ANALYSIS AND INTERVENTION ON AGGREGATES OF HISTORICAL CENTERS: A CASE STUDY IN L'AQUILA

Speaker: Prof. Francesca da Porto

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CIVIL, ARCHITECTURAL AND ENVIRONMENTAL ENGINEERING

L'AQUILA: WORKING GROUP 'HISTORIC CENTRES'

- Carry out a pilot case study of an aggregate building in L'Aquila historic centre, to give an operational methodology that allows working according to the ord. 3820;

- The work has been carried out by the "Working group for the evaluation of seismic safety and intervention strategies on masonry buildings in historic centres".

- Department of Civil Defence
- ReLUIS consortium
- Vice-commissioner for cultural heritage

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METHODOLOGY OF ANALYSIS

1. IDENTIFICATION OF THE AGGREGATE
2. HYPOTHESYS ON THE FORMATION AND EVOLUTION OF THE AGGREGATE
3. GEOMETRIC SURVEY
4. COSTRUCTIVE – STRUCTURAL SURVEY
5. CRITICAL SURVEY – STATE OF DAMAGE
6. INSTRUMENTAL TESTS – ON SITE TESTS
7. STRUCTURAL ANALYSIS AND SEISMIC VULNERABILITY
8. DEFINITION OF INTERVENTION

GUIDE LINES

METHODOLOGY OF ANALYSIS

LINEE GUIDA PER IL RILIEVO, L'ANALISI ED IL PROGETTO DI INTERVENTI DI RIPARAZIONE E CONSOLIDAMENTO SISMICO DI EDIFICI IN MURATURA IN AGGREGATO

BOZZA

Dipartimento Protezione Civile

ReLUIS

Ufficio del Vice-Commissario Delegato per la Messa in Sicurezza dei Beni Culturali

Struttura Tecnica di Missione

BOZZA – Ottobre 2010

Versione 3 (Capitoli 1, 2, 3 e 4 - Appendici A e B)

1

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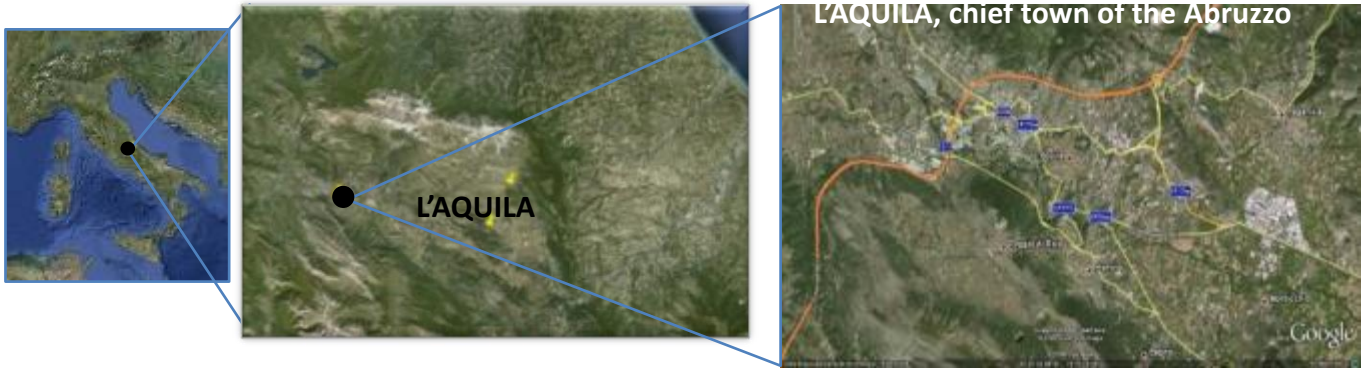
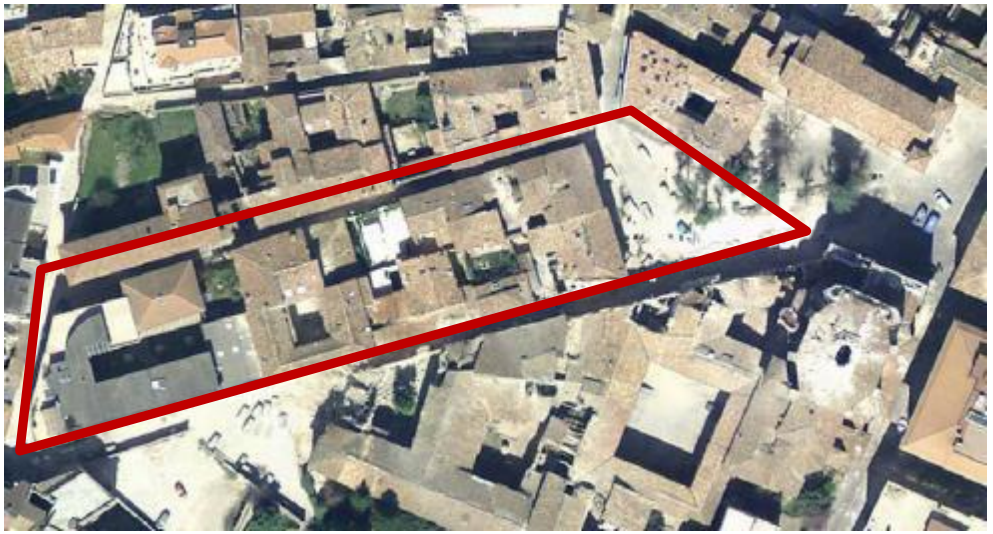
KNOWLEDGE PHASE

IDENTIFICATION OF THE AGGREGATE BUILDING

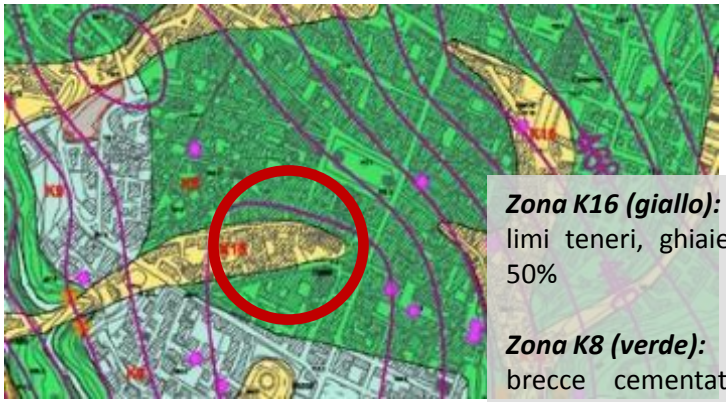




KNOWLEDGE PHASE

STUDY OF THE SITE MORPHOLOGY

1 - Morphological development of the aggregate



Zona K16 (giallo):
limi teneri, ghiaie, sabbie, Dr=30-50%

Zona K8 (verde):
brecce cementate e luoghi in matrice limosa bianca

2 - Preliminary geotechnical analysis of the soil: microzoning map

KNOWLEDGE PHASE

ANALYSIS OF HISTORIC SECTIONS AND ARCHIVE MATERIAL

Historic section of **1500.**

Historic section of **1700**.

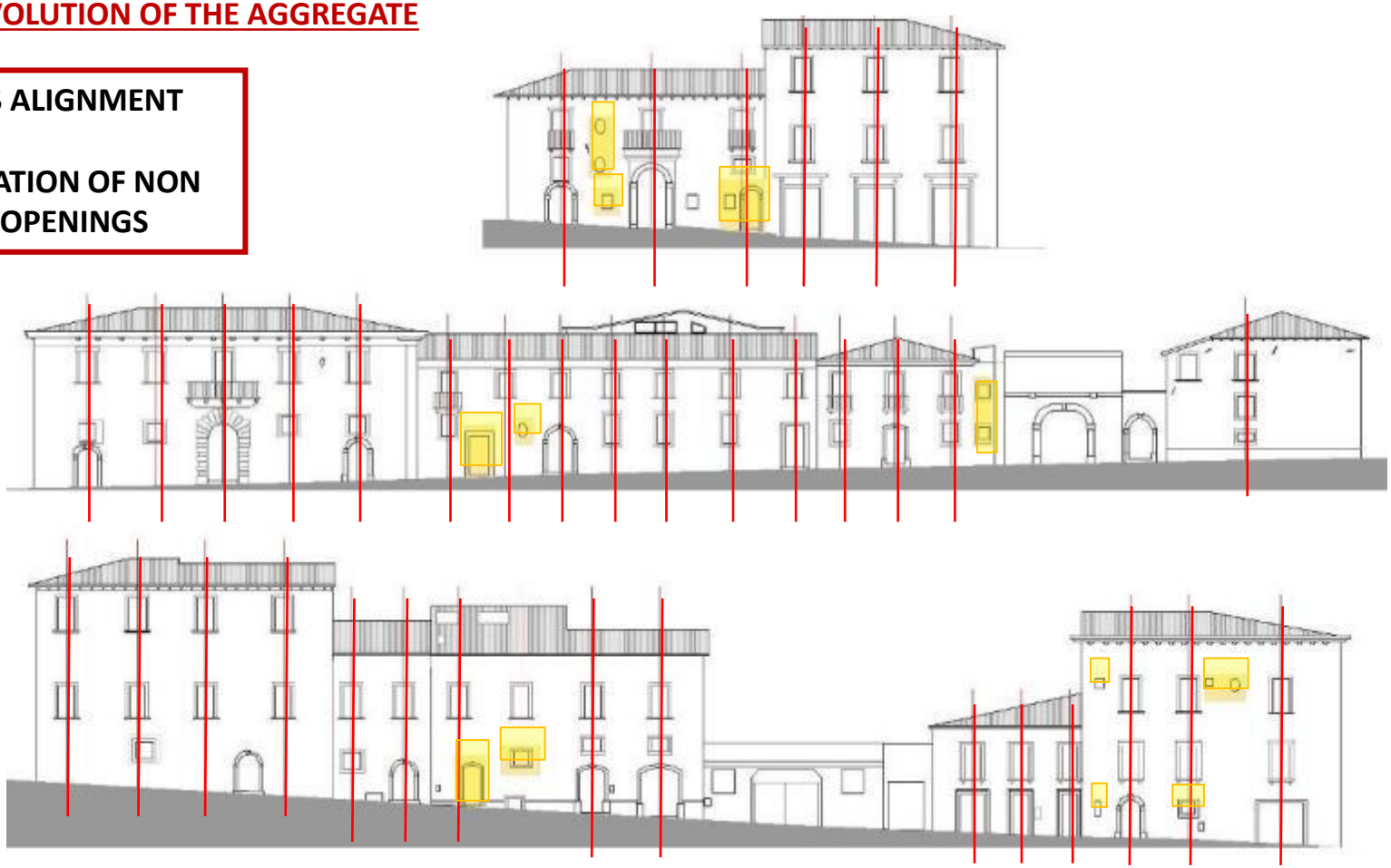
Historic section of **1703**.
The earthquake-induced damages are highlighted

Historic section of **1858**.

KNOWLEDGE PHASE

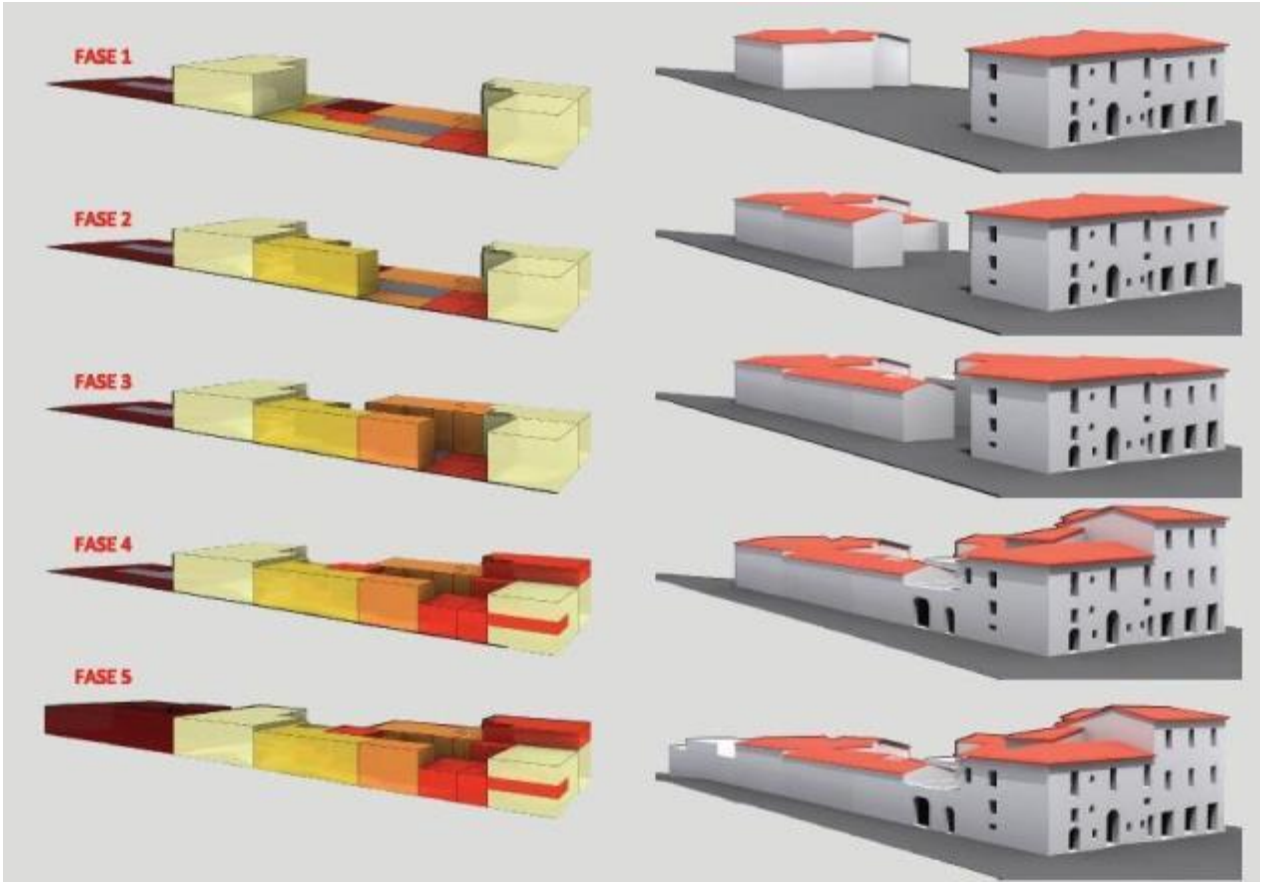
STUDY OF THE EVOLUTION OF THE AGGREGATE

- **OPENINGS ALIGNMENT**
- **IDENTIFICATION OF NON ORIGINAL OPENINGS**



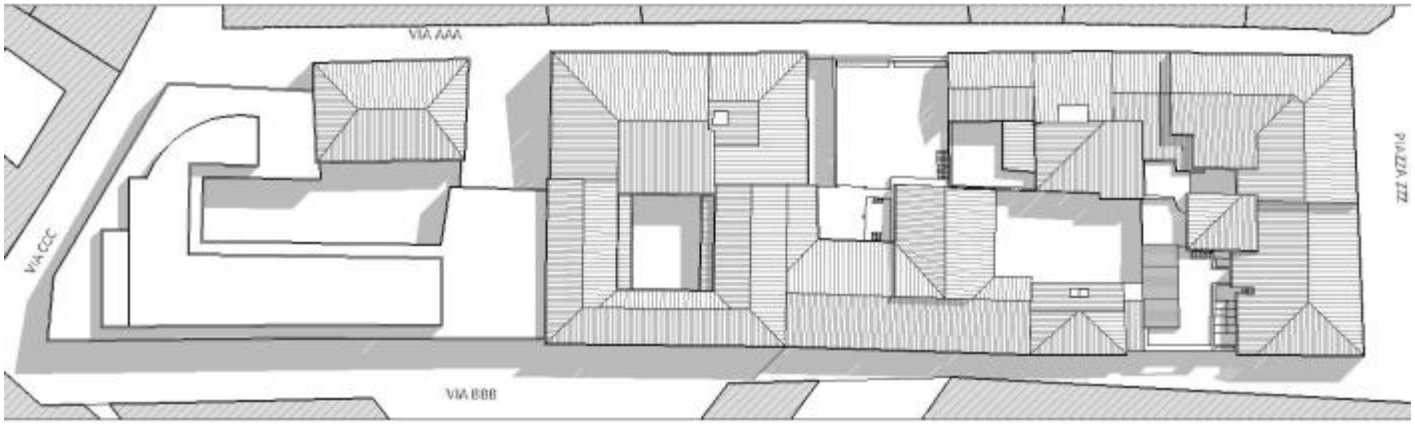
KNOWLEDGE PHASE

HYPOTHESIS ON THE EVOLUTION OF THE AGGREGATE



SURVEY PHASE: Geometric survey

IDENTIFICATION OF THE PLAN AND ELEVATION CHARACTERISTICS OF THE CONSTRUCTION ELEMENTS



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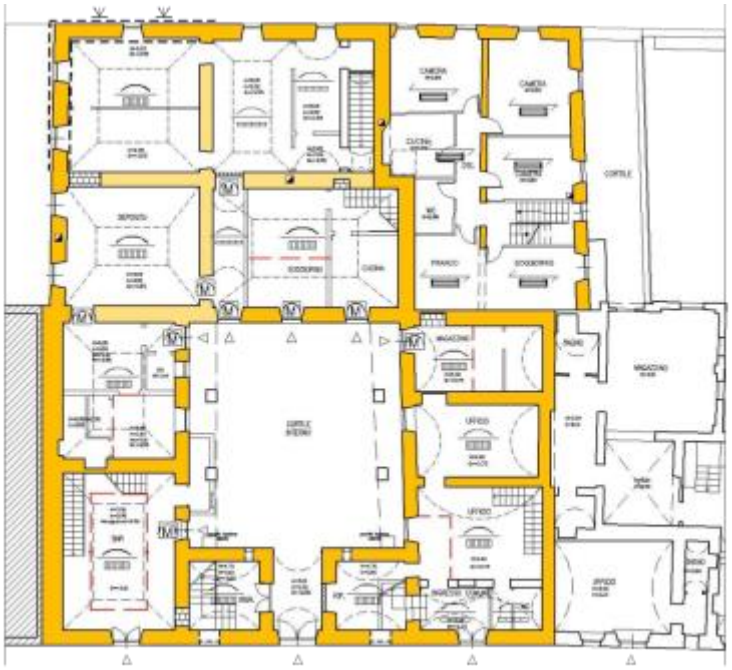
SURVEY PHASE: Structural survey

ANALYSIS OF THE LOCAL CONSTRUCTION TECHNIQUE



PIANTA PIANO TERRA

SUMMARY TABLE OF THE ANALYSIS OF:

-VERTICAL ELEMENTS

- HORIZONTAL ELEMENTS

PIANTA PIANO PRIMO

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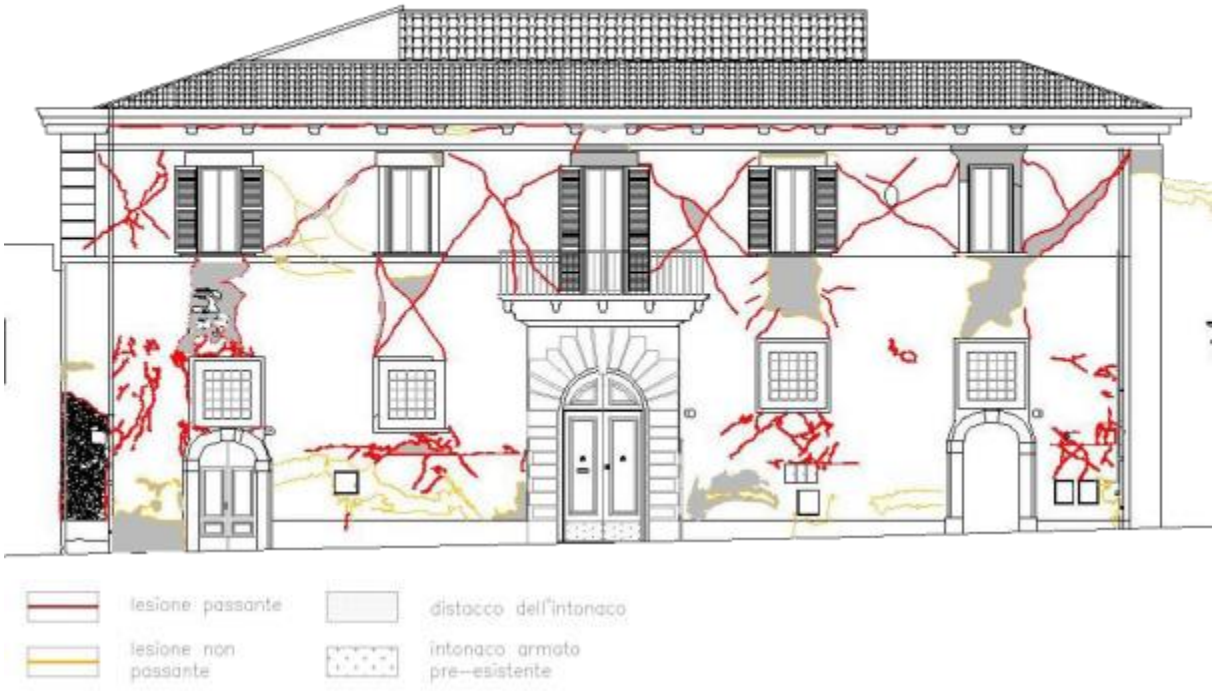
SURVEY PHASE: Critical survey

ANALYSIS OF THE CRACK PATTERN



SURVEY PHASE: Critical survey

IDENTIFICATION OF THE ACTIVATED MECHANISMS

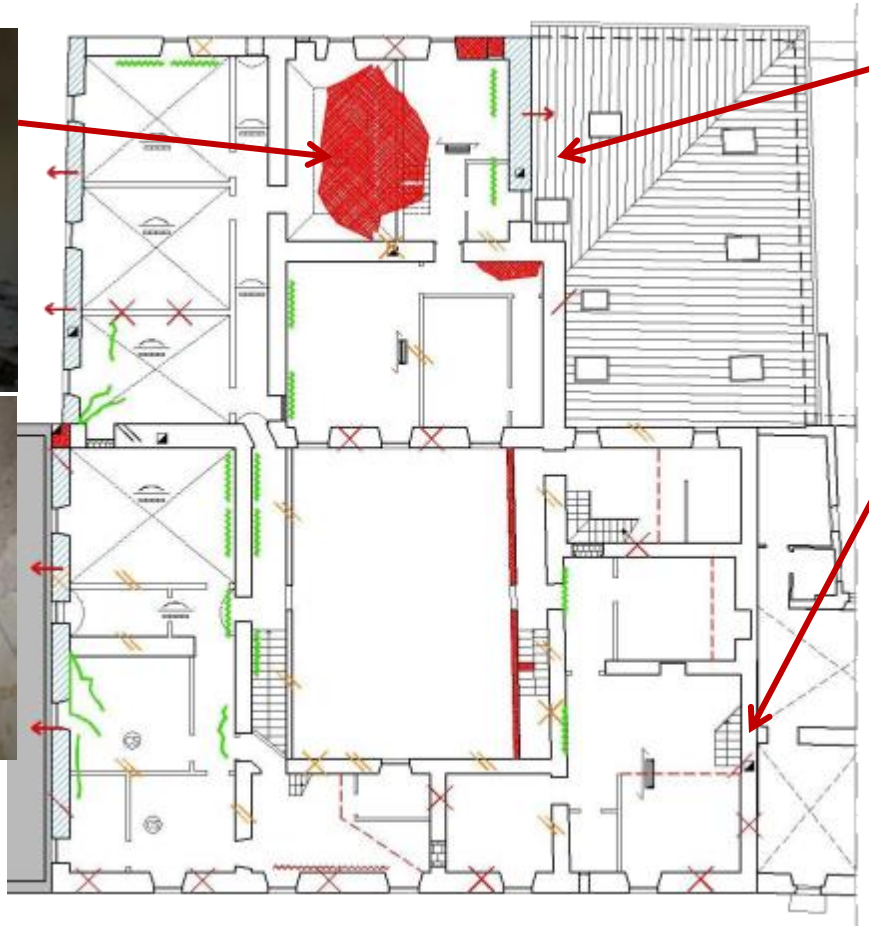
SIMPLE OVERTURNING

OVERTURNING WITH INVOLVEMENT OF THE WEDGE

SURVEY PHASE: Critical survey

IDENTIFICATION OF THE VULNERABILITIES

COLLAPSE OF THIN VAULTS



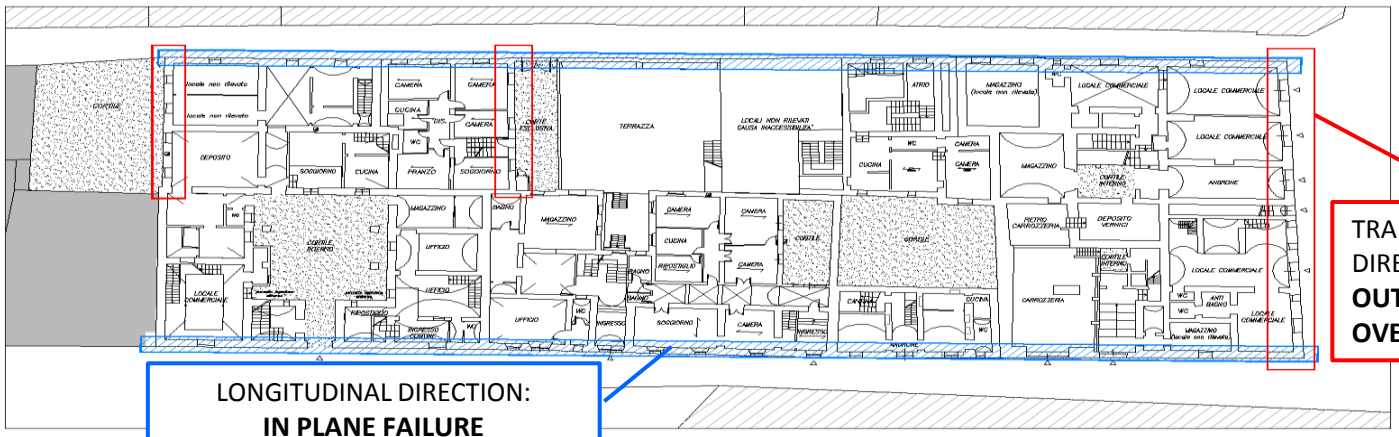
WEAKENING OF MASONRY

R.C TIE BEAM

SURVEY PHASE: Critical survey

IDENTIFICATION OF THE VULNERABILITIES

GLOBAL BEHAVIOUR OF THE AGGREAGATE



TRANSVERSAL DIRECTION:
OUT-OF-PLANE OVERTURNING

LONGITUDINAL DIRECTION:
IN PLANE FAILURE

SURVEY PHASE: Critical survey

STUDY OF THE DAMAGE PATTERN AND OF THE INTRINSIC VULNERABILITIES

ELEMENTS VULNERABILITIES


LACK OF CONNECTIONS


INSUFFICIENT MASONRY QUALITY

- LACK OF CHAINS
- INSUFFICIENT STATIC BEHAVIOUR
- PRESENCE OF PUSHING ELEMENTS
- VARIATION OF THE RESISTANT AREA AMONG FLOORS

LOCALIZED VULNERABILITIES


IRREGULAR DISTRIBUTION OF OPENINGS


PRESENCE OF NON ORIGINAL ELEMENTS

ON SITE TEST

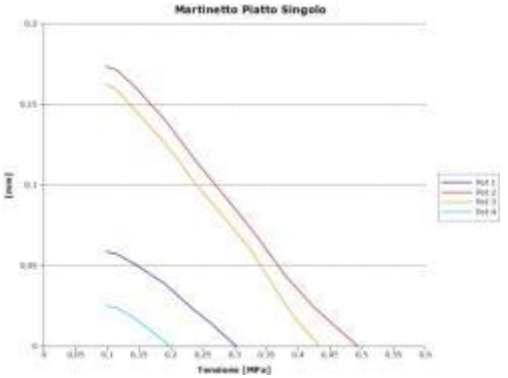
TEST CAMPAIGN

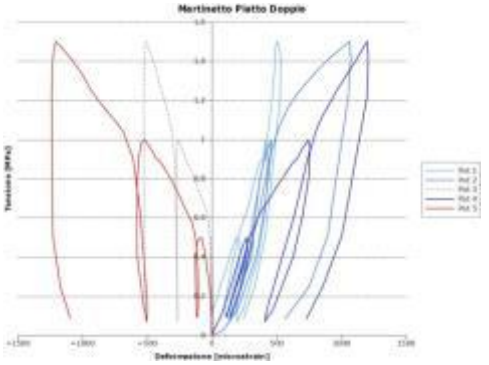
1. **SONIC TESTS**
2. **TOMOGRAPHIC TESTS**
3. **SINGLE AND DOUBLE FLAT JACK TESTS**
4. **INJECTABILITY TESTS**
5. **VERIFICATION TESTS WITH SINGLE AND DOUBLE FLAT JACK**

SONIC TESTS

FLAT JACK TESTS

- SINGLE: STATE OF STRESS
- DOUBLE: IDENTIFICATION OF MECHANICAL PROPERTIES

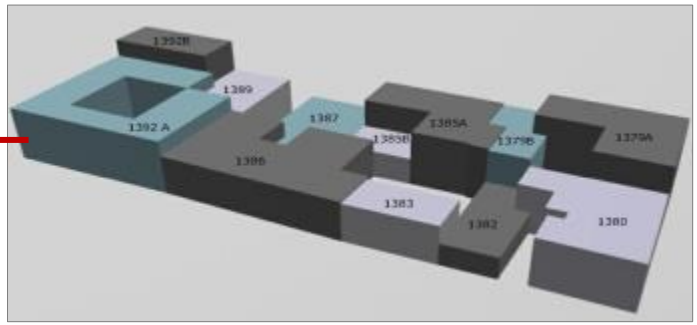




STRUCTURAL ANALYSIS AND SEISMIC VULNERABILITY

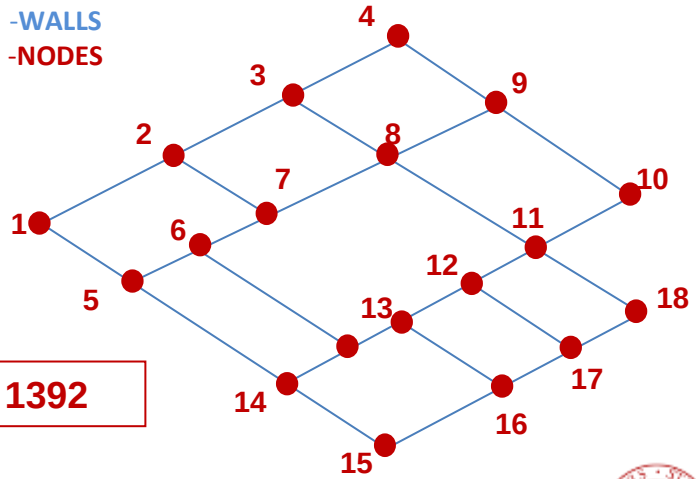
VERIFICATION THROUGH SIMPLIFIED MODELS: VULNUS

1) SUBDIVISION OF THE AGGREGATE INTO 12 STRUCTURAL UNITS (U.S.)



2) OUTLINE OF THE RESISTANT SYSTEM

-WALLS
-NODES



U.S 1392

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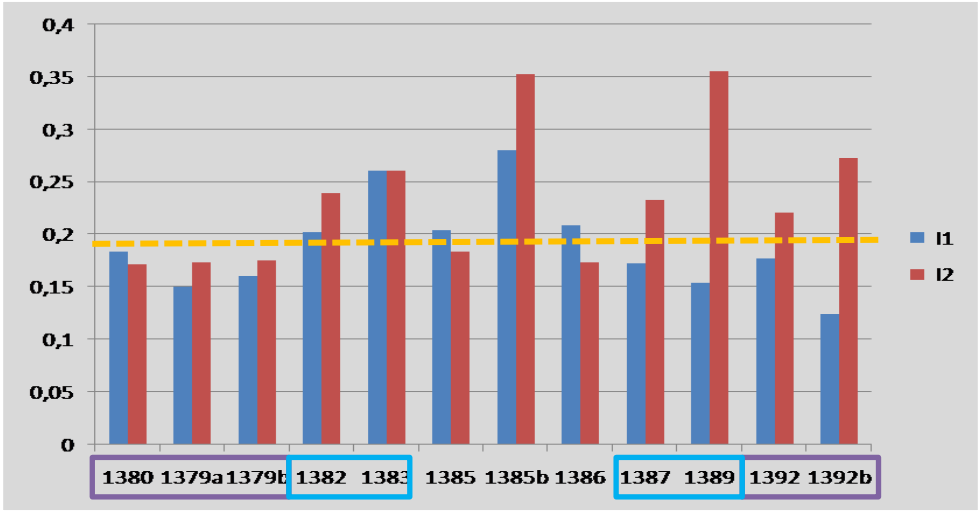
STRUCTURAL ANALYSIS AND SEISMIC VULNERABILITY

VERIFICATION THROUGH SIMPLIFIED MODELS: VULNUS

I1 :SHEAR STRENGTH OF MASONRY WALLS PARALLEL TO SEISMIC ACTION

I2: OUT-OF-PLANE STRENGTH OF MASONRY WALLS PERPENDICULAR TO SEISMIC ACTION



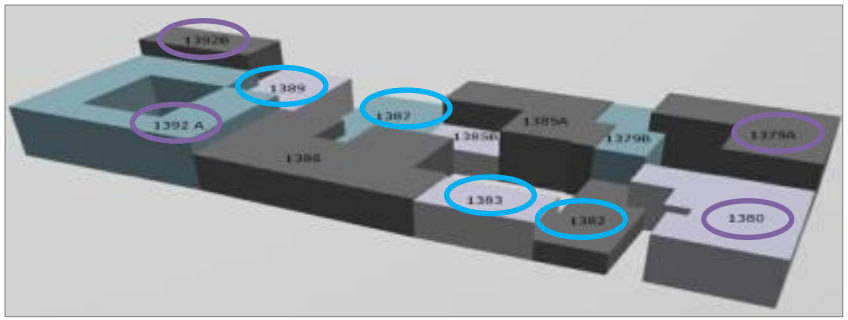
- LOW VALUES OF I1 AND I2 FOR TALL BUILDINGS OR BUILDINGS AT THE ENDS OF THE AGGREGATE
- LOW VULNERABILITY FOR SQUAT OR INTERNAL BUILDINGS

OBJECTIVE
IDENTIFICATION
OF MOST VULNERABLE
MECHANISMS FOR EACH U.S.

I1<I2

HIGHER IN-PLANE VULNERABILITY

CAUSE:
-GEOMETRY OF THE AGGREGATE
- MATERIAL



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STRUCTURAL ANALYSIS AND SEISMIC VULNERABILITY

VERIFICATION OF THE LOCAL COLLAPSE MECHANISMS: c – SISMA 3.0 PRO

EVALUATION OF SINGLE MACROELEMENTS BASED ON LOCAL MODELS AND ON KINEMATIC ANALYSIS, CALCULATION OF TIES

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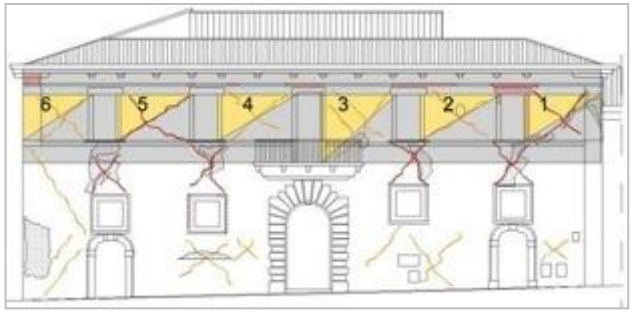
OUT-OF-PLANE MECHANISMS

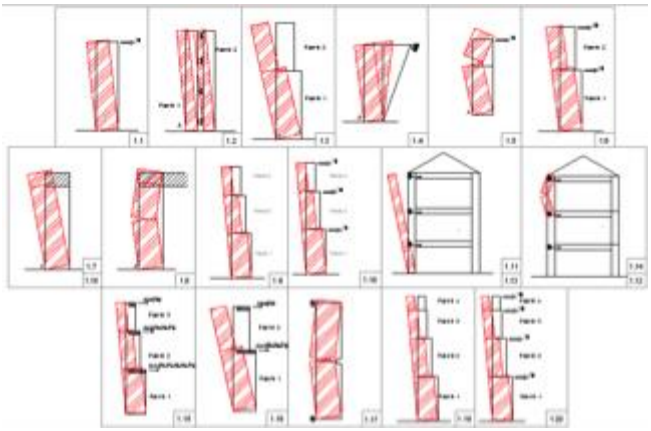
IN-PLANE MECHANISMS

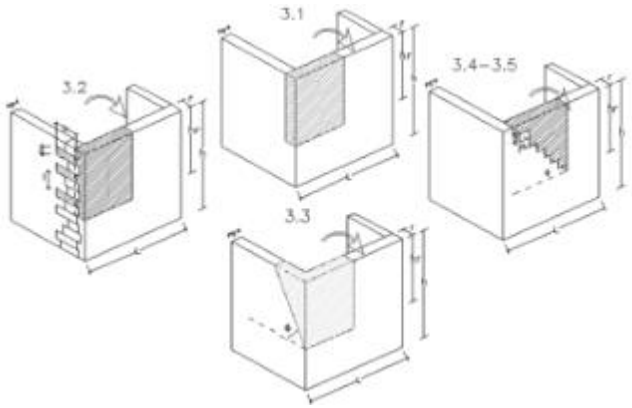


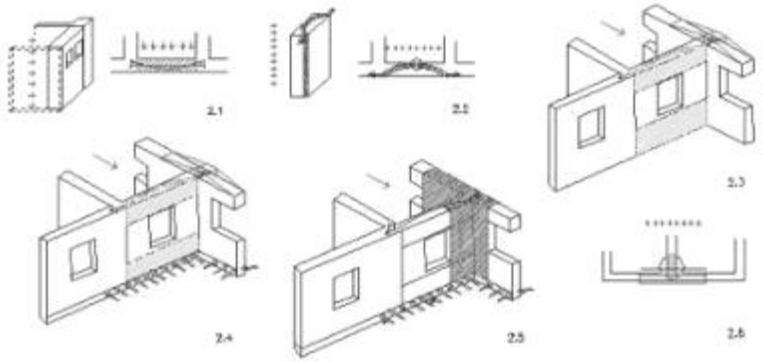
STRUCTURAL ANALYSIS AND SEISMIC VULNERABILITY

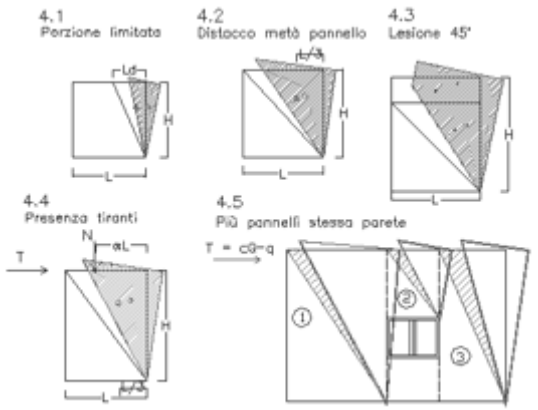
VERIFICATION OF THE LOCAL COLLAPSE MECHANISMS: c – SISMA 3.0 PRO

C-Sisma 3.0 PRO allows analyzing:









STRUCTURAL ANALYSIS AND SEISMIC VULNERABILITY

VERIFICATION OF THE LOCAL COLLAPSE MECHANISMS

GLOBAL OVERTURNING

ANALISI LINEARE								
t [m]	M_S [kNm]	M_R [kNm]	α_0	M* [t]	e*	a_0^* [m/s²]	$\overline{a_0^*}$ [m/s²]	$a_0^* \geq \overline{a_0^*}$
0,15	46,24	11072,63	0,004	154,65	0,7495	0,040	1,313	NO

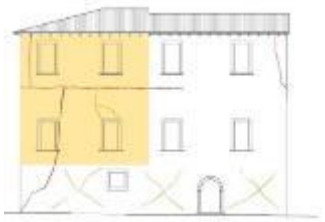
ANALISI NON LINEARE					
θ [rad]	d_{k0}[m]	d_0^*[m]	d_u^*[m]	$\overline{d_u^*}$ [m]	$d_u^* \geq \overline{d_u^*}$ [m]
0,0204	0,1152	0,1536	0,0615	0,2209	NO

NOT VERIFIED
ULTIMATE DISPLACEMENT CAPACITY
27%

PARTIAL OVERTURNING

ANALISI LINEARE								
t [m]	M_S [kNm]	M_R [kNm]	α_0	M* [t]	e*	a_0^* [m/s²]	$\overline{a_0^*}$ [m/s²]	$a_0^* \geq \overline{a_0^*}$
0,11	342,91	5146,99	0,067	96,18	0,8217	0,589	1,31	NO

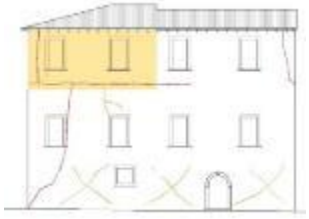
ANALISI NON LINEARE					
θ [rad]	d_{k0}[m]	d_0^*[m]	d_u^*[m]	$\overline{d_u^*}$ [m]	$d_u^* \geq \overline{d_u^*}$ [m]
0,067	0,300	0,365	0,1461	0,1804	NO



NOT VERIFIED
ULTIMATE DISPLACEMENT CAPACITY
80%

ANALISI LINEARE								
t [m]	M_S [kNm]	M_R [kNm]	α_0	M* [t]	e*	a_0^* [m/s²]	$\overline{a_0^*}$ [m/s²]	$a_0^* \geq \overline{a_0^*}$
0,041	179,54	1080,87	0,166	48,04	0,947	1,274	2,64	NO

ANALISI NON LINEARE					
θ [rad]	d_{k0}[m]	d_0^*[m]	d_u^*[m]	$\overline{d_u^*}$ [m]	$d_u^* \geq \overline{d_u^*}$ [m]
0,1648	0,3570	0,3764	0,1506	0,1245	SI



HIGH HORIZONTAL THRUSTS DUE TO THRUSTING ELEMENTS

VERIFIED
ULTIMATE DISPLACEMENT CAPACITY **120%**

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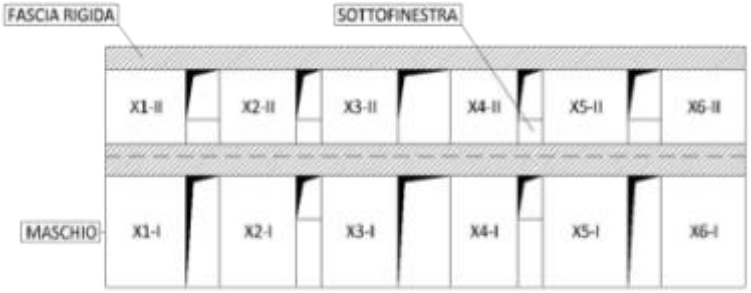
STRUCTURAL ANALYSIS AND SEISMIC VULNERABILITY

GLOBAL MECHANISMS: IN-PLANE VERIFICATIONS

LINEAR STATIC ANALISYS

PROSPETTO SUD



VERIFICA LINEARE LIVELLO I								
SETTO	$V_{Sd,x}$	$M_{Sd,x}$	V_t	$\eta=V_t/V_{Sd}$	$V_t>V_u$	M_u	$\eta=M_u/M_{Sd}$	$M_u>M_{Sd}$
	kN	kNm	kN			kNm		
X1	165,65	430,70	82,05	0,50	FALSO	137,00	0,32	FALSO
X2	152,41	396,26	77,66	0,51	FALSO	69,76	0,18	FALSO
X3	151,53	393,97	67,69	0,45	FALSO	196,16	0,50	FALSO
X4	121,26	315,27	61,68	0,51	FALSO	126,31	0,40	FALSO
X5	183,47	477,03	89,80	0,49	FALSO	194,68	0,41	FALSO
X6	180,79	470,06	84,74	0,47	FALSO	228,76	0,49	FALSO
TOTALE	**955,11**		**463,63**	**0,49**	FALSO			

VERIFICA LINEARE LIVELLO II								
SETTO	$V_{Sd,x}$	$M_{Sd,x}$	V_t	$\eta=V_t/V_{Sd}$	$V_t>V_u$	M_u	$\eta=M_u/M_{Sd}$	$M_u>M_{Sd}$
	kN	kNm	kN			kNm		
X1	102,76	223,50	72,71	0,71	FALSO	224,56	1,00	VERO
X2	96,01	208,83	72,72	0,76	FALSO	214,94	1,03	VERO
X3	95,56	207,85	70,72	0,74	FALSO	208,12	1,00	VERO
X4	79,77	173,50	61,36	0,77	FALSO	176,03	1,01	VERO
X5	111,72	243,00	89,12	0,80	FALSO	287,30	1,18	VERO
X6	110,38	240,08	85,17	0,77	FALSO	276,06	1,15	VERO
TOTALE	**592,21**		**451,81**	**0,76**	FALSO			

Flexure $$M_u = \frac{l^2 t\,\sigma_0}{2}\left(1-\frac{\sigma_0}{0.85\cdot f_d}\right)$$

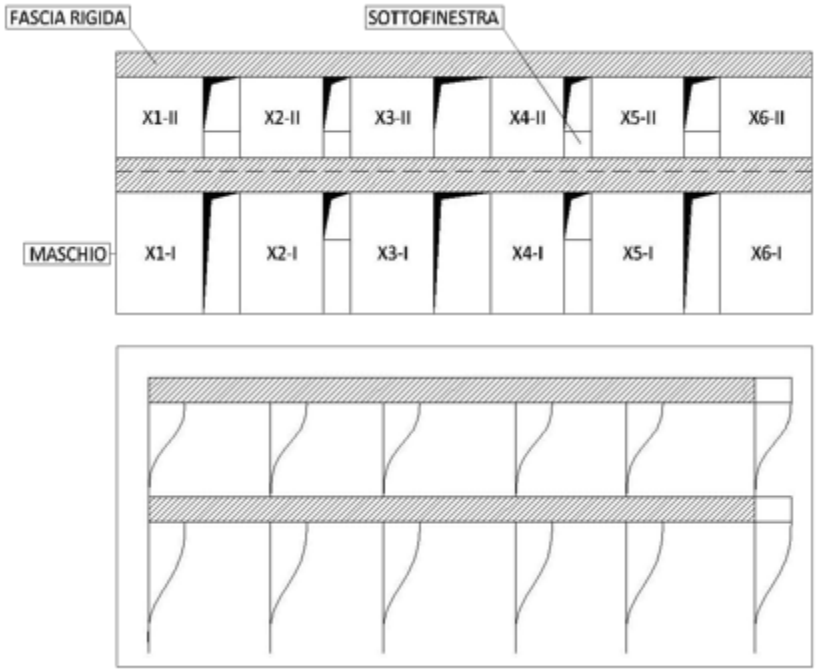
Shear $$V_t = l\cdot t\cdot\frac{1.5\tau_{0_d}}{b}\cdot\sqrt{1+\frac{\sigma_0}{1.5\cdot\tau_{0_d}}}$$

STRUCTURAL ANALYSIS AND SEISMIC VULNERABILITY

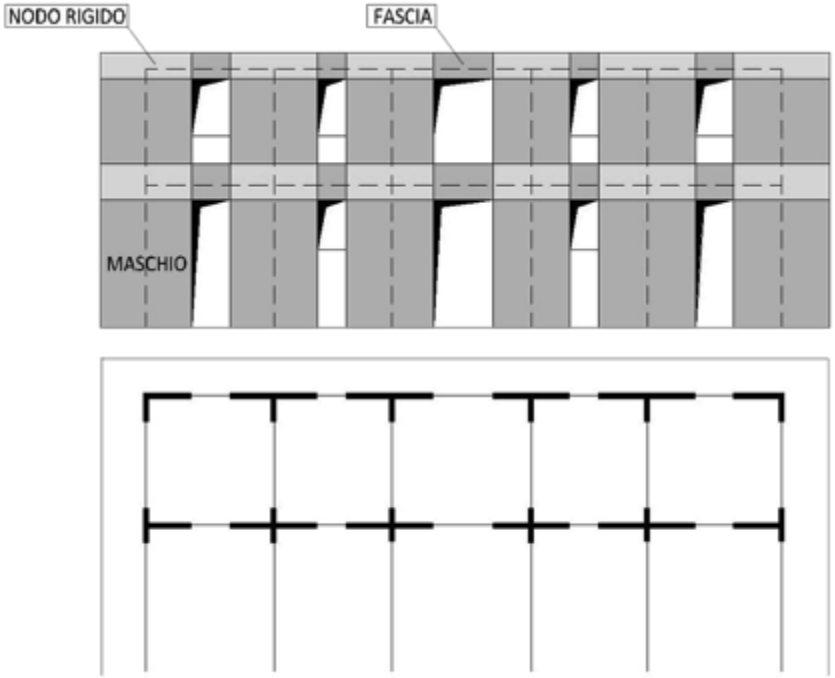
GLOBAL MECHANISMS: IN-PLANE VERIFICATIONS

NON LINEAR STATIC ANALISYS

MACROMODEL WITH RIGID SPANDRELS



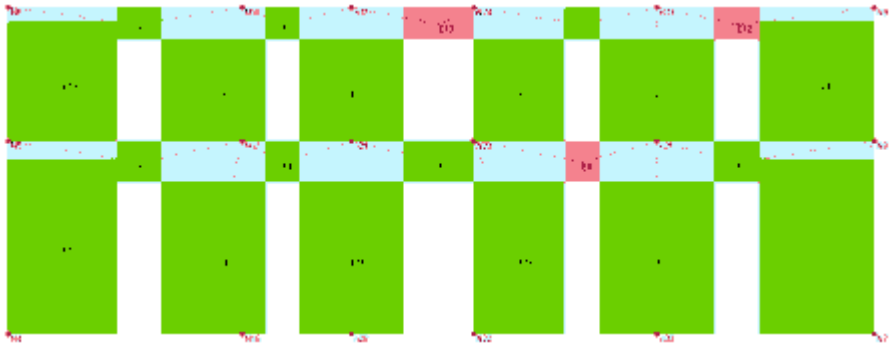
MACROMODEL WITH DEFORMABLE SPANDRELS



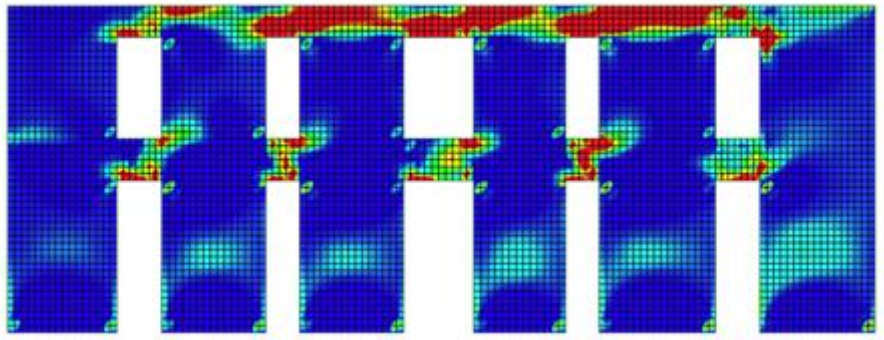
STRUCTURAL ANALYSIS AND SEISMIC VULNERABILITY

GLOBAL MECHANISMS: IN-PLANE VERIFICATIONS

MACROMODEL WITH DEFORMABLE SPANDRELS



FINITE ELEMENT MODEL



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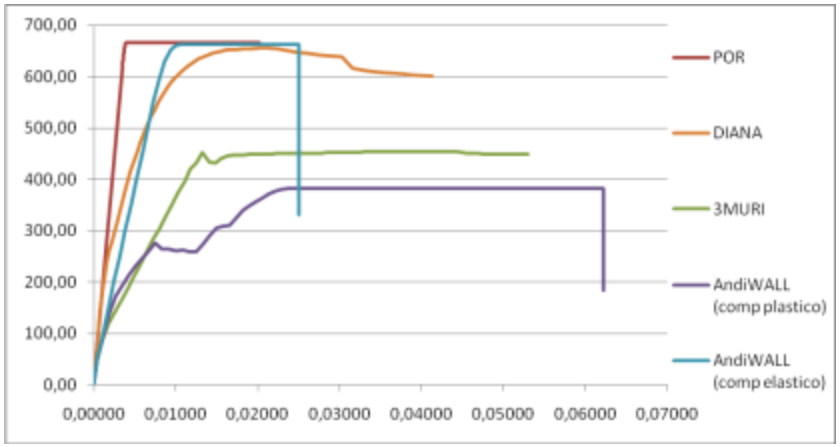

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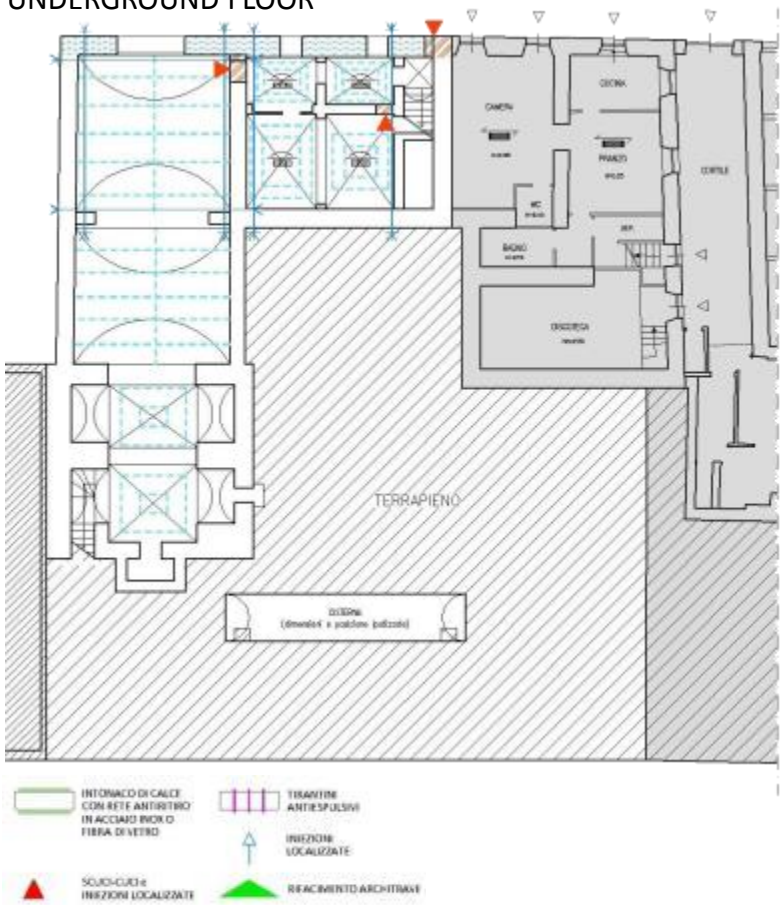
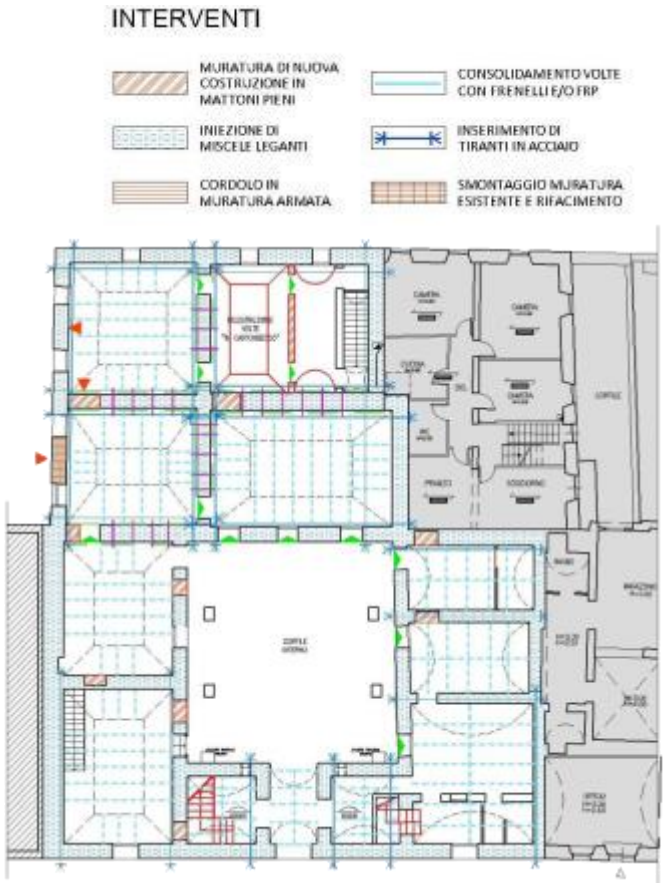
DESIGN OF INTERVENTIONS

UNDERGROUND FLOOR





GROUND FLOOR

DESIGN OF INTERVENTIONS

MASONRY WALLS: NEW CONSTRUCTION

Closing of openings, cavities, chimneys and modification of the original structural condition that may compromise the continuity of the mansory wall and the connection between orthogonal walls

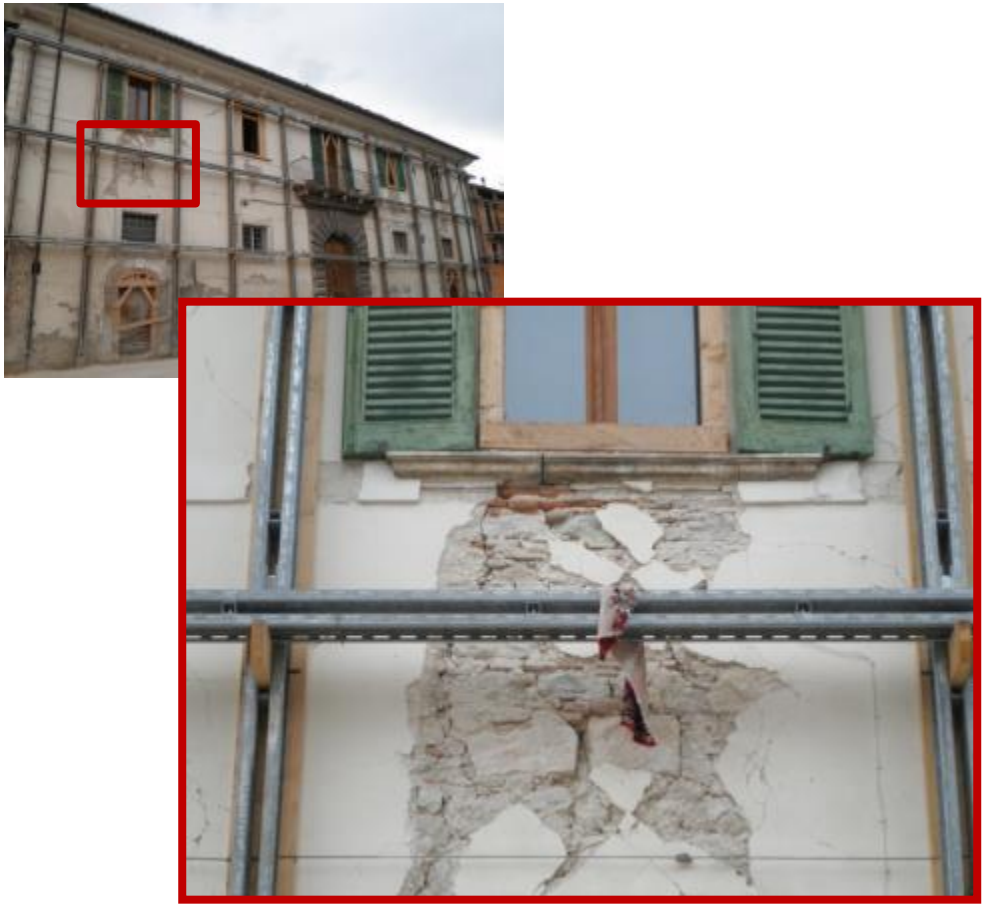
CHIMNEY

LACK OF CONNECTION BETWEEN ORTHOGONAL FLOORS

CLOSING OF AN EXISTING DOOR

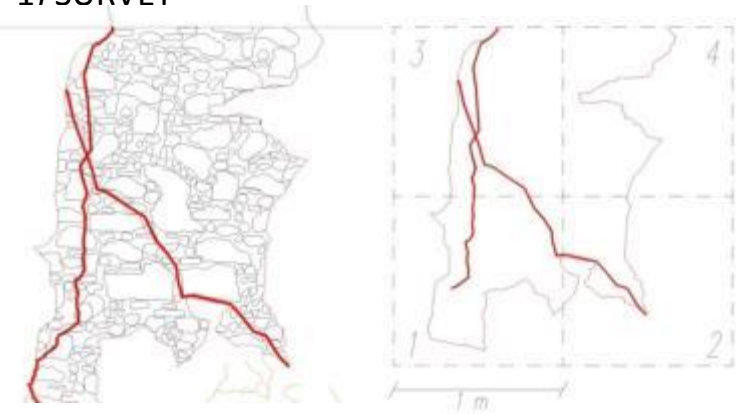
DESIGN OF INTERVENTIONS

MASONRY WALLS: SCUCI - CUCI

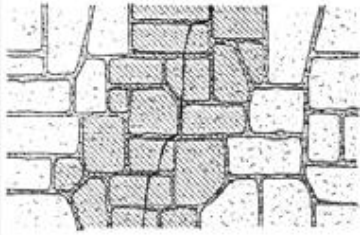


INTERVENTION PHASES:

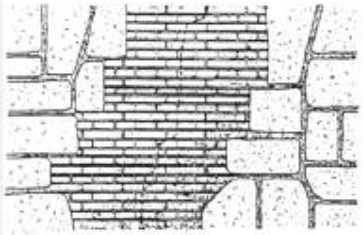
1) SURVEY



2) SUBDIVISION IN PARTS



STONE



BRICK

DESIGN OF INTERVENTIONS

MASONRY WALLS: GROUT INJECTION

DESIGN OF INTERVENTIONS

MASONRY WALLS: GROUT INJECTION

INTERVENTION PHASES:

1) GROUT PREPARATION

2) WALL PREPARATION

3) DRILLING AND PREPARATION OF PIPES

4) EXECUTION OF THE INJECTIONS

5) ON SITE CONTROLS

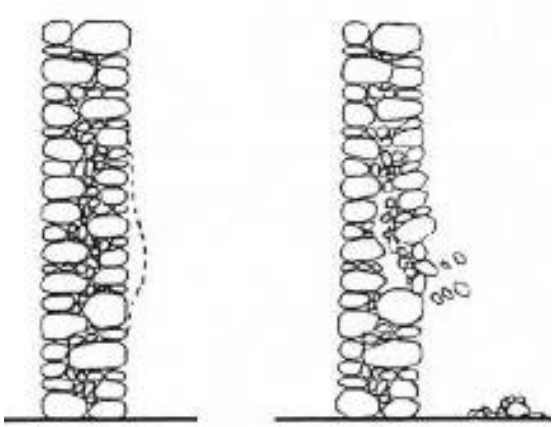
6) EFFECTIVENESS CONTROLS

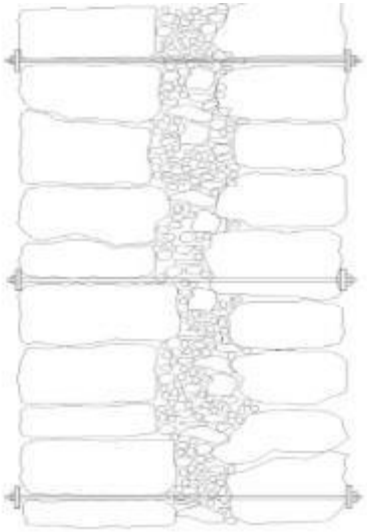





DESIGN OF INTERVENTIONS

MASONRY WALLS: ANTI EXPULSION TIES





INTERVENTION PHASES:

1) DRILLING HOLES:
φ20-25 mm 1HOLE/1MQ

2) INSERTION OF TIES:
φ 16-20 mm STAINLESS STEEL

3) LOCKING OF THE TIE

DESIGN OF INTERVENTIONS

ARCHES AND VAULTS

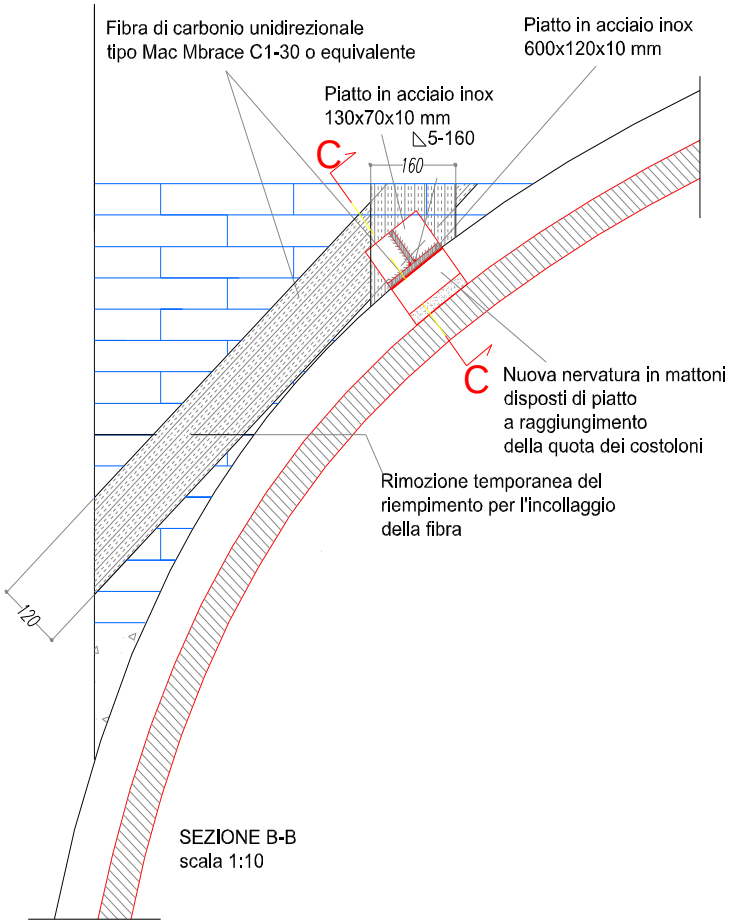
- REDUCTION OF THRUST BY MEANS OF THE REMOVAL OF NON STRUCTURAL MASSES
- RESET OF THE INTERNAL PRESSURE CURVE AND GLOBAL STIFFENING OF THE STRUCTURE


INSPECTION

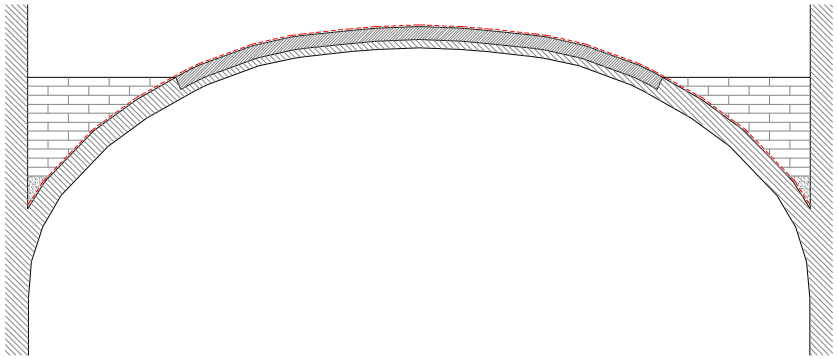
CRACK AT THE SPRINGINGS

DESIGN OF INTERVENTIONS

ARCHES AND VAULTS: FRENELLI AND FRP



SEZIONE B-B
scala 1:10



sezione A-A
scala 1:20

DESIGN OF INTERVENTIONS

ARCHES AND VAULTS: FRP

PRE INTERVENTION

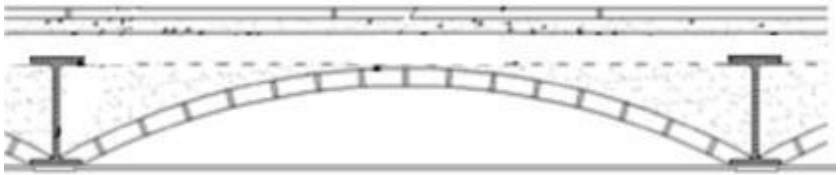


EXECUTION

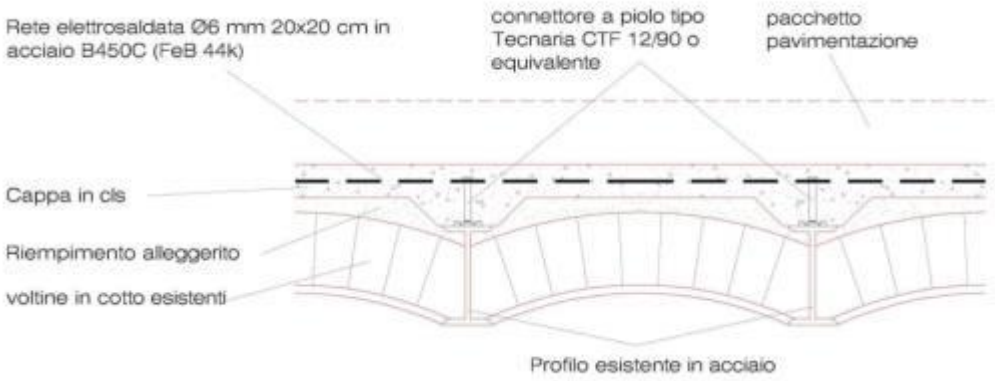

APPLICATION OF FRP STRIPS

DESIGN OF INTERVENTIONS

FLOORS: IMPROVEMENT OF THE IN PLANE STIFFNESS

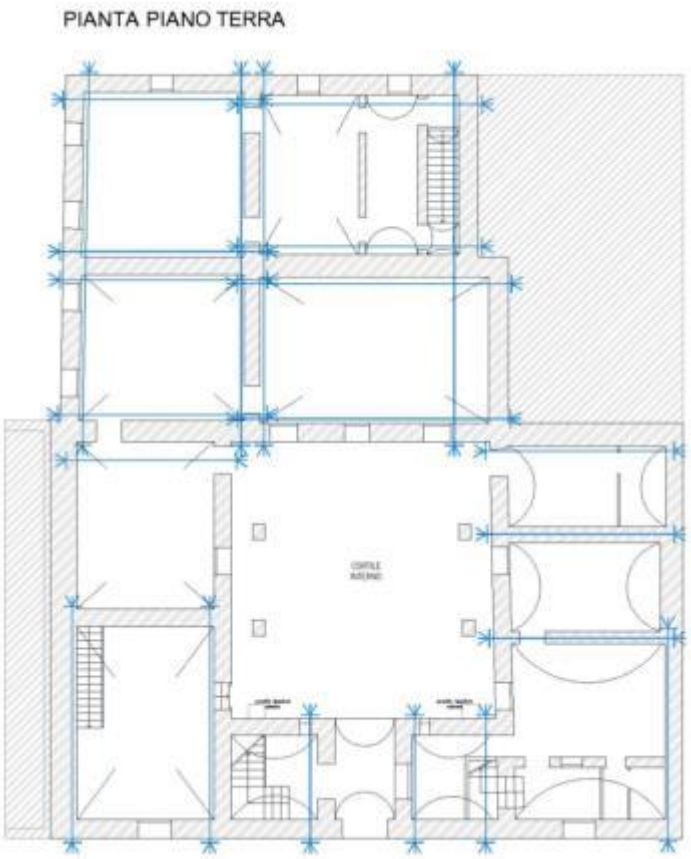


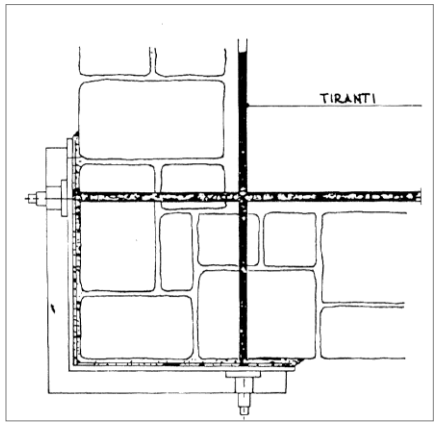
STRENGTHENING OF FLOORS WITH A COLLABORATIVE RC SLAB

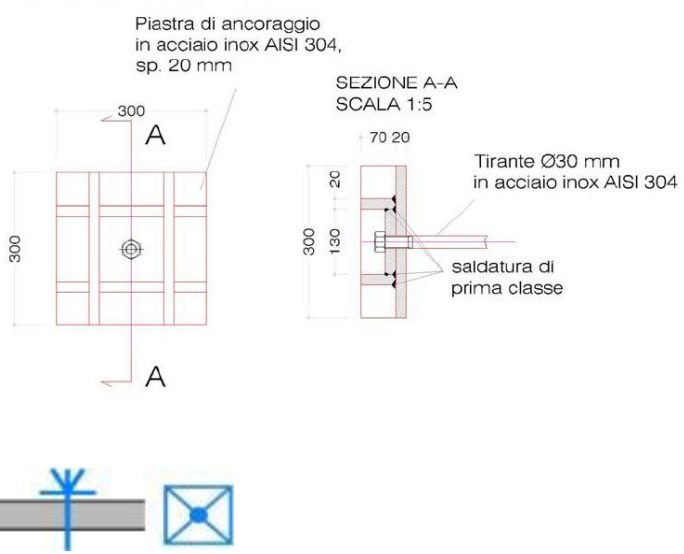


DESIGN OF INTERVENTIONS

CONNECTIONS:TIES



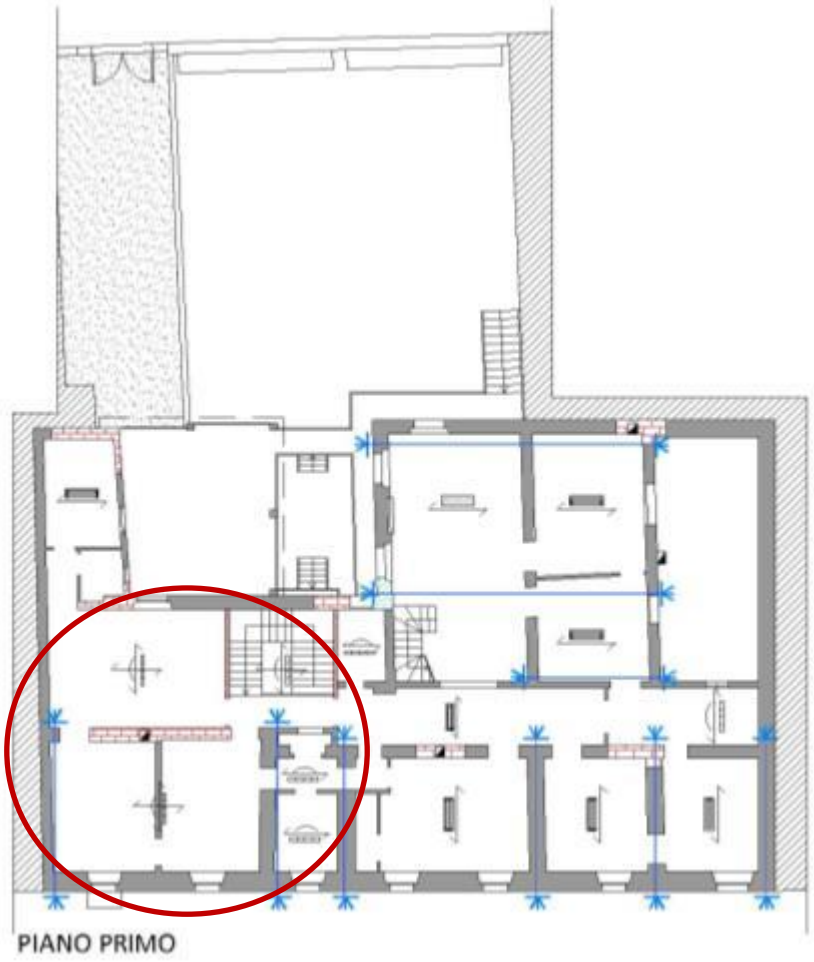




DESIGN OF INTERVENTIONS

CONNECTIONS:TIES

IT IS NECESSARY A STRENGTHENIN INTERVENTION OF MASONRY IN THE ANCHORAGE ZONE

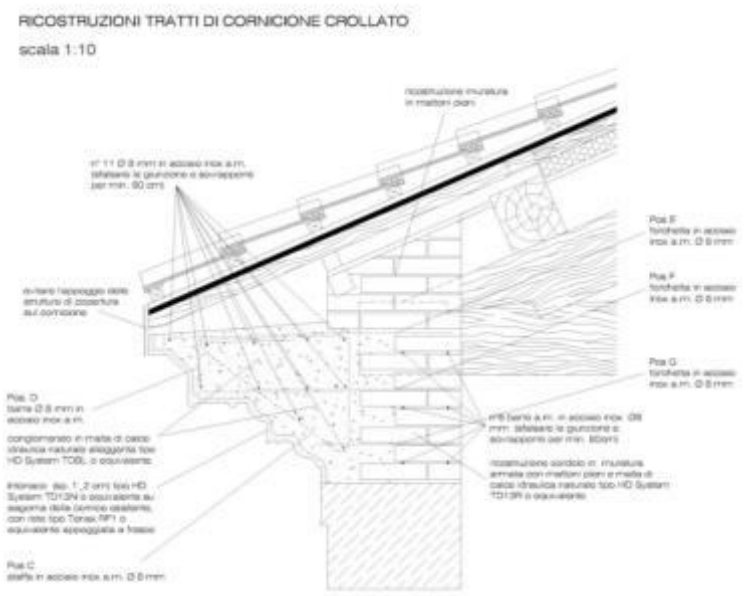


NEW MASONRY WALLS:

RESET OF THE MASONRT CONTINUITY

DESIGN OF INTERVENTIONS

CONNECTIONS: PERIMETER TIE BEAMS



DESIGN OF INTERVENTIONS

FLOORS – TO – WALLS CONNECTIONS

FLOORS-TO-WALLS ANCHORAGE IN ORDER TO AVOID THE EXTRACTION OF THE BEAMS,

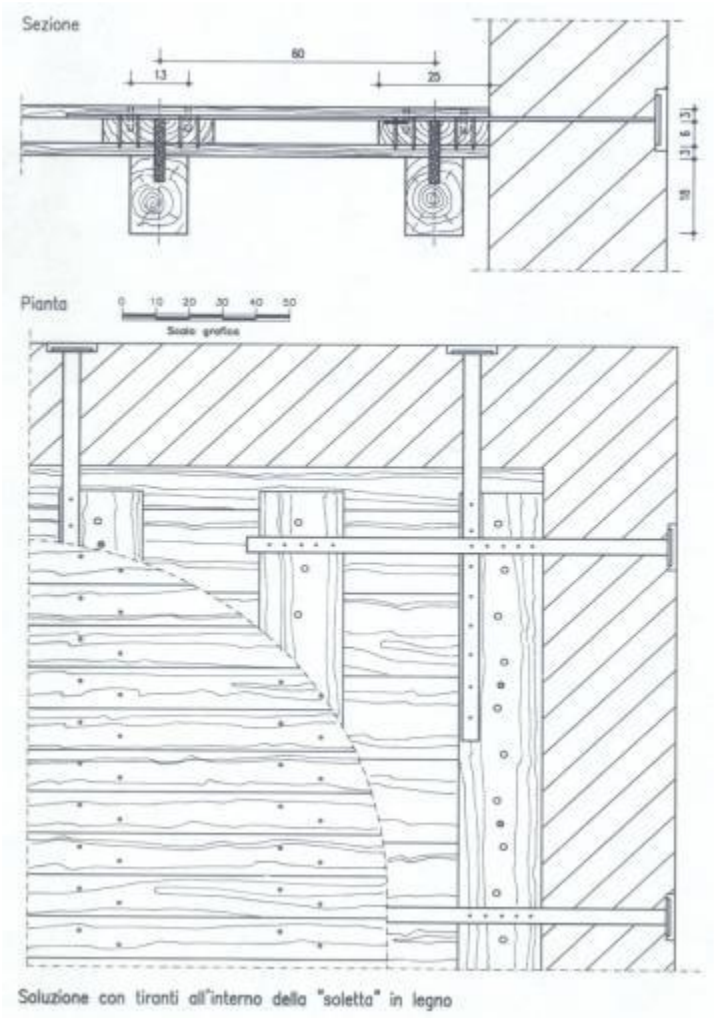
REDISTRIBUTE THE HORIZONTAL ACTIONS AND PREVENT THE OVERTURNING OF WALLS

COLLAPSE INDUCED BY THE LACK OF CONNECTION WITH THE FLOOR AND THE ORTHOGONAL WALLS

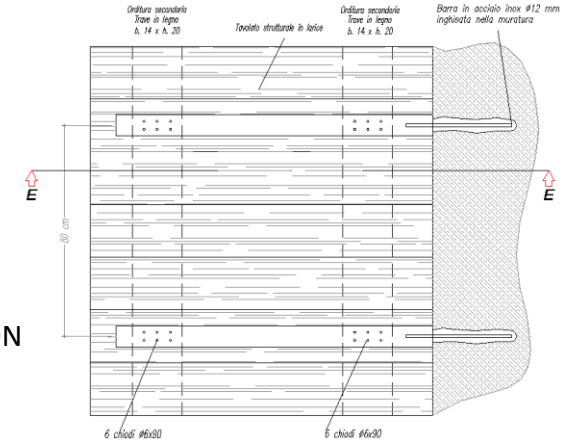
DETACHMENT OF THE WALL FROM THE FLOOR AND THE ORTHOGONAL WALLS

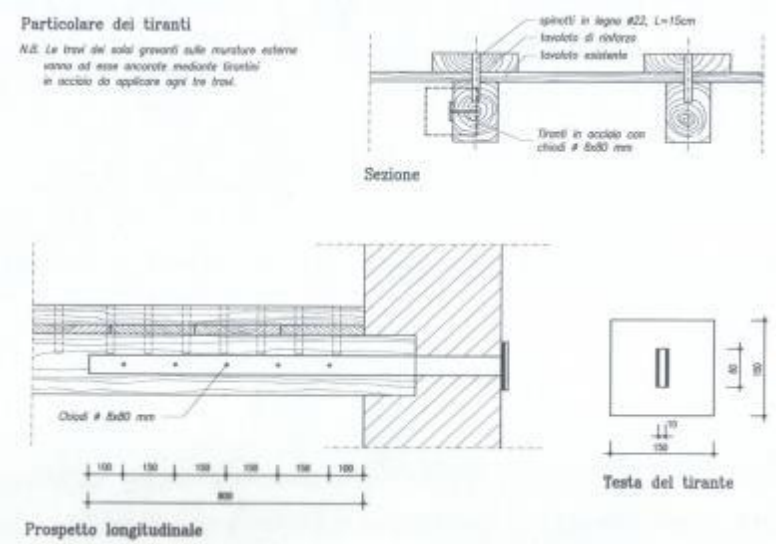
DESIGN OF INTERVENTIONS

FLOORS – TO – WALLS CONNECTIONS



EXAMPLE OF CONNECTION WITH TIMBER FLOORS





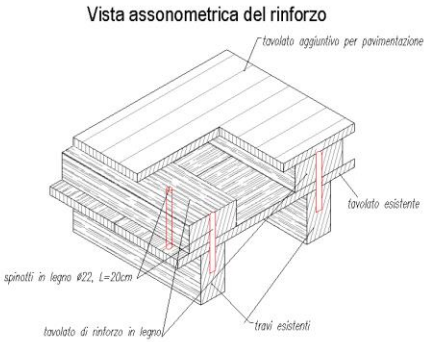
DESIGN OF INTERVENTIONS

TIMBER FLOORS

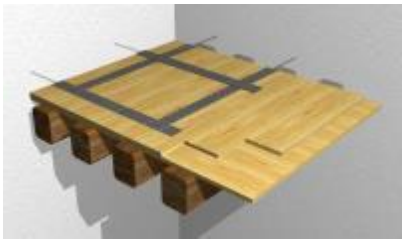
Interventions aimed at the **in-plane stiffening of existing floors** must be carefully evaluated since the horizontal seismic action is transferred to the different masonry walls in function of the floor plane action, depending on its stiffness.

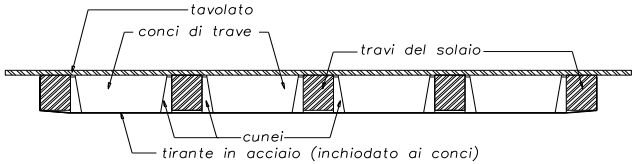
In plane and flexural floors stiffening with 'dry' techniques is obtained by providing, at the extrados of the existing floor, a further layer composed by **wooden planks**, with orthogonal direction respect the existing.

The use of **metallic belts or FRP strips**, disposed in a crossed pattern and fixed at the extrados of the wooden floor or the use of metallic tie-beams bracings, may improve the stiffening effect.



DRY TECHNIQUE





sezione trasversale del solaio (rinforzo con conci di legno e tirante in acciaio)

INSERTION OF WOODEN ELEMENTS AND TIES AT THE INTRADOS

APPLICATION OF STEEL STRIPS AT THE EXTRADOS

THANKS FOR YOUR ATTENTION

Prof. Francesca da Porto