piana	391	322	26	0,004021	6,651
Canale	391	161	22	0,002084	3,447

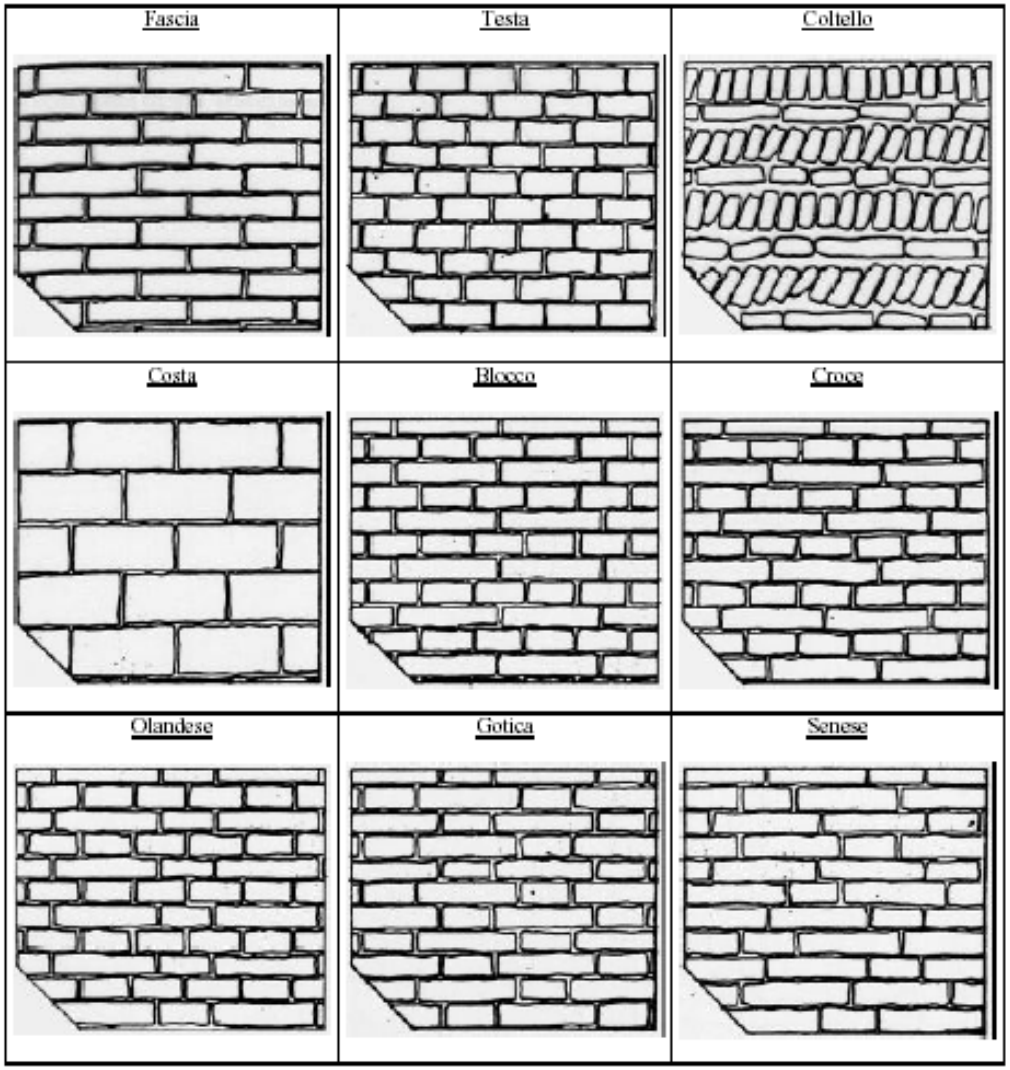








Texture


Fascia
Testa
Coltello
Costa
Blocco
Croce
Olandese
Gotica
Senese

Masonry quality

A method for masonry quality evaluation
(ReLUIS Project 2005-2008)

⇩

Identification of the **"good constructive practice"** of masonry buildings
(simple criteria to define if the local constructive rule is respected or not)

The study takes into consideration an isolated and homogeneous wall.
It is subjected to different actions:

- **Vertical** loads
- Actions that are **parallel** to the wall plane
- Actions that are **perpendicular** to the wall plane

Good constructive practice parameters influence wall response according to actions applied on it.

Masonry quality

The **good constructive practice** is the set of constructive solutions that are applied during walls construction and that allow walls monolithical behaviour. During the last centuries, local technicians observed static and seismic behaviour of masonry walls in order to choose the best constructive solutions.

Problems:

- some parameters can be only defined through wall investigations (investigation methods on masonry buildings).

Good constructive practice parameters:

MQ. = mortar quality;
P.T. = presence of transversal connecting elements;
EL.S. = elements shape;
D.EL. = elements dimension;
S.J. = stagger of vertical joints;
HOR. = horizontality of the courses;
RE.EL. = elements strength.

Assessment:

R. = respected;
P.R. = partially respected;
N.R. = non-respected.

Masonry quality

Mortar

Mortar regularizes the contact between stones, distributes actions equally and, if it has a good quality, ensures masonry cohesive strength. The strength of mortar can be considered a fundamental parameter if the monolithic behavior of the wall can not be guaranteed by other local constructive rule parameters

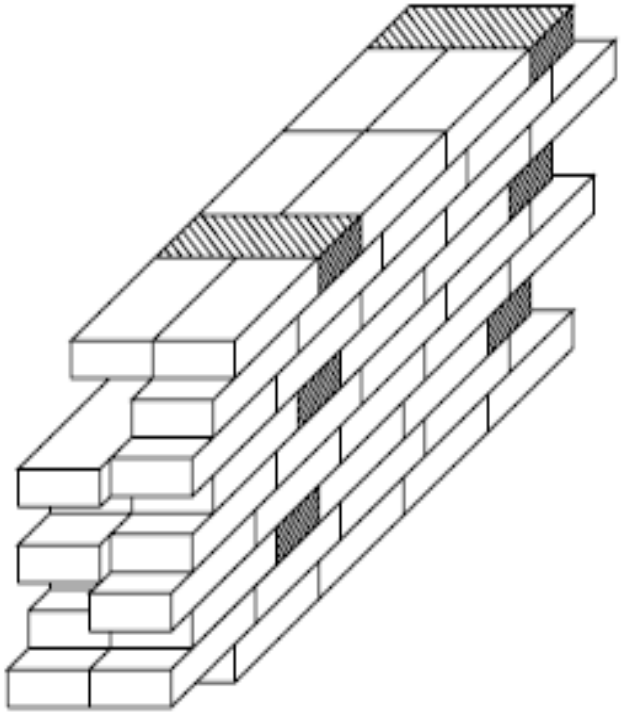
respected

partially respected

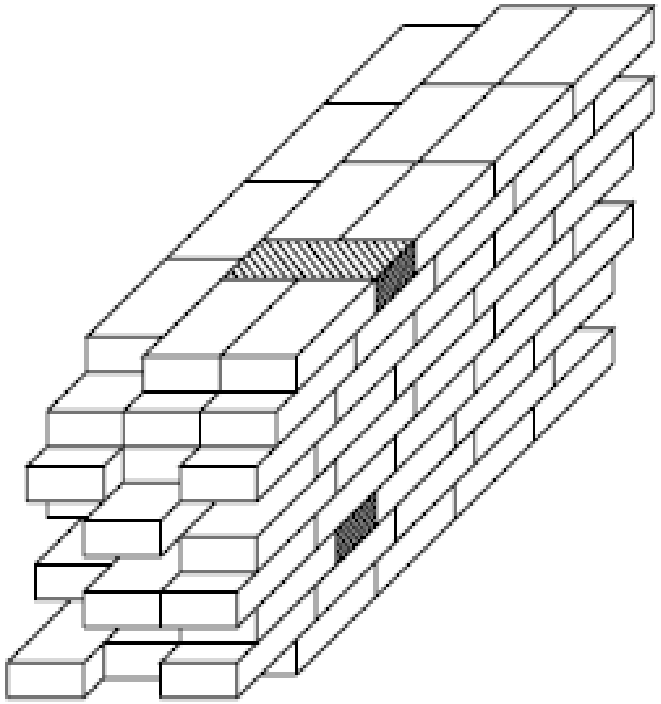
non-respected

Masonry quality

Presence of transversal connecting elements (bondstones)



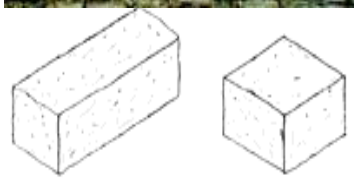
respected



non-respected

Masonry quality

Squared resistant elements



Square blocks

Rough blocks

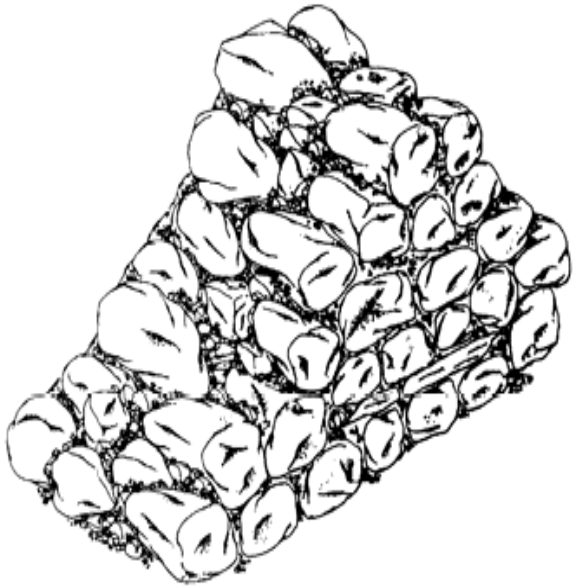
Rubble masonry

Masonry quality

Resistant elements having significant sizes compared to wall thickness

respected

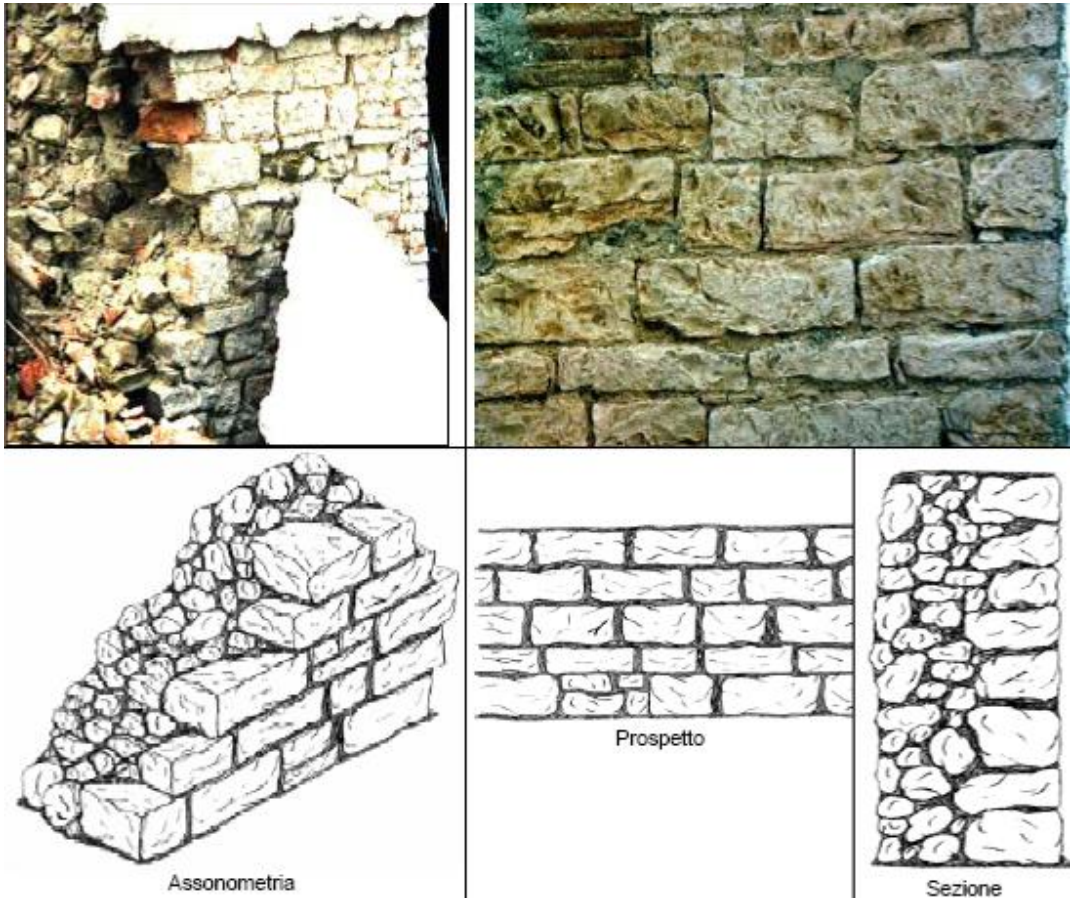
partially respected



non-respected

Masonry quality

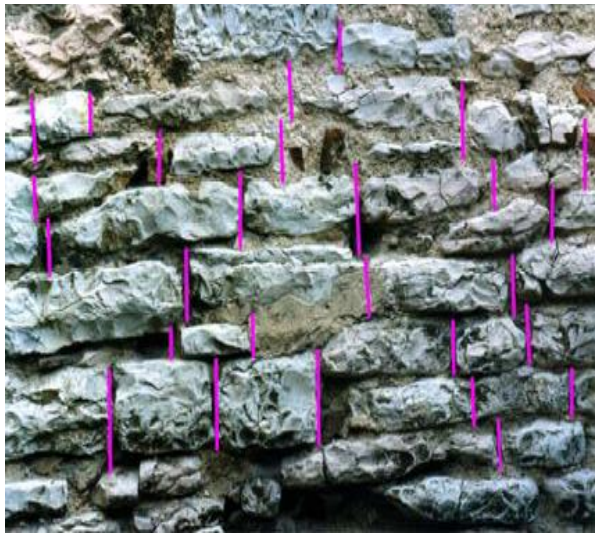
Squared resistant elements EL.S.
Elements dimension D.EL.



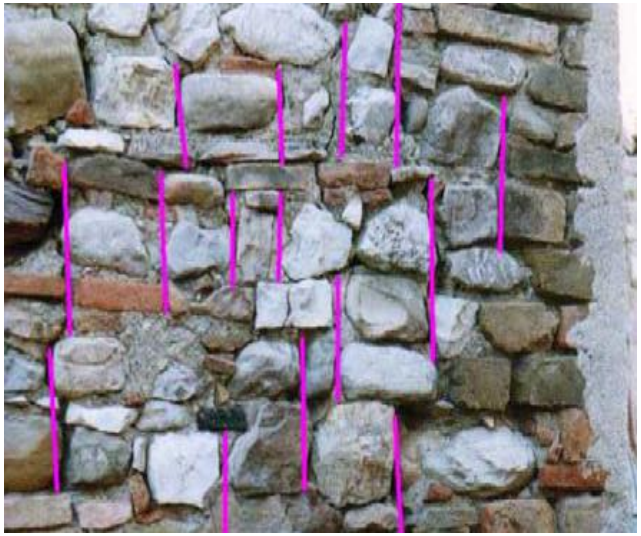
Masonry quality

Stagger of vertical joints

respected



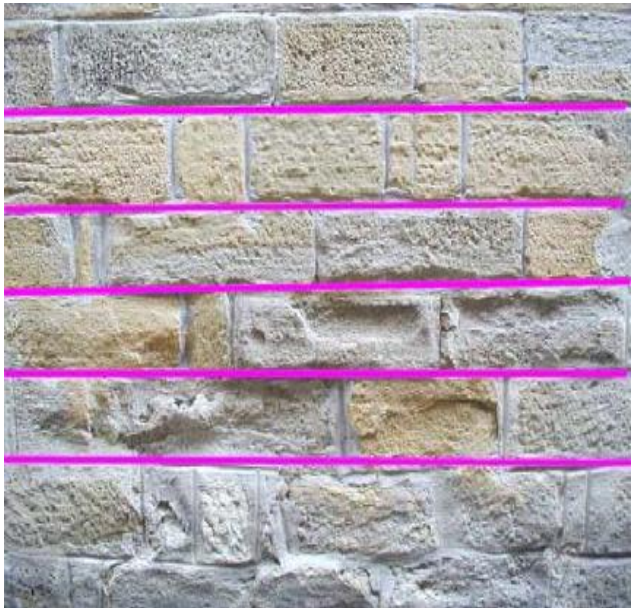
partially respected



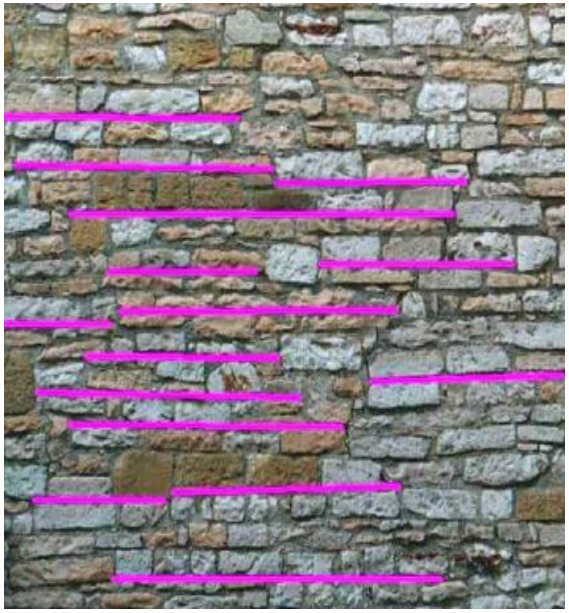
non-respected

Masonry quality

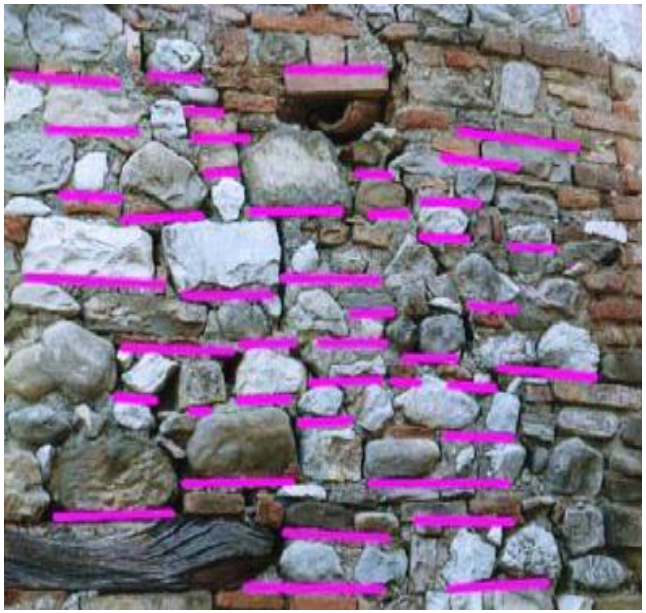
Horizontality of the courses



respected

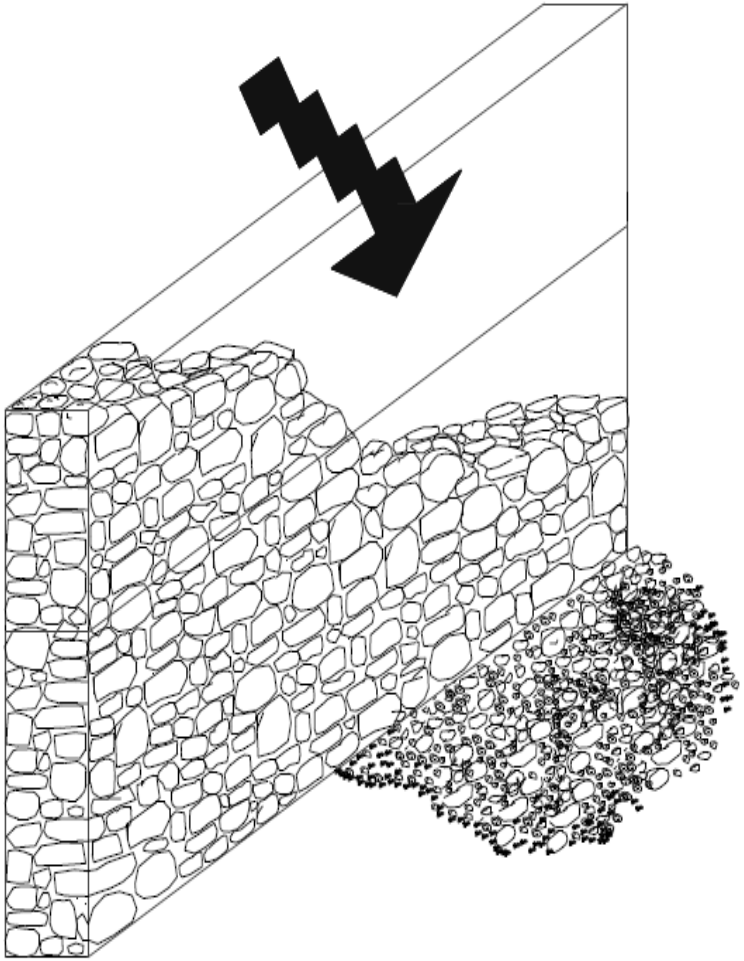


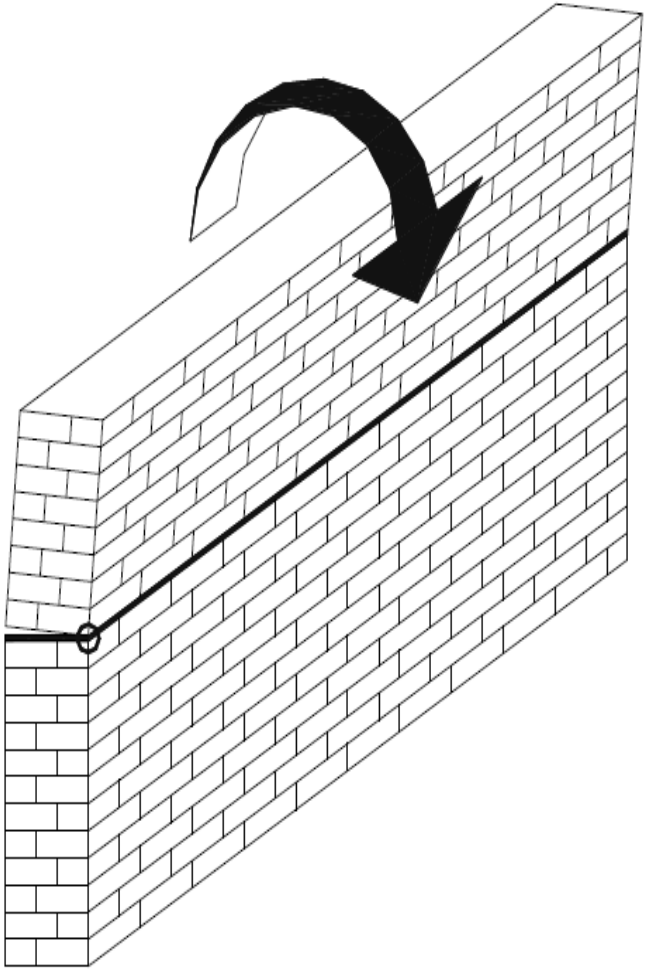
partially respected



non-respected

Masonry quality





HOR.

THE ABRUZZO EARTHQUAKE - 2009

L'AQUILA

GOVERNMENT'S PALACE

SPANISH FORTRESS

L'AQUILA

ANIME SANTE

SANTA MARIA PAGANICA

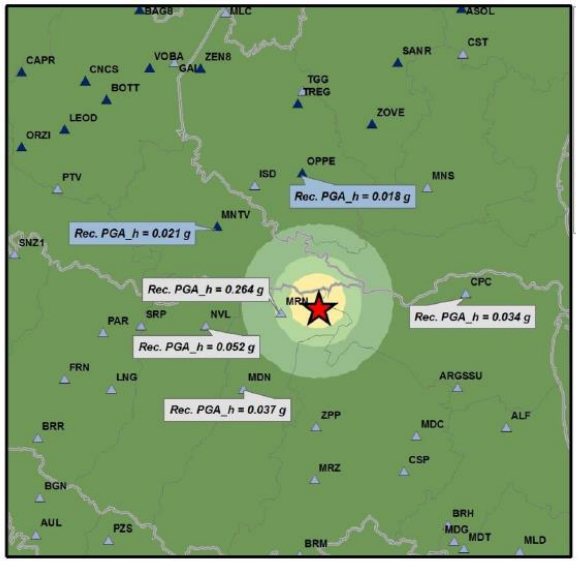
MINOR CENTRES: PAGANICA

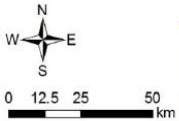
MINOR CENTRES: VILLA SANT'ANGELO

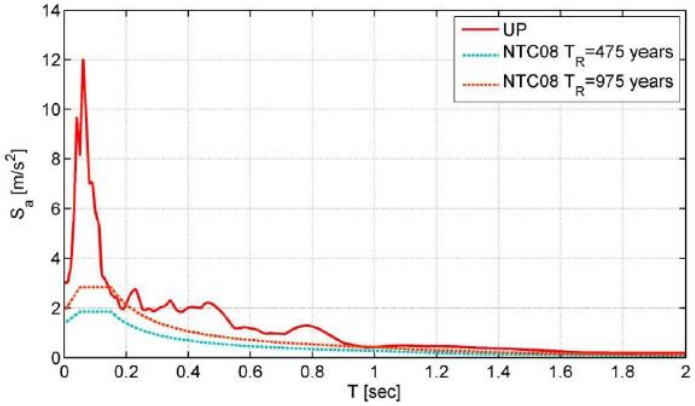
EMILIA EARTHQUAKE - 2012

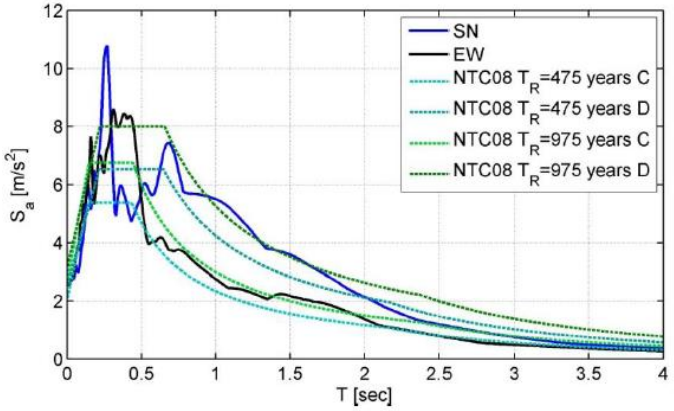
20 Maggio 2012, Mirandola

	PGA (g)	PGV (m/s)	PGD (m)
SN	0.264	0.463	0.105
EW	0.262	0.300	0.081
UP	0.310	0.059	0.018

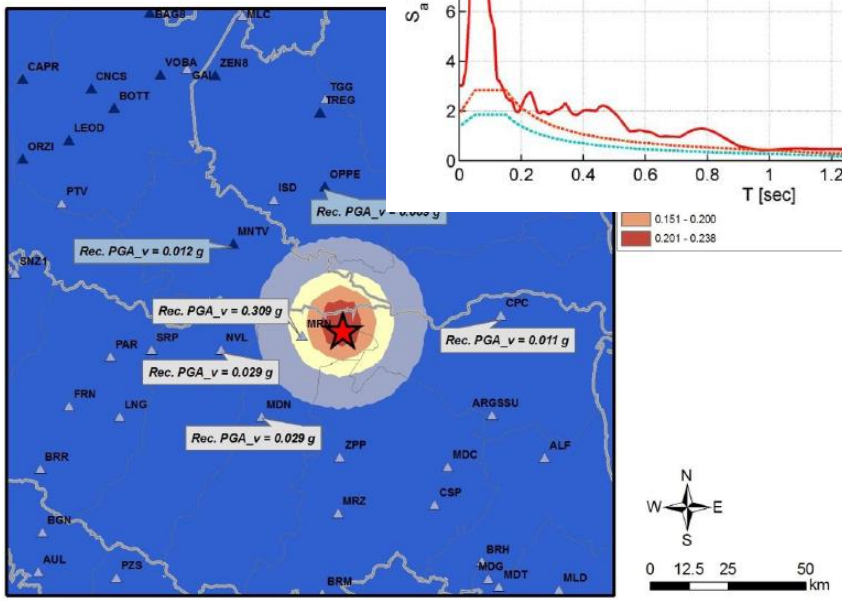








Horizontal



Vertical

EMILIA EARTHQUAKE - 2012

Cavezzo

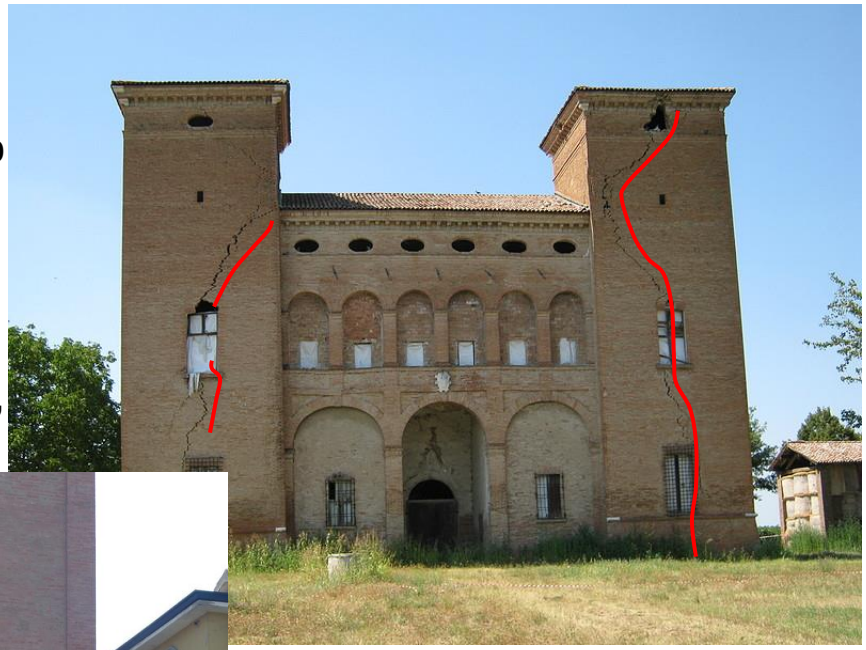
THE PROBLEM OF MASONRY QUALITY

2009

San Michele, Villa Sant'Angelo

2012

San Prospero



San Prospero, Cavezzo

Collegiata Santa Maria

Maggiore, Mirandola

THE PROBLEM OF MASONRY QUALITY

SAN MICHELE ARCANGELO, CELANO

GOVERNMENT PALACE, L'AQUILA

THE PROBLEM OF MASONRY QUALITY

SAN MICHELE, VILLA SANT'ANGELO

SAN GIOVANNI, SAN DEMERIO NEI VESTINI

THE PROBLEM OF MASONRY QUALITY

2012 Emilia

Collegiata Santa Maria Maggiore, Mirandola

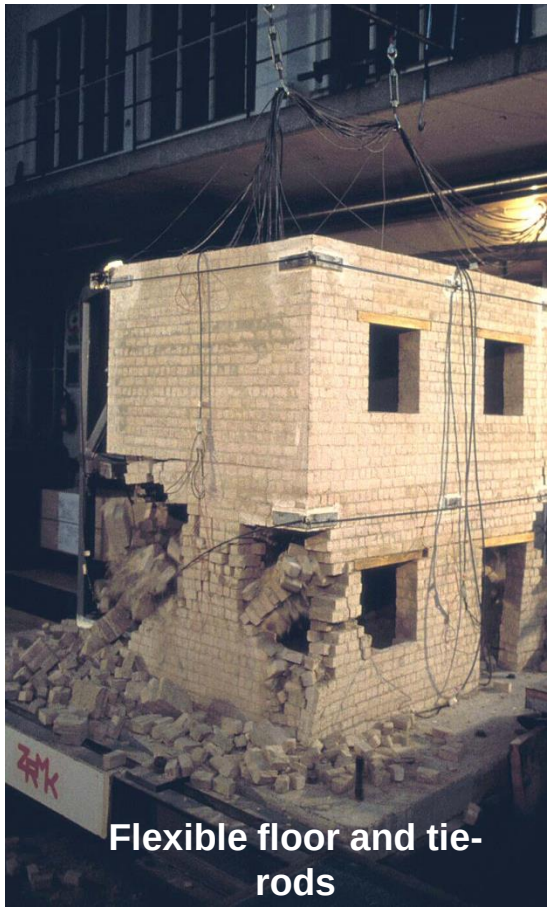
Novi, SS Rovereto

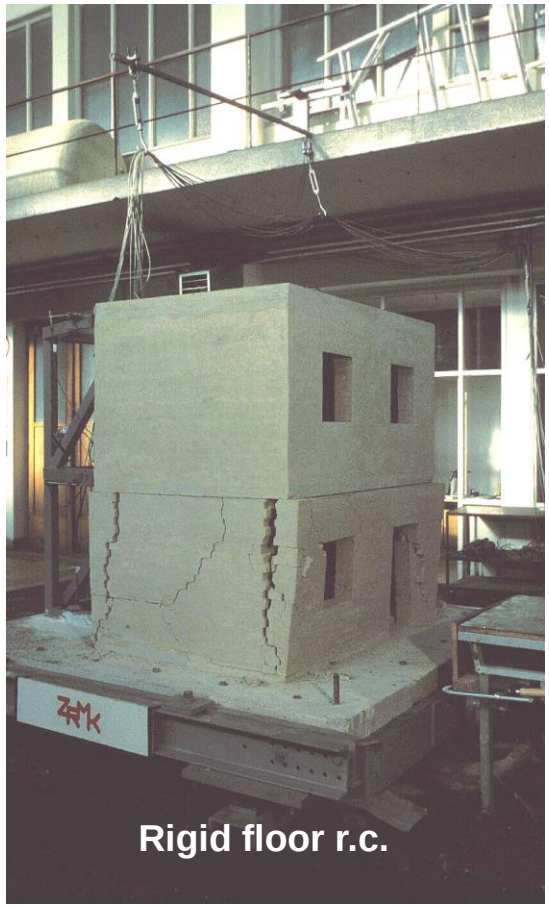
San Martino, Buonacompra

CONTENTS

- Masonry typologies and masonry quality
- Damages and failure mechanisms: in-plane and out-of-plane behavior
- Building typologies:
  - churches
  - towers
- Damages connected to unappropriated retrofitting strategies/technologies

SEISMIC BEHAVIOR OF MASONRY BUILDINGS





Brick masonry building models after shaking table tests

(ZAG Slovenia, M. Tomazevic)

Examples of out of plane mechanisms of external walls

• ***Damage***:

Total façade collapse

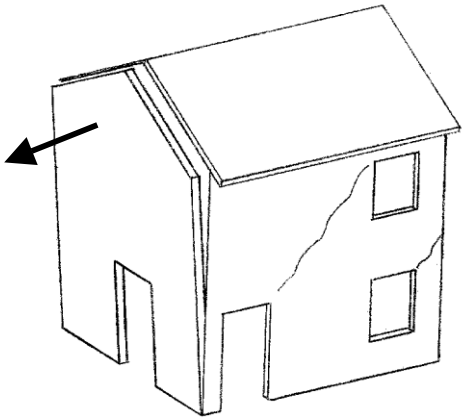
• ***Mechanism:***

Out of plane rotation of the façade with formation of a cylindrical horizontal hinge at the base of the wall

· ***Structural causes:***

Scarce connection between orthogonal walls

Absence of ties and tie beams



• ***Damage***:

Collapse of the corner

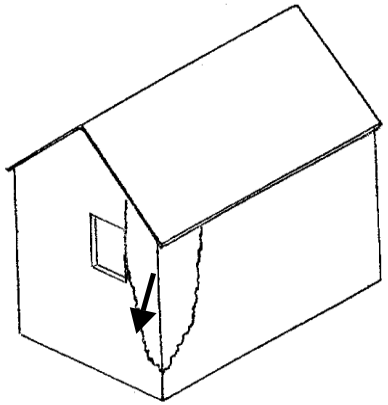
• ***Mechanism:***

Out of plane rotation of the masonry corner

· ***Structural causes:***

Scarce connection between orthogonal walls and between floors and walls

Presence of openings close by the corner



Examples of out of plane mechanisms of external walls

Mechanisms generated by the roof structures

• ***Damage***:

Local collapse of the tympanum

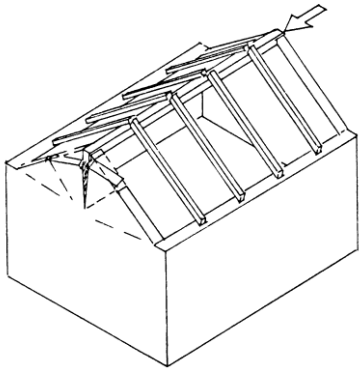
Local collapse of the cornice

• ***Mechanism:***

Out of plane rotation of portion of the façade due to the pounding of the top roof beam

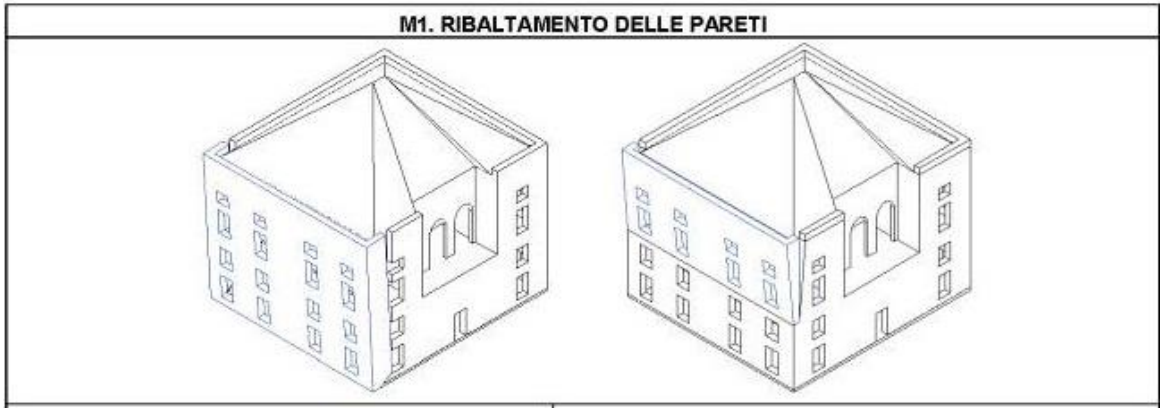
· ***Structural causes:***

Scarce connection between roof and orthogonal walls



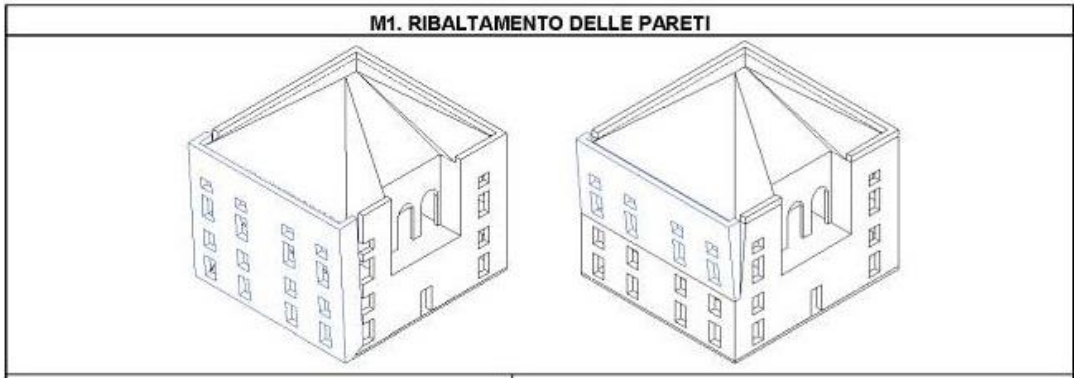
Other out of plane mechanisms of external walls

DAMAGES ON BULDINGS



PALACE IN VIA ROMA, L'AQUILA

DAMAGES ON BULDINGS



Examples of in plane mechanisms for external walls

Shear cracking in the lintels

• ***Damage***:

Crossed or diffused diagonal cracks above the lintels

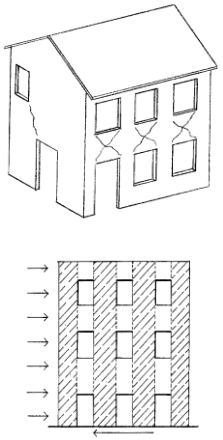
• ***Mechanism:***

Shear cracking of the spandrel walls due to in-plane flexural behaviour

· ***Structural causes:***

Presence of weak lintels

Masonry piers between openings with small height and thickness



Shear cracking in the masonry piers

• ***Damage***:

Crossed (in the central masonry piers) or inclined diagonal cracks in the squat masonry piers

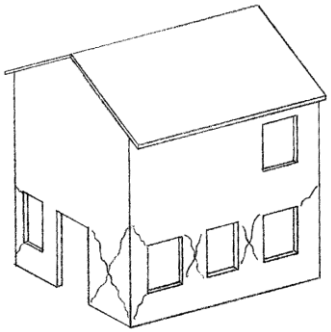
• ***Mechanism:***

Shear cracking of the wall under in-plane actions

· ***Structural causes:***

Presence of many openings

Scarce quality of the masonry or presence of discontinuities



Examples of other mechanisms

In plane overturning of the masonry piers

• ***Damage***:

Horizontal cracks (tensioned corner) localized mainly at the base of the building

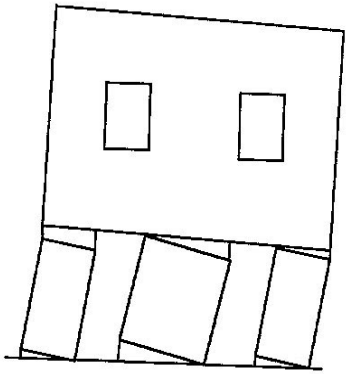
Eventual crushing of the compressed toe, due to attainment of maximum compressive strength

• ***Mechanism:***

Overturning of the masonry piers due to in-plane rotation

· ***Structural causes:***

Excessive slenderness of the masonry piers due to the presence of many openings or large openings



Buildings interaction: detachment of adjacent buildings

• ***Damage***:

Vertical cracking at the joint between adjacent buildings

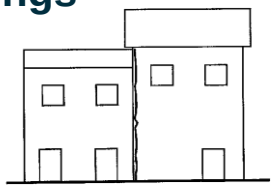
• ***Mechanism:***

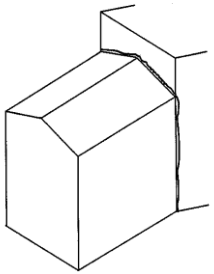
Different seismic response of adjacent buildings characterized by the presence of ineffective joint

• ***Structural causes:***

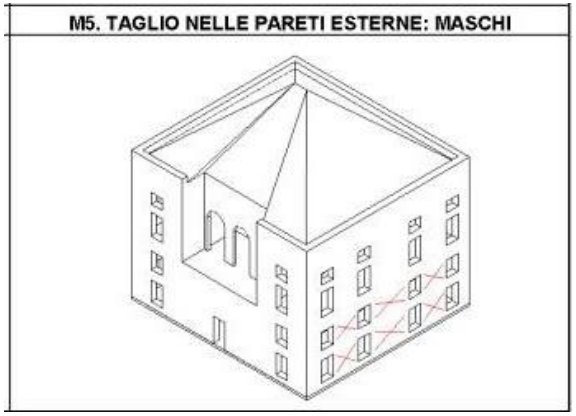
Scarce connection between the buildings

Different stiffness of connecting structural bodies

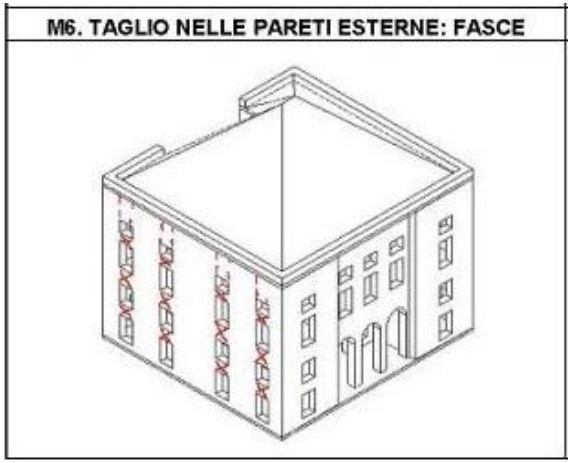




DAMAGES ON BULDINGS



TWO PALACES IN VILLA SANT'ANGELO, AQ



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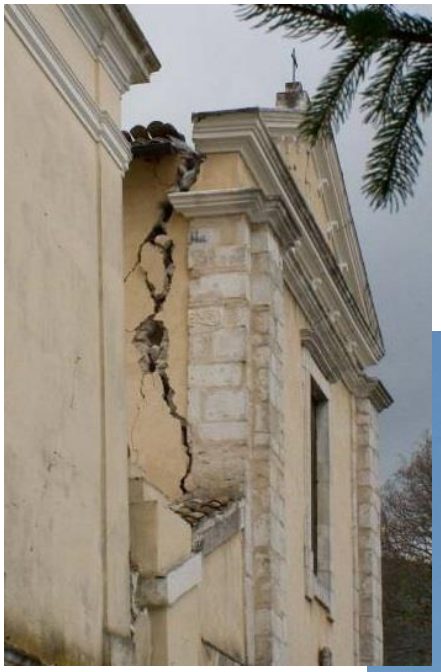
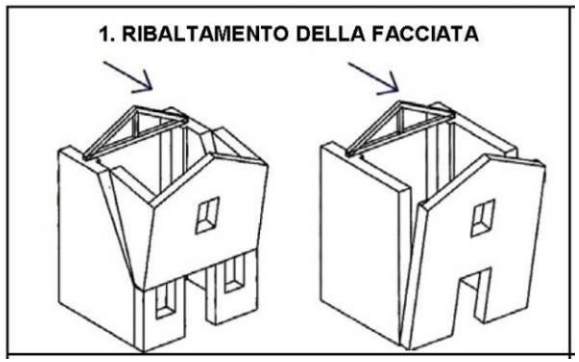
DAMAGES ON CHURCHES

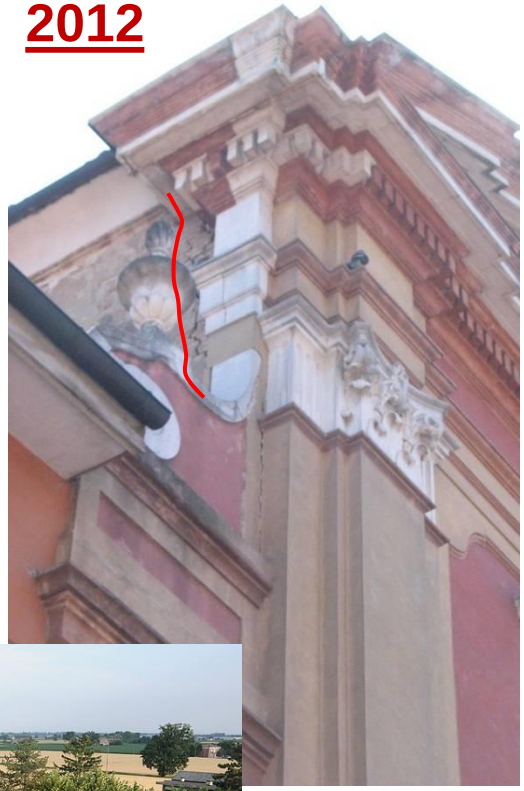
2009



Santa Gemma,
Goriano Sicoli (AQ)



2012



San Filippo,
Cento

San Martino,
Buonacompra

DAMAGES ON CHURCHES

2009

Santa Maria Assunta, Carpi

San Biagio D'Amiterno, L'Aquila

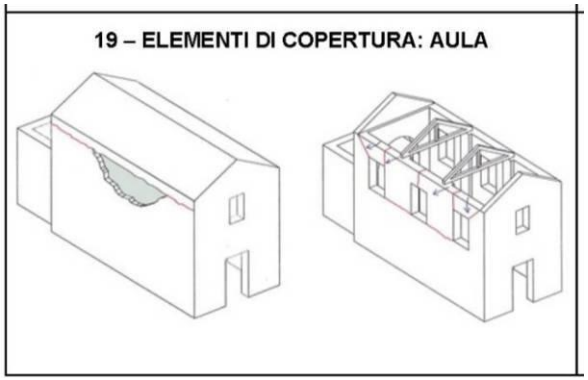
2012

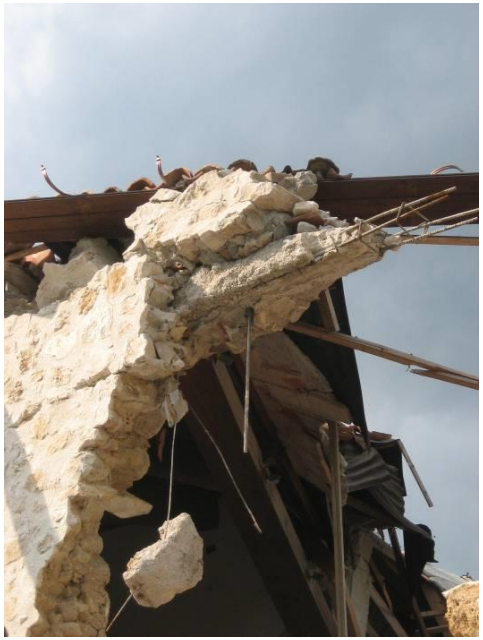
Oratorio SS Sacramento, Mirandola

DAMAGES ON CHURCHES

2009

Chiesa di San Michele e Chiesa Parrocchiale, Villa Sant'Angelo (AQ)

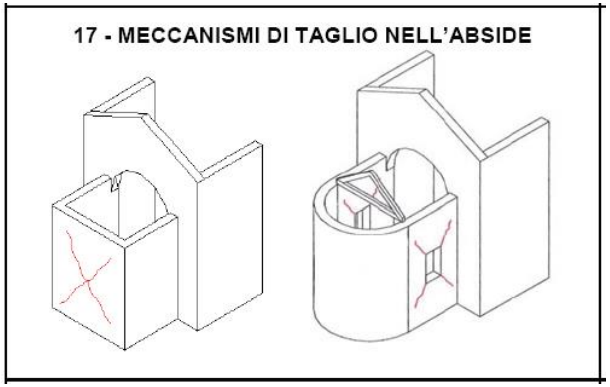




2012

San Francesco D'Assisi, Mirandola

DAMAGES ON CHURCHES



2009

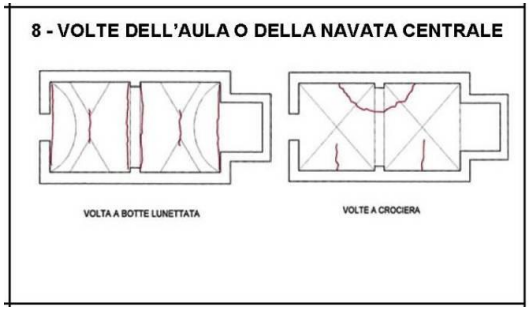
Santa Margherita, L'Aquila

San Domenico, L'Aquila

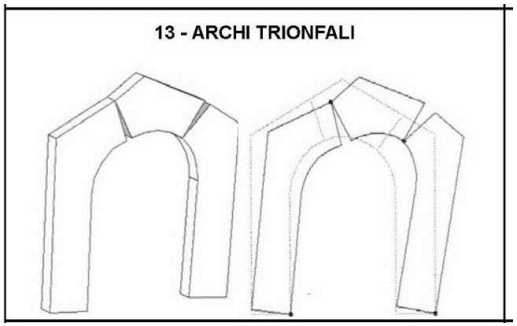
2012

Chiesa di San Nicolò, Carpi (MO)

DAMAGES ON CHURCHES



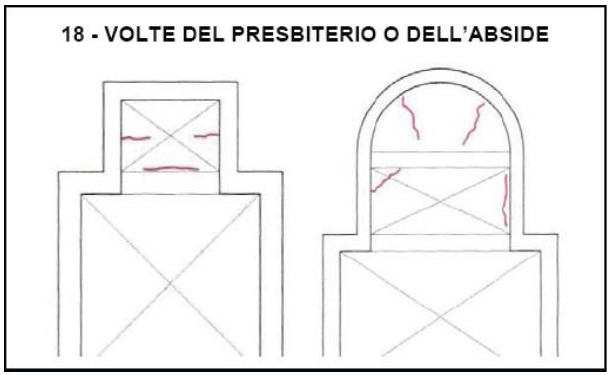
BEATA ANTONIA, L'AQUILA



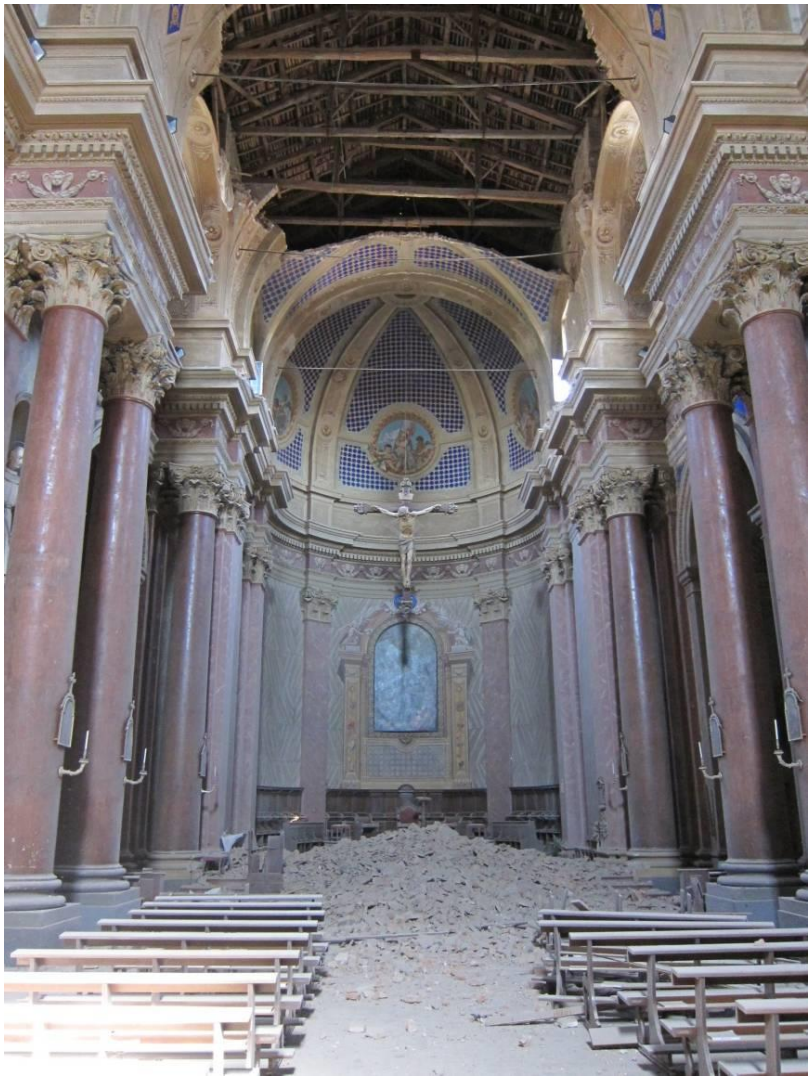
SAN MARCIANO E NICANDRO, L'AQUILA

2009

Oratorio di Sant'Antonio, L'Aquila

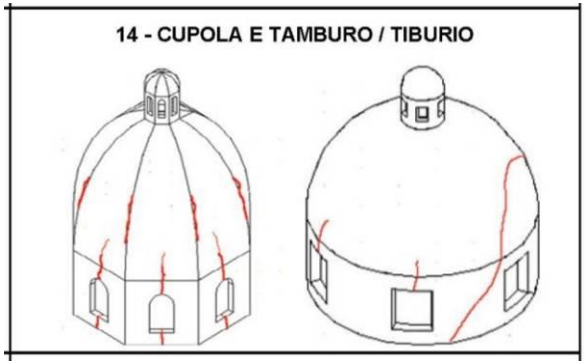


2012

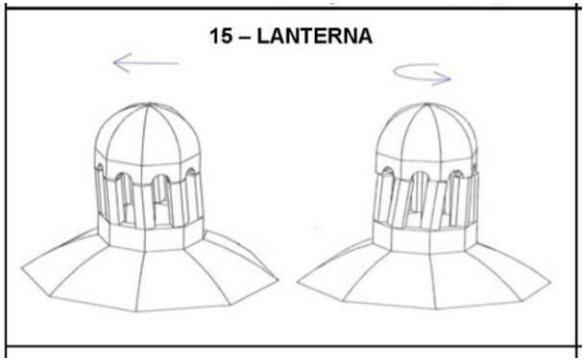


Chiesa di San Francesco, Carpi (MO)

DAMAGES ON CHURCHES



ANIME SANTE, L'AQUILA



SANT'AGOSTINO, L'AQUILA

DAMAGES ON CHURCHES

2012 Emilia

Santissimo Crocifisso

San Nicolò

Sant'Ignazio

Basilica Cattedrale Santa Maria Maggiore

DAMAGES ON CHURCHES

2012 Emilia

Polesine

San Nicolò, Carpi

Oratorio Beata Vergine, Tommaselle

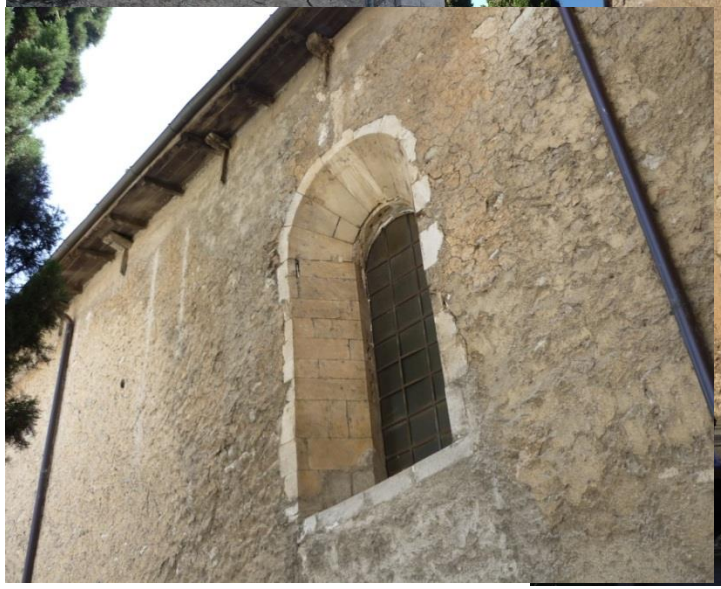
Carpi

Mirandola

Cattedrale Santa Maria Maggiore, Carpi

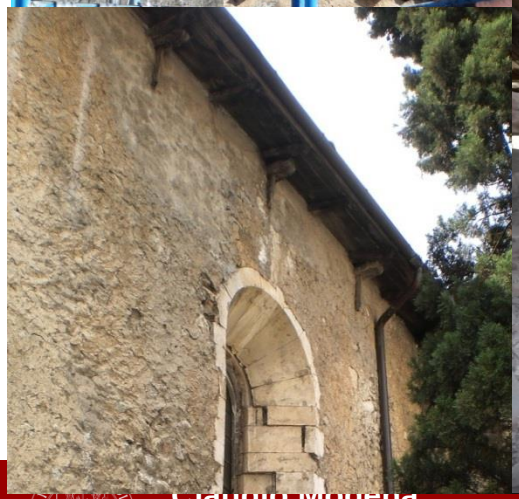
DAMAGES ON CHURCHES

Santa Maria del Soccorso – L'Aquila



DAMAGES ON CHURCHES

Santa Maria del Soccorso – L'Aquila



DAMAGES ON CHURCHES

S. Giovanni - Casentino, L'Aquila

DAMAGES ON CHURCHES

S. Giovanni - Casentino, L'Aquila

DAMAGES ON CHURCHES

S. Giovanni - Casentino, L'Aquila

DAMAGES ON CHURCHES

St. Pietro Apostolo – Onna, L'Aquila

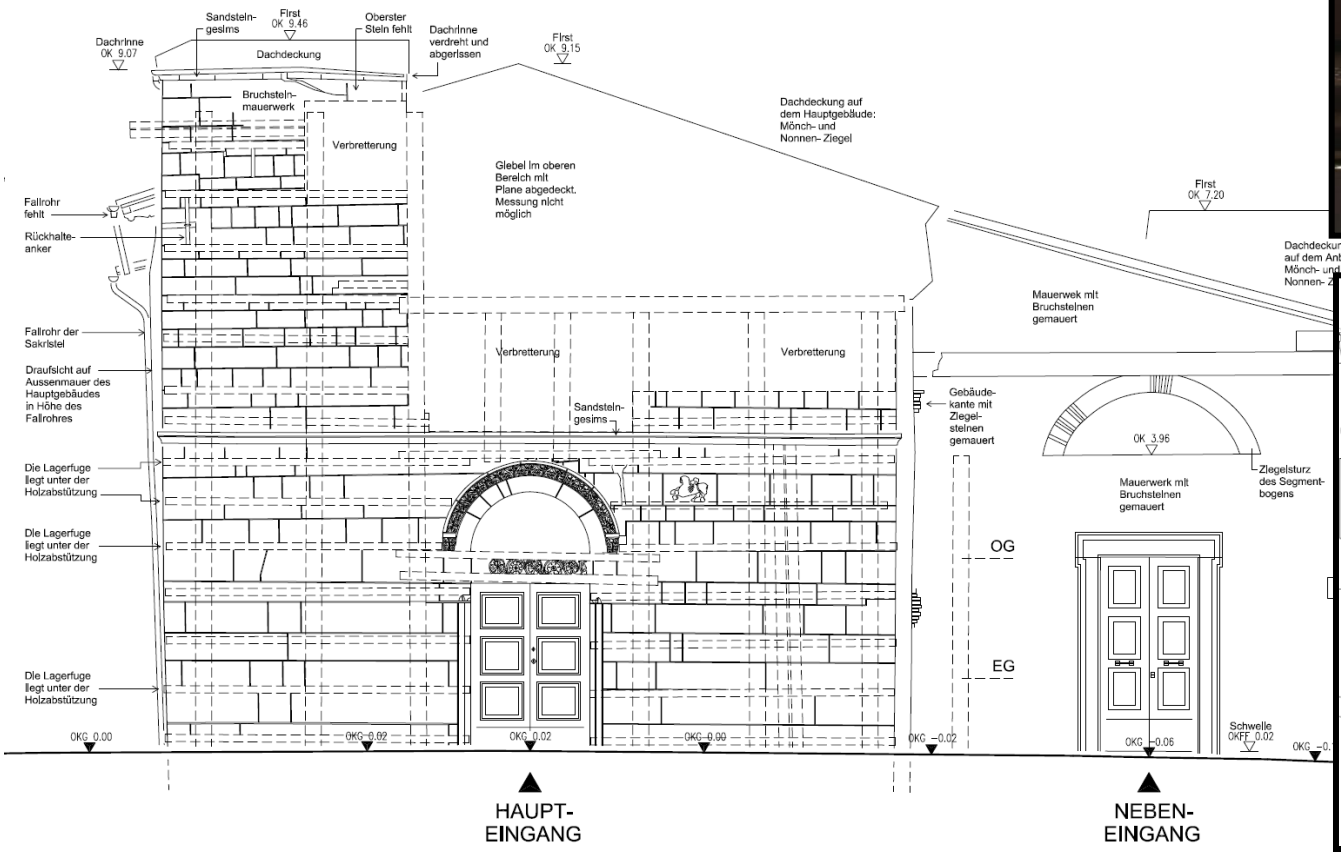
The German government immediately signaled desire to help the local community, it **especially financed the rebuilding of the church, dedicated to St. Pietro Apostolo, also severely damaged by the seismic action.**

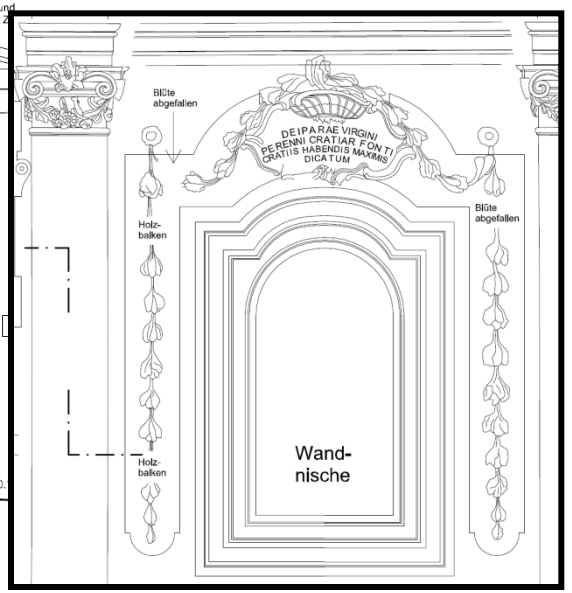
The 4th June 2010 an agreement for the reconstruction of the church has been signed between the Italian Ministry of Cultural Heritage and the Federal Ministry of Transportation, Building and Urban Development of the Federal Republic of Germany.

DAMAGES ON CHURCHES

St. Pietro Apostolo – Onna, L'Aquila

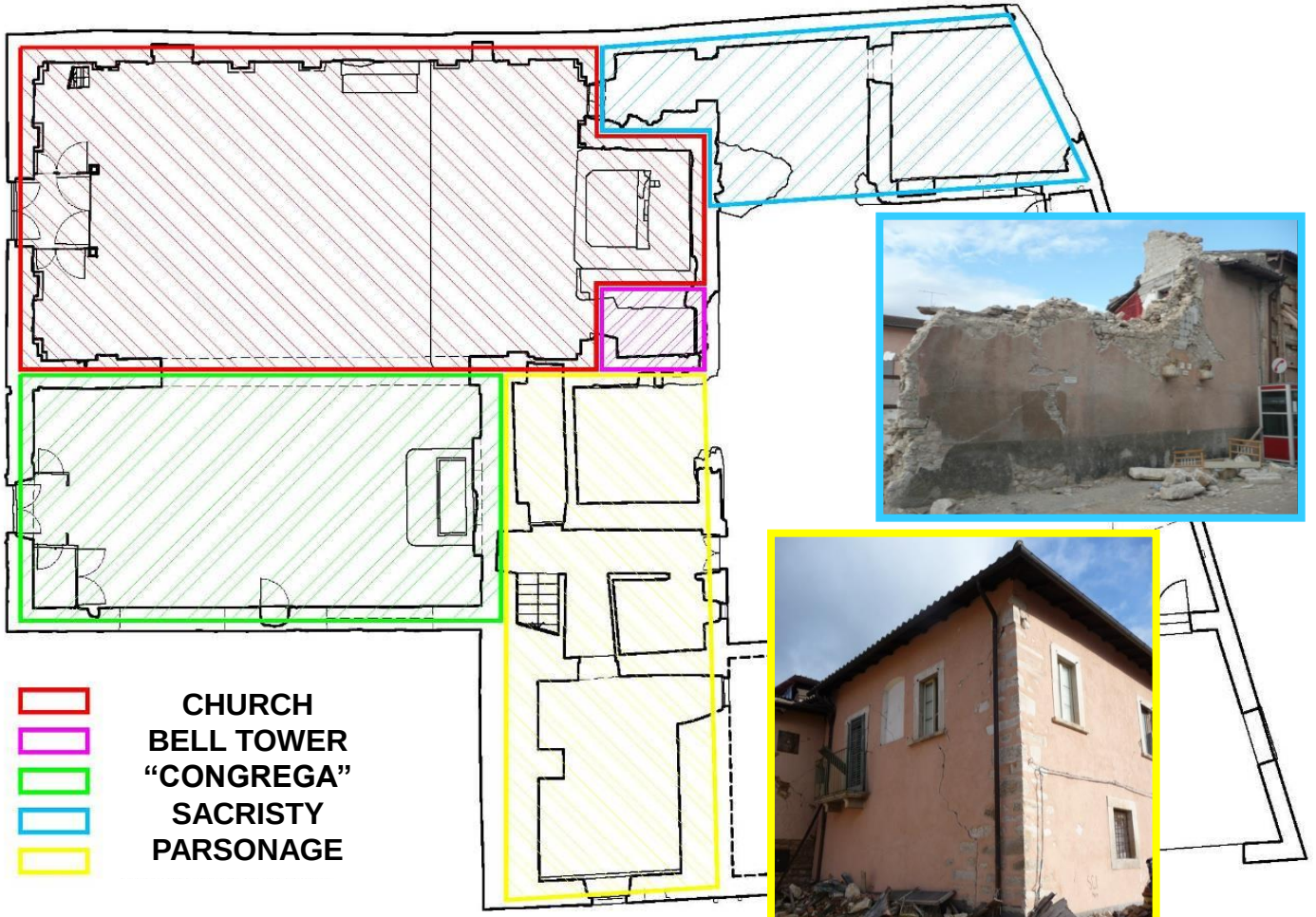
The church and annexed buildings survey began with the **GEOMETRIC SURVEY** of the structure and the decoratives.





DAMAGES ON CHURCHES

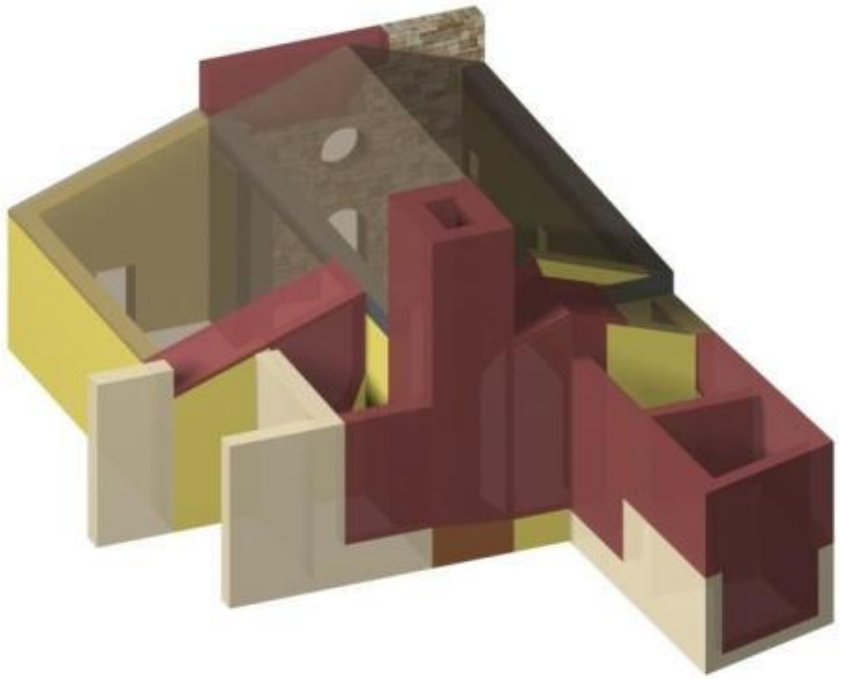
The church is included in an **AGGREGATE**, that include some buildings with different history and structural typology.

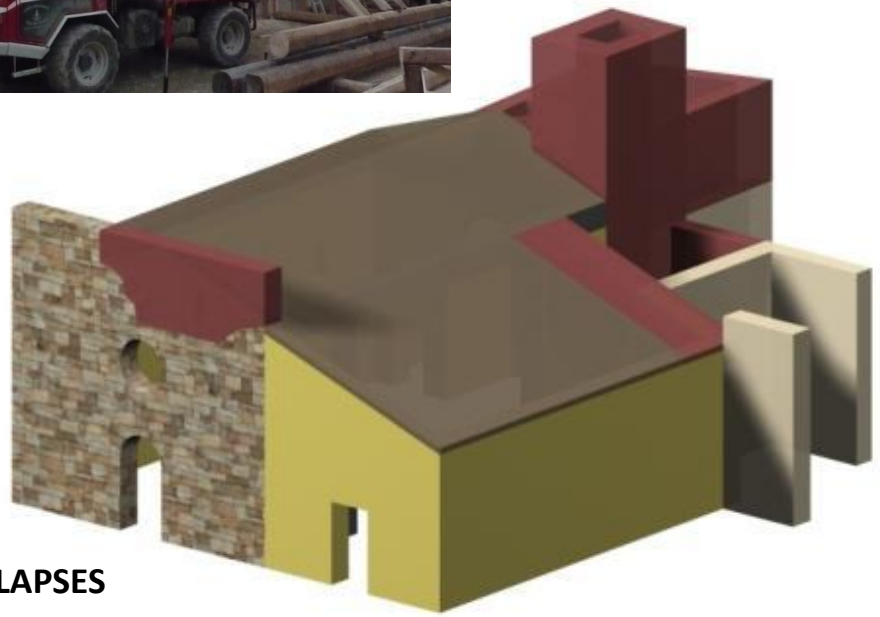


DAMAGES ON CHURCHES

St. Pietro Apostolo – Onna, L'Aquila

The damage survey was performed to define the structural faults that, among the structural features, caused the collapses and the severe damages.





SCHEMATIZATION OF THE MAIN COLLAPSES

DAMAGES ON CHURCHES

St. Pietro Apostolo – Onna, L'Aquila: FAÇADE

The façade showed a double damage mechanism:
-**the global overturning;**
-**the overturning of the upper part (that collapsed)**.

DAMAGES ON CHURCHES

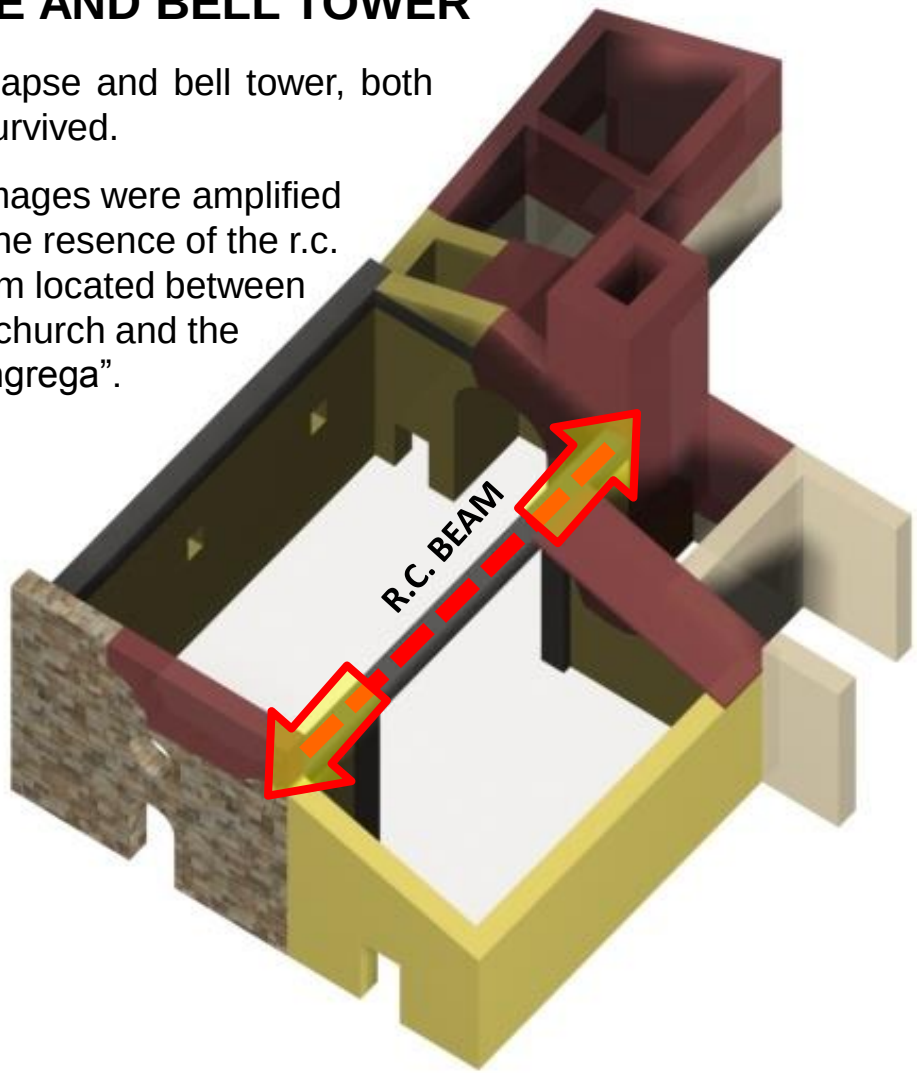
St. Pietro Apostolo – Onna, L'Aquila: APSE AND BELL TOWER

The most severe damages are concentrated into the apse and bell tower, both totally callapsed; only a portion of about 1,5 m height survived.

APSE

BELL TOWER

Damages were amplified by the resence of the r.c. beam located between the church and the "congrega".

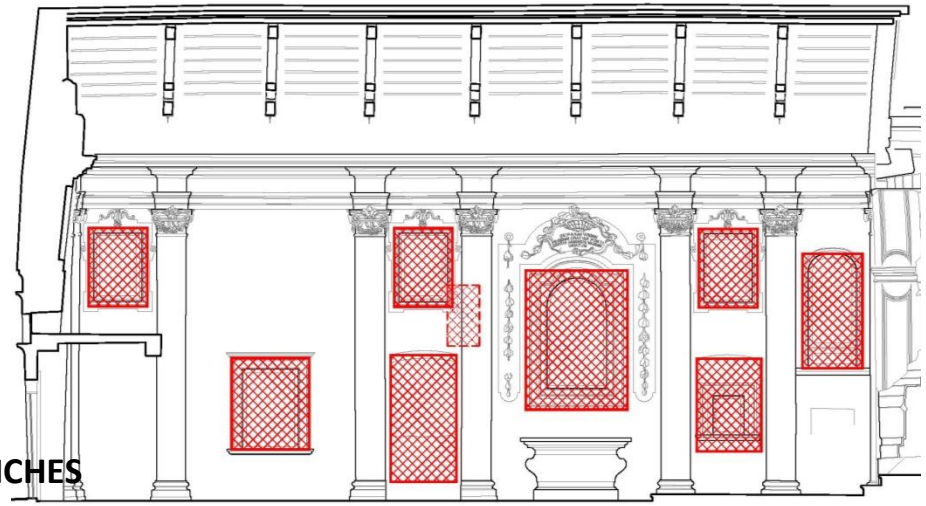


DAMAGES ON CHURCHES

St. Pietro Apostolo – Onna, L'Aquila

LONGITUDINAL WALLS

The longitudinal walls show the damages due to their in plane behaviour. The presence of several niches and openings worsen the wall property.



LEFT LONGITUDINAL WALL – PRESENCE OF OPENINGS AND NICHES

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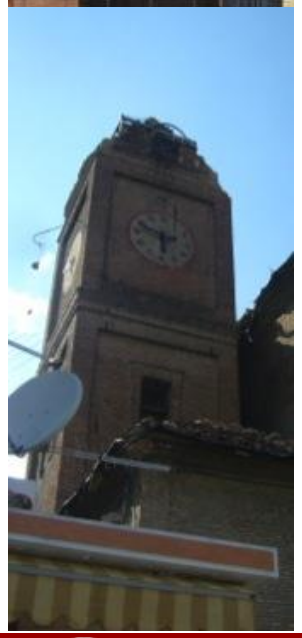
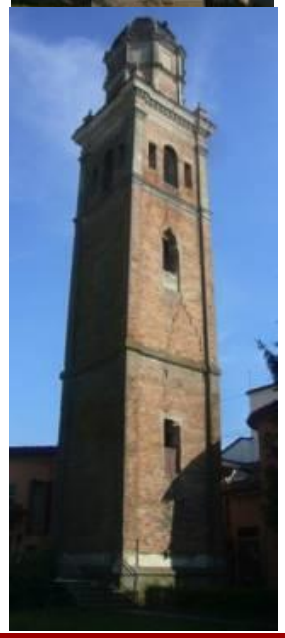
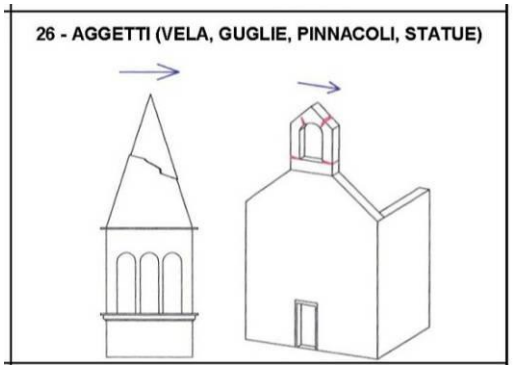
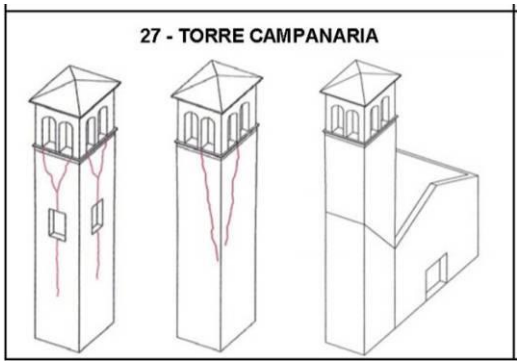
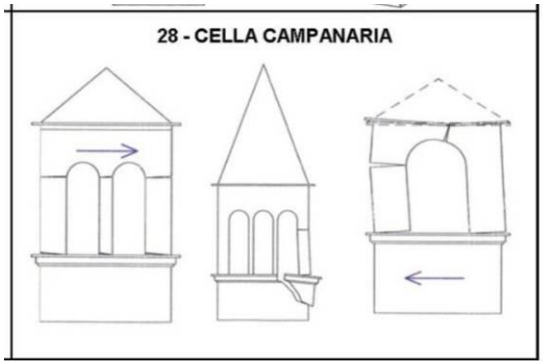





DAMAGES ON BELL TOWERS



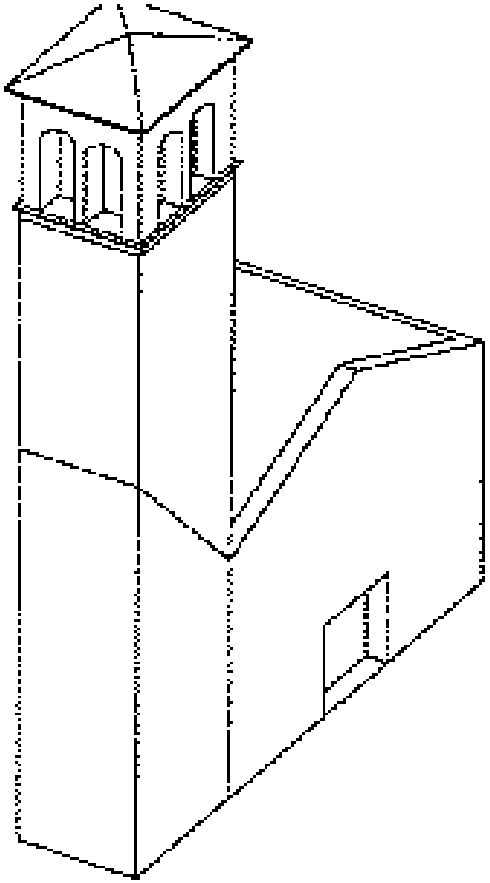


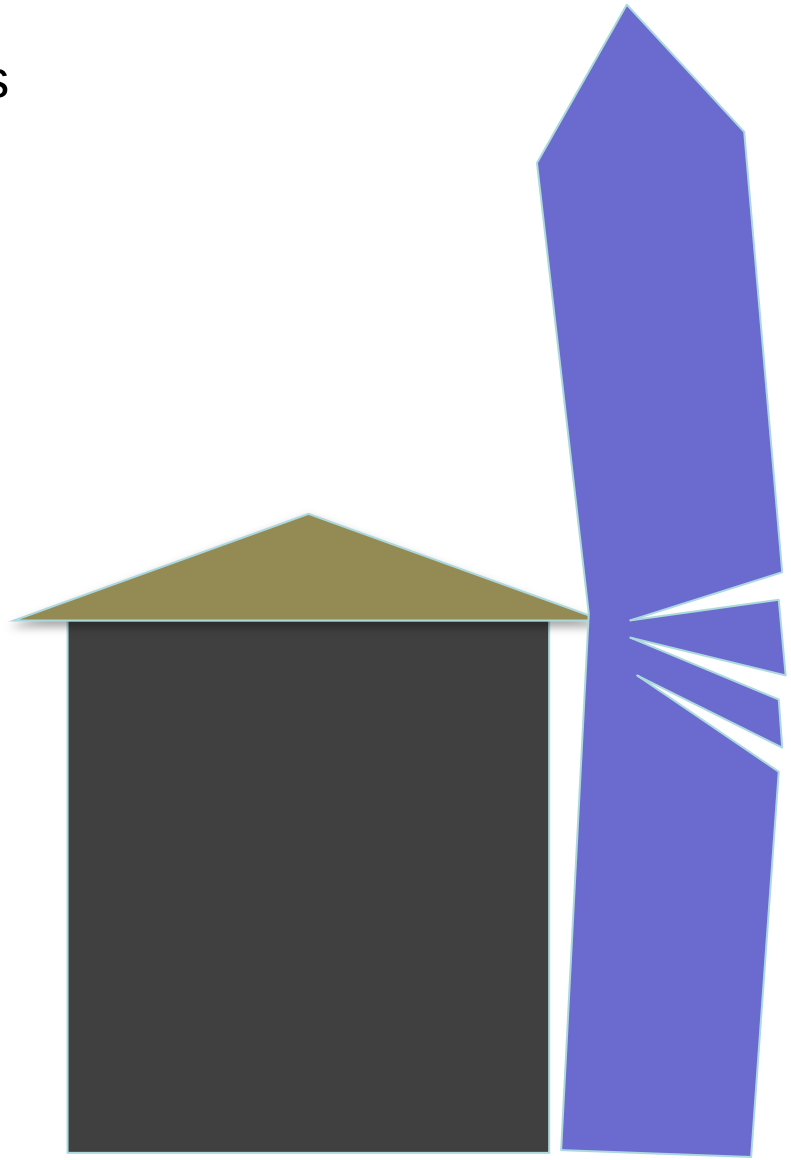


CHIESA DI SAN MICHELE & CHIESA PARROCCHIALE, VILLA SANT'ANGELO (AQ)

Church and bell tower in Mirabello: isolated bell tower

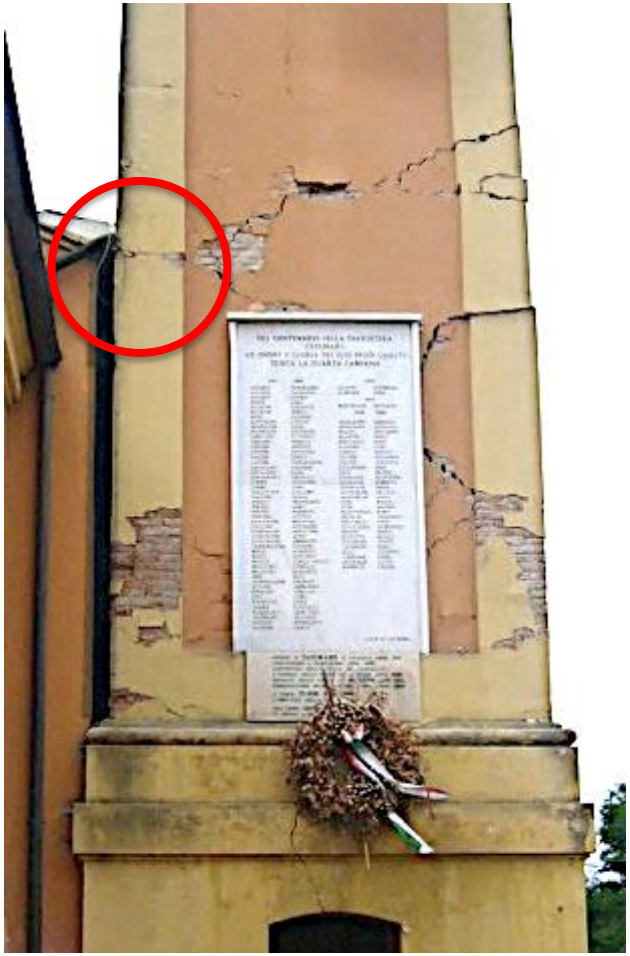
Bell towers connected to other buildings





Bell towers connected to other buildings

San Martino a Carano



Casumaro

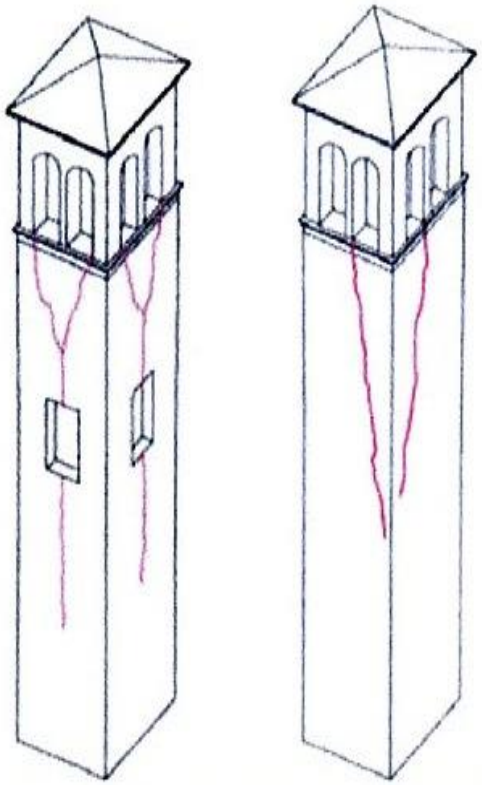
Cavezzo

Santi Senesio e Teopompo - Medolla

San Possidonio

Isolated bell towers

vertical cracks

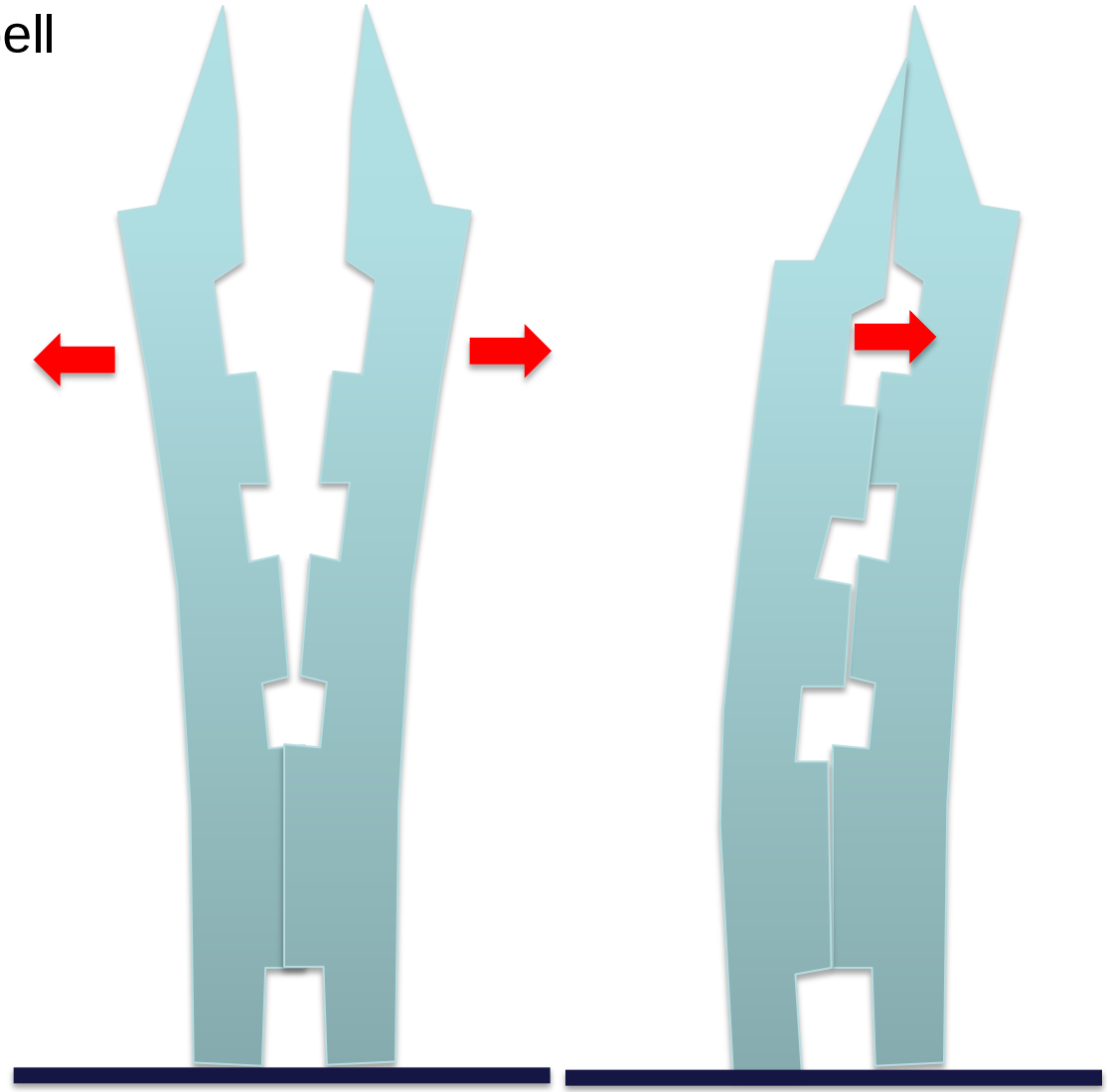


S. Michele - Novi

Rovereto

Isolated bell towers

vertical cracks



S. Michele - Novi

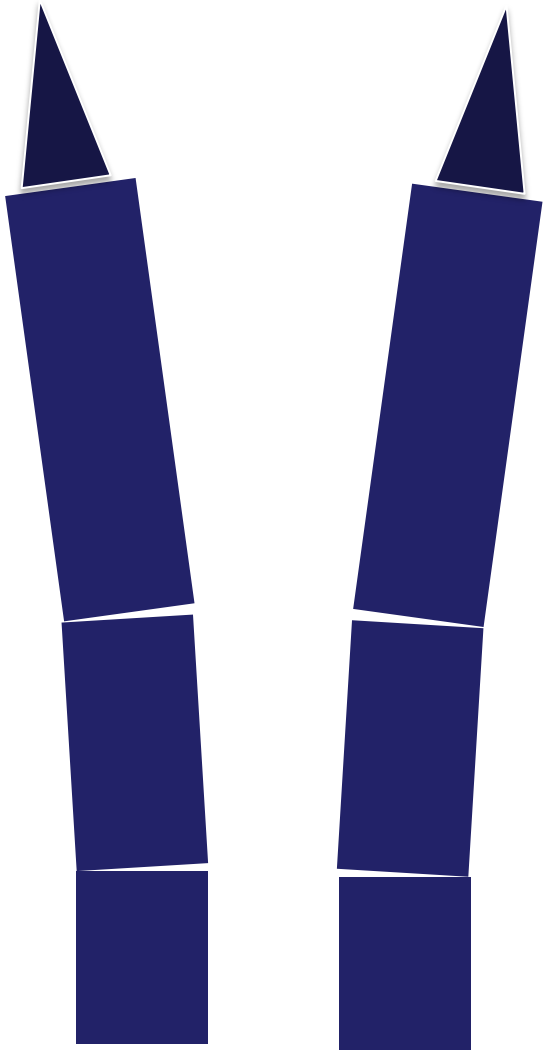
Isolated bell towers

vertical cracks

San Pietro - Fossa

Isolated bell towers

horizontal cracks

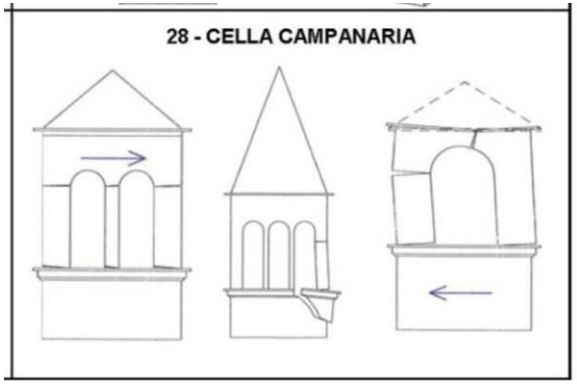


Isolated bell towers

horizontal cracks

San Giacomo a Roncole

DAMAGES ON BELL TOWERS



2004

2012

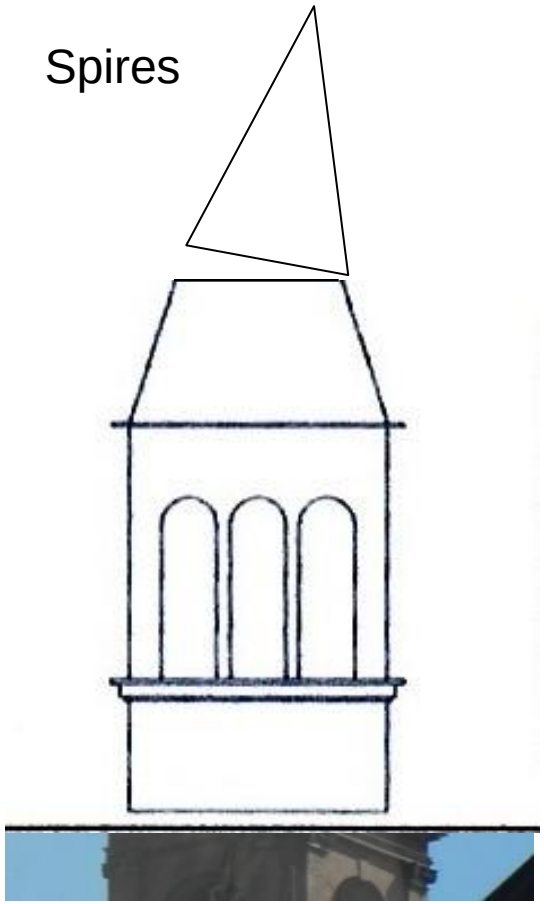
Chiesa San Nicolò, Carpi (MO)

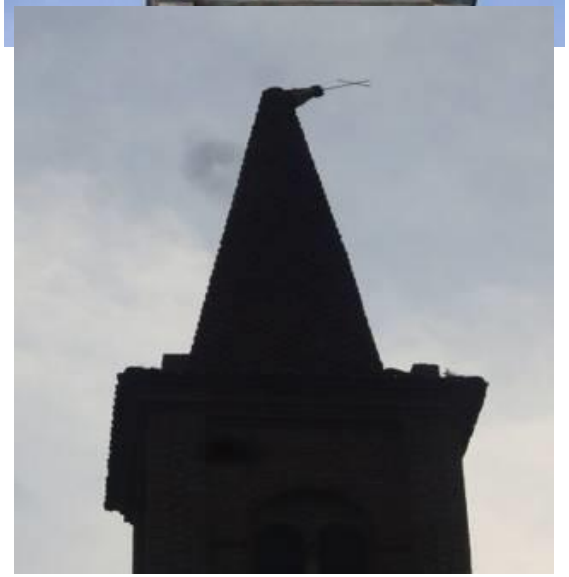
Chiesa dell'Annunciazione, Salò (BS)

2009

Chiesa Parrocchiale, Villa Sant'Angelo (AQ)

Spires





CONTENTS

- Masonry typologies and masonry quality
- Damages and failure mechanisms: in-plane and out-of-plane behavior
- Building typologies:
  - churches
  - towers
- Damages connected to unappropriated retrofitting strategies/technologies

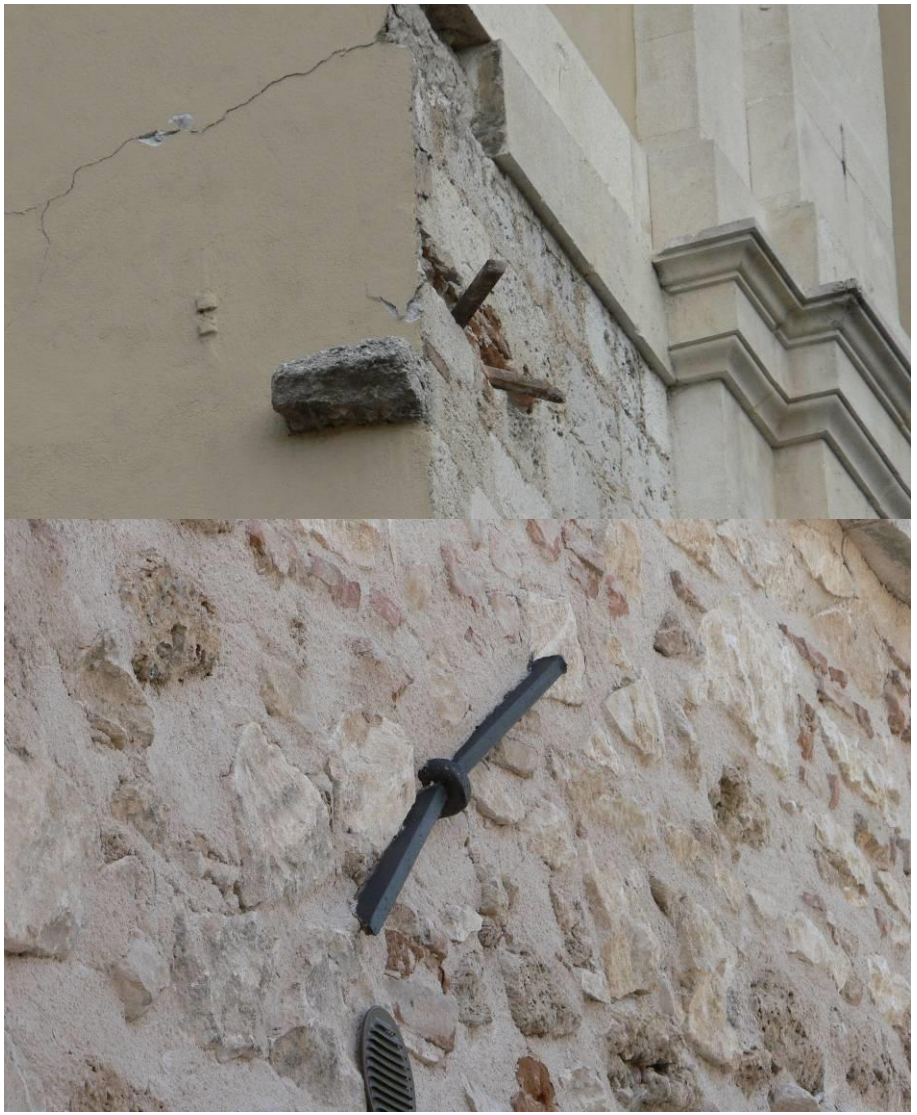
DAMAGE DUE TO PAST INTERVENTIONS: ABSENCE OF TIES

BEATA ANTONIA, L'AQUILA

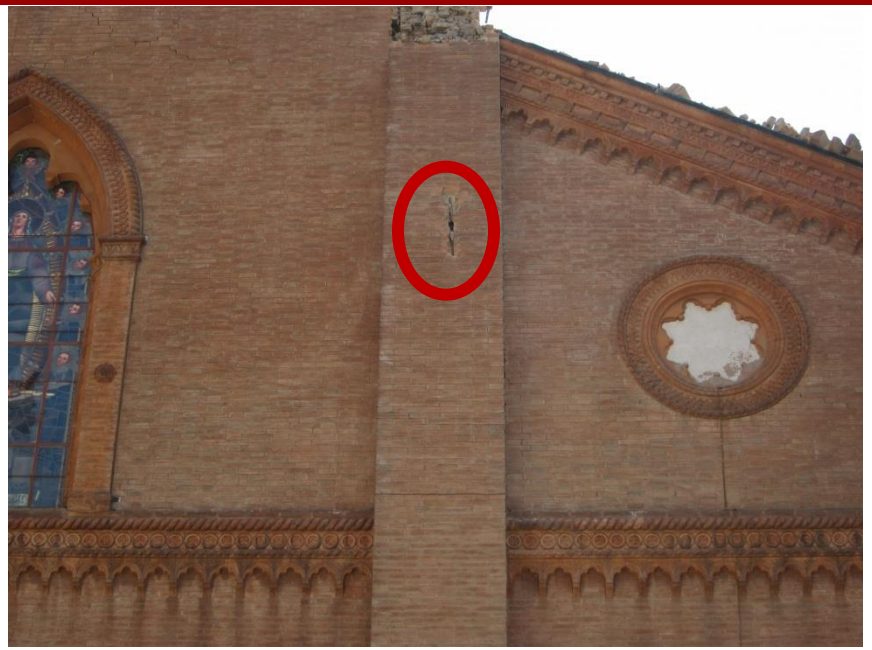
DAMAGE DUE TO PAST INTERVENTIONS: ABSENCE OF TIES

SPANISH FORTRESS, L'AQUILA

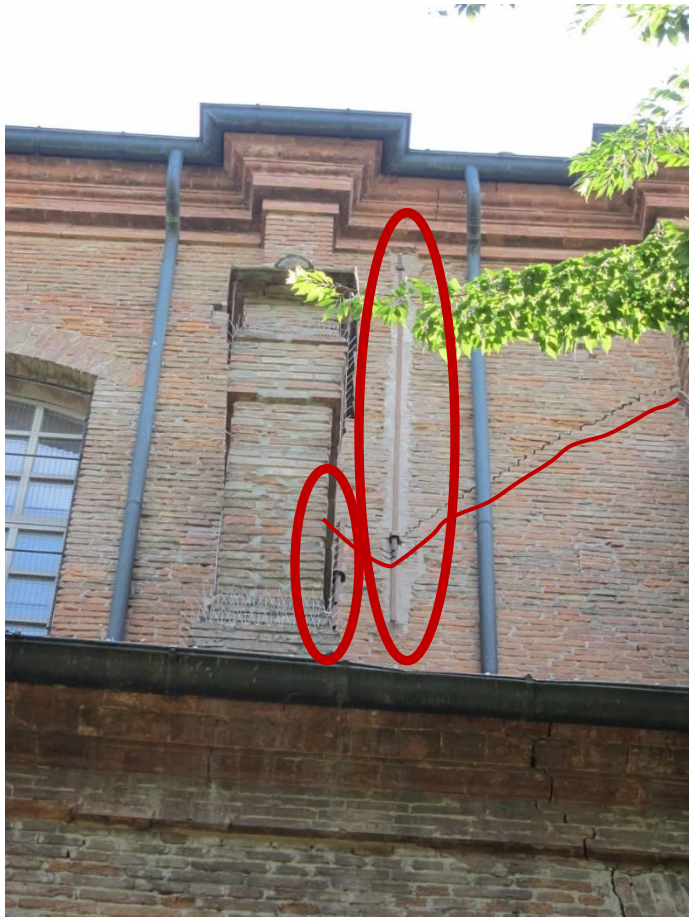
PRESENCE OF TIES



2012 Collegiata Santa Maria Maggiore, Mirandola



2012 Chiesa del Gesù, Mirandola



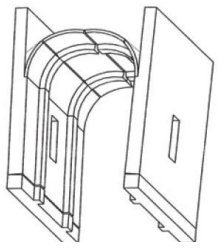
PRESENCE OF WOODEN TIES

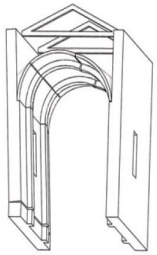
USE OF REINFORCED CONCRETE

SAN MARCO, L'AQUILA

USE OF REINFORCED CONCRETE

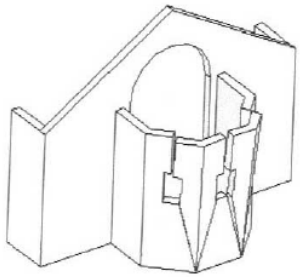
SAN MARCO, L'AQUILA





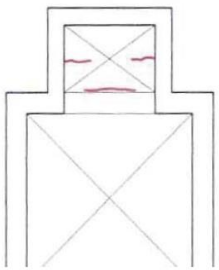
USE OF REINFORCED CONCRETE

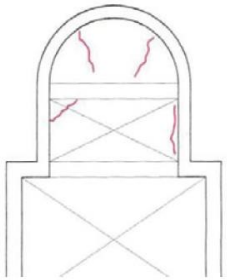
SAN MARCO, L'AQUILA



USE OF REINFORCED CONCRETE

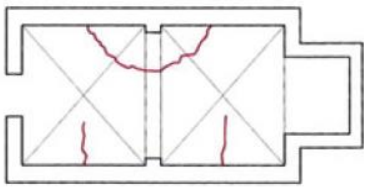
SAN MARCO, L'AQUILA



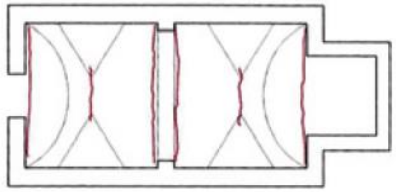


USE OF REINFORCED CONCRETE

SAN MARCO, L'AQUILA



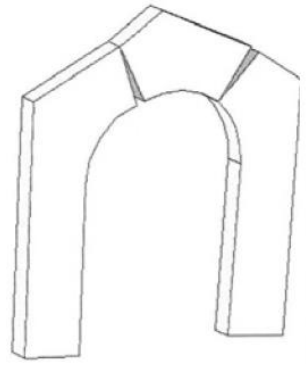
VOLTE A CROCIERA

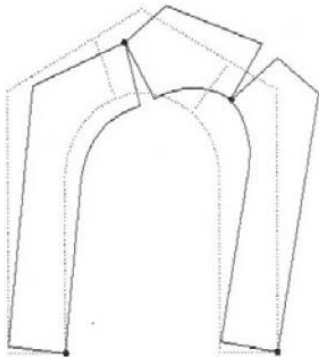


VOLTA A BOTTE LUNETTATA

USE OF FRP

SAN MARCO, L'AQUILA





MASONRY QUALITY

SAN MARCO, L'AQUILA

USE OF REINFORCED CONCRETE

SAN MARCO, L'AQUILA

USE OF REINFORCED CONCRETE

SAN DOMENICO, L'AQUILA

USE OF REINFORCED CONCRETE

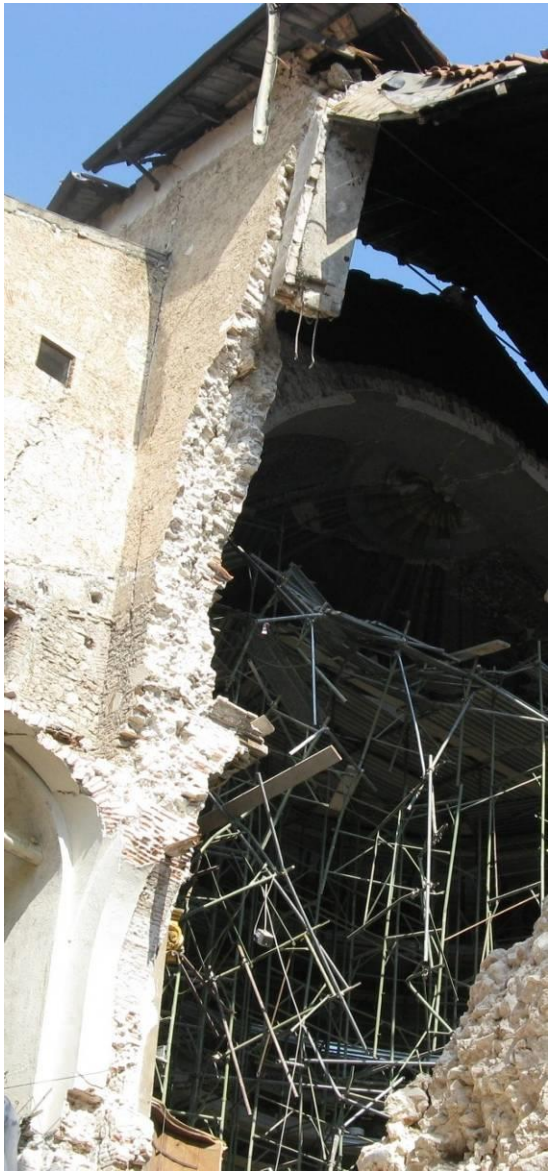
SAN DOMENICO, L'AQUILA

USE OF REINFORCED CONCRETE

SAN DOMENICO, L'AQUILA

USE OF REINFORCED CONCRETE

CATHEDRAL, L'AQUILA



USE OF REINFORCED CONCRETE

THEATRE, L'AQUILA

PALACE IN ROMA STREET, L'AQUILA

USE OF REINFORCED CONCRETE

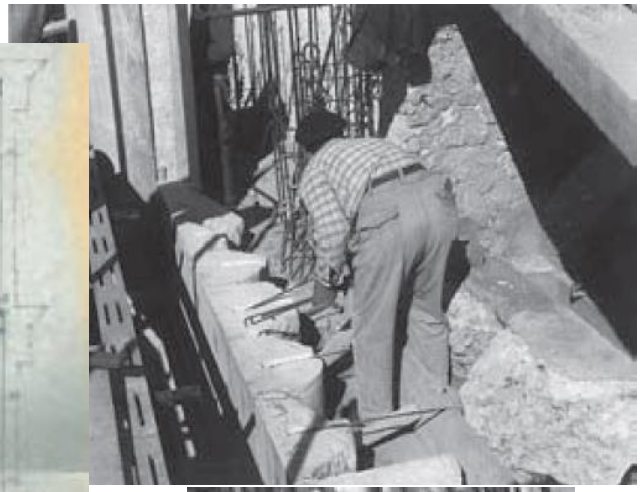
SAN PIETRO APOSTOLO, ONNA

2009 Fortezza Spagnola, L'Aquila

2012 Chiesa Cimitero Urbano, Carpi

USE OF REINFORCED CONCRETE

SAN BERNARDINO, L'AQUILA



National Commission for Culture and the Arts
National Museum, Philippines
Bakas Pilipinas
ICOMOS Philippines
University of Santo Tomas - Center for Conservation of Cultural Property and Environment in the Tropics

JANUARY 13 – 14, 2016

Thank you for your attention!

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