ACQUIRING KNOWLEDGE OF THE STRUCTURE:

KNOWLEDGE LEVELS, CONFIDENCE FACTORS, TEST METHODS

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Safety standards for historical structures

Codes

- **ISO 13822** – bases for design of structures – assessment of existing structures (first edition 2001)
- **Italian code** 'Technical standard for construction' DM 14/01/08 and its explicative documents – (2008)
- **EN 1998-3 Eurocode 8** – Design of structures for earthquake resistance Part 3 assessment and retrofitting of buildings

Guidelines

- **Iscarsah** Recommendations for the analysis, conservation, and structural restoration of architectural heritage
- **Italian guidelines** for the assessment and the reduction of seismic risk of cultural heritage buildings

ISRAEL ANTIQUITIES AUTHORITY רשות העתיקות

MAIN PRINCIPLES FOR EXISTING BUILDINGS (I)

A SUBSTANTIAL PART OF THE NEW ITALIAN SEISMIC CODE IS COMPLETELY DEVOTED TO EXISTING BUILDINGS OF DIFFERENT TYPOLOGIES: R.C. STRUCTURES, STEEL STRUCTURES AND MASONRY BUILDINGS. THE MAIN PRINCIPLES FOR EXISTING BUILDINGS ARE:

1) The degree of uncertainty which affects the safety evaluations of existing buildings and the design of the interventions (… state of the art at the time of construction; non evident effects of conceptual and constructive defects; non evident effects of earthquakes or accidental actions …) is quantified and taken into account *through the use of adequate confidence factors in the safety assessment as well as the use of methods of analysis and assessment that depends on the completeness and reliability of available information*

Knowledge level	Confidence factor
LC1	1.35
LC2	1.20
LC3	1.00

2) The difference between UPGRADING (necessary when adding storeys, changing use of the building with consequent increase of loads >20%, substantially changing the building shape and structural behaviour) and IMPROVEMENT (when acting on single structural elements or on monumental buildings), is kept and detailed. *The obligation of safety evaluation for upgrading intervention and the necessity of some kind of evaluation for the improvements is stated.*

MAIN PRINCIPLES FOR EXISTING BUILDINGS (II)

… AND IN PARTICULAR FOR MASONRY BUILDINGS:

3) The damage on buildings retrofitted after the 1979 earthquake, obtained during the Umbria-Marche earthquake in 1997, underlined the limits of some strengthening techniques which became very popular and even compulsory according to the previous seismic code: they in fact frequently showed scarce performances (injections, jacketing) or even worsened the structural behaviour (jacketing, replacement of flexible floors with stiff floors) of existing masonry buildings.

The execution of interventions that locally change the stiffness of the structure has to be adequately evaluated. The renovation of flexible floors into stiff floors cause a different distribution of seismic actions that can be favourable/unfavourable and has to be taken into account into the modelling and analysis phases.

4) The experience of the Umbria-Marche earthquake, together with experimental and theoretical studies that were carried out, has also underlined some characteristics of the seismic response which are due to the interaction with close buildings or which are due to local effects occurring before a global behaviour can be developed.

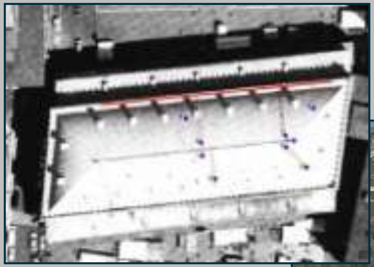
For aggregate buildings and mixed structural types, proper structural models have to be chosen. For the evaluation of existing buildings, besides global seismic analyses, local analyses by means of the kinematic mechanisms approach have to be carried out.

Italian Standard & Guidelines – Building knowledge

The **knowledge of the masonry historical building**, using particular techniques of analyses and interpretation, is the basis for a reliable appraisal of the seismic safety and for the choice of an effective improvement.

Steps:

Building identification
Functional characterisation of the building
Geometrical survey
Historical analyses of events and past interventions
Material and structural survey and conservation state
Mechanical characterization of materials
Ground and foundations
Monitoring



Different knowledge levels and confidence factors CF

LEVEL OF KNOWLEDGE & CONFIDENCE FACTORS

TO CALCULATE THE CAPACITY OF THE STRUCTURAL ELEMENTS THE MATERIAL PROPERTIES HAVE TO BE DIVIDED BY THE CONFIDENCE FACTOR, OBTAINED ON THE BASIS OF THE GAINED LEVEL OF KNOWLEDGE

Knowledge level	Geometry	Constructive details	Material properties	Analysis method	Confidence factor FC
LC1	Structural survey	Limited on-site inspections	Limited on-site testing	All	1.35
LC2		Extended and comprehensive on-site inspections	Extended on-site testing	All	1.20
LC3			Comprehensive on-site testing	All	1.00

$$f_{cd} = f_m / (FC \times \gamma_m)$$

1. GEOMETRY

Structural survey

2. CONSTRUCTIVE DETAILS

Limited on-site inspection

Extended & comprehensive on-site inspections

3. MATERIAL PROPERTIES

Limited on-site testing

Extended on-site test

Comprehensive on-site test

LC1 (FC = 1.35)

LC2 (FC = 1.20)

LC3 (FC = 1.00)

Italian Guidelines – § 4 – Building knowledge

The confidence factor is determined as:

$$F_C = 1 + \sum_{k=1}^{4} F_{Ck}$$

<table>
<tr><th>Geometrical survey</th><th>Material and constructive details inspection</th><th>Materials mechanical properties</th><th>Ground and foundations</th></tr>
<tr><td>Full geometrical and structural survey
$F_{C1} = 0.05$</td><td>Limited material and constructive details on site inspection
$F_{C2} = 0.12$</td><td>mechanical properties obtained from old data
$F_{C3} = 0.12$</td><td>Limited inspections on ground and foundation, absence of geological data
$F_{C4} = 0.06$</td></tr>
<tr><td rowspan="2">Full geometrical and structural survey, with crack and deformation patterns
$F_{C1} = 0$</td><td>Extended material and constructive details on site inspection
$F_{C2} = 0.06$</td><td>Limited on site testing on material mechanical properties
$F_{C3} = 0.06$</td><td>Limited inspections on ground and foundation, presence of geological data
$F_{C4} = 0.03$</td></tr>
<tr><td>Comprehensive material and constructive details on site inspection
$F_{C2} = 0$</td><td>Extended on site testing on material mechanical properties
$F_{C3} = 0$</td><td>Extended and comprehensive inspections on ground and foundation
$F_{C4} = 0$</td></tr>
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INFORMATION FOR STRUCTURAL ASSESSMENT

BUILDING GEOMETRY

GEOMETRY, PARTICULAR ELEMENTS (SUCH AS CHIMNEYS, NICHES, ETC), CRACK PATTERN & OUT OF PLUMBS

- by means of surveys

CONSTRUCTION DETAILS

CONNECTIONS, LINTELS, ELEMENTS TO COUNTERACT THRUSTS, VULNERABLE ELEMENTS, MASONRY TIPOLOGY

- limited *in situ inspection*
- extended & comprehensive *in situ inspection*

MATERIAL PROPERTIES

PARTICULARLY AIMED AT THE MECHANICAL CHARACTERIZATION OF MASONRY, THROUGH INSPECTIONS, NDT, MDT & DT

- limited *in situ testing* (inspections)
- extended *in situ testing* (MDT & NDT)
- comprehensive *in situ testing* (DT)

KNOWLEDGE LEVEL AND CONFIDENCE FACTORS

INVESTIGATION PLAN

1. HYPOTHESYS ON THE BUILDING EVOLUTION

2. IDENTIFICATION OF PLAN-ELEVATION CHARACTERISTICS

3. INTERPRETATION OF CRACK AND DEFORMATION PATTERNS

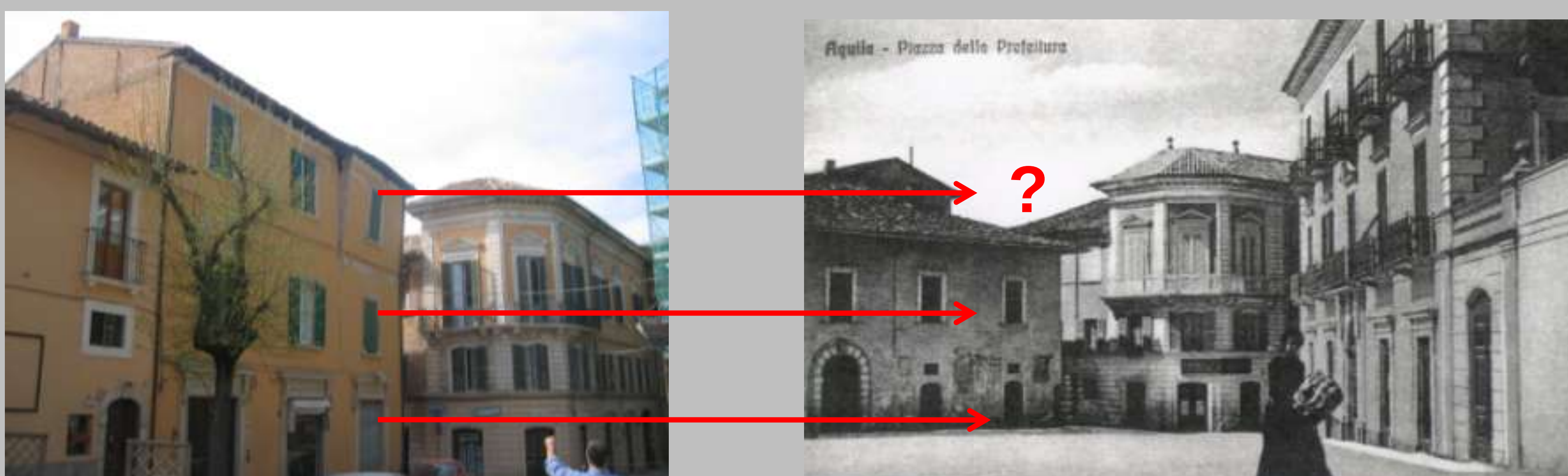
4. IDENTIFICATION AND CHARACTERIZATION OF CONSTRUCTION DETAILS/ELEMENTS

5. MASONRY TIPOLOGY

6. MATERIALS CHARACTERIZATION

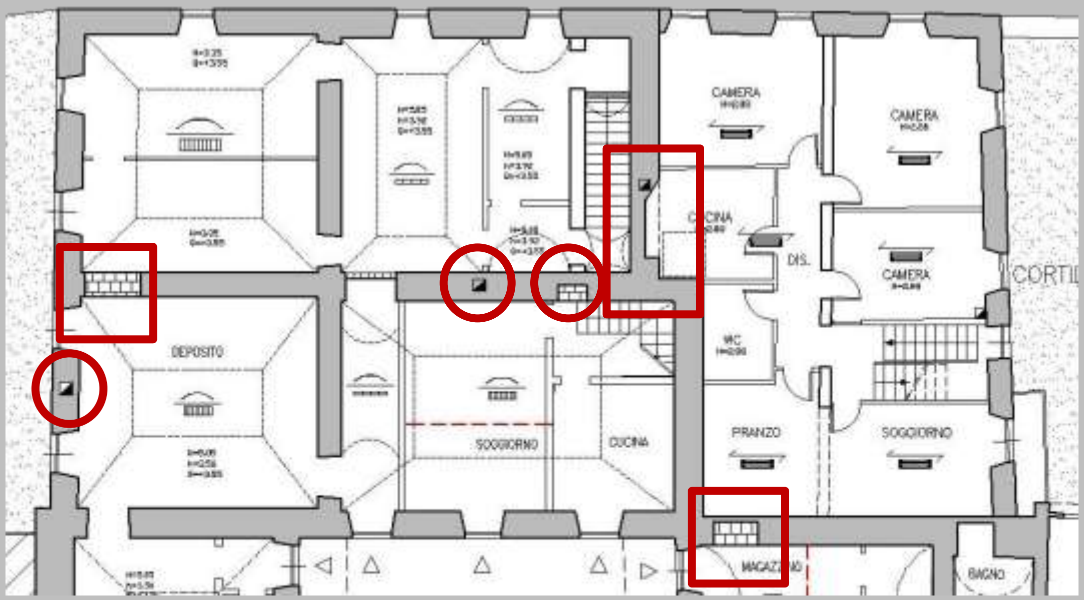
IDENTIFICATION OF RESISTING STRUCTURAL SCHEME, DEFINITION OF ACTIONS AND MECHNICAL PARAMETERS

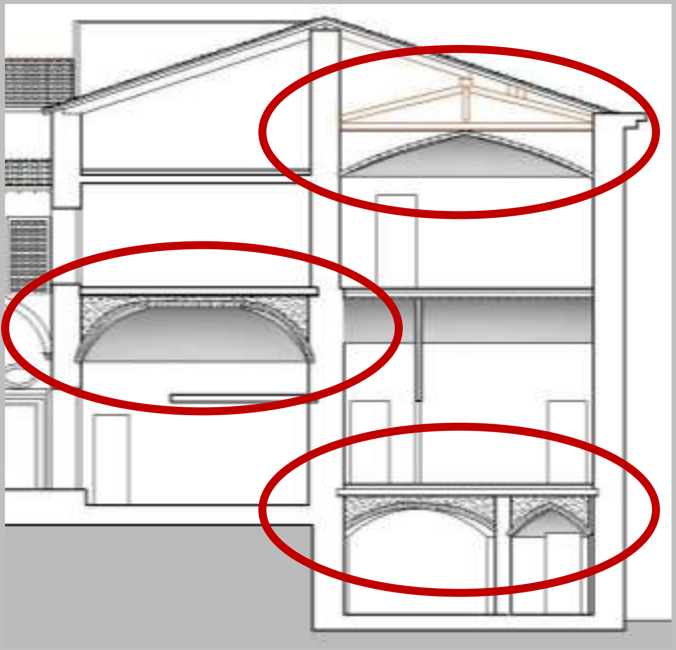
AN EXAMPLE OF HISTORIC SURVEY / BEHAVIOUR



1. GEOMETRY

Geometrical survey includes: survey at each floors of all masonry elements and eventual niches, voids, chimneys, vault survey, floors, roofing, stairs, understaning of loads, foundations.



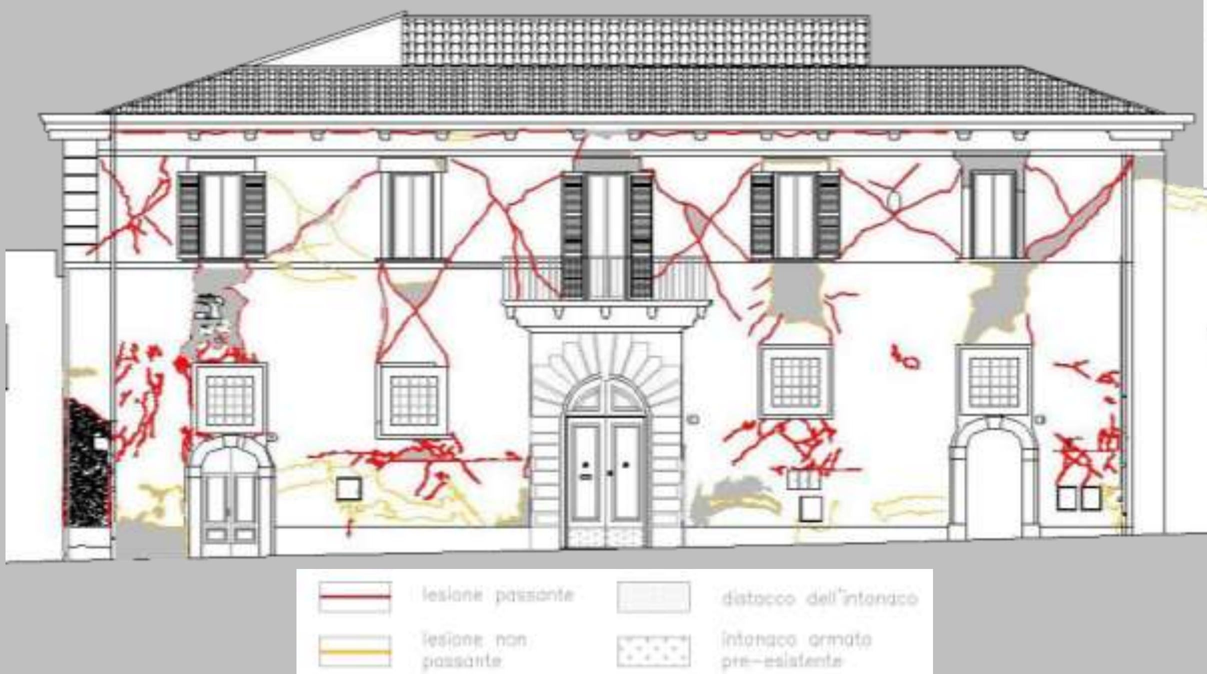


ACQUIRING KNOWLEDGE OF THE STRUCTURE

PROF. FRANCESCA DA PORTO

1. GEOMETRY

Survey and representation of eventual crack and deformation pattern.



2. CONSTRUCTION DETAILS

a) quality of connections between walls;

b) type and quality of connections between horizontal diaphragms and walls;

c) type and efficiency of lintels above openings;

d) presence and efficiency of elements to counteract horizontal trusts;

e) Presence of structural or non structural elements with high vulnerability;

f) type of masonry

EXPERIMENTAL INVESTIGATION ON THE BEHAVIOR OF SPANDRELS IN ANCIENT MASONRY BUILDINGS (Gattesco, Clemente, Macorini, Noè)

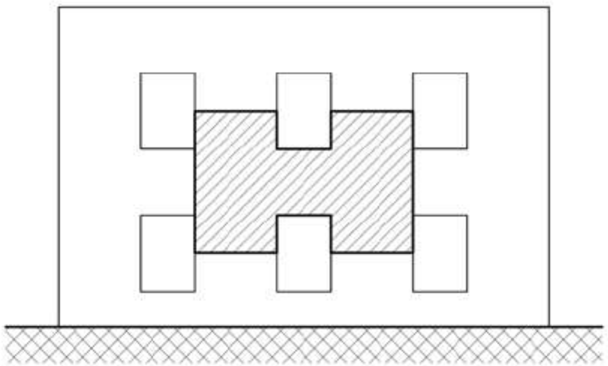


Figure 1. Wall with openings sample.

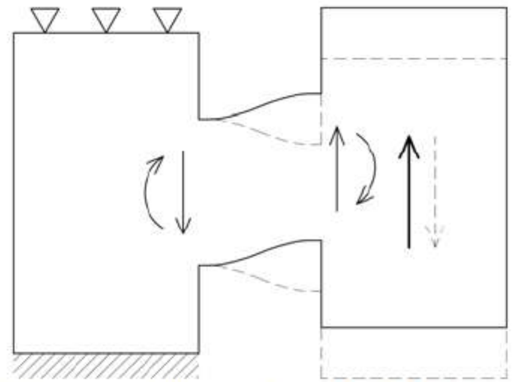
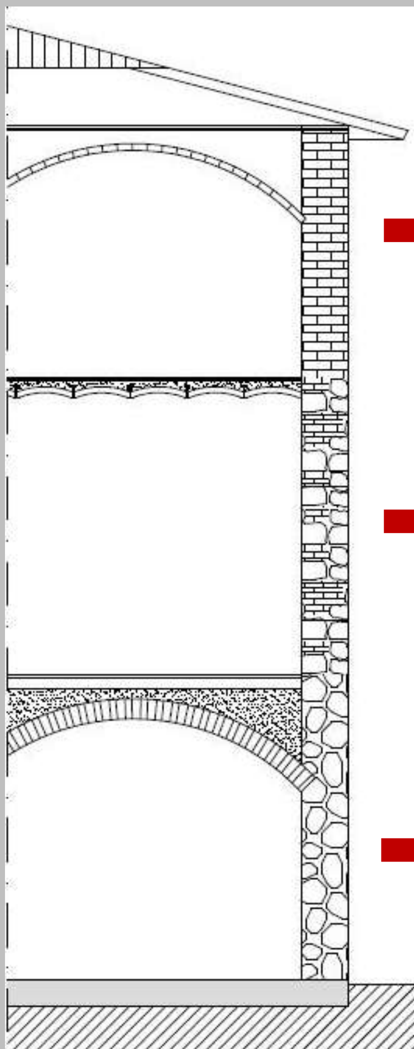
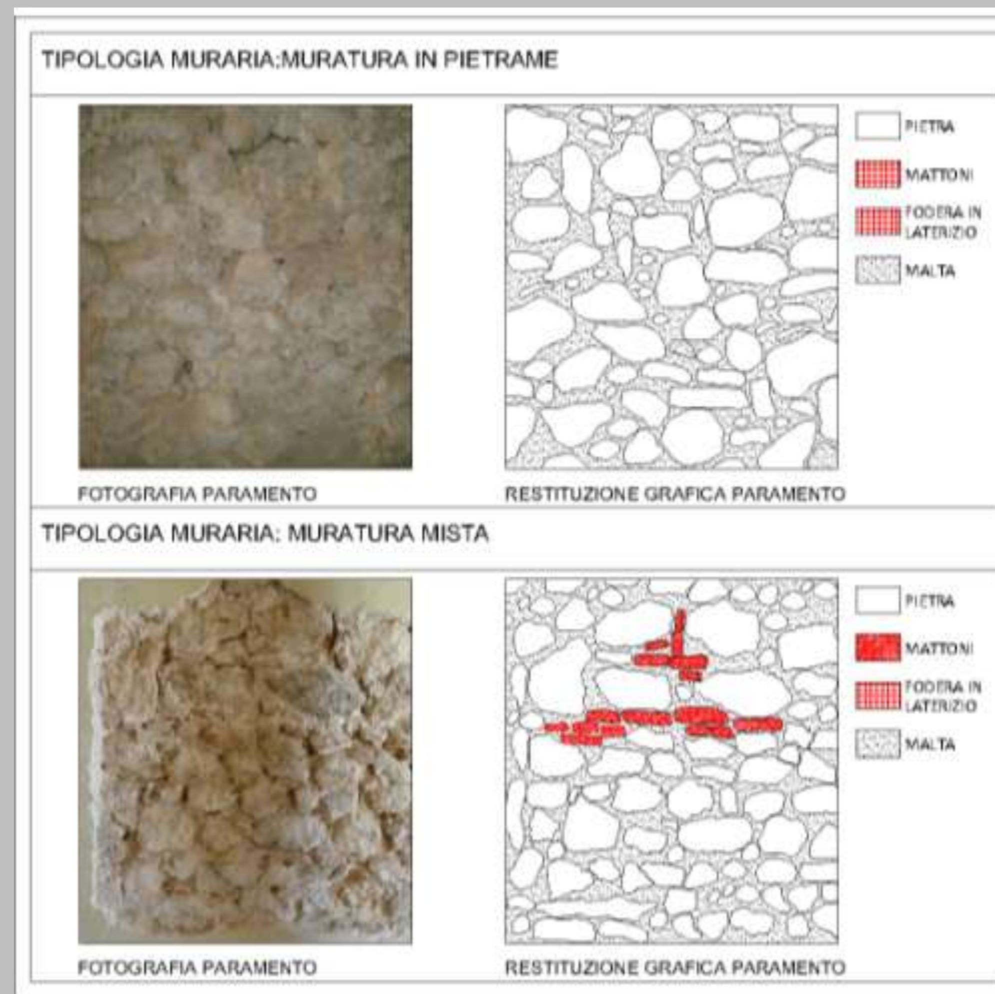


Figure 2. Schematic spandrel loading.

(b)

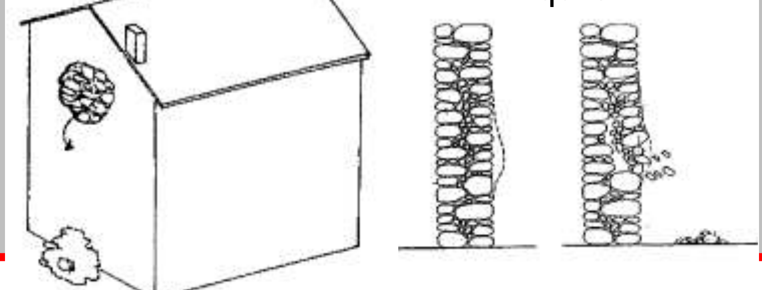
2. CONSTRUCTION DETAILS: MASONRY TYPE





2. CONSTRUCTION DETAILS: MASONRY TYPE

Costa della Pinciara Street, L'Aquila



Santa Gemma, Goriano Sicoli (AQ)

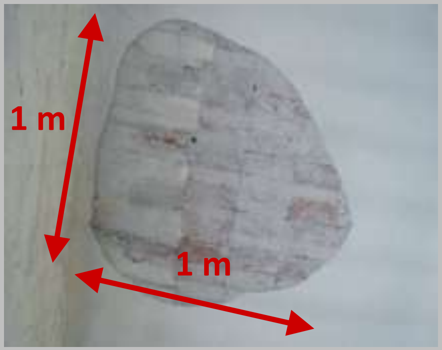
2. CONSTRUCTION DETAILS

This critical analysis is carried out by means of visual inspections, by removing plaster and small masonry dismantling, in order to check both masonry texture and masonry in its thickness, considering also the connections between walls and between walls and floors.

***Limited on-site verifications*: based on visual surveys, usually through tests on the masonry that lead to superficial examination**

***Extended and comprehensive on-site verifications:* based on visual surveys, usually through tests on the masonry that lead to <u>both</u> superficial and deep examination, and of the connection between orthogonal walls.**

3. MATERIAL PROPERTIES

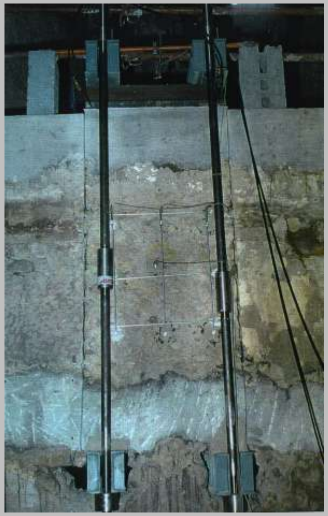


Limited on-site investigations:

Information on the material properties, in order to determine the masonry typology. They are based on visual examinations on the masonry surface.

Extended on-site investigations:

Tests with double flat jack and characterization tests of the mortar and of stones or bricks. Non-destructive tests (sonic tests, etc…).



Comprehensive on-site investigations:

Quantitative information on the material resistance through on-site or laboratory tests (diagonal compression tests on panels or combined tests of vertical compression and shear). Non-destructive tests can be employed in combination, but not in place of the ones above described.

USE OF TESTS ON MATERIALS AND STRUCTURES FOR THE EVALUATION OF THE BEARING CAPACITY

(Binda, 1994)

EXPERIMENTAL TESTS

- ***on-site***
  - **Qualitative tests**
    - • Historical investigations
    - • Survey of the crack outline
    - • Moisture
    - • Other NDT (sonic tests, radar, thermograph, etc)
  - **Quantitative tests**
    - • Geometric survey
    - • Monitoring and control of the structure
    - • Measurements of the local stress state (flat jacks, etc.)
  - Qualitative and quantitative data: geometric and mechanic parameters
- ***laboratory***
  - **Sampling**
    - Chemical tests
    - Physical tests
    - Mechanical tests
  - Input parameters for the calculation models

Determination of the bearing capacity of the structure

VALUES OF THE MECHANICAL PROPERTIES (Enc. 11.D)

Table 11.D.1 Reference values of the mechanical parameters (maximum and minimum) and average specific weight for different masonry typologies

Tipologia di muratura	f_m (N/cm²) min-max	τ_0 (N/cm²) min-max	E (N/mm²) min-max	G (N/mm²) min-max	w (kN/m³)
Muratura in pietrame disordinata (ciottoli, pietre erratiche e irregolari)	60 90	2,0 3,2	690 1050	115 175	19
Muratura a conci sbozzati, con paramento di limitato spessore e nucleo interno	110 155	3,5 5,1	1020 1440	170 240	20
Muratura in pietre a spacco con buona tessitura	150 200	5,6 7,4	1500 1980	250 330	21
Muratura a conci di pietra tenera (tufo, calcarenite, ecc.)	80 120	2,8 4,2	900 1260	150 210	16
Muratura a blocchi lapidei squadrati	300 400	7,8 9,8	2340 2820	390 470	22
Muratura in mattoni pieni e malta di calce	180 280	6,0 9,2	1800 2400	300 400	18
Muratura in mattoni semipieni con malta cementizia (es.: doppio UNI)	380 500	24 32	2800 3600	560 720	15
Muratura in blocchi laterizi forati (perc. foratura < 45%)	460 600	30,0 40,0	3400 4400	680 880	12
Muratura in blocchi laterizi forati, con giunti verticali a secco (perc. foratura < 45%)	300 400	10,0 13,0	2580 3300	430 550	11
Muratura in blocchi di calcestruzzo (perc. foratura tra 45% e 65%)	150 200	9,5 12,5	2200 2800	440 560	12
Muratura in blocchi di calcestruzzo semipieni	300 440	18,0 24,0	2700 3500	540 700	14

f_m = average compression resistance of the masonry

τ_0 = average shear resistance of the masonry

E = average value of the normal elasticity modulus

G = average value of the tangential elasticity modulus

w = average specific weight of the masonry

VALUES OF THE MECHANICAL PROPERTIES (Enc. 11.D)

Table 11.D.2 Corrective coefficients of the mechanical parameters

Tipologia di muratura	Malta buona	Ricorsi o listature	Connessione trasversale	Iniezioni di malta	Intonaco armato
Muratura in pietrame disordinata (ciottoli, pietre erratiche e irregolari)	1,5	1,3	1,5	2	2,5
Muratura a conci sbozzati, con paramento di limitato spessore e nucleo interno	1,4	1,2	1,5	1,7	2
Muratura in pietre a spacco con buona tessitura	1,3	1,1	1,3	1,5	1,5
Muratura a conci di pietra tenera (tufo, calcarenite, ecc.)	1,5	-	1,5	1,7	2
Muratura a blocchi lapidei squadrati	1,2	-	1,2	1,2	1,2
Muratura in mattoni pieni e malta di calce	1,5	-	1,3	1,5	1,5
Muratura in mattoni semipieni con malta cementizia (es.: doppio UNI)	1,3	-	-	-	1,3
Muratura in blocchi laterizi forati (perc. foratura < 45%)	1,3	-	-	-	1,3
Muratura in blocchi laterizi forati, con giunti verticali a secco (perc. foratura < 45%)	1,3	-	-	-	1,3
Muratura in blocchi di calcestruzzo (perc. foratura tra 45% e 65%)	1,3	-	-	-	1,3
Muratura in blocchi di calcestruzzo semipieni	1,3	-	-	-	1,3

MECHANICAL PROPERTIES: USE OF EXPERIMENTAL RESULTS

… THE BELONGING TO AN HIGHER KNOWLEDGE LEVEL INVOLVES ALSO THE POSSIBILITY OF CONSIDERING HIGHER STRENGTH VALUES (IN COMPARISON TO THE PROPOSED RANGES IN TAB. 11.D.1)

LC1 – Resistance and elastic modulus: the minimum of the range

LC2 – Resistance and elastic modulus: the average of the range

LC3 – a) If three experimental values of resistance and elastic modulus are available: average of the experimental values

LC3 – b) If two experimental values of resistance and elastic modulus are available: average of the experimental values, if it is inferior to the upper bound of the table value.

LC3 – c) If one experimental value of resistance and elastic modulus is available: the experimental value is assumed as the value of resistance if it is included in the table range. If not, the average value of the table is assumed.

MECHANICAL PROPERTIES - ENC. 11.D – EXAMPLE

TAB. 11.D.1

Tipologia di muratura	f_m (N/cm^2) min-max	τ_0 (N/cm^2) min-max	E (N/mm^2) min-max	G (N/mm^2) min-max	w (kN/m^3)
Muratura in pietrame disordinata (ciottoli, pietre erratiche e irregolari)	60 90	2,0 3,2	690 1050	115 175	19
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Muratura in mattoni semipieni con malta cementizia (es.: doppio UNI)	380 500	24 32	2800 3600	560 720	15
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Muratura in blocchi di calcestruzzo (perc. foratura tra 45% e 65%)	150 200	9,5 12,5	2200 2800	440 560	12
Muratura in blocchi di calcestruzzo semipieni	300 440	18,0 24,0	2700 3500	540 700	14

TAB. 11.D.2

Tipologia di muratura	Malta buona	Ricorsi o listature	Connessione trasversale	Iniezioni di malta	Intonaco armato
Muratura in pietrame disordinata (ciottoli, pietre erratiche e irregolari)	1,5	1,3	1,5	2	2,5
Muratura a conci sbozzati, con paramento di limitato spessore e nucleo interno	1,4	1,2	1,5	1,7	2
Muratura in pietre a spacco con buona tessitura	1,3	1,1	1,3	1,5	1,5
Muratura a conci di pietra tenera (tufo, calcarenite, ecc.)	1,5	-	1,5	1,7	2
Muratura a blocchi lapidei squadrati	1,2	-	1,2	1,2	1,2
Muratura in mattoni pieni e malta di calce	1,5	-	1,3	1,5	1,5
Muratura in mattoni semipieni con malta cementizia (es.: doppio UNI)	1,3	-	-	-	1,3
Muratura in blocchi laterizi forati (perc. foratura < 45%)	1,3	-	-	-	1,3
Muratura in blocchi laterizi forati, con giunti verticali a secco (perc. foratura < 45%)	1,3	-	-	-	1,3
Muratura in blocchi di calcestruzzo (perc. foratura tra 45% e 65%)	1,3	-	-	-	1,3
Muratura in blocchi di calcestruzzo semipieni	1,3	-	-	-	1,3

Example: masonry in whole bricks and lime mortar:

f_{cd} (LC1) = 180 / (FC = 1.35) x (γ_m = 2) = 67 N/cm^2

f_{cd} (LC2) = ((180+280)/2) / (FC = 1.20) x (γ_m = 2) = 96 N/cm^2

f_{cd} (LC3) = (even superior) ((180+280)/2) / (FC = 1.00) x (γ_m = 2) = 115 N/cm^2

…and if the goodness of the mortar and the presence of transversal connection is demonstrated:

$f_{cd\,(min)}$ = 180 / (1.35x2) x 1,5 x 1,3 = 130 N/cm^2

INVESTIGATION METHODS ON MASONRY BUILDINGS

INVESTIGATIONS ON MATERIALS

INVESTIGATIONS ON MASONRY

MONITORING AND CONTROL OF THE STRUCTURES

Destructive tests

- Laboratory
- On-site

• mono-axial direct compression
• diagonal compression
• shear-compression

Minor destructive tests (MDT)

• direct inspections, endoscopies, core boring
• single flat jacks
• double flat jacks
• shove test
• pull-out test
• dilatometer

Non-destructive tests (NDT)

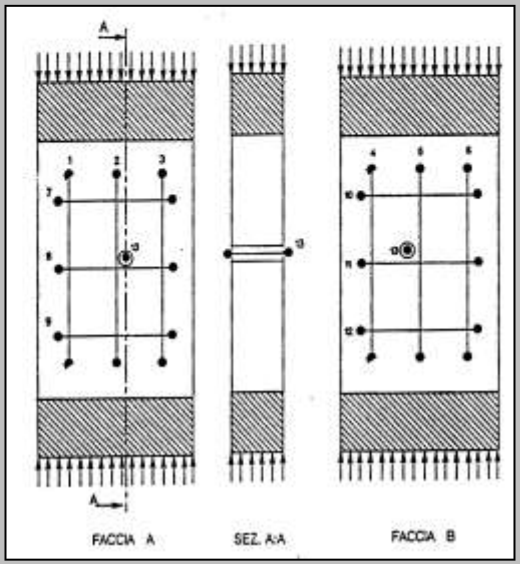
- passive

• surveys and maps
• pictures
• displacements measurements
• spontaneous phenomena (magnetometers)

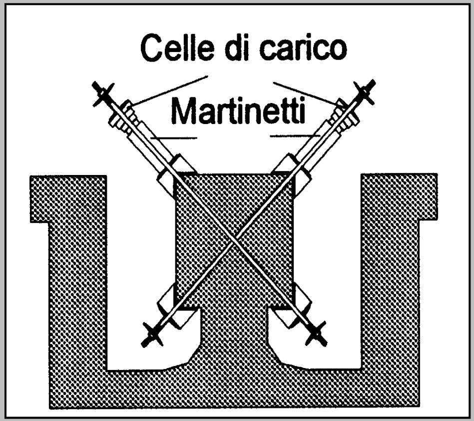
- active

• sonic and ultrasonic tests
• radiography, georadar
• thermographs
• sclerometer
• dynamic tests

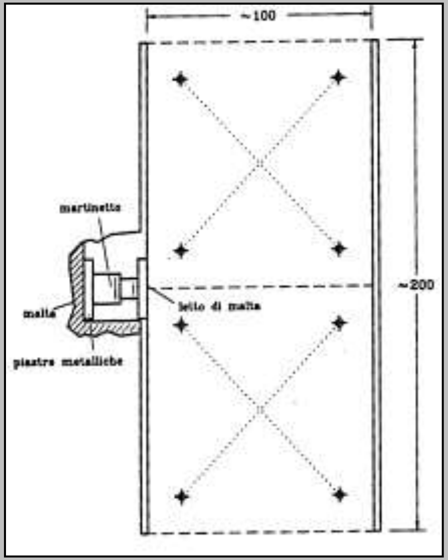
DESTRUCTIVE TESTS



UNIAXIAL COMPRESSION



DIAGONAL COMPRESSION



SHEAR-CPOMPRESSION

Direct evaluation of mechanical properties

- strength
  - compression
  - shear
- deformability
  - elastic modulus
  - shear modulus
  - Poisson coefficient

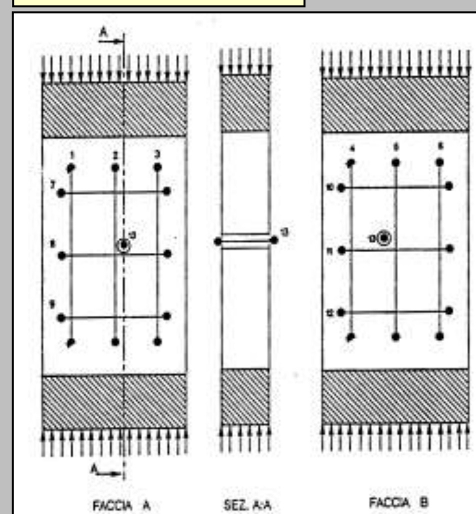
ORIGIN OF THE TABLES 11.D.1 & 11.D.2 (I)

Resistance of the masonry walls: compression

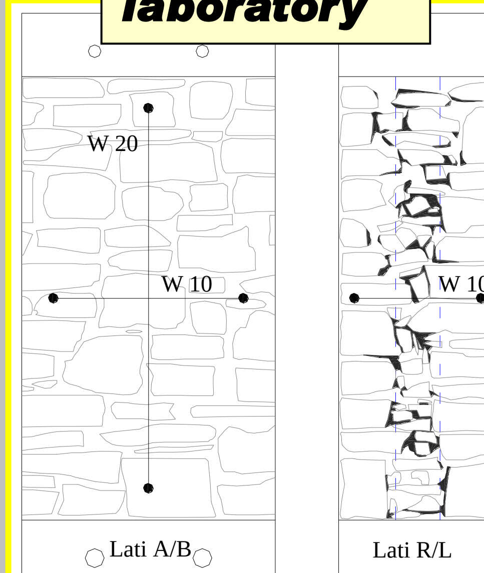
(Bettio, Modena 1993)

Mechanical properties of the original masonry and after consolidation interventions (E, ν, f_m) through experimental tests

On-site

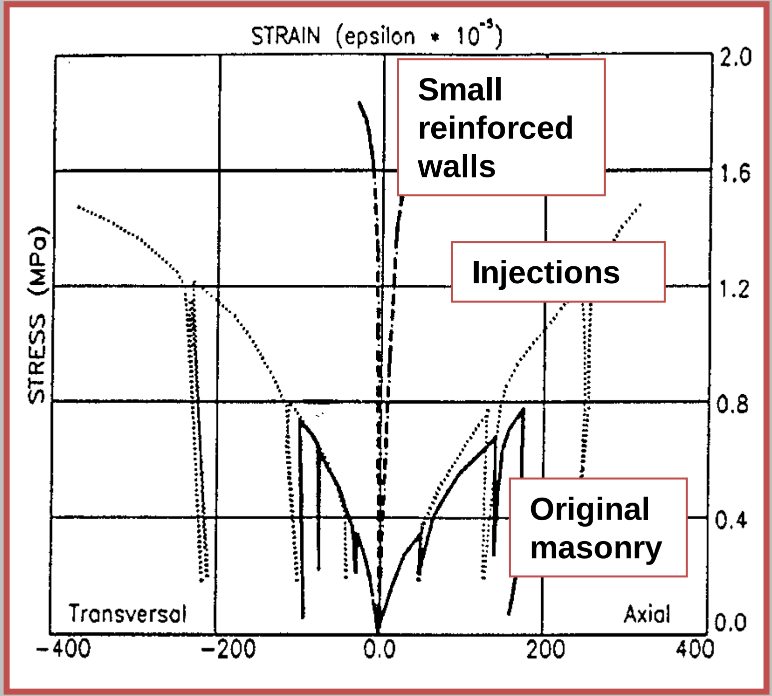


laboratory



ORIGIN OF THE TABLES 11.D.1 & 11.D.2 (II)

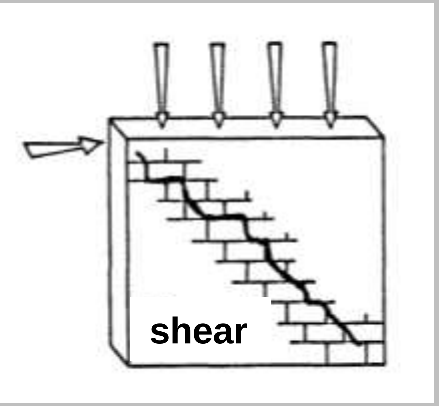
Resistance of the masonry walls: compression



The compression behavior underlines the differences in terms of resistances and stiffness brought from different kinds of intervention.

ORIGIN OF THE TABLES 11.D.1 & 11.D.2 (III)

Resistance of the masonry walls: the shear collapse mechanism with diagonal crack is prevalent.



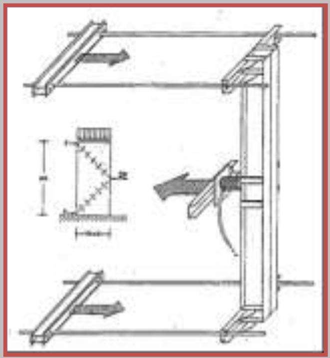
$$f_t = \sigma_t = \sqrt{\left(\frac{\sigma_o}{2}\right)^2 + (b\tau_{H_{max}})^2} - \frac{\sigma_o}{2}$$

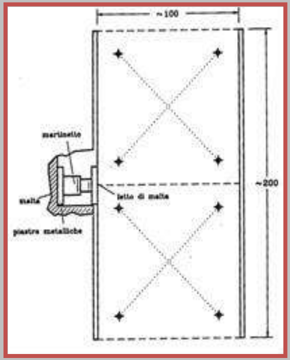
The shear failure happens when the principal tension stress reaches the limit value f_t, assumed as the conventional tension resistance of the masonry.

ORIGIN OF THE TABLES 11.D.1 & 11.D.2 (IV)

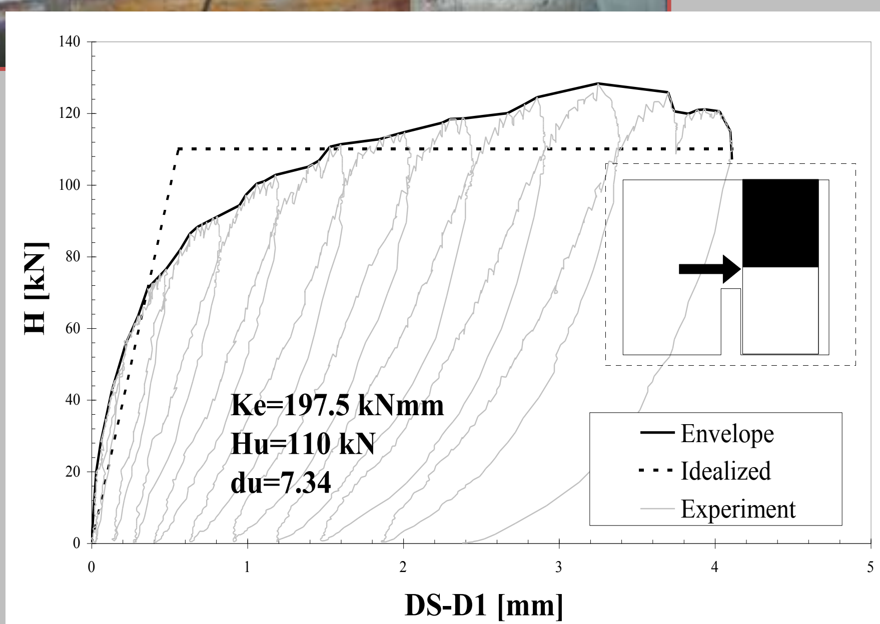
Mechanical properties of the original masonry and after the consolidation intervention (τ_0, G) through experimental tests

Shear and compression





ORIGIN OF THE TABLES 11.D.1 & 11.D.2 (V)



$$\sigma_o = 0.15 \text{ MPa}$$

$$\tau = 0.19 \text{ MPa}$$

$$f_t = \sqrt{\left(\frac{\sigma_o}{2}\right)^2 + (1.1\tau)^2} - \frac{\sigma_o}{2} = 0.14 \text{ MPa}$$

$$G_e = \frac{K_e}{\frac{A_w}{1.2h} - \frac{1}{1.2}\frac{K_e}{E}\left(\frac{h}{l}\right)^2} = 424 \div 432 \text{ MPa}$$

$$G_s = \frac{K_s}{\frac{A_w}{1.2h} - \frac{1}{1.2}\frac{K_s}{E}\left(\frac{h}{l}\right)^2} = 220 \div 320 \text{ MPa}$$

MINOR DESTRUCTIVE TESTS

INVESTIGATIONS ON MATERIALS

INVESTIGATIONS ON MASONRY

MONITORING AND CONTROL OF THE STRUCTURES

Destructive tests

- Laboratory
- On-site

• mono-axial direct compression
• diagonal compression
• shear-compression

Minor destructive tests (MDT)

• direct inspections, endoscopies, core boring
• single flat jacks
• double flat jacks
• shove test
• pull-out test
• dilatometer

Non-destructive tests (NDT)

passive

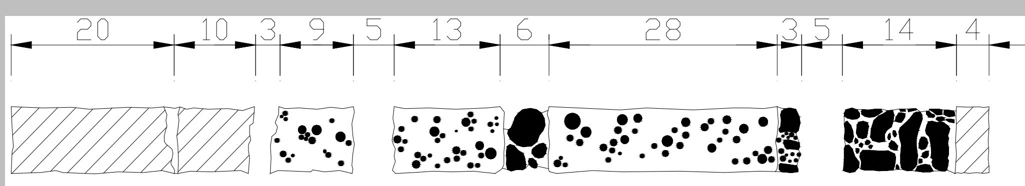
• surveys and maps
• pictures
• displacements measurements
• spontaneous phenomena (magnetometers)

active

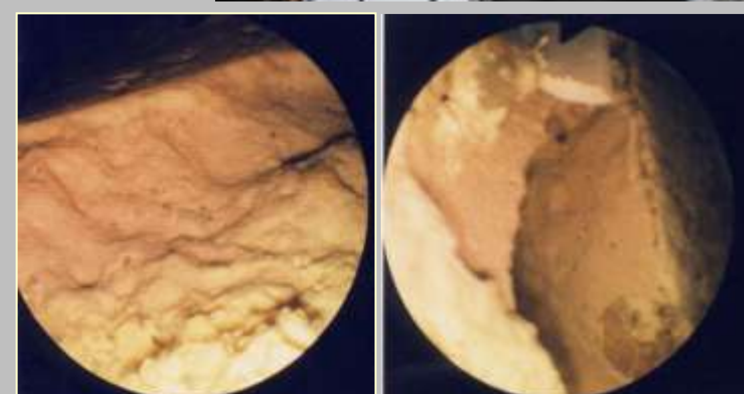
• sonic and ultrasonic tests
• radiography, georadar
• thermographs
• sclerometer
• dynamic tests

Coring and borehole video-endoscopy:

To understand the morphology of a masonry wall it is important a **direct inspection**. Sometimes it could be performed by removing few bricks or stones. **Coring** should be done with a rotary driller using a diamond cutting edge. A small camera may be inserted into the borehole allowing a detailed study of its surface and try a reconstruction of the wall



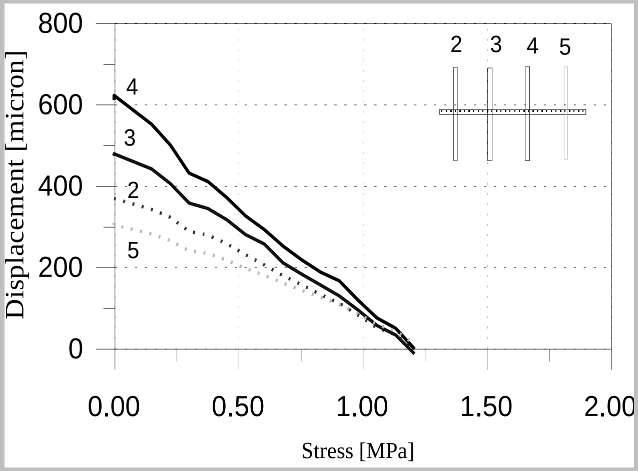
Drilled core and reconstruction (Binda, 2000)



Single flat jack test

The determination of the **state of stress** is based on the stress relaxation caused by a cut perpendicular to the wall surface; the stress release is determined by a partial closing of the cutting, i.e. the distance after the cutting is lower than before. A thin **flat-jack** is placed inside the cut and the pressure is gradually increased to obtain the distance measured before the cut.

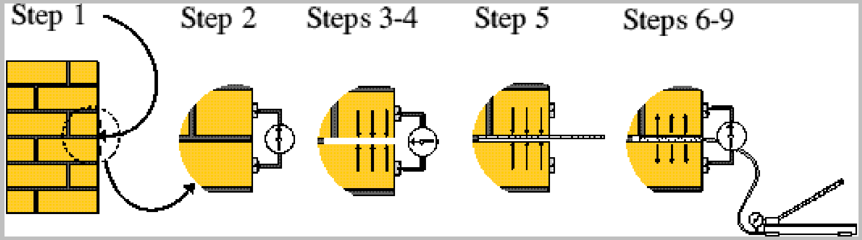
Single flat-jack test (detection of state of stress) carried out at the Monza Tower (Binda, 1998)



The equilibrium relationship is the fundamental requirement for all the applications where the flat-jack are currently used (ASTM, 1991):

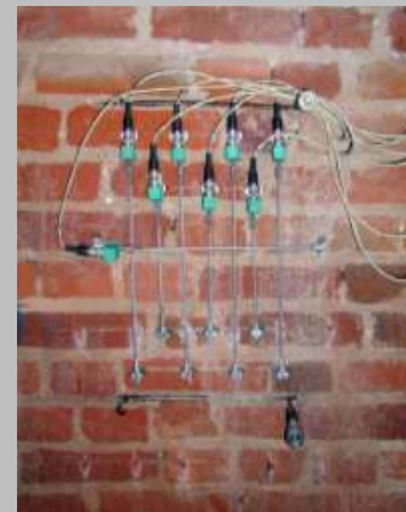
$$S_f = K_j K_a P_f$$

S_f = calculated stress value
K_j = jack calibration constant (<1)
K_a = slot/jack area constant (<1)
P_f = flat-jack pressure

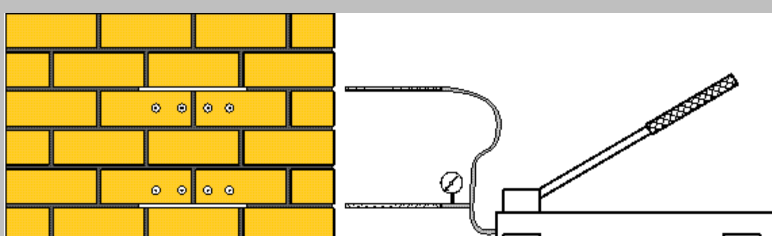


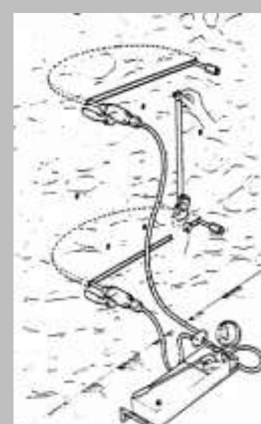
Double flat jack test

The test described can also be used to determine the **deformability characteristics** of a masonry. A second cut is made, parallel to the first one and a second jack is inserted, at a distance of about 40 to 50 cm from the other. The two jacks delimit a masonry sample of appreciable size to which a uni-axial compression stress can be applied.

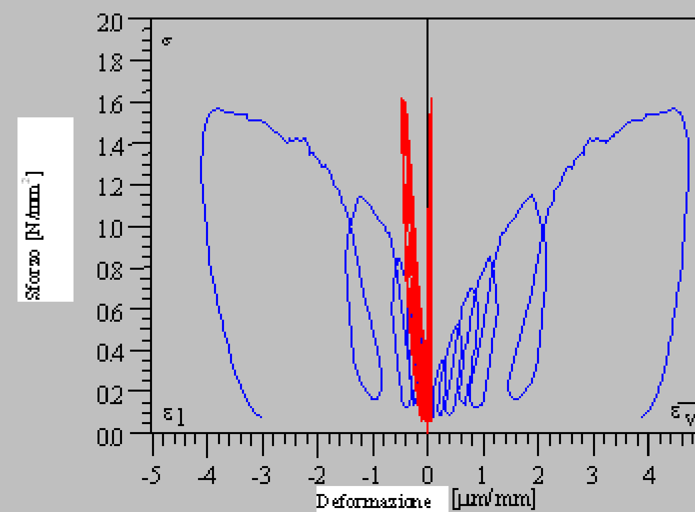


Double flat-jack test (stress-strain behaviour) on West side of the Monza Tower (Binda, 1998)

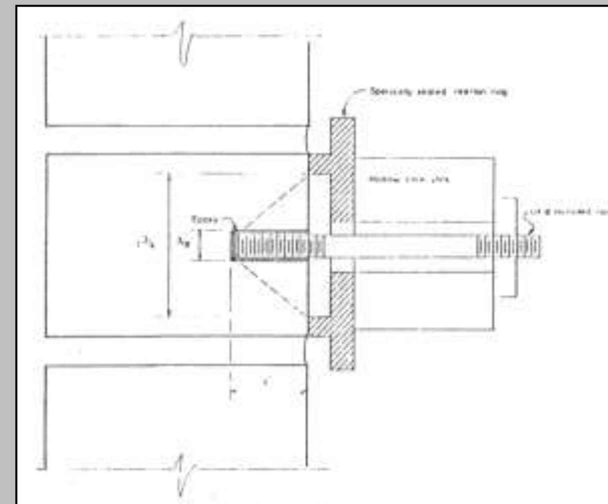




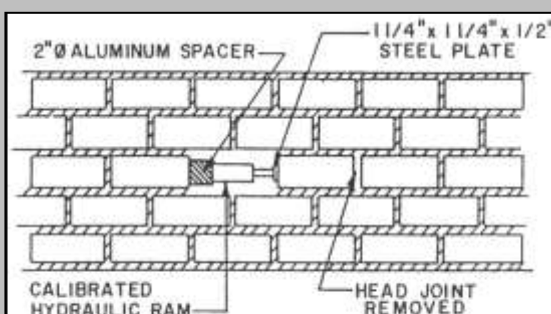
Rilem committee MDT, 2003



DRILL ENERGY TEST

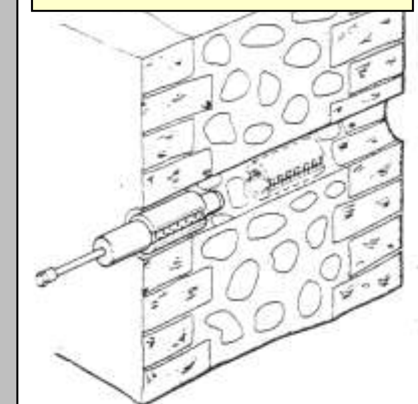


PULL OUT TEST



SHOVE TEST

DILATOMETER



NON DESTRUCTIVE TESTS

INVESTIGATIONS ON MATERIALS

INVESTIGATIONS ON MASONRY

MONITORING AND CONTROL OF THE STRUCTURES

Destructive tests

- Laboratory
- On-site

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Non-destructive tests (NDT)

- passive

• surveys and maps
• pictures
• displacements measurements
• spontaneous phenomena (magnetometers)

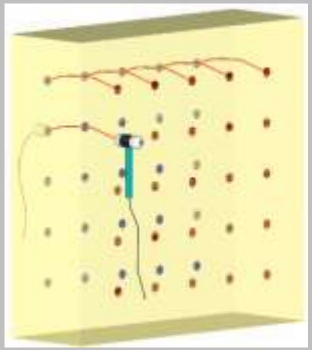
- active

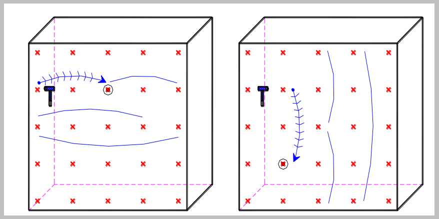
• sonic and ultrasonic tests
• radiography, georadar
• thermographs
• sclerometer
• dynamic tests

Sonic pulse velocity test

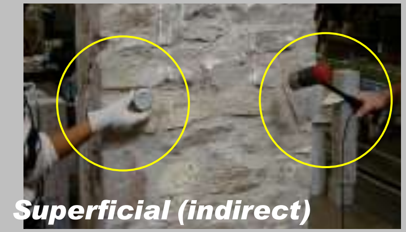
The use of sonic tests has the following aims:

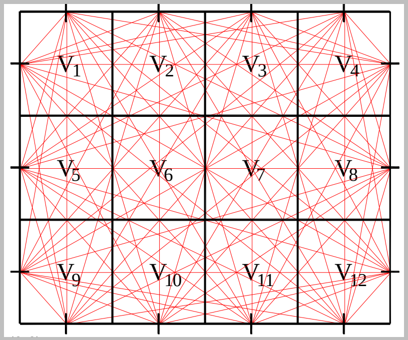
- to qualify masonry through the morphology of the wall section;
- to detect the presence of voids and flaws;
- to find crack and damage patterns;
- to control the effectiveness of repair by injection technique.

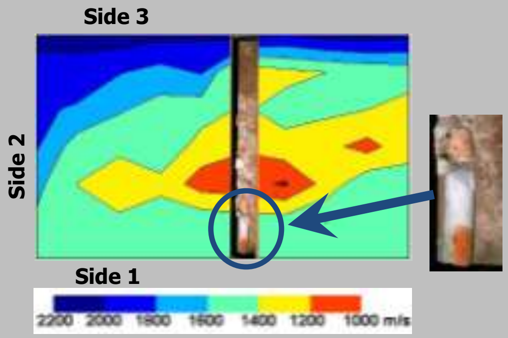




horizontal vertical





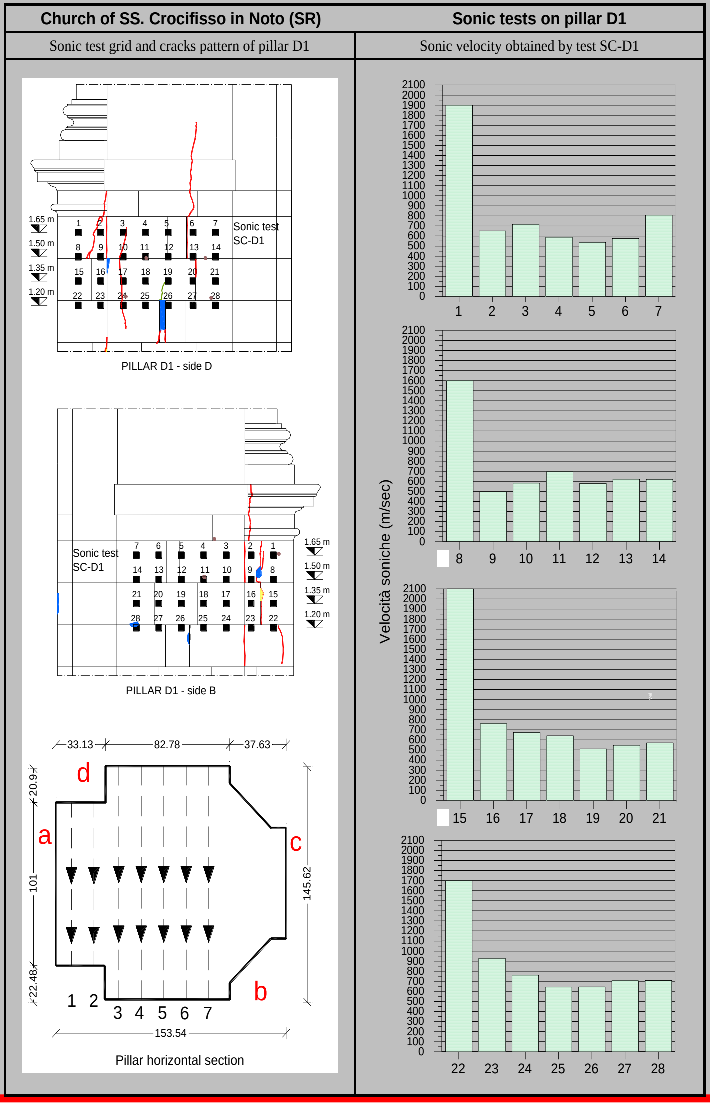


Sonic Tomography

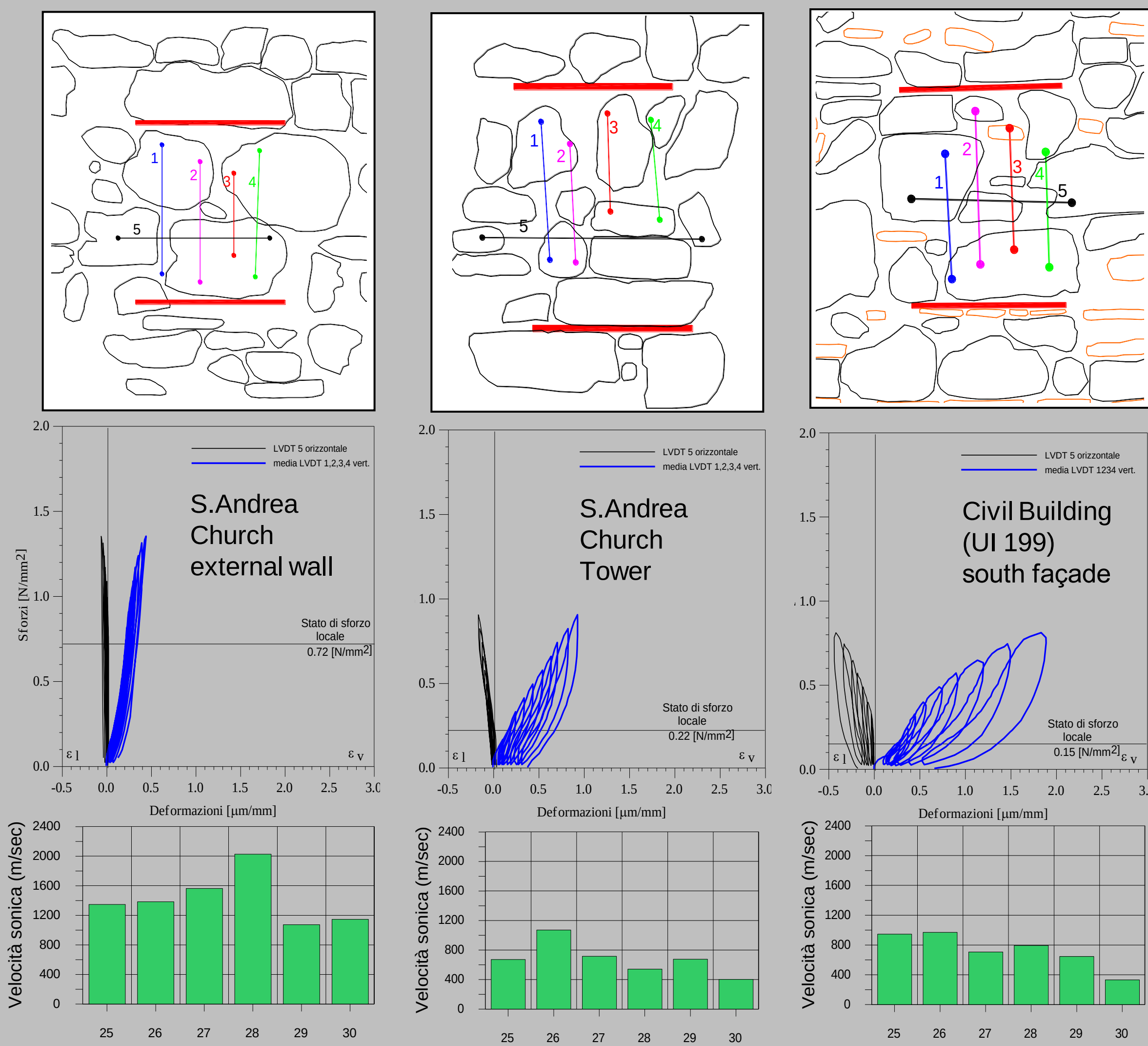
Sonic test

The velocity and waveform of stress waves generated by mechanical impacts can be affected by:

- Input frequency generated by different types of instrumented hammers and transducers;
- Number of mortar joints crossed from the source to the receiver location: the velocity tends to decrease with the number of joints;
- Local and overall influence of cracks.



Local and overall influence of cracks: sonic tests on a pillar of the church of SS. Crocifisso in Noto - SR (Binda, 1999)



Complementarity of in situ tests

Flat jack tests: some results obtained with single and double flat-jack tests on the external wall of a church, of a bell tower and of a civil building in Campi Alto di Norcia (PG)

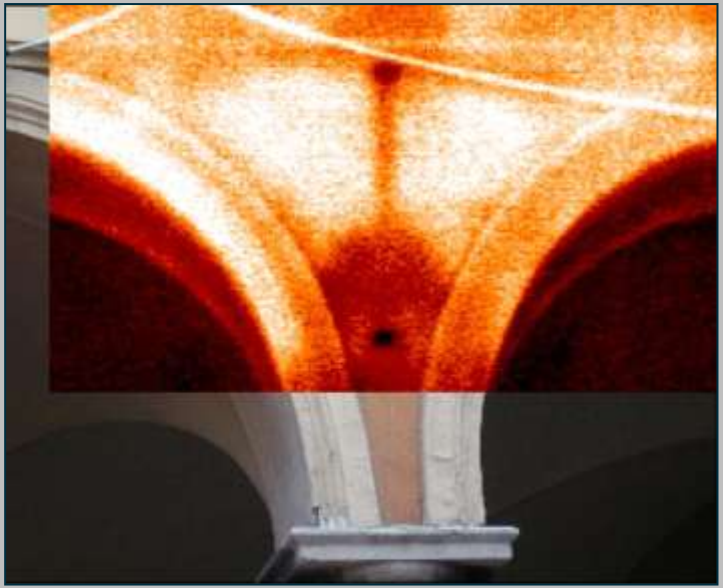
Sonic tests: representative results of the diagonal surface sonic measurements on the same walls

Thermovision

The **thermographic analysis** is based on the thermal conductivity of a material and may be passive or active. The passive application analyses the radiation of a surface during thermal cycles. If the survey is active, forced heating to the surfaces analyzed are applied

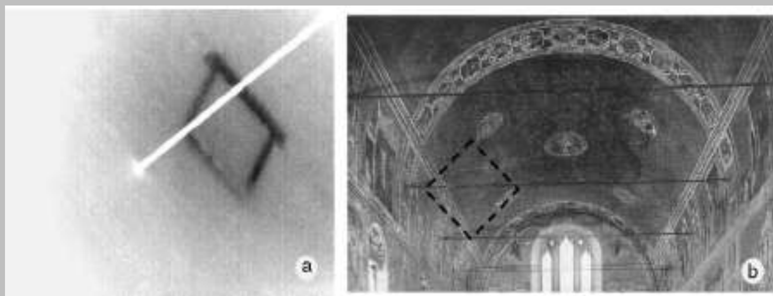
Thermovision can be very useful in diagnostic:

- to identify areas under renderings and plasters,
- to survey cavities,
- to detect inclusions of different materials,
- to detect water and heating systems,
- to detect moisture presence.

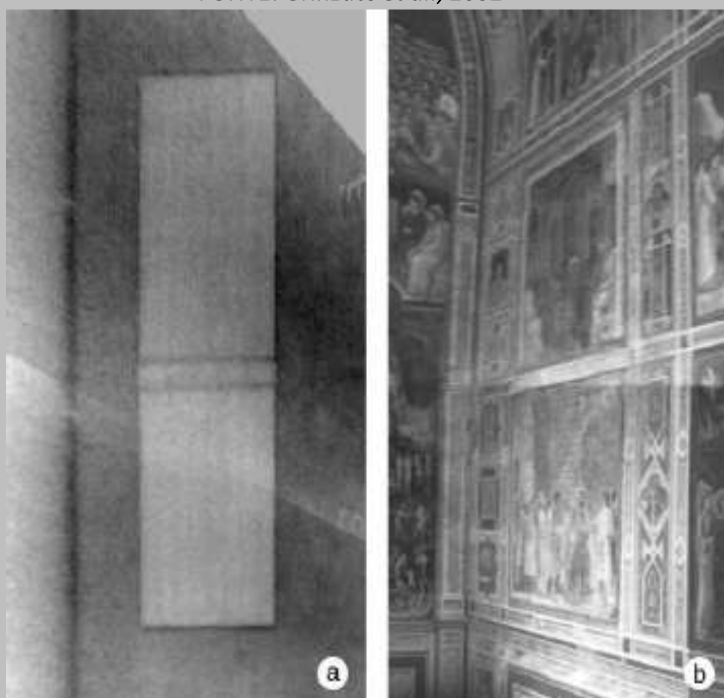


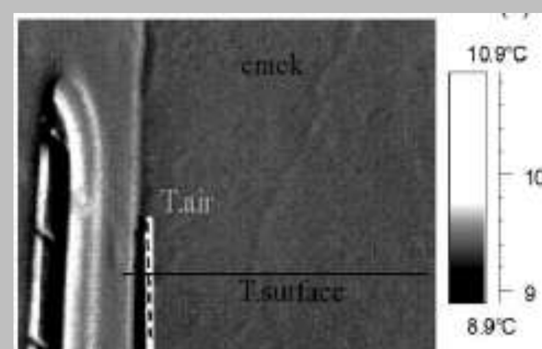
Investigation on hidden steel tie rods

Monitoring of the Scrovegni Chapel by IR thermography: Giotto at infrared



FONTE: Grinzato et al., 2002

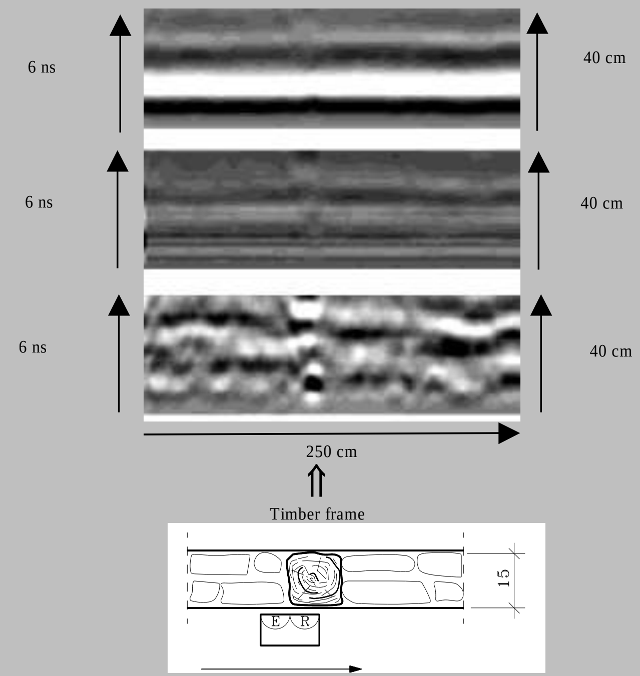




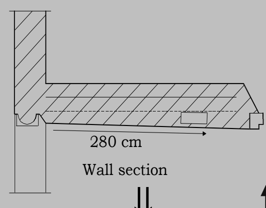
Georadar

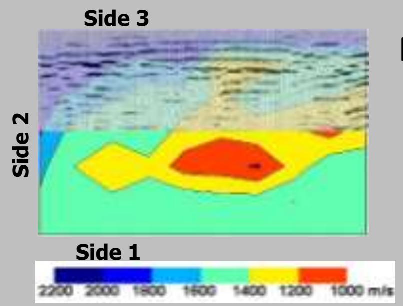
When applied to masonry, the applications of radar procedures can be the following:

- to locate the position of large voids and inclusions of different materials, like steel, wood, etc.;
- to qualify the state of conservation or damage of the walls;
- to define the presence and the level of moisture;
- to detect the morphology of the wall section in multiple leaf masonry.

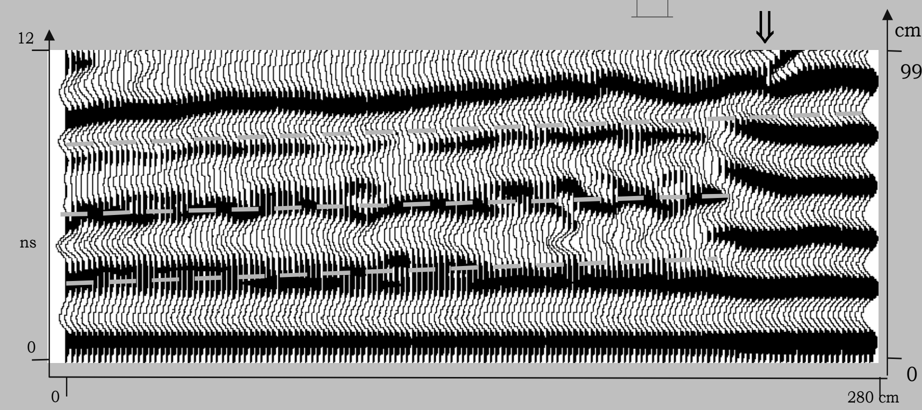


Local and overall influence of cracks





Radar vs Sonic



Radargram of the wall section at the Malpaga Castle

ACQUIRING KNOWLEDGE OF THE STRUCTURE

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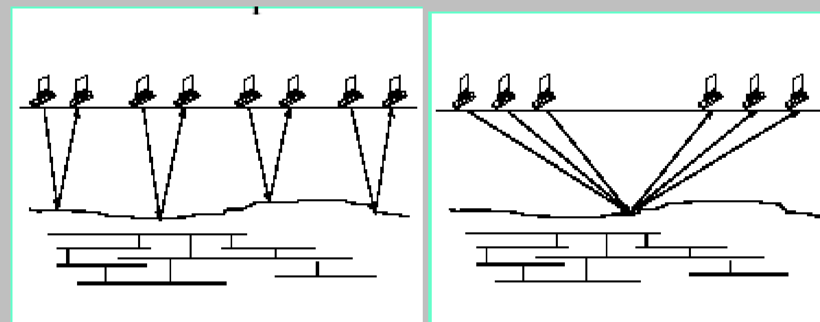
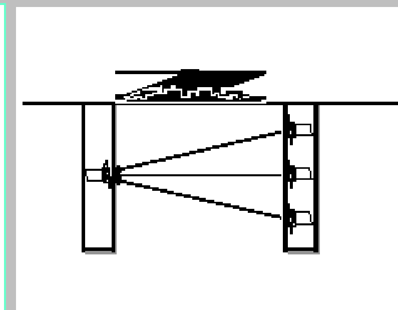
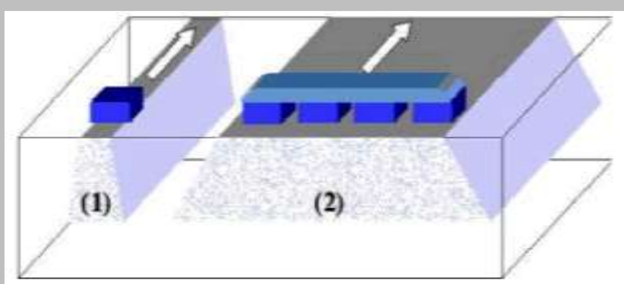
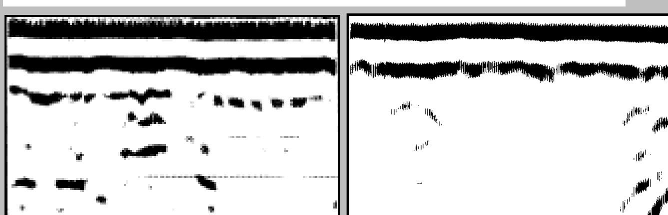


Echo-radar

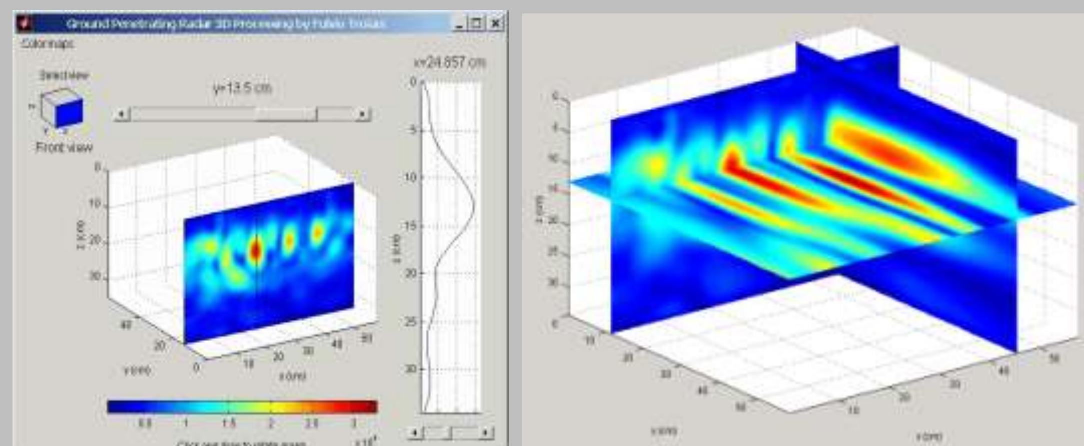


Radar in transparency





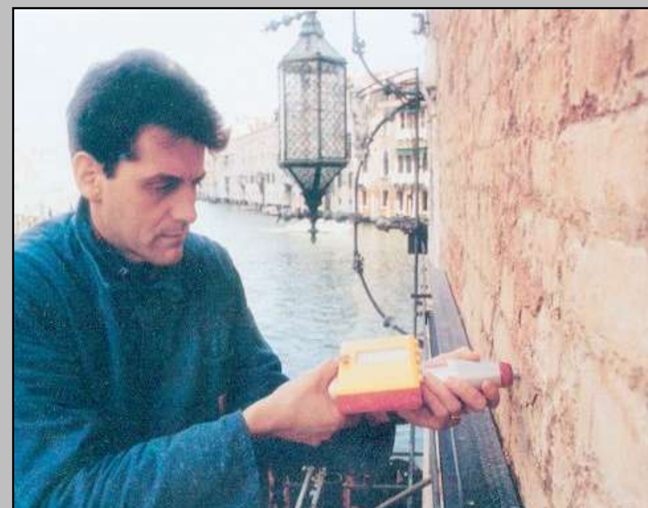
Echo-radar before and after grout injection

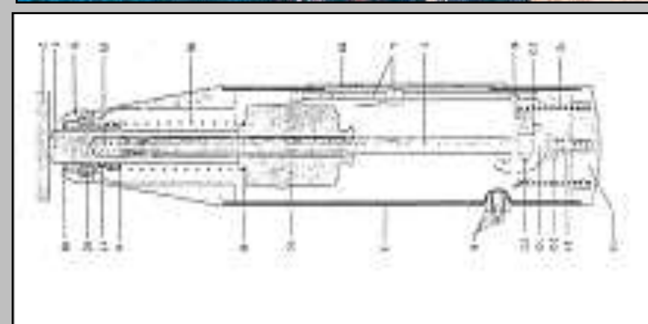


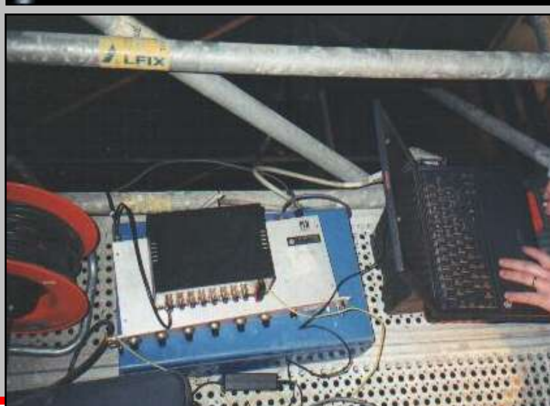
Software for 3D processing of echo-radar (Zanzi, 2003)

pacometer

Schimdt rebound hammer

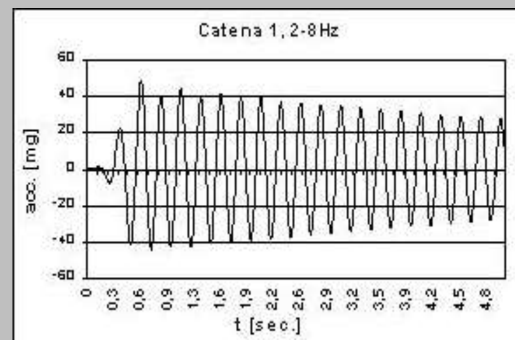


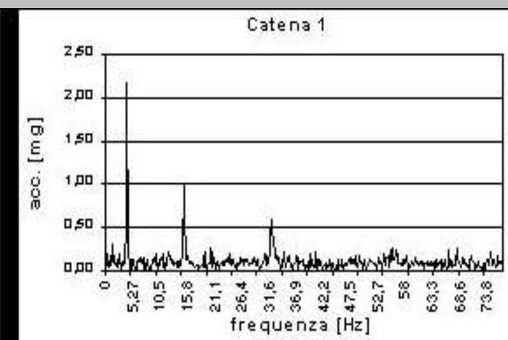




Dynamic tests on ties

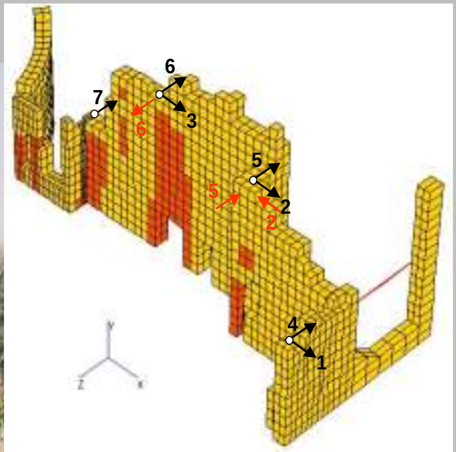
$$T=(f * \lambda)^2 * \mu$$



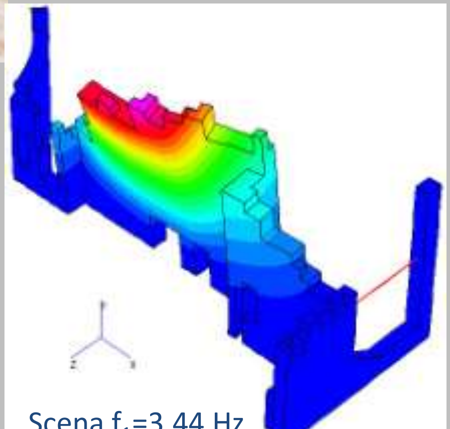


Catena	Sezione	peso specifico	lunghezza libera	frequenza propria	Tiro
	mm	kg/m	m	Hz	kg
1	30 x 60	14,148	17	4,102	6879,93
2	30 x 60	14,148	17	3,906	6238,17
3	30 x 60	14,148	17	3,125	3992,94
4	30 x 60	14,148	17	4,102	6879,93
5	30 x 60	14,148	17	3,516	5054,64

Dynamic identification tests



Proprietà 1	E	1.2E+03	MPa
	ρ	1.3E+03	kg/m³
Proprietà 2	E	3.2E+03	MPa
	ρ	1.3E+03	kg/m³
Proprietà 3	E	1.2E+03	MPa
	ρ	1.5E+03	kg/m³



Scena f_1=3.44 Hz

Acquiring Knowledge of the Structure

Prof. Francesca da Porto

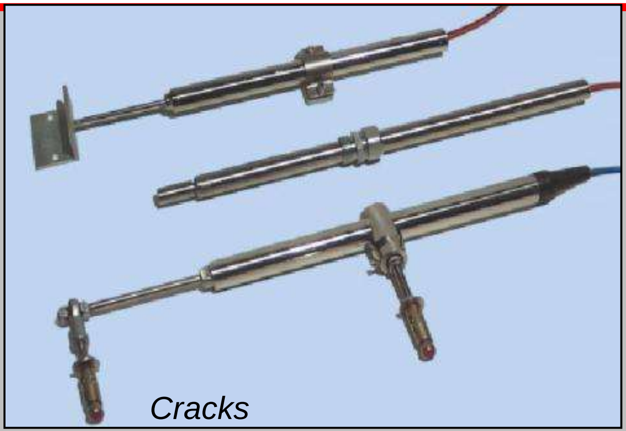
MONITORING AND CONTROL OF STRUCTURES

- ***continuous*** → Measure of Increasing parameters → *Crack patterns, stress states, etc.*
- ***discontinuous*** → Measure of variation of parameters compared to a stationary state → *Dynamic excitation, static loadingi, etc.*
- ***static*** → Measure of parameters related to quasi-static effects of actions → *Displacement, deformations, stresses, temperature, cracks, out-of-plumb, tilting, damage, etc*
- ***dynamic*** → *Time-history* measurement of vibrations → *accelerations, velocity, time-displacements*
- ***periodic*** → Measurement at regular time intervalls
- ***permanent*** → Measurement at very frequent time intervals → *MONITORING SYSTEMS*

Acquiring Knowledge of the Structure

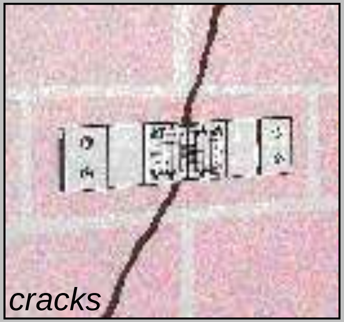
Prof. Francesca da Porto

cracks



Cracks

Tilting



cracks

data-logger

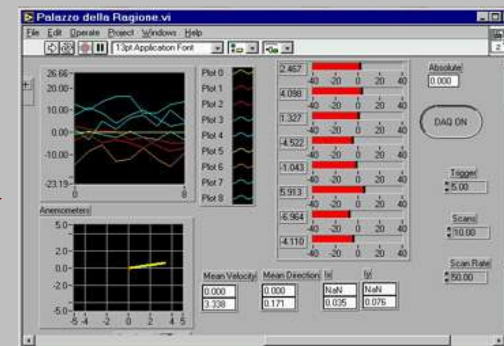
Extensimeters

Heavy masses monitoring

Piezometers

Example of monitoring: Palazzo della Ragione (Padova, XIII-XV cen.)

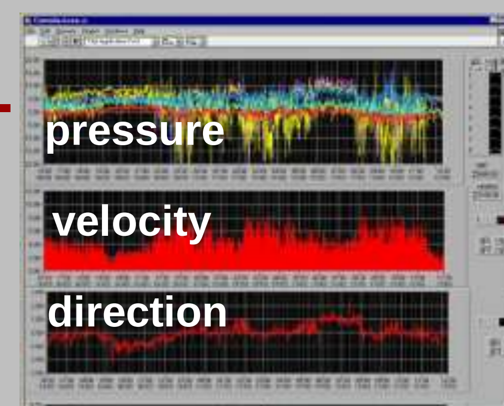
- Wind effect moniting
- stepped sine test
- FE modelling
- modal identification
- on-line data management

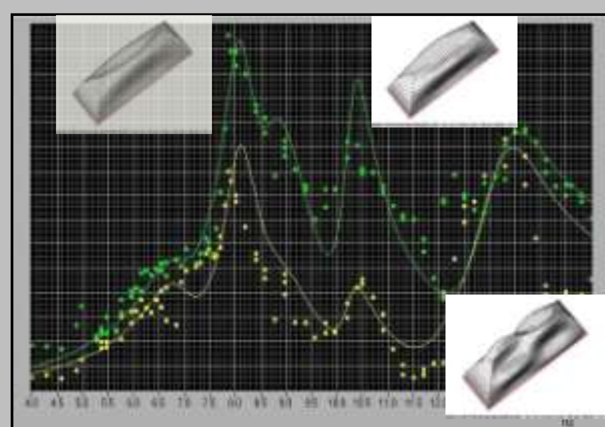


Data acquisition

www database

Web monitoring home page



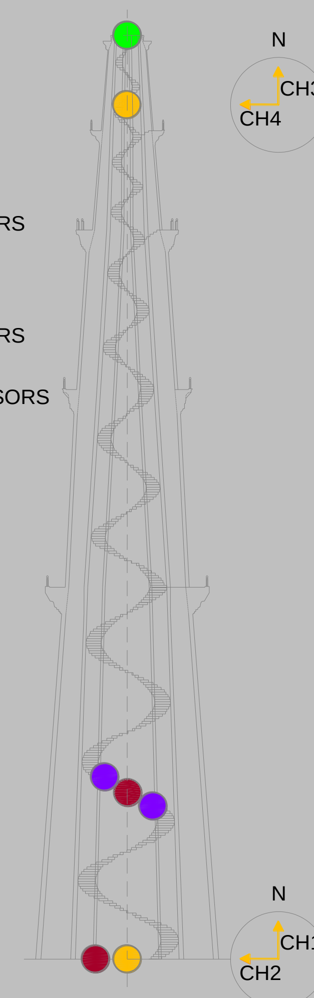


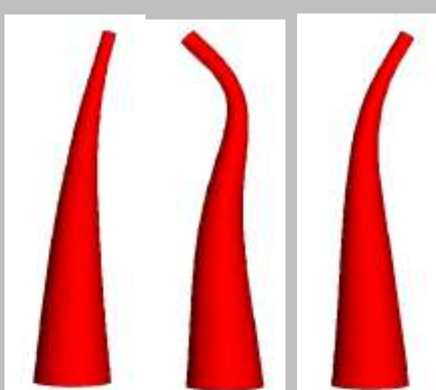
Modal Analysis

Example of a monitoring system for the control of the behavior: Qutb Minar – New Delhi (India)

- Positioning of **sensors**:
  1 - acceleration transducers
  2 - temperature and R.H. sensor
  3 - displacement transducer
  4 - wind velocity and direction transducer
- Data acquisition and analysis

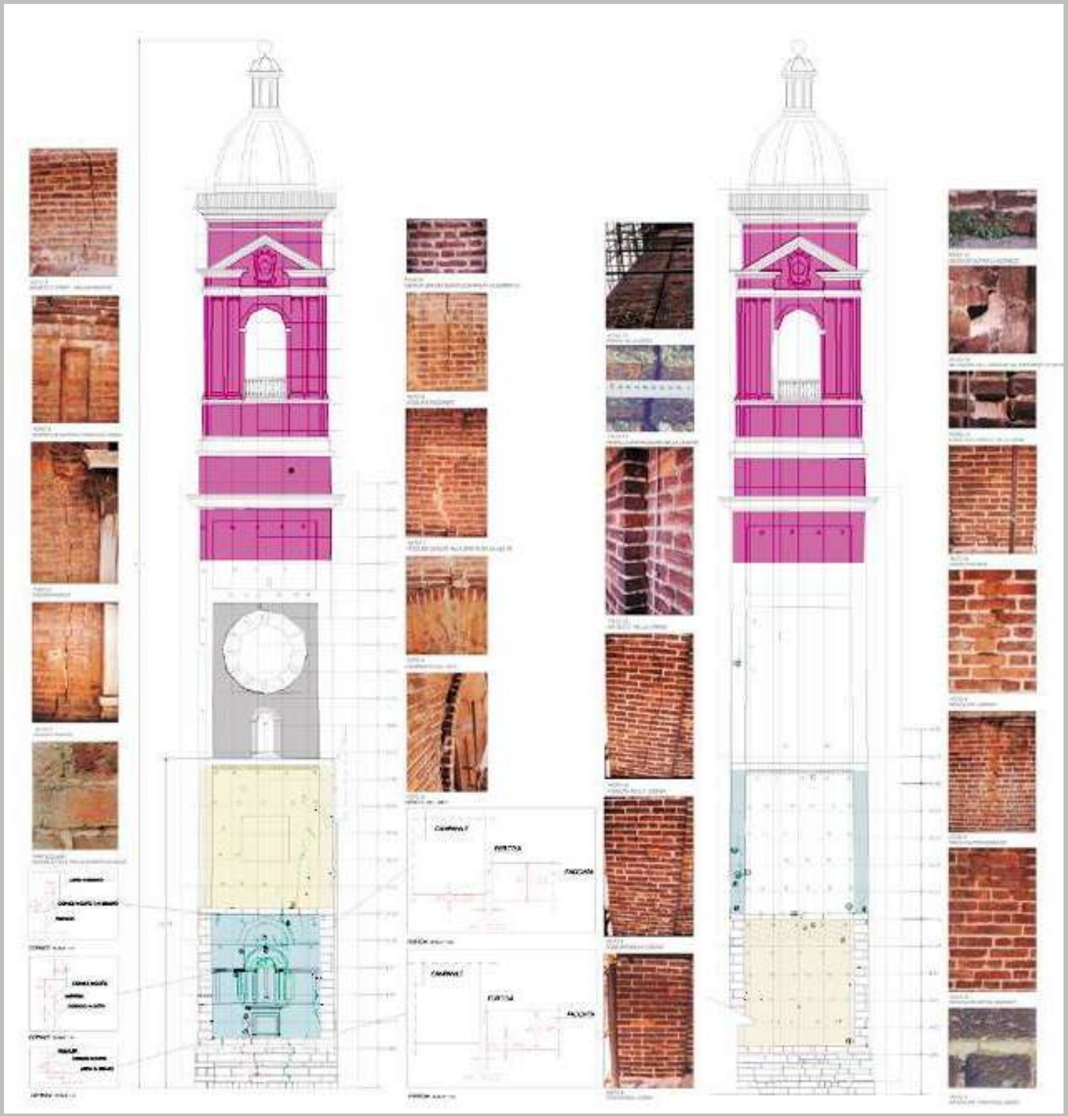
ACCELERATION TRANSDUCERS
ANEMOMETER
DISPLACEMENT TRANSDUCERS
TEMPERATURE AND RH SENSORS





0.62 Hz 1.96 Hz 3.82 Hz

Example of monitoring: Monza Bell Tower XVI cen.)



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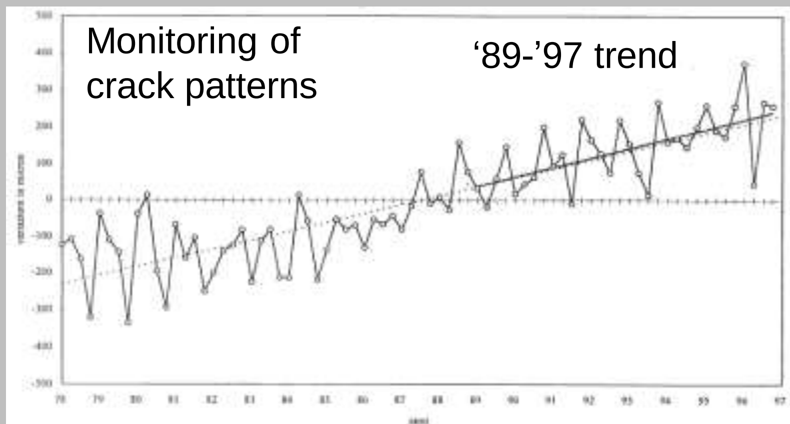


PROSPETTO DELL'EDIFICIO	PANNELLO 12-13-14-15

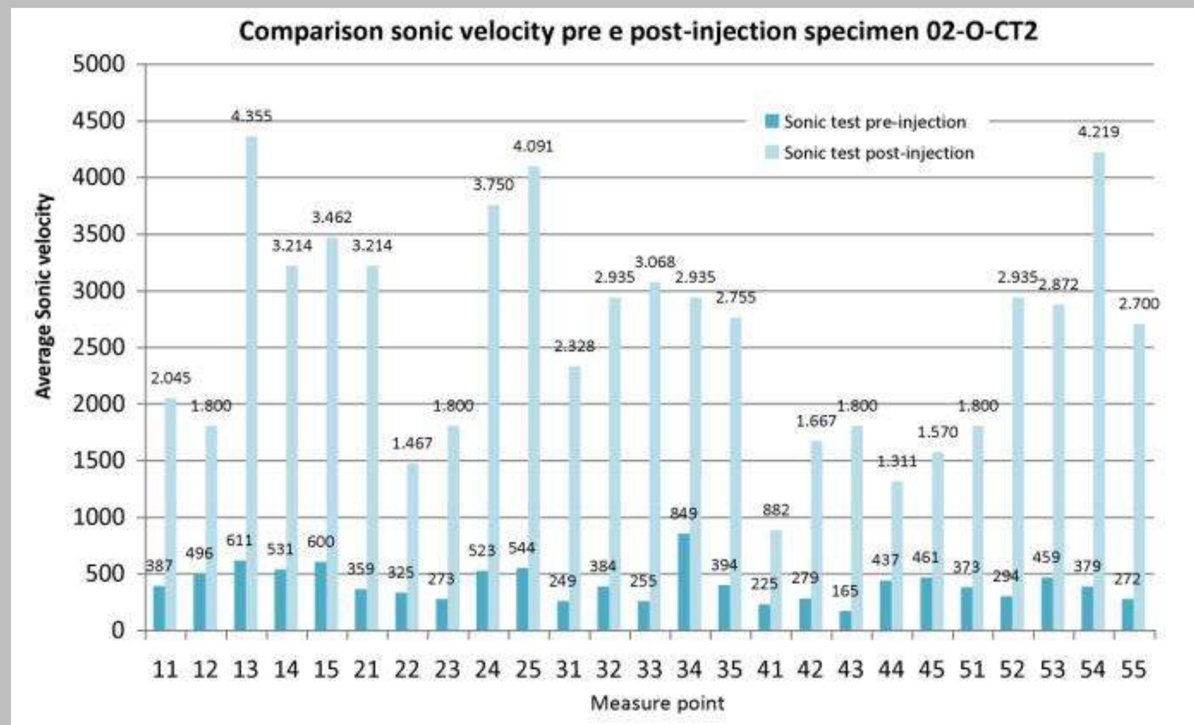
Esterno

Interno

Descrizione	PANNELLI 12-13-14-15 POST-INIEZIONE

ABRUZZO – INTEGRATION NDT / DT

ABRUZZO – INTEGRATION NDT / DT



Sonic pulse velocity before and after grout injections (m/s)

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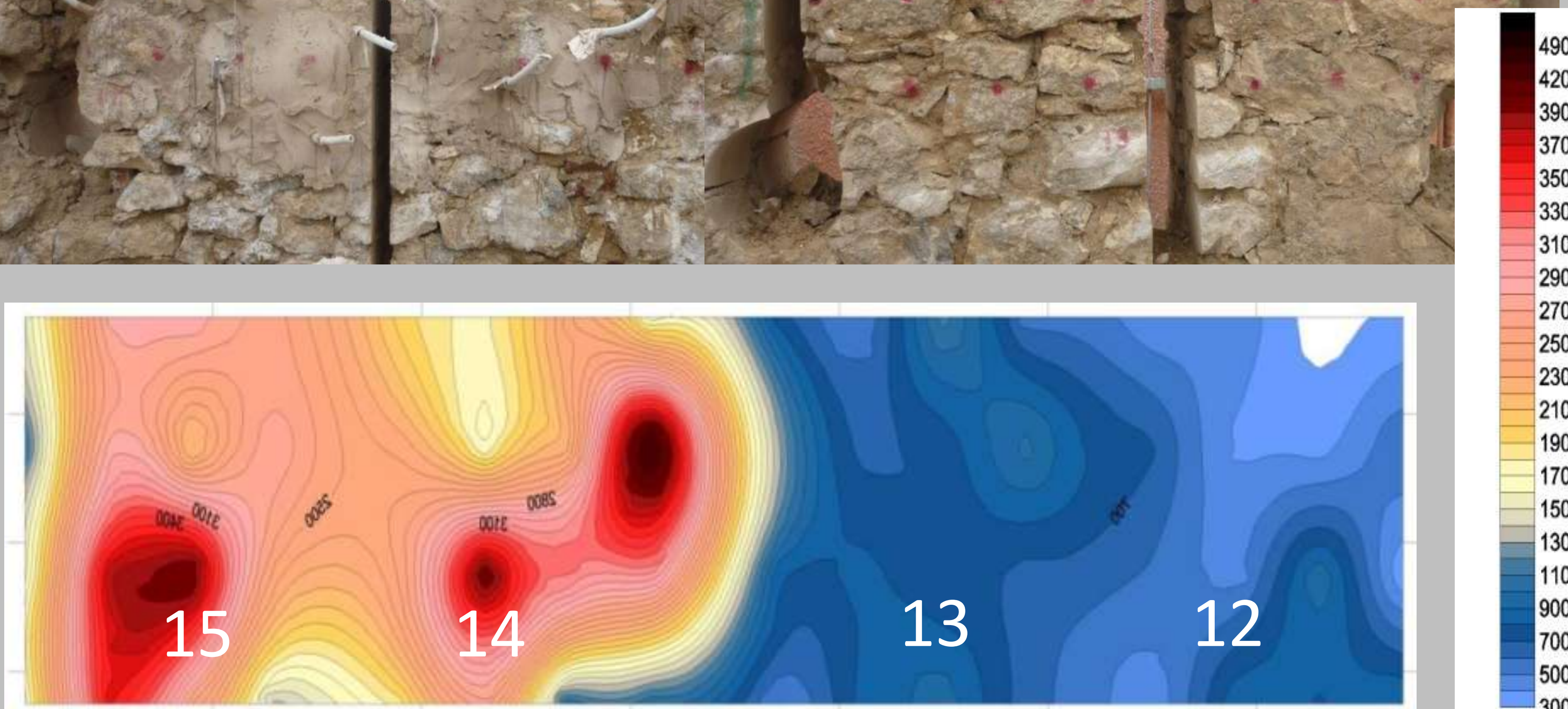
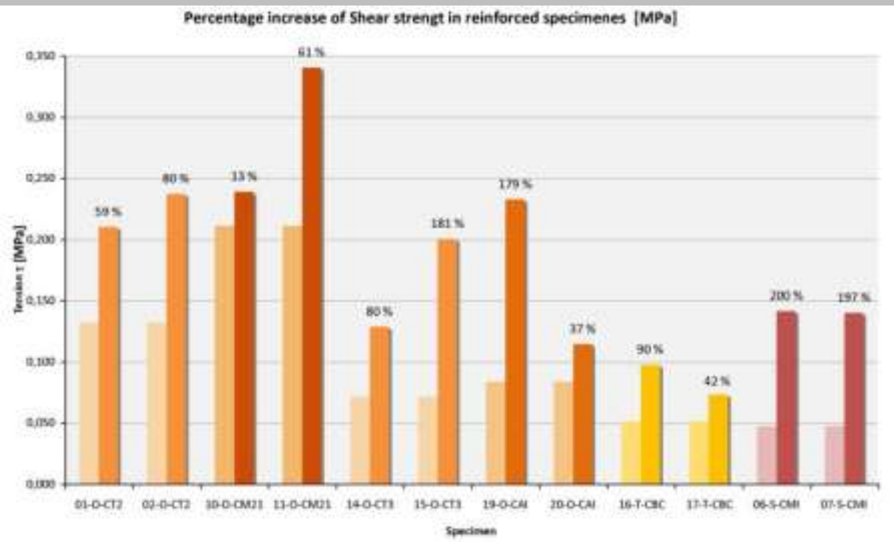
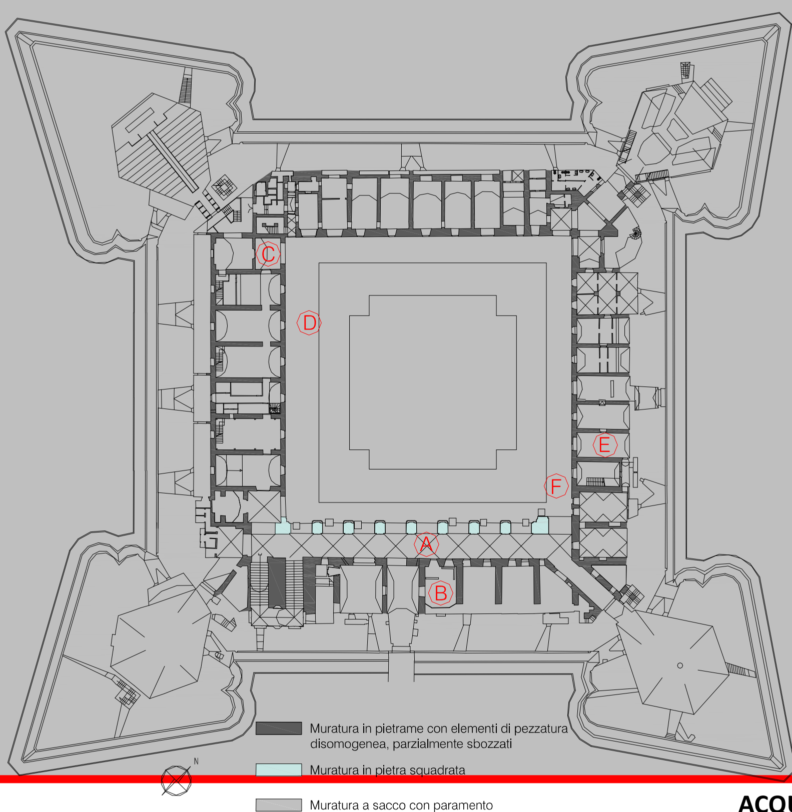


ACQUIRING KNOWLEDGE OF THE STRUCTURE

PROF. FRANCESCA DA PORTO



L’AQUILA: FORTEZZA SPAGNOLA



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POLITECNICO DI MILANO — **Dipartimento di Ingegneria Strutturale – Sezione Murature e Beni Culturali. Responsabile: prof.ssa L. Binda**

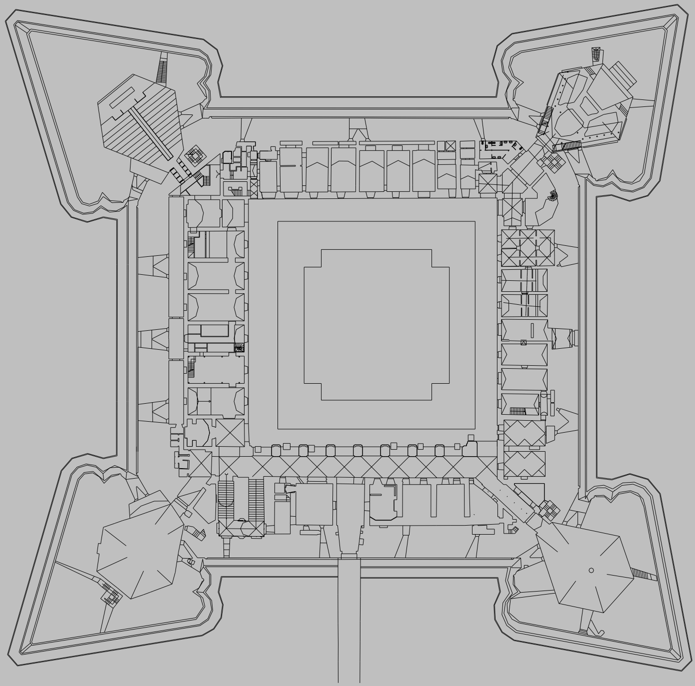
ISTITUTO SUPERIORE PER LA CONSERVAZIONE ED IL RESTAURO — **Dr. Roberto Ciabattoni, Dr. Carlo Cacace**

Attività di indagine

- **Identificazione dinamica**
- **Prove soniche per trasparenza**
- **Tomografia sonica**
- **Termografia attiva**
- **Prove con martinetti singoli**
- **Prove con martinetti doppi**
- **RADAR**

Monitoraggio strutturale

- **Controllo dei parametri ambientali**
- **Monitoraggio statico**
- **Monitoraggio dinamico**



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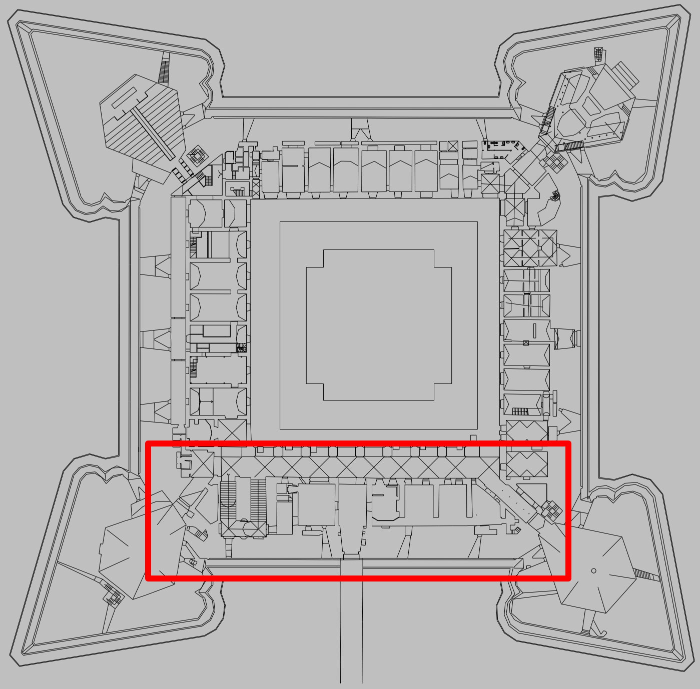

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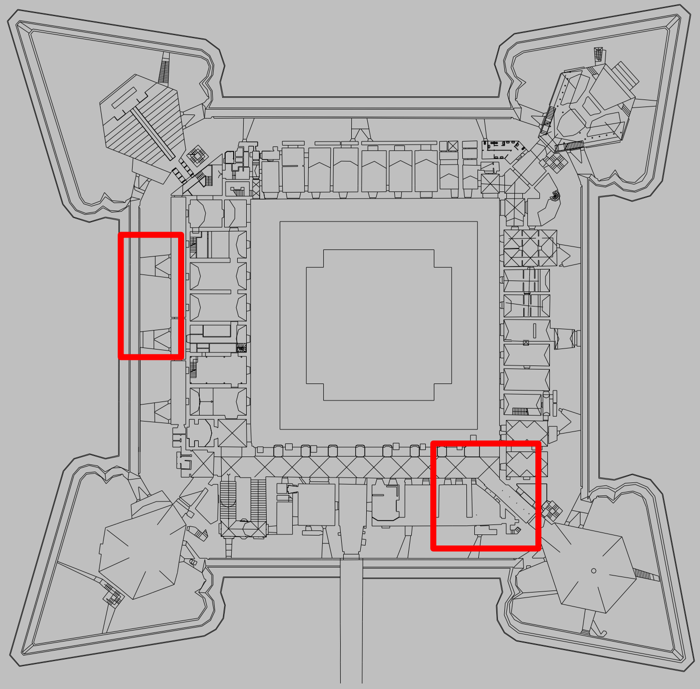

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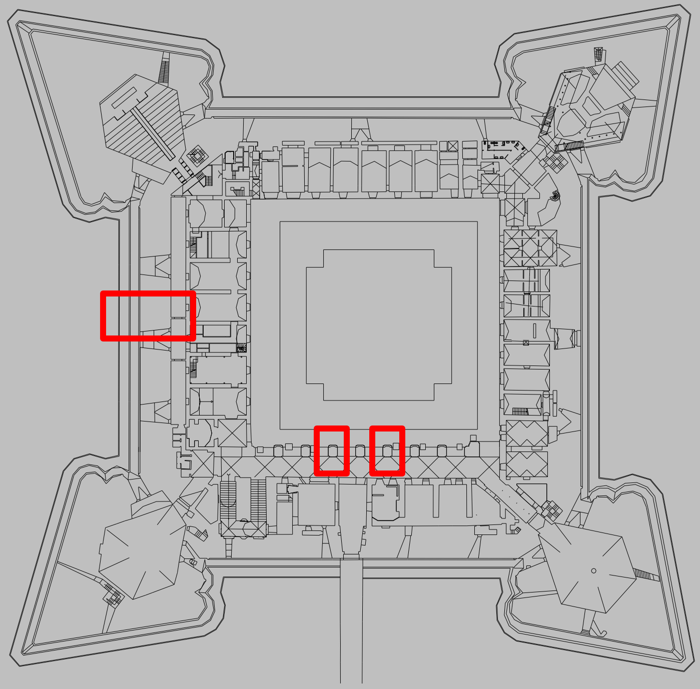

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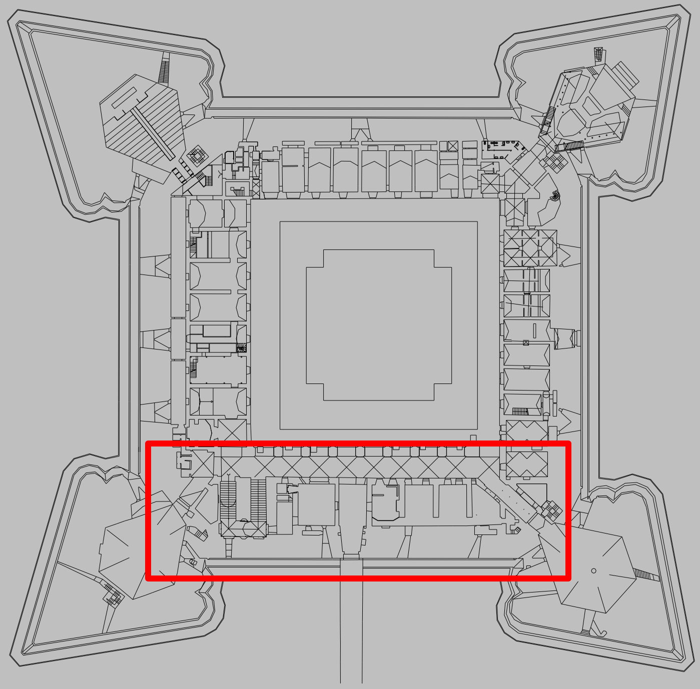
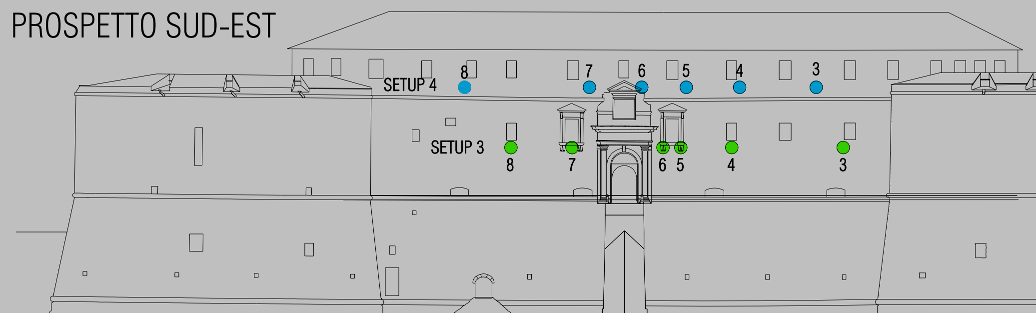


ACQUIRING KNOWLEDGE OF THE STRUCTURE

PROF. FRANCESCA DA PORTO



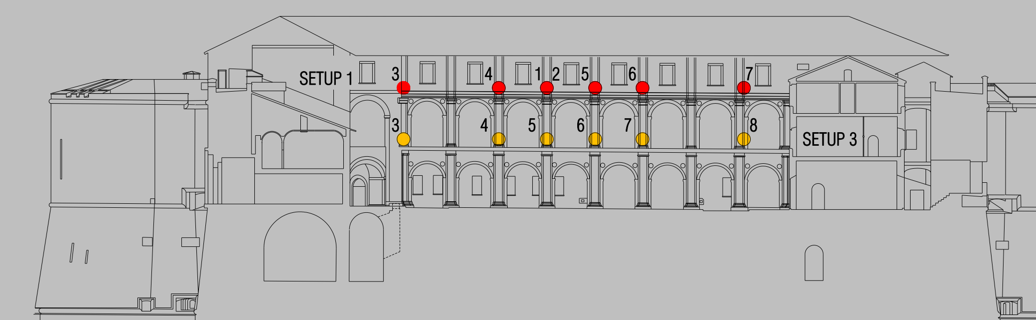

PROSPETTO SUD-EST



5 setup overall 27 acquisition positions.

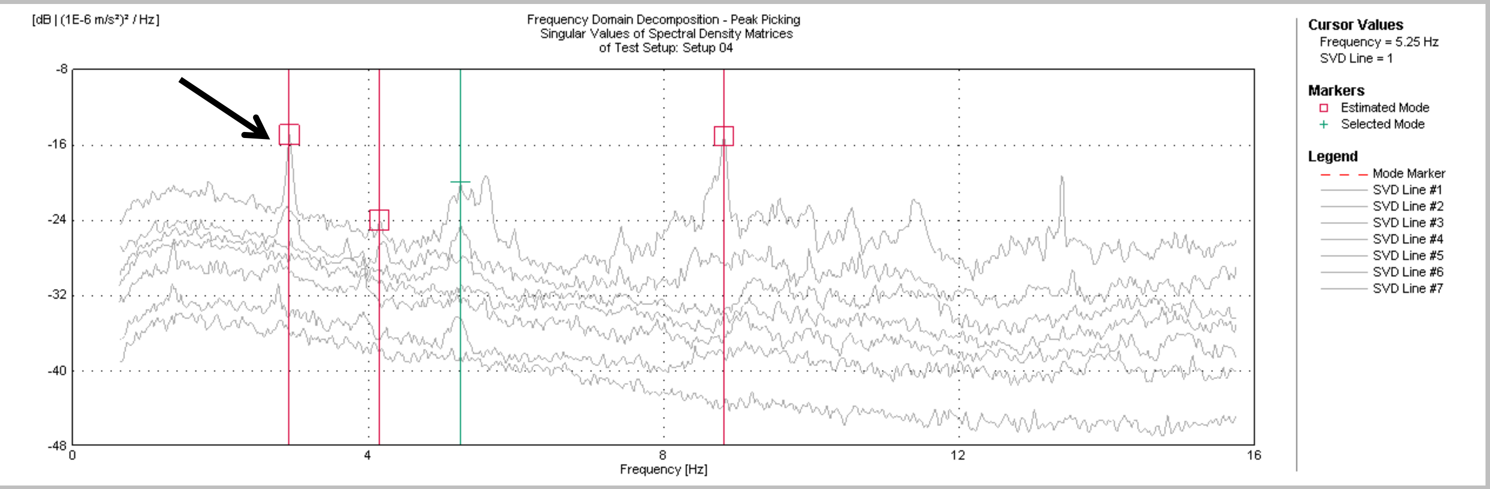
8 sensors, of which 2 are fixed (X ed Y).

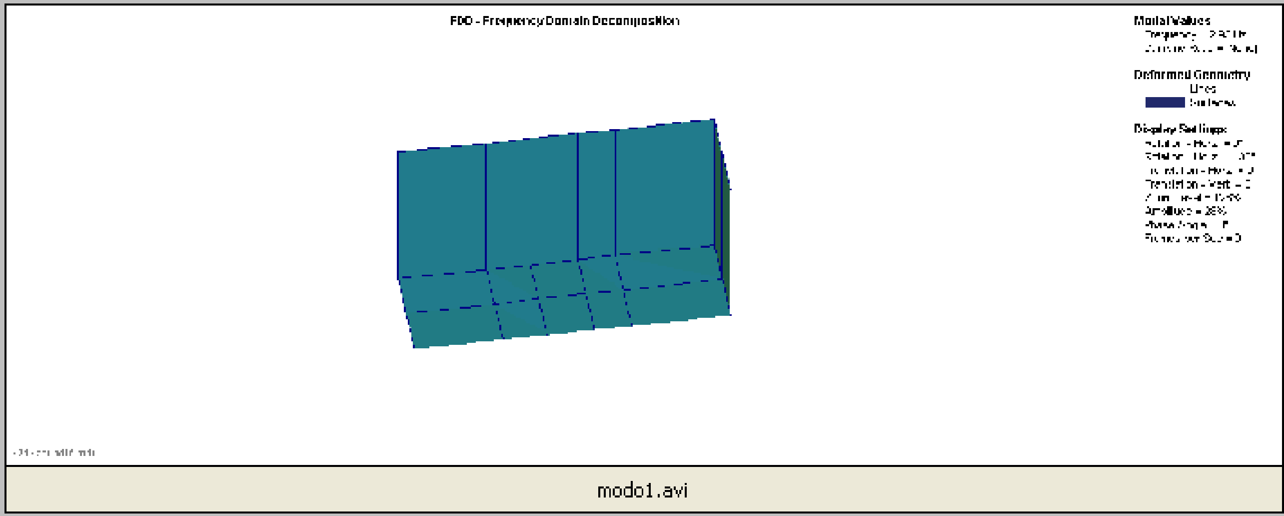
On the internal and external façades.



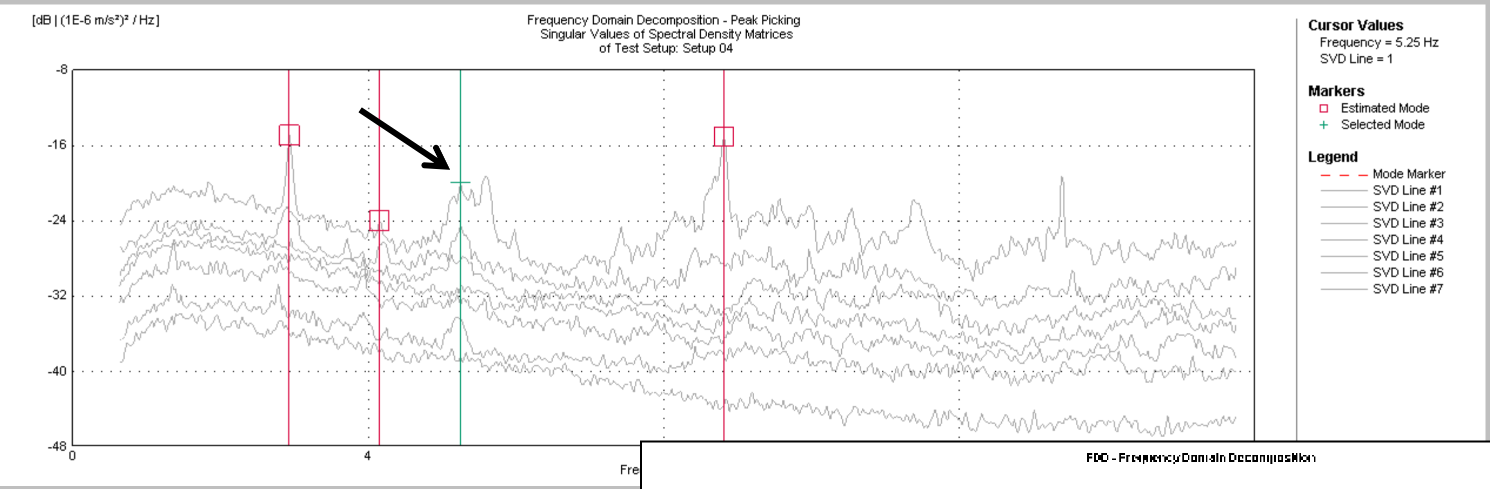
PROSPETTO-SEZIONE BB'

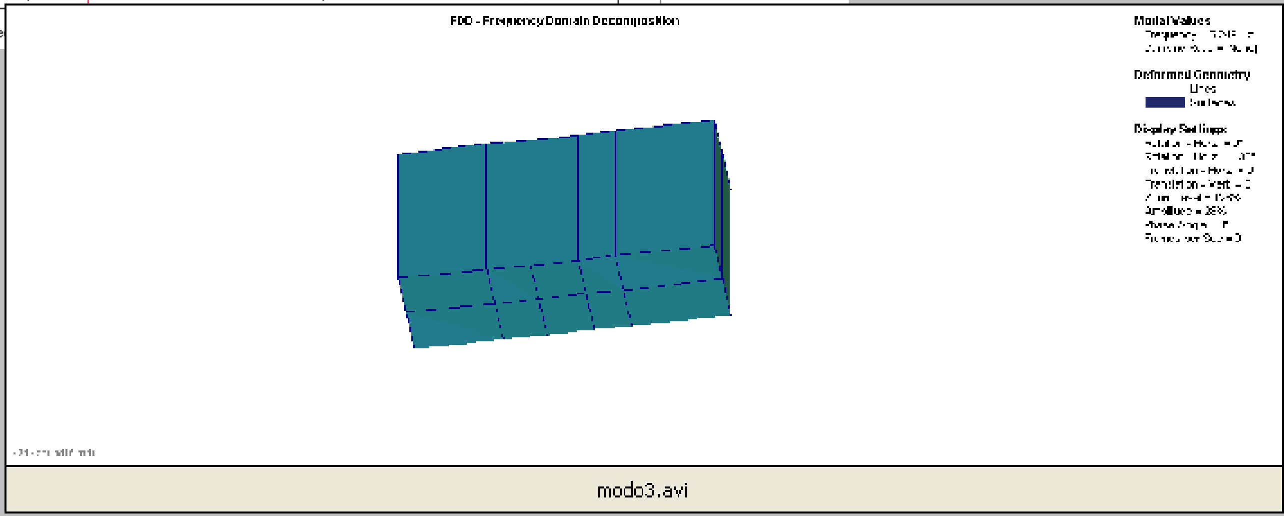
First flexural mode, at a frequency of 2,93 Hz, for all the measurements





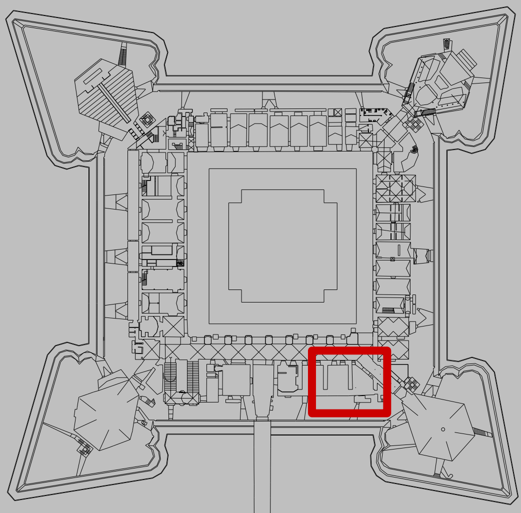
Another mode emerging from all the measurements is a flexural mode in opposition for the two façades at 5,2 – 5,4 Hz. Other vibration modes are not identified with all set-ups, and are related to the damage and disconnection of the two façades.

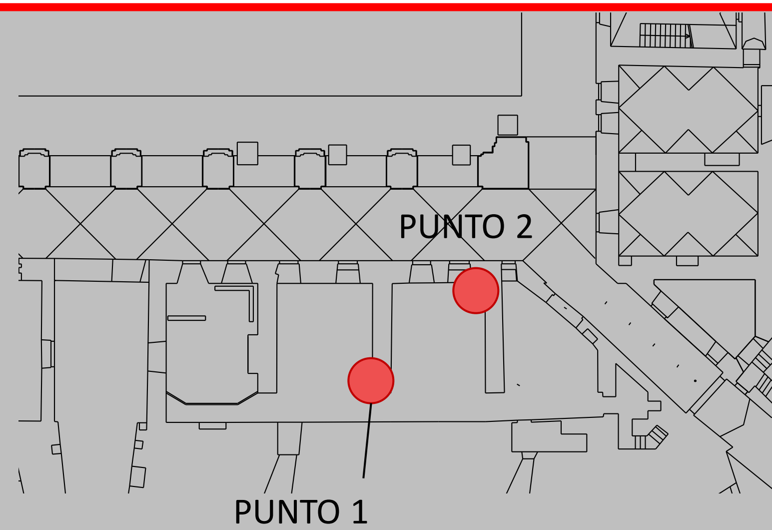




Acquiring Knowledge of the Structure

Prof. Francesca da Porto



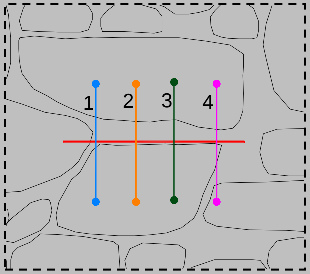


SONIC TESTS

SINGLE FLAT JACK TESTS

Acquiring Knowledge of the Structure

Prof. Francesca da Porto

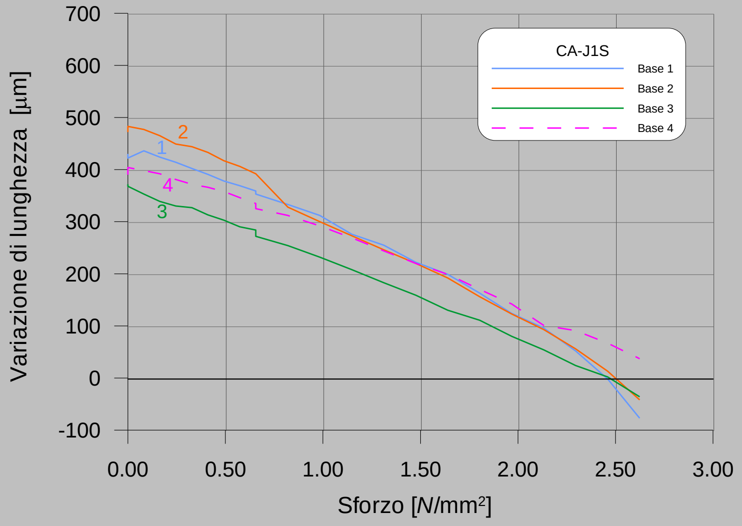


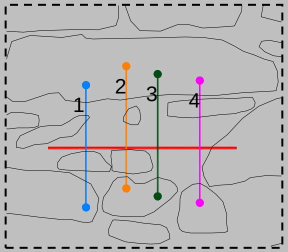
Point 1

State of stress

↓

2.47 N/mm^2



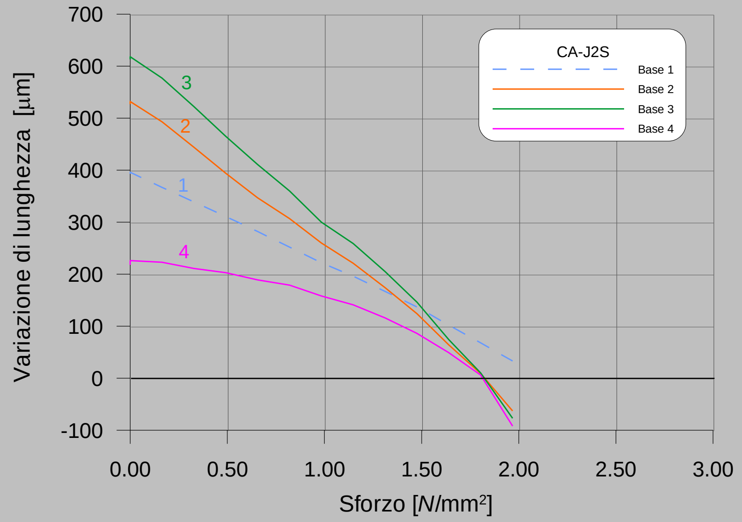


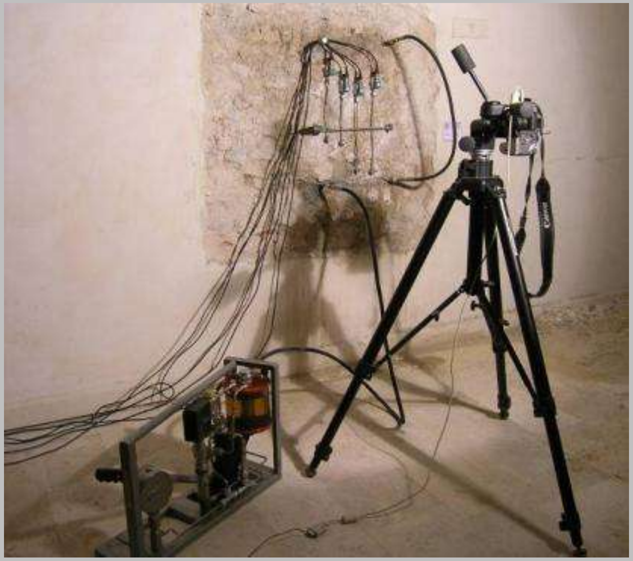
Point 2

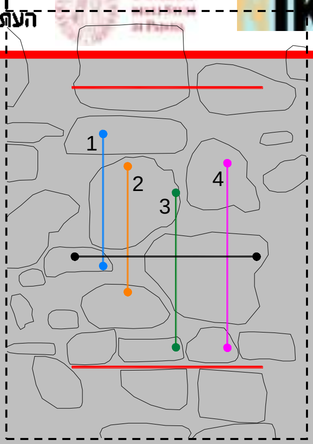
State of stress

↓

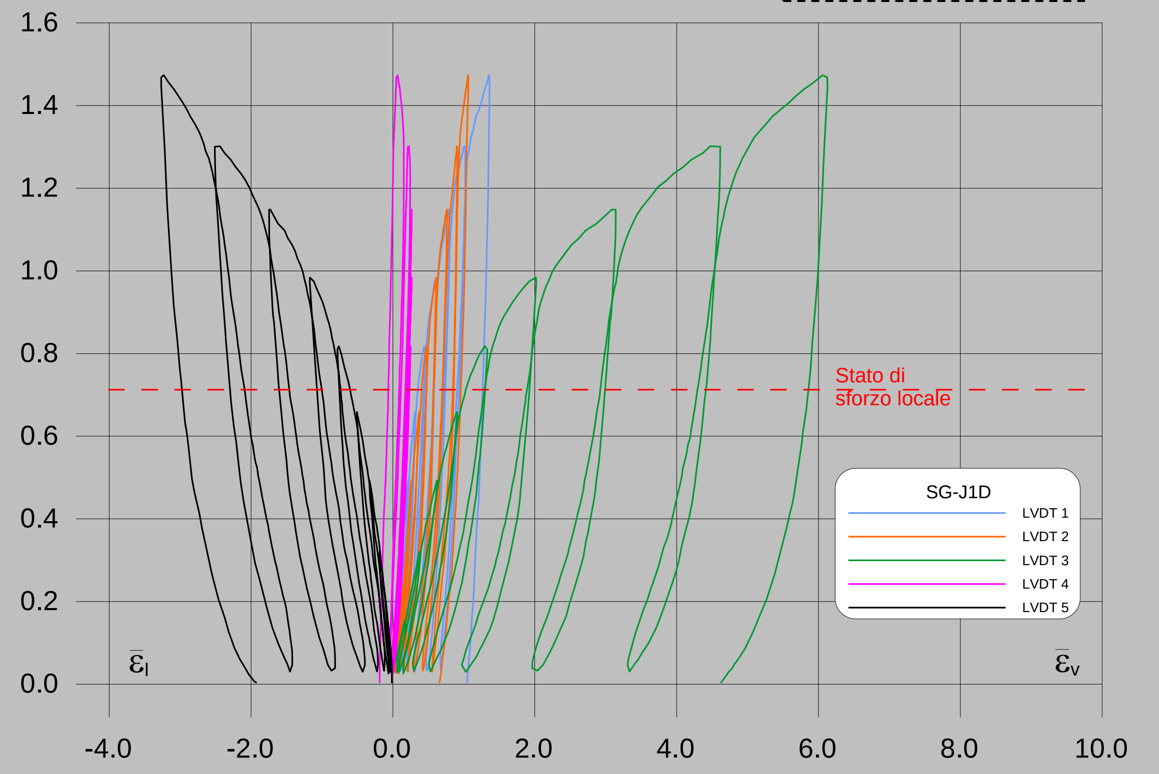
1.82 N/mm^2







DOUBLE FLAT JACK – CA-J3D



ACQUIRING KNOWLEDGE OF THE STRUCTURE

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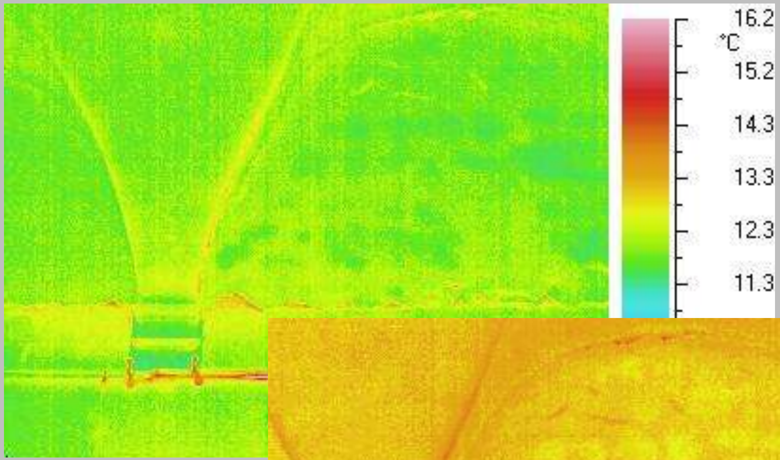
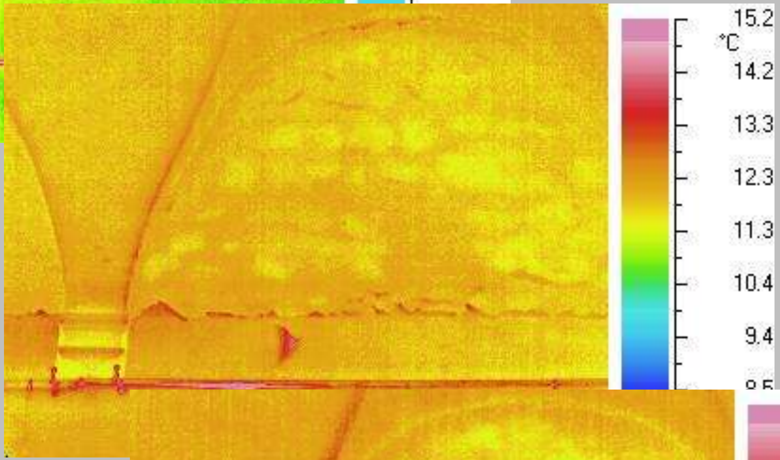
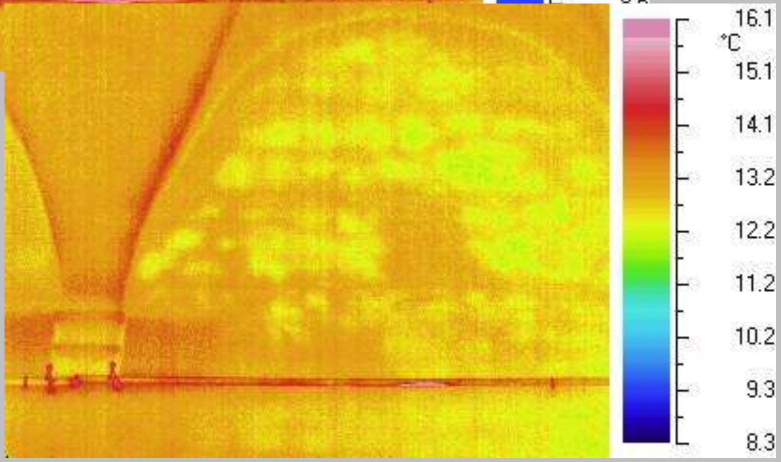
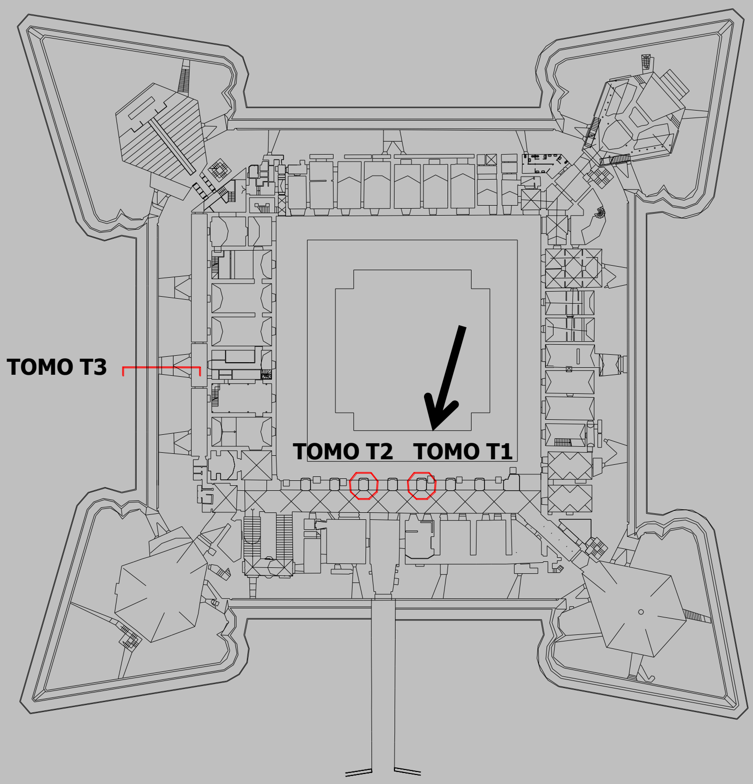


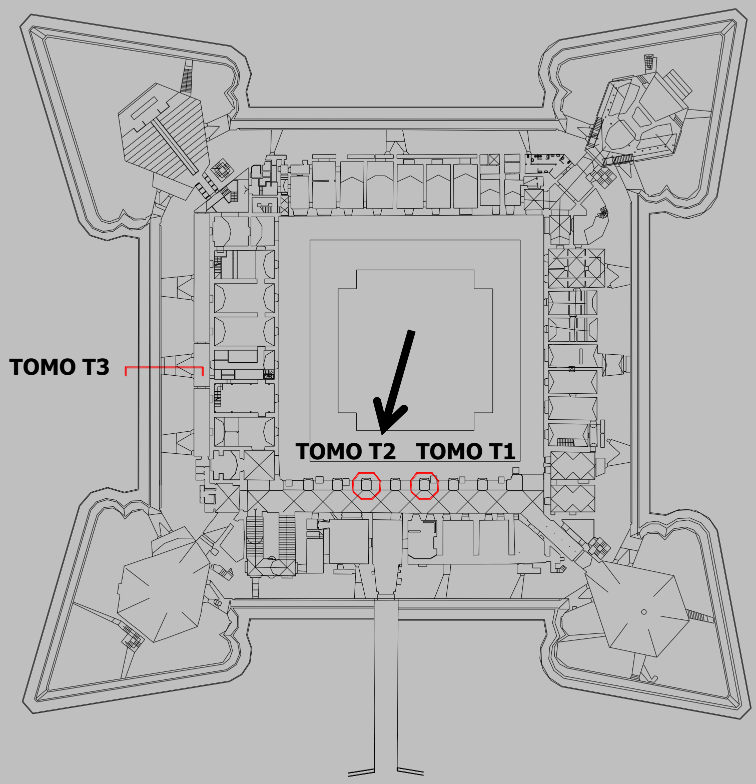




SONIC TESTS



SONIC TESTS



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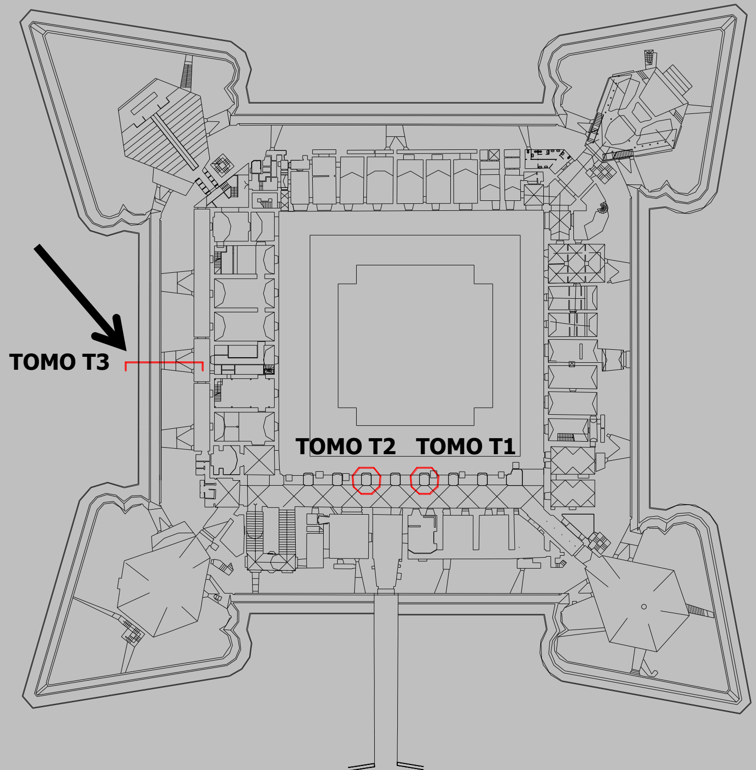

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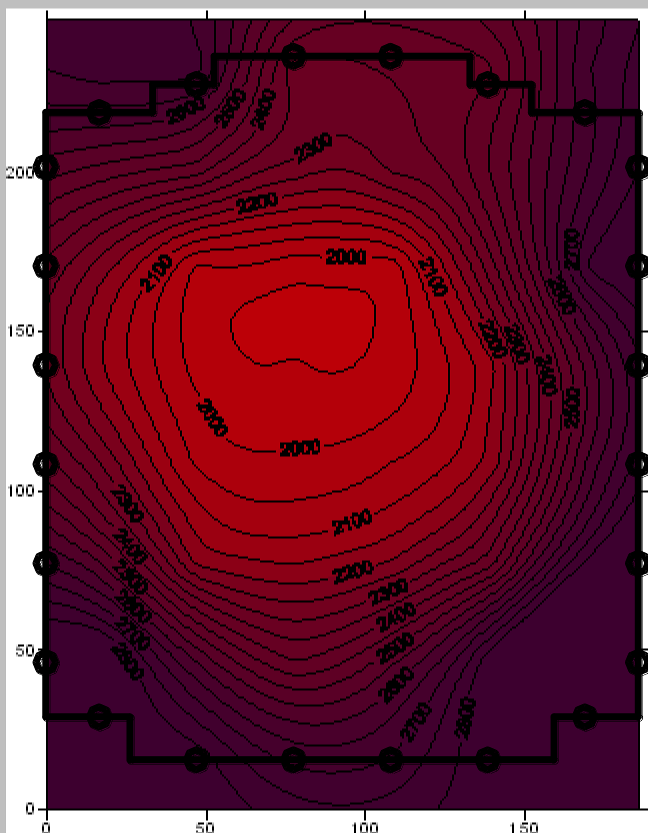
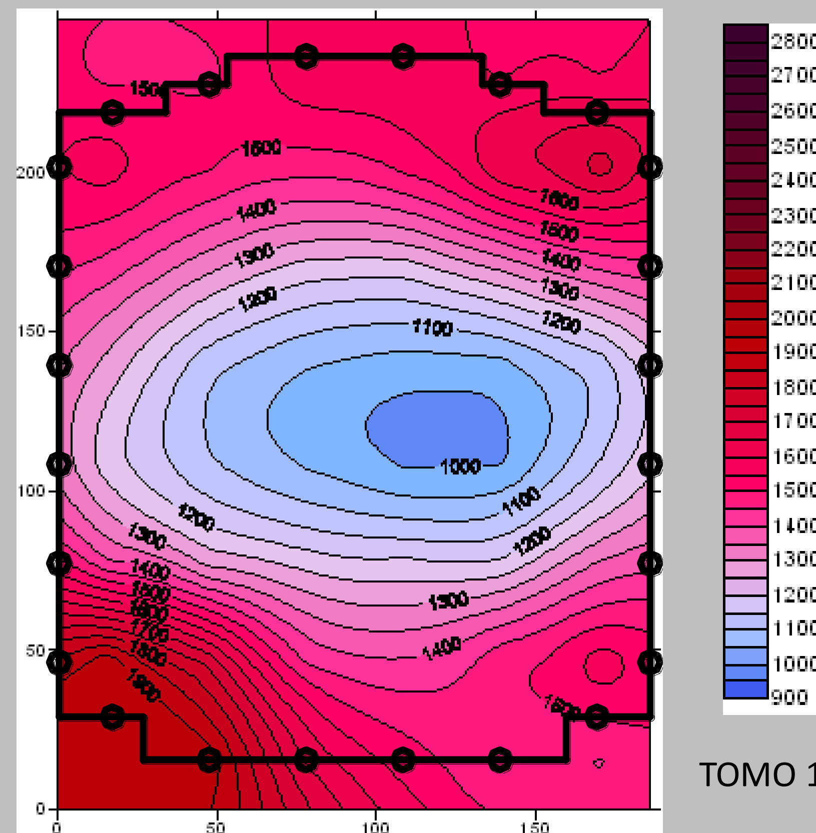
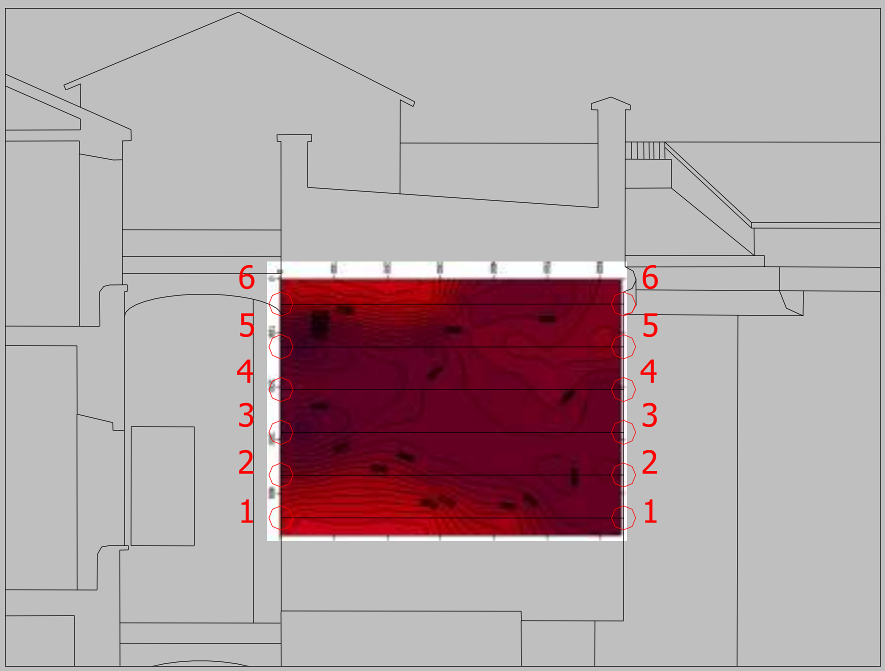


TOMO 2



TOMO 1

SONIC TESTS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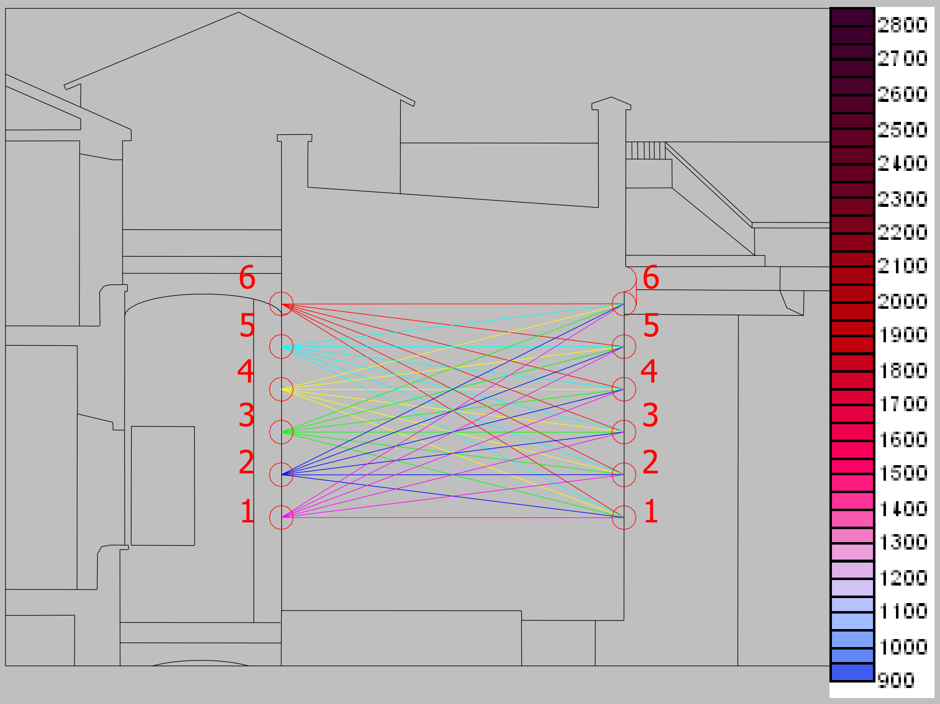
6
5
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2100
2000
1900
1800
1700
1600
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1400
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1200
1100
1000
900

MONITORING SYSTEM: STATIC

ACQUIRING KNOWLEDGE OF THE STRUCTURE

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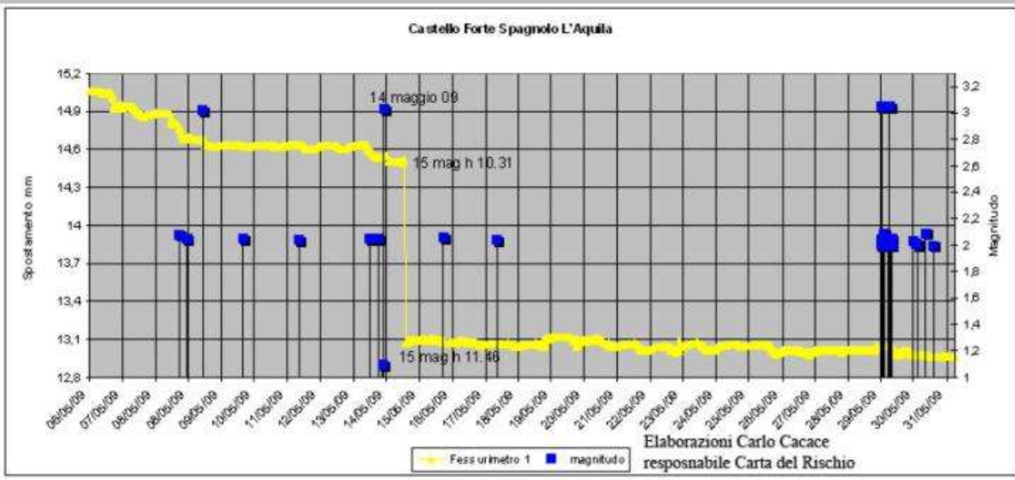
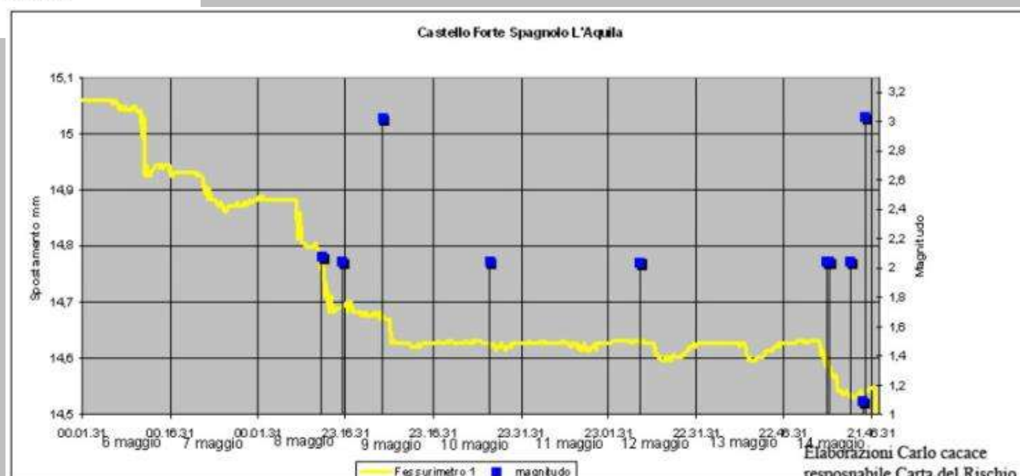
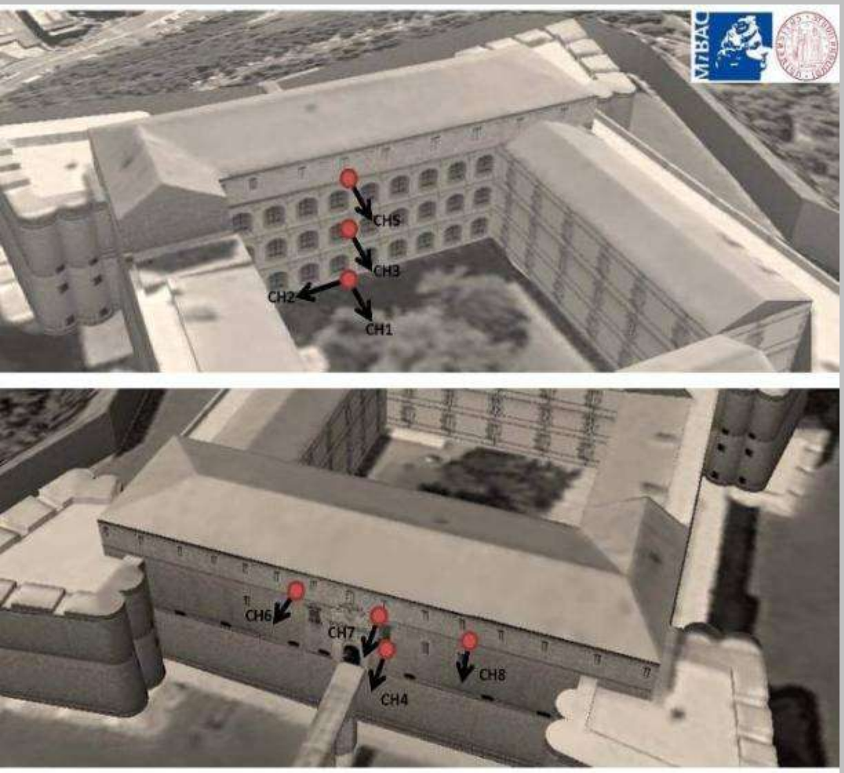


Maggio 2009 rappresentazione delle magnitudo (IGNV) e i rilevamenti dei fessurimetri Il giorno 15 maggio Sono stati applicati i tiranti e si giustifica il salto (chiusura della fessura).



Maggio 2009 rappresentazione delle magnitudo (IGNV) e i rilevamenti dei fessurimetri. Il mese è suddiviso due momenti prima dei tiranti. (06-15/05)

MONITORING SYSTEM: DYNAMIC



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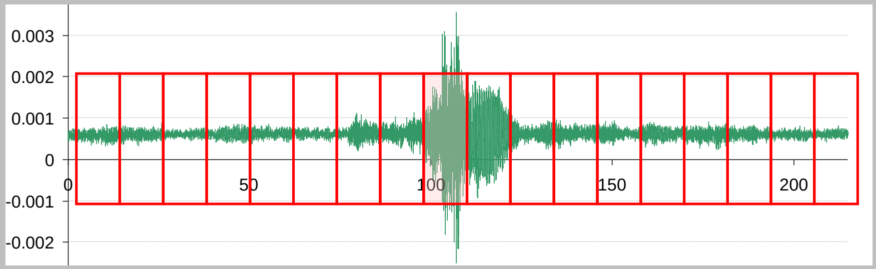

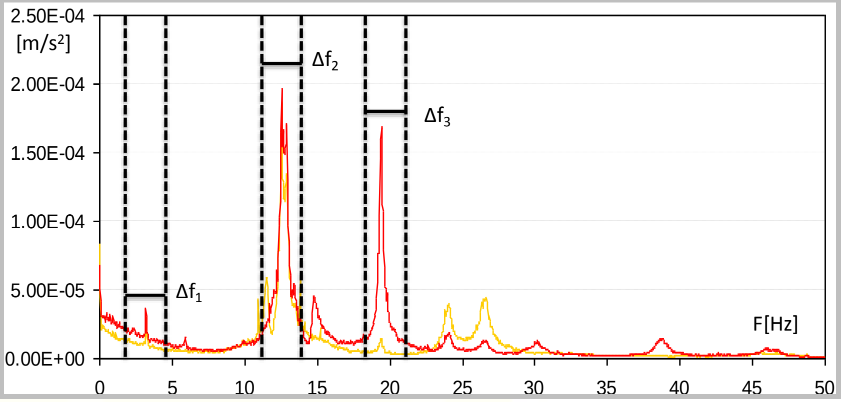

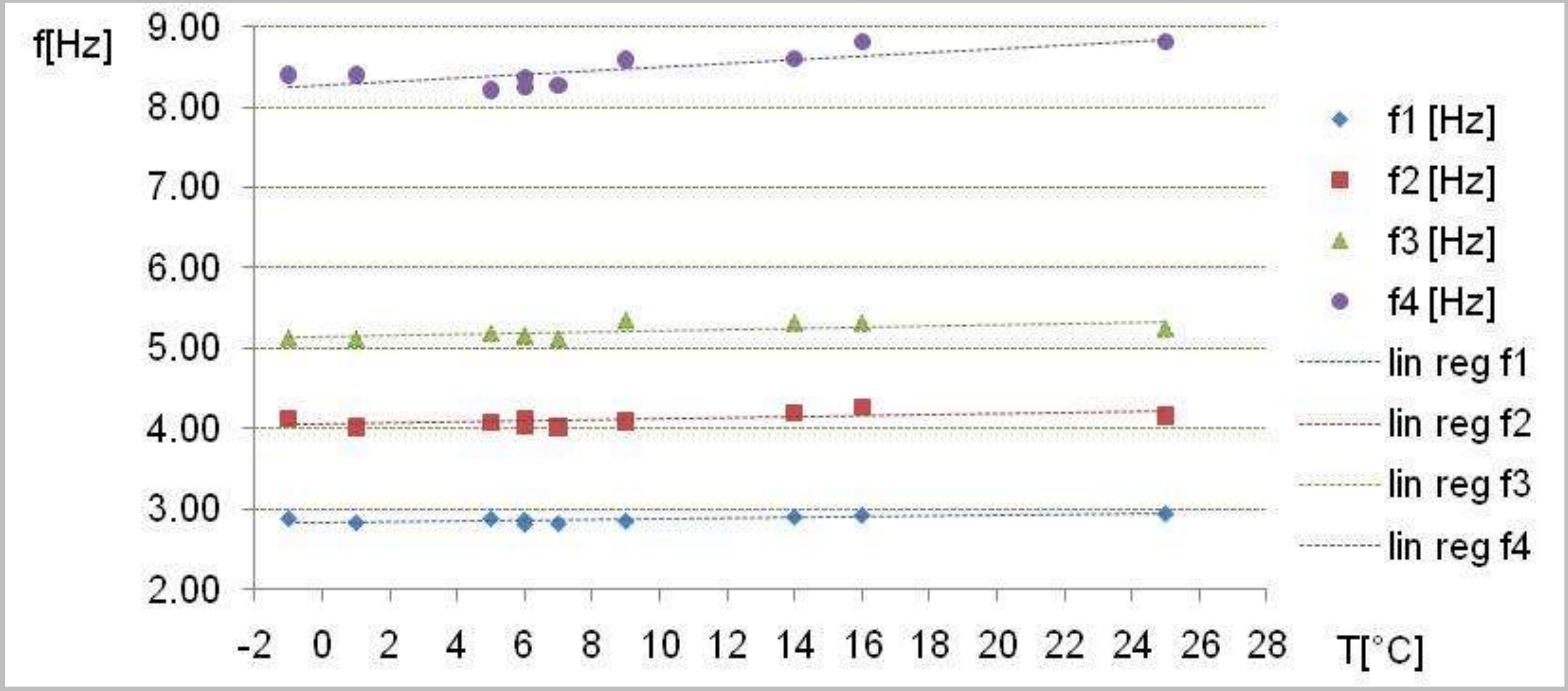

THANK YOU!

SPEAKER: PROF. FRANCESCA DA PORTO

DEPARTMENT OF STRUCTURAL & TRANSPORTATIONS ENGINEERING
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