



**REte dei Laboratori Universitari di Ingegneria Sismica**

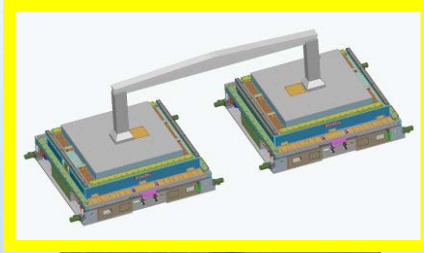
# **Modelli e tecniche nei progetti di intervento**

**Gaetano Manfredi**

**Chairman of Consortium ReLUIS**

*Dipartimento di Ingegneria Strutturale*  
Università degli Studi di Napoli Federico II

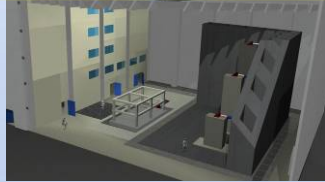




**University of Napoli  
Federico II AMRA**

**2 GdL, Dual table system:**

**2 X 3x3 mq, 20tx2,5m, 1.0 m/s**



**University of Pavia  
Eucentre**

**1 GdL, Large mass:**

**5x7 mq, 300tm, 1-1.5 m/s**



**University of Basilicata**

**Large shear wall:**

**Pseudodynamic test**

**ENEA  
UTS MAT**

**6 GdL: 4x4 mq, 9.1t, 0.5 m/s**

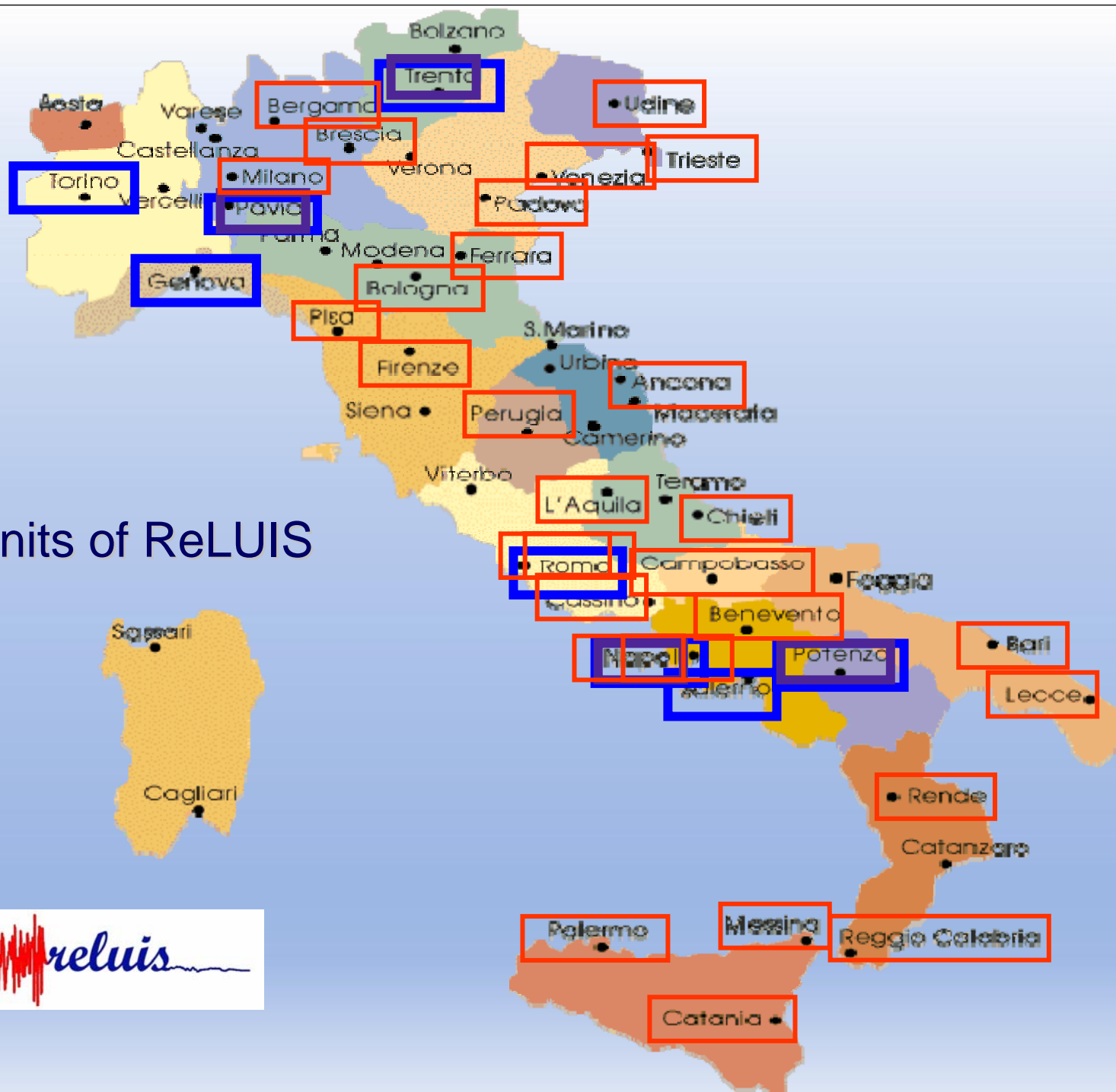


**Università di Trento**

**Large shear wall**

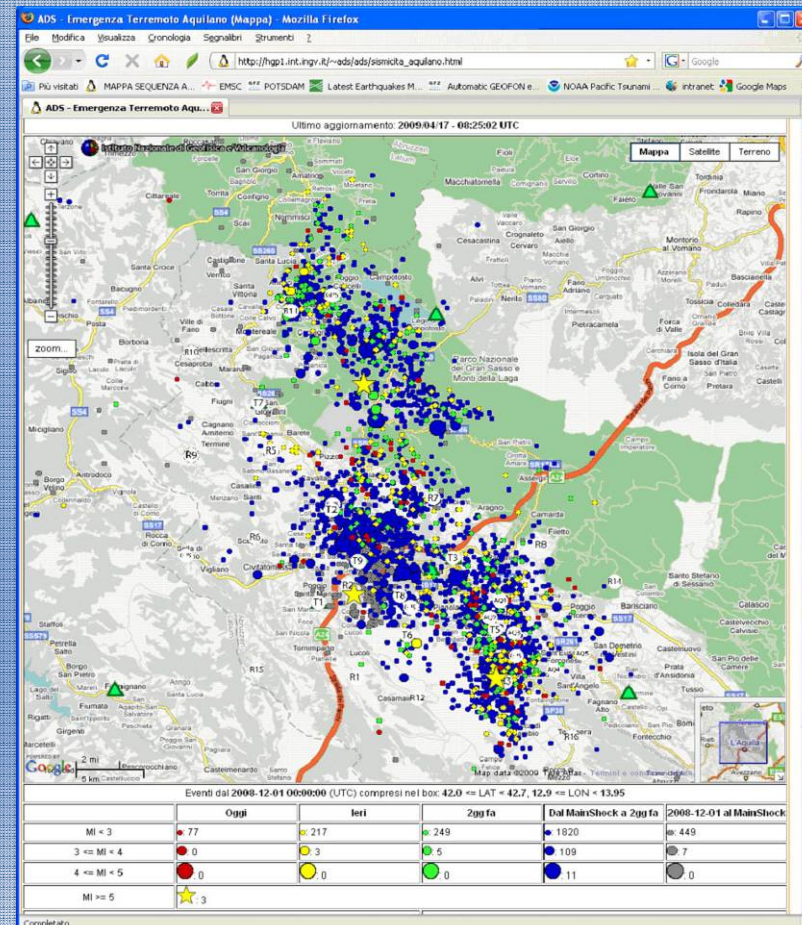
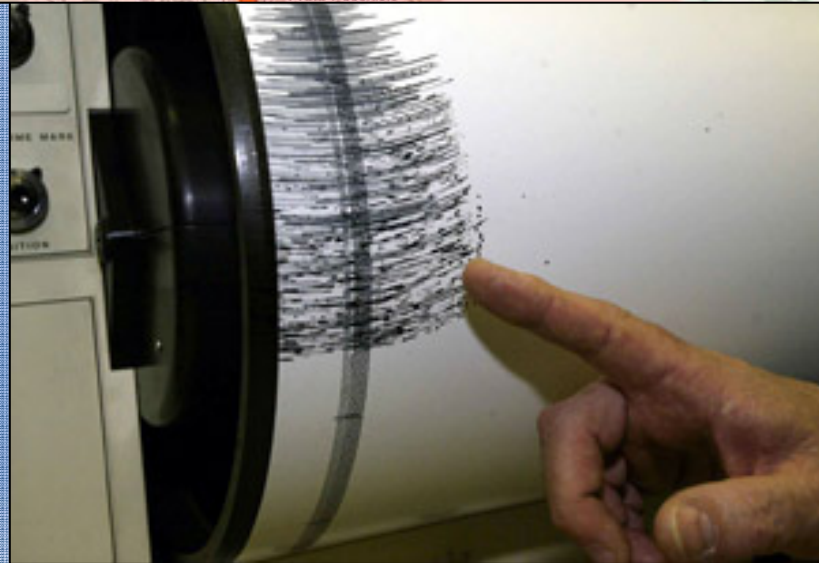
**Pseudodynamic test**

## Research units of ReLUIS Consortium



# April 6 2009 H. 3.32 a.m.

# MI 5.8 – Richter Mw 6.3



# Historic seismicity

## TERREMOTI ABRUZZESI CON INTENSITA' >IX

- Sulmona del 1315  
(Sulmona, I = IX)
- Abruzzo 1349  
(I = IX-X)
- L'Aquila del 1461  
(L'Aquila, I = X)
- Amatrice 1639  
(Amatrice, I = X)
- Norcia/Aquila del 1703  
(Norcia-L'Aquila, I = XI)
- Maiella del 1706  
(Maiella, I = IX-X)
- Avezzano del 1915  
(Avezzano, I = XI)



□ Zone sismogenetiche    □ Magnitudo    + Epicentro calcolato



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# Damage to RC Buildings

# L'Aquila Earthquake: Structural damages

## Columns



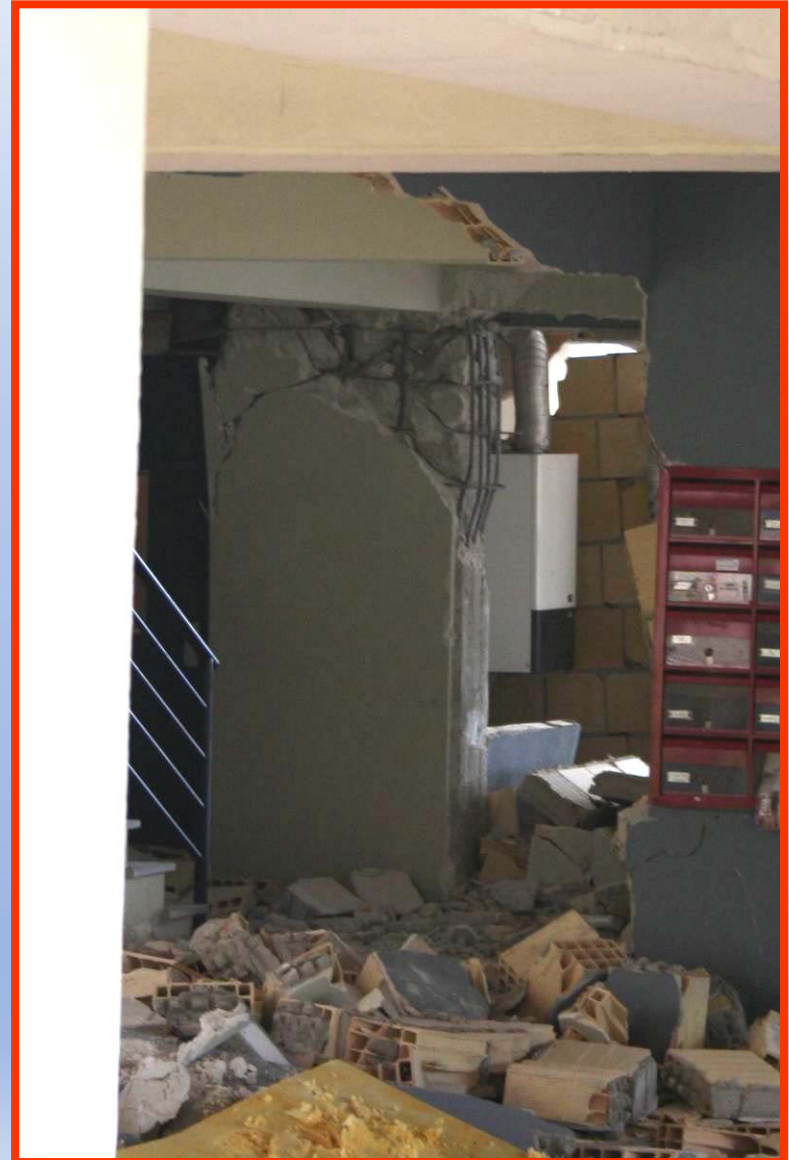
# L'Aquila Earthquake: Structural damages

## Columns

Shear Failure at the rectangular column end.

The stirrups spacing seems to be higher than 200mm.

Poor concrete quality





# L'Aquila Earthquake: Structural damages

## Columns

Shear Failure



# L'Aquila Earthquake: Structural damages

## Columns

Shear Failure on the short columns due to the basement wall



# L'Aquila Earthquake: Structural damages

## Beam-Columns Joints



Lack of stirrups in the joint



Buckling of longitudinal rebar from column to the joint

# L'Aquila Earthquake: Structural damages

## Beam-Columns Joints



No stirrups in the joint



Poor concrete quality

# L'Aquila Earthquake: Structural damages

## Shear Walls



# L'Aquila Earthquake: Structural damages

## Shear Walls



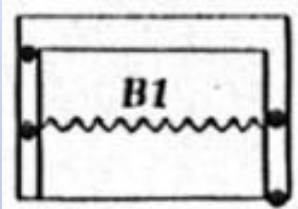
# L'Aquila Earthquake: Structural damages

## Staircase

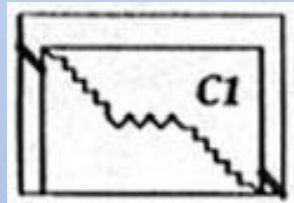


# L'Aquila Earthquake: Non-Structural members damages

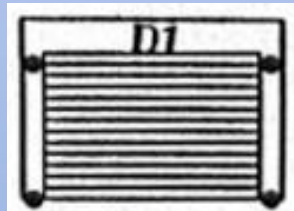
## Infills



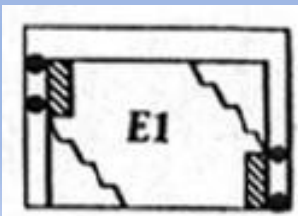
Failure due to horizontal crack at partition's mid-height



Failure due to diagonal crack: it could be followed by shear failure of rc frame



Failure due to the horizontal sliding along the partition's joint: in case of poor mortar or in case of poor bond between mortar and bricks

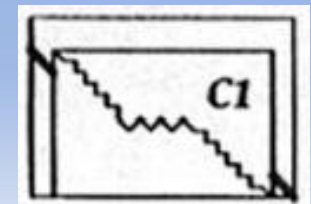


Failure due to partition's crushing near corners



# L'Aquila Earthquake: Non-Structural members damages

## Infills



# L'Aquila Earthquake: Non-Structural members damages

## Infills

Discontinuity due to openings

Overturning of external partition's panel



# L'Aquila Earthquake: Non-Structural members damages

## Infills



**Overturning of external  
partiton's panel**

*High slenderness*

*No lateral restrains*

# L'Aquila Earthquake: Non-Structural members damages

## Infills

*No lateral restrain.*

Failure of external corner with damage of two sides.

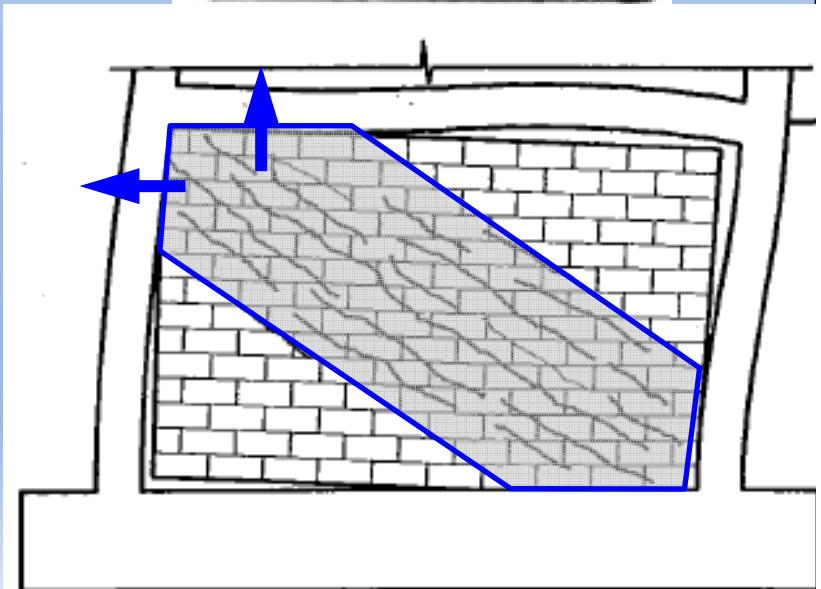
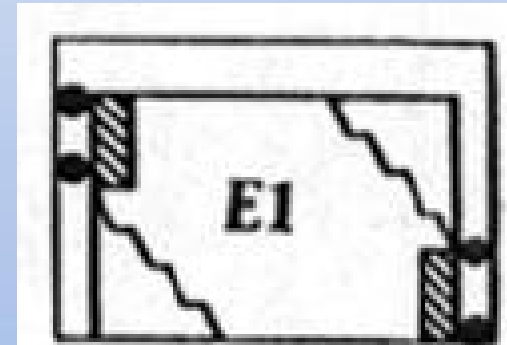


# L'Aquila Earthquake: Non-Structural members damages

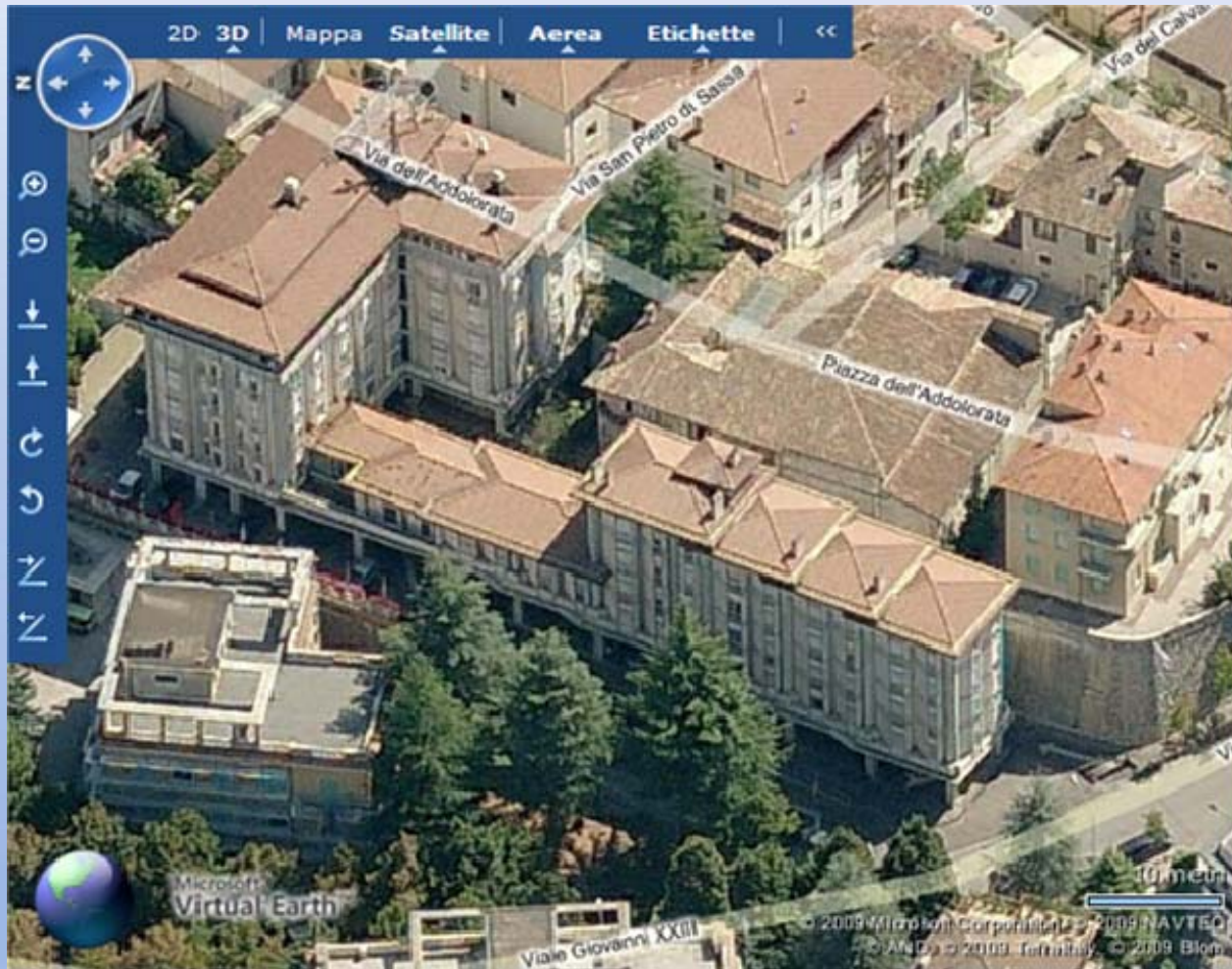
## Infills

Typical partition crushing on corners due to the compressive stresses.

Diagonal flexural crack on the columns' end



# L'Aquila Earthquake: Structural Collapses



Hotel Duca degli Abruzzi

# L'Aquila Earthquake: Structural Collapses



**BEFORE**



**AFTER**

**Hotel Duca degli Abruzzi**

# L'Aquila Earthquake: Structural Collapses



**Hotel Duca degli Abruzzi**

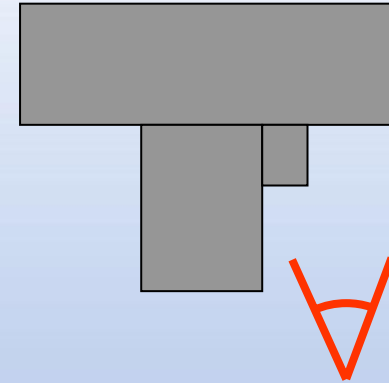


# L'Aquila Earthquake: Structural collapses



The buildings of "Pettino"

# L'Aquila Earthquake: Structural collapses



The buildings of  
"Pettino"



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# **Damage to Masonry Buildings in Hystorical Center**



Onna  
6/7 aprile

San Gregorio  
7 aprile





Tempera: collapse of head board buildings



L'Aquila: lack of transversal wall at the upper level of the building

### ***Damages and Vulnerability***

*Structural Behavior and building location in the masonry buildings' aggregate*



Poggio Picenze: Local collapse due to a wall discontinuity



Villa Sant'Angelo: alteration of the original structural configuration: wooden tie, originally well connected to the external wall by means of an iron device, has been cut during an heavy refurbishment



Tempera: the heavy roof caused the collapse of masonry walls

Villa Sant'Angelo: the r.c. roof implied the masonry walls collapse.





L'Aquila: at second floor it was inserted a r.c. stair.



Paganica: insertion of a deep r.c. slab

## ***Damages and Vulnerability***

### ***Floor slabs and Vaults***





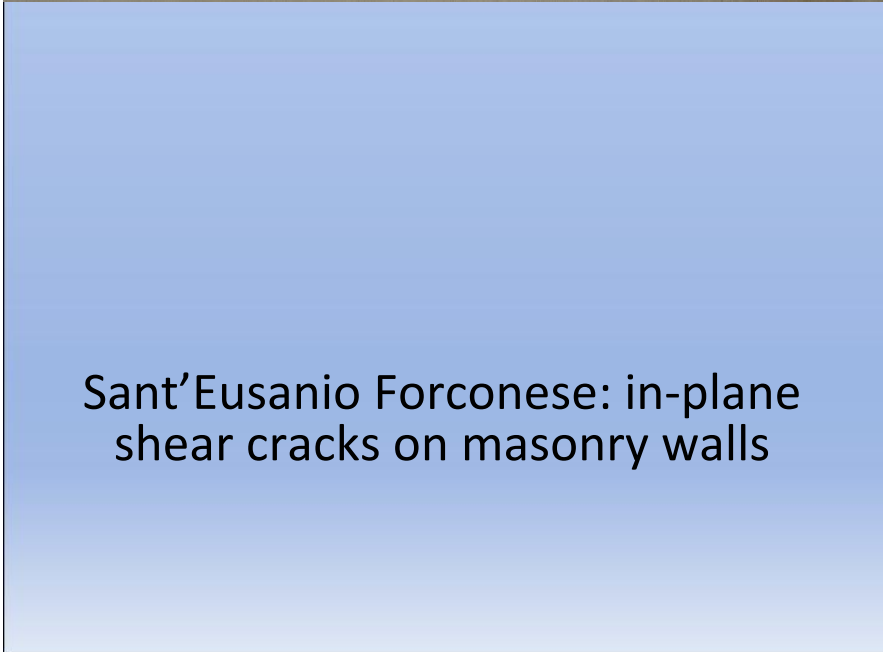
Castelnuovo: poor connection between masonry walls.



Paganica: overturning crack involving a portion of masonry wall.



Villa Sant'Angelo: in-plane shear cracks on the whole facade wall.



Sant'Eusanio Forconese: in-plane shear cracks on masonry walls





# The retrofitting

## Structural Safety Assessment: In-situ inspections

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**THE BUILDINGS WERE RATED IN ORDER TO ORGANIZE THE REPAIR/RECONSTRUCTION PROCESS.**

**The “A” buildings were able to be inhabited again;**

**The “B” and “C” buildings required some light repairs before being reopened to habitants. The repairs on the “B” and “C” buildings were first priority. This is done in an effort to return people to their homes as quickly as possible. Many of the residents whose homes were considered “B” or “C” level have been temporary accomodated hotels and private homes accommodations because the repairs to their homes will not require as much time.**

# Structural Safety Assessment: In-situ inspections

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**THE BUILDINGS WERE RATED IN ORDER TO ORGANIZE THE REPAIR/RECONSTRUCTION PROCESS.**

**The “E” buildings are treated in a second stage of the reconstruction**

Before the repairs were able to begin, many of the displaced people needed a more permanent shelter than a tent. The Civil Protection Department decided this mainly due to the climate in L’Aquila. The people needed to be out of the tent camps before winter hit.

**The C.A.S.E. project came out of this need.**

The project consisted of the following goals:

- Homes and Neighborhoods Available in Five to Six Months
- Anti-seismic Security using an “Isolation” technique
- High Level of Standard of Living
- High-Tech, Self-Sufficient MEP Systems
- Environmental Sustainability and Green Design



# "Light Reconstruction" - Buildings "B", "C"

## Financial Contribution Allowed

**Rating B:** Temporarily unusable building (fully or partially) but will be fit for use with mainly non-structural interventions.

**Rating C:** Partially unusable building.

✓ Total refund of repair intervention costs + local strengthening of structural or non-structural members up to **150 €/mq.**;



### Local strengthening interventions:

- It is related to single structural members;
- no significant mass and stiffness variation;
- the local member's capacity increase should be evaluated;
- the analysis of the whole structure is not necessary.

# "Heavy Reconstruction" - Buildings "E"

## Financial Contribution Allowed

**Rating E: Unusable building (structural damages).**

- ✓ Total refund of repair intervention costs + seismic rehabilitation (up to 80%) up to **400-600 €/mq.**
- ✓ In case of "E" buildings with a low level of structural damages it is also possible to perform only the local strengthening of structural or non-structural members up to **250 €/mq.;**



# "Heavy Reconstruction" - Buildings "E"

## Financial Contribution Allowed

**Rating E: Unusable building (structural damages).**

✓ Reconstruction or replacement in case of:

- 1) Totally collapsed buildings
- 2) Masonry structures partially collapsed (more than 25% in volume)
- 3) Reinforced Concrete Structures, average compressive cylindrical strength lower than 8 MPa
- 4) Reinforced Concrete Structures, more than 50% of storey's columns with a drift higher than 1.5%



✓ Specific Recommendation for masonry aggregates



# RECONSTRUCTION PROCESS:

## ReLUIS ACTIVITY



Several expert technicians in seismic risk (Ph.D, or master) perform the technical investigation both on:

**“Light Reconstruction” - Buildings “B”, “C”**

**“Heavy Reconstruction” - Buildings “E”**

# RECONSTRUCTION PROCESS:

ReLUIS ACTIVITY



"Light Reconstruction" - Buildings "B", "C"

**WEBSITE: ReLUIS** [www.reluis.it](http://www.reluis.it)

## DESIGN KIT

### GUIDELINES AND DESIGN EXAMPLES

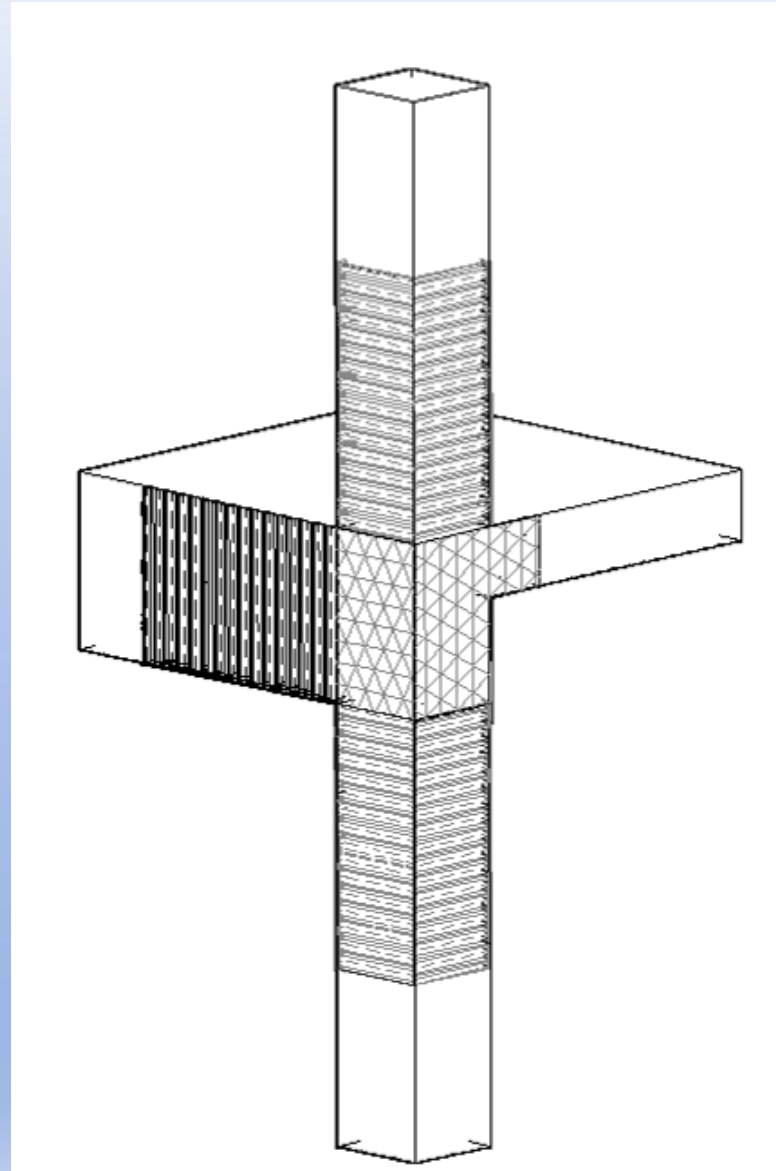
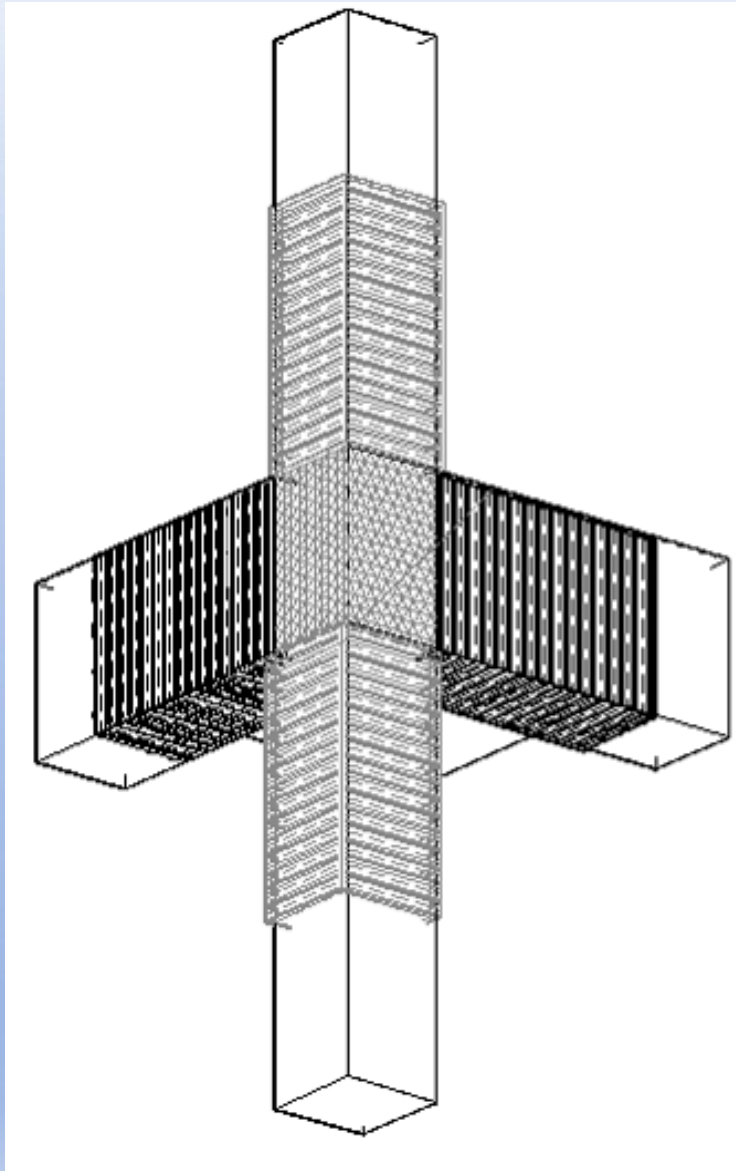
#### GUIDELINES FOR REPAIR AND LOCAL STRENGTHENING OF STRUCTURAL AND NON STRUCTURAL MEMBER



1. Repair of damaged non structural members (A.1);
2. Local repair of structural members (A.4);
3. Interventions to avoid overturning of internal or external partitions (B.1);
4. Local strengthening interventions on reinforced concrete or masonry structures according to seismic codes (8.4.3, DM 14.01.08 and Circolare n. 617, 2 febbraio 2009 (B.2).



# Local Strengthening: External Joints

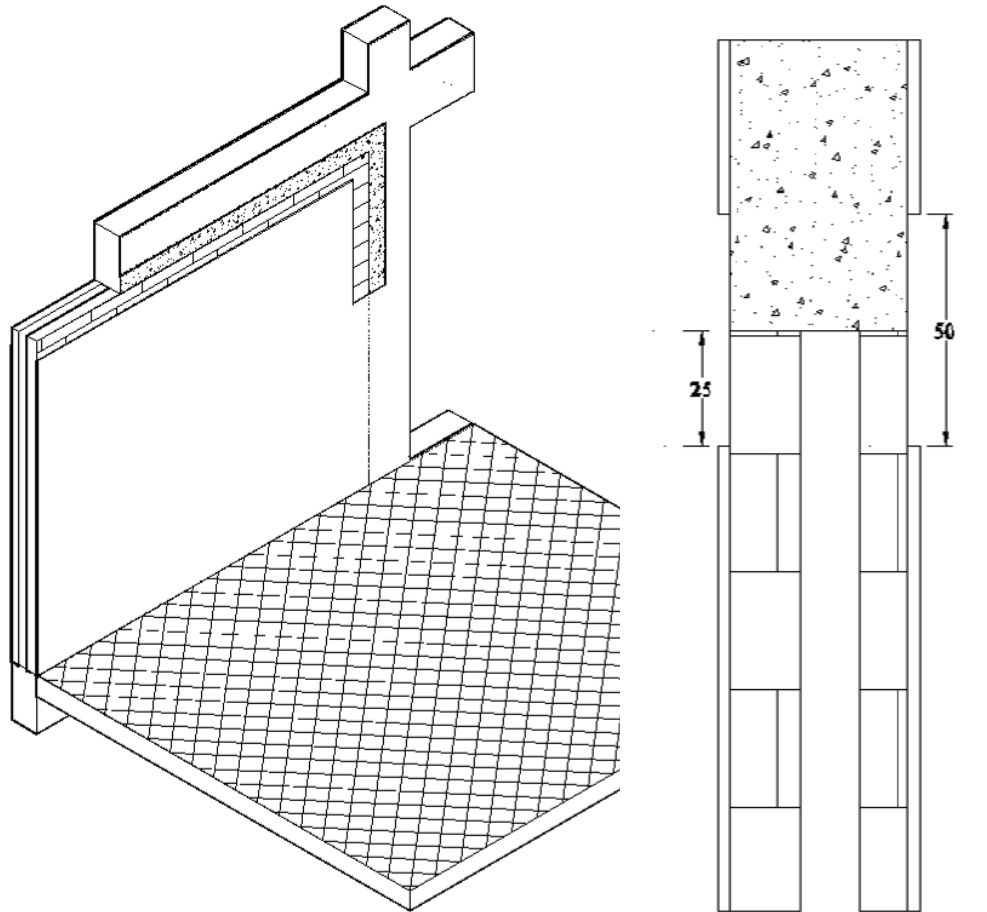


**U-shaped sheets on beams' end with uniaxial CFRP sheets**

# Local Strengthening: External Joints



# Partitions' Anti-Overturning



Plaster removal along the partition's perimeter.



## DESIGN KIT

### GUIDELINES AND DESIGN EXAMPLES

#### LOCAL COLLAPSE MECHANISMS IN EXISTING MASONRY STRUCTURES

**1** | **RIBALTAMENTO SEMPLICE DI PARETE**

Il meccanismo è manifestato attraverso la rotazione rigida di intere facciate o porzioni di pareti rispetto ad assi in prevalenza orizzontali alla base di esse e che percorrono la struttura muraria sollecitata da azioni fuori dal piano.

**Condizioni di blocco della parete interessata dal meccanismo:**

- Assenza di vincolo in sommità;
- Assenza di collegamento alle pareti ortogonali.

**Carenze vulnerabilità associate al meccanismo:**

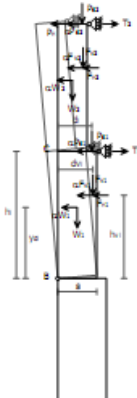
- Assenza di cordolo o catene ai piani;
- Orizzontamenti deformabili ai nodi mal collegati;
- Interventazioni murarie di cattiva qualità;
- Presenza di spinte non contrastate sulla parete;
- Muratura a sacco o paramenti mal collegati.

**Sistemi che annullano l'avvenuta attivazione del meccanismo:**

- Lavori verticali in corrispondenza delle intervensioni murarie (angoli e murati murati);
- Fuori piano della parete ribaltante;
- Sfilamento delle travi degli orizzontamenti.

**Differenziali varianti del meccanismo**  
Il ribaltamento può coinvolgere:

- uno o più livelli della parete in relazione alla presenza di collegamento ai diversi orizzontamenti;
- l'intero spessore del muro o il solo paramento esterno, in relazione alle caratteristiche della struttura muraria (a sacco, carsoia di diazoni);
- diverse geometrie della parete in relazione alla presenza di discontinuità o di aperture.



**Momento stabilizzante:**

$$M_s = \sum W_i \cdot \frac{a_i}{2} + \sum F_{1i} \cdot d_{1i} + \sum P_{2i} \cdot d_i + \sum T_i \cdot h_i$$

**Momento ribaltante:**

$$M_r = e \cdot \left[ \sum W_i \cdot \gamma_{0i} + \sum F_{1i} \cdot h_i + \sum P_{2i} \cdot h_i \right] + \sum F_{2i} \cdot h_{2i} + P_{2i} \cdot h_i$$

**Moltiplicatore di collasso:**

$$\alpha = \frac{\sum W_i \cdot \frac{a_i}{2} + \sum F_{1i} \cdot d_{1i} + \sum T_i \cdot h_i + \sum F_{2i} \cdot h_{2i} + P_{2i} \cdot h_i}{\sum W_i \cdot \gamma_{0i} + \sum F_{1i} \cdot h_i + \sum P_{2i} \cdot h_i}$$

1. Synthetic description of collapse mechanisms;
2. Sketch and photos of real collapses;
3. Constrains of masonry walls;
4. Vulnerability due to the mechanism.



## DESIGN KIT

### GUIDELINES AND DESIGN EXAMPLES

#### DESIGN EXAMPLE OF LOCAL STRENGTHENING: CHAINS

Sezione	GEOMETRIA DELLA FACCIATA (*)						Seccaggio della muratura $\gamma_m$ (kN/m <sup>3</sup> )	Abitamento della camera dentro l'abaco risultante rispetto all'asse muratura differita (**)
	Quota esterna (m)	Quota del interramento (m)	Altezza della trave interramento al punto di incastratura (m)	Altezza della trave interramento a punto di incastratura (m)	Altezza della trave interramento a punto di incastratura (m)	Altezza della trave interramento a punto di incastratura (m)		
1	0,00	0,00	1,00	1,00	1,00	1,00	0,00	
2	0,00	0,00	1,00	1,00	1,00	1,00	0,00	
3	0,00	0,00	1,00	1,00	1,00	1,00	0,00	
4	0,00	0,00	1,00	1,00	1,00	1,00	0,00	

Sezione	CARATTERISTICO GEOMETRICO DEI RINFORZI						Quota del cuneo della trave interramento rispetto all'asse muratura differita (**)
	Sezione della trave interramento rispetto all'asse muratura differita (**)	Sezione della trave interramento rispetto all'asse muratura differita (**)	Sezione della trave interramento rispetto all'asse muratura differita (**)	Sezione della trave interramento rispetto all'asse muratura differita (**)	Sezione della trave interramento rispetto all'asse muratura differita (**)	Sezione della trave interramento rispetto all'asse muratura differita (**)	
1	0,00	0,00	0,25	0,00	0,00	0,00	0,00
2	0,00	0,00	0,25	0,00	0,00	0,00	0,00
3	0,00	0,00	0,25	0,00	0,00	0,00	0,00
4	0,00	0,00	0,25	0,00	0,00	0,00	0,00

Sezione	AZIONI SULLA CORDOBA						Assieme della trave interramento rispetto all'asse muratura differita (**)
	Reazione della trave interramento rispetto all'asse muratura differita (**)	Reazione della trave interramento rispetto all'asse muratura differita (**)	Carico interramento rispetto all'asse muratura differita (**)	Carico interramento rispetto all'asse muratura differita (**)	Carico interramento rispetto all'asse muratura differita (**)	Carico interramento rispetto all'asse muratura differita (**)	
1	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2	0,00	0,00	0,00	0,00	0,00	0,00	0,00
3	0,00	0,00	0,00	0,00	0,00	0,00	0,00
4	0,00	0,00	0,00	0,00	0,00	0,00	0,00

(\*) Nel caso di pareti murarie con travi interrate, il carico interramento deve essere preso in considerazione anche nel caso di sezioni murarie interrate. (\*\*) Da sempre, il carico di geometria irregolare (tracce) in basso, ridotto o aumentato, deve essere considerato nel momento di dimensionamento.

Sezione	MOMENTO DELLE AZIONI SULLA TRAVE			
	Reazione della trave interramento rispetto all'asse muratura differita (**)	Reazione della trave interramento rispetto all'asse muratura differita (**)	Carico interramento rispetto all'asse muratura differita (**)	Carico interramento rispetto all'asse muratura differita (**)
1	0,00	0,00	0,00	0,00
2	0,00	0,00	0,00	0,00
3	0,00	0,00	0,00	0,00
4	0,00	0,00	0,00	0,00

Sezione	MOMENTO DELLE AZIONI SULLA PARETE			
	Reazione della trave interramento rispetto all'asse muratura differita (**)	Reazione della trave interramento rispetto all'asse muratura differita (**)	Carico interramento rispetto all'asse muratura differita (**)	Carico interramento rispetto all'asse muratura differita (**)
1	0,00	0,00	0,00	0,00
2	0,00	0,00	0,00	0,00
3	0,00	0,00	0,00	0,00
4	0,00	0,00	0,00	0,00

Sezione	MOMENTO DELLE AZIONI SULLA CORDOBA			
	Reazione della trave interramento rispetto all'asse muratura differita (**)	Reazione della trave interramento rispetto all'asse muratura differita (**)	Carico interramento rispetto all'asse muratura differita (**)	Carico interramento rispetto all'asse muratura differita (**)
1	0,00	0,00	0,00	0,00
2	0,00	0,00	0,00	0,00
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4	0,00	0,00	0,00	0,00

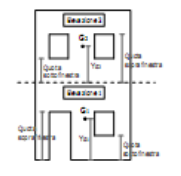


Fig. 1 - Diagramma di dettaglio della parete muraria



Fig. 2 - Diagramma di dettaglio della parete muraria

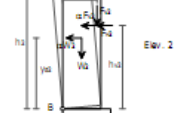


Fig. 3 - Diagramma di dettaglio della parete muraria

To avoid the out of plane overturning of masonry walls.

1. Verification at Life Safety limit state with linear analysis ;
2. Verification at Life Safety limit state with non linear analysis;
3. Constructions' details .





# RECONSTRUCTION PROCESS: ReLUIs CHECKS

## CHECK LIST: DOCUMENTATION

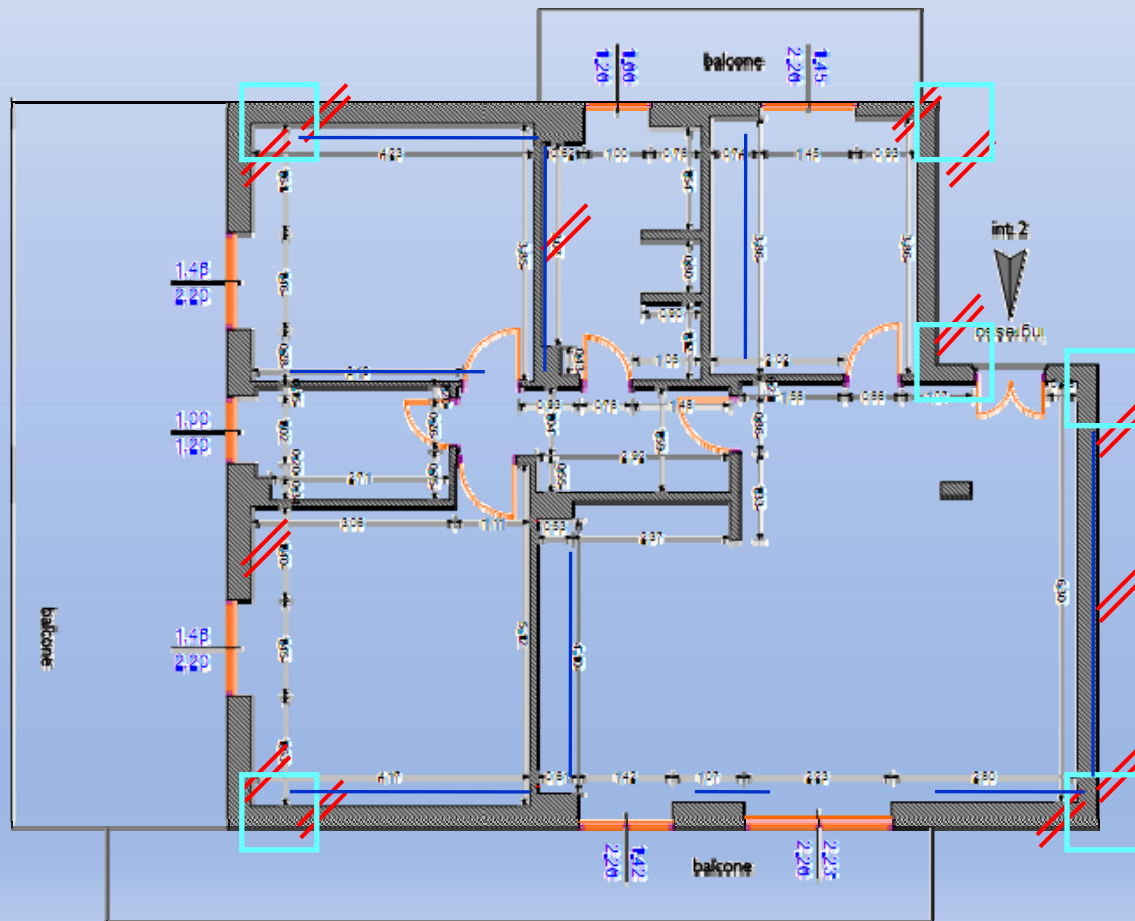
### STRUCTURE DESCRIPTION AND DAMAGES' REPORT



# RECONSTRUCTION PROCESS: ReLUIs CHECKS

## CHECK LIST: DOCUMENTATION

### DESCRIPTION AND DESIGN OF INTERVENTIONS



#### REPAIR INTERVENTION

- //** F/03-005 Stuccatura e rinzeppatura di lesioni profonde su murature in laterizio forato.
- //** NP 84 Ripresa di lesione con funzione antiribaltamento mediante apposizione di rete in fibra di vetro su strato di malta bicomponente ad elevata duttilità .
- NP 05 RASATURA ARMATA PER INTERNO. Rasatura armata per recupero di parti interne interessate da lesioni di intonaco.

#### LOCAL STRENGTHENING INTERVENTIONS (up to 150 €/m<sup>2</sup>)

- F/ 1-45 Rinforzo strutturale su elementi inflessi e pressoinflessi mediante l'applicazione di nastri in fibra di carbonio.

# RECONSTRUCTION PROCESS: ReLUIS CHECKS

**“Ligth” Reconstruction – BUILDINGS “B” – “C”**

*Damages to non structural*

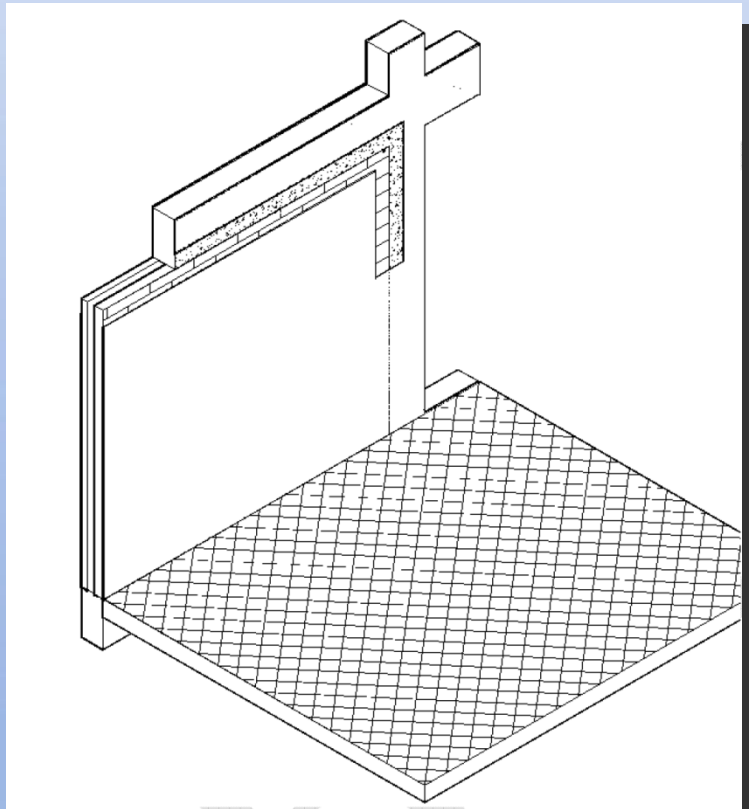


1. External panel of partition collapse;
2. Partition overturning:
3. Cracks on partitions.

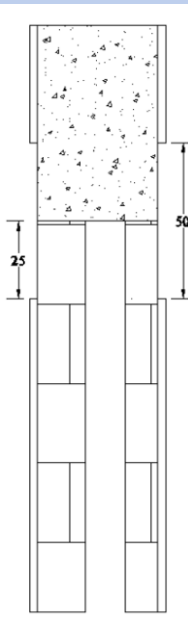
# RECONSTRUCTION PROCESS: ReLUIS CHECKS

## “Ligth” Reconstruction – BUILDINGS “B” – “C”

### Partitions' Anti-Overturning



3D View



Section

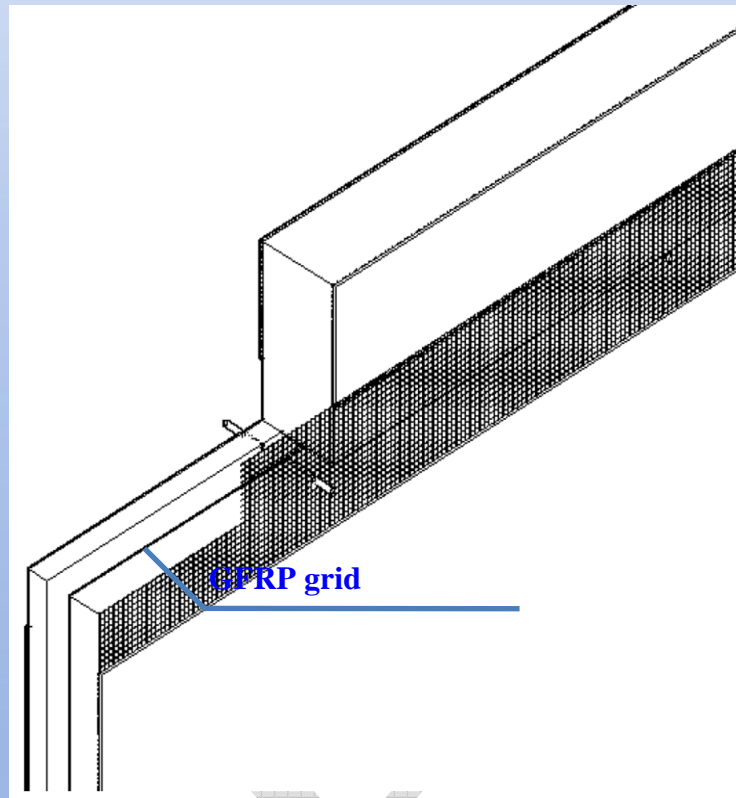
1. Plaster removal along the partition's perimeter;



# RECONSTRUCTION PROCESS: ReLUIS CHECKS

## “Ligth” Reconstruction – BUILDINGS “B” – “C”

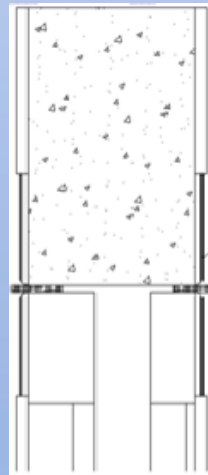
### Partitions' Anti-Overturning



3D View

2. Hole in the partition;

3. Installation of a first layer of cementitious mortar and GFRP alcali-resistant grid;



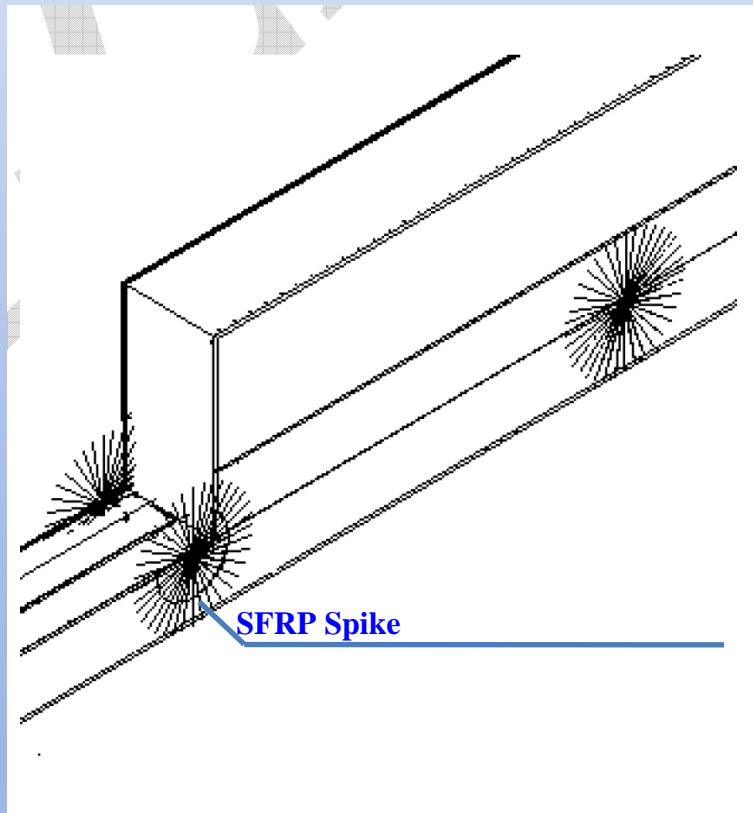
Section



# RECONSTRUCTION PROCESS: ReLUIS CHECKS

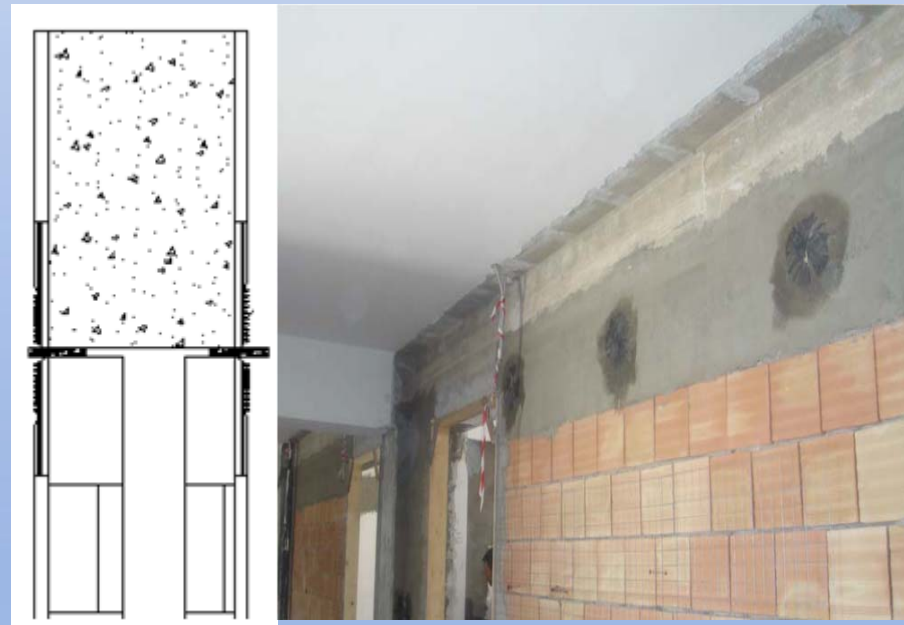
## “Ligth” Reconstruction – BUILDINGS “B” – “C”

### Partitions' Anti-Overturning



3D View

#### 4. SFRP spikes;



Section

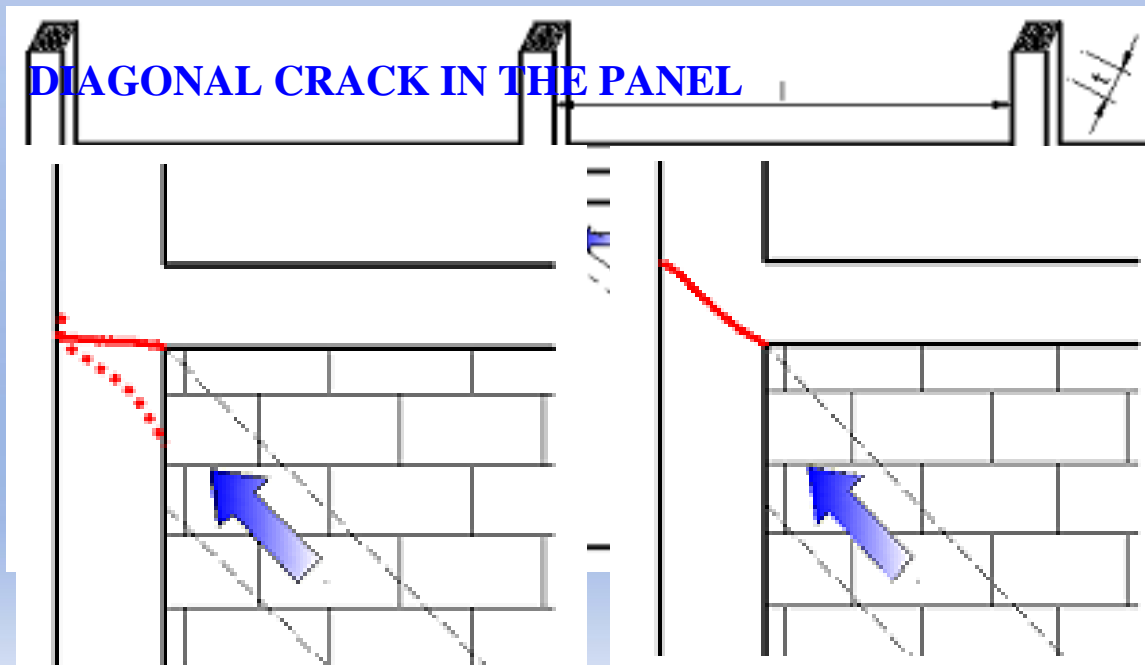
# RECONSTRUCTION PROCESS: ReLUIS CHECKS

“Ligth” Reconstruction – **BUILDINGS “B” – “C”**

**Structural Damages (Repair or Local Interventions)**

**DAMAGE OF STRUCTURAL MEMBER**  
**JOINT FAILURE:**

Cracks due to the actions provided by partition.  
**PSEUDO-HORIZONTAL CRACK** at column-joint panel interface.

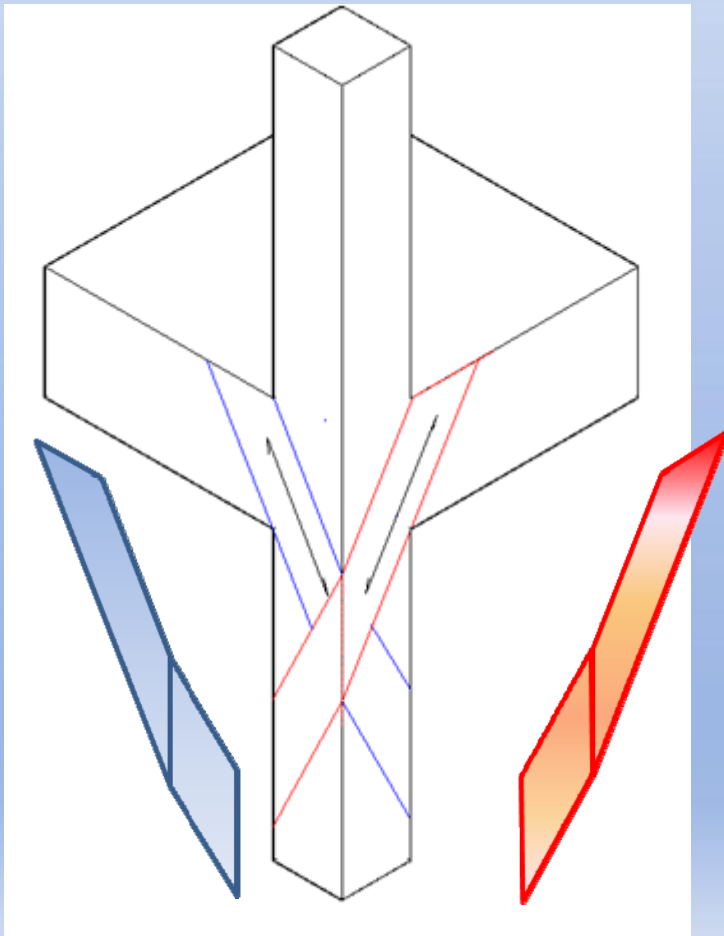


# RECONSTRUCTION PROCESS: ReLUIS CHECKS

“Ligth” Reconstruction – **BUILDINGS “B” – “C”**

**Structural Damages (Repair or Local Interventions)**

Strengthening of external Joints



**1. DIAGONAL UNIAXIAL STEEL SHEETS** designed to resist to partitions' actions .

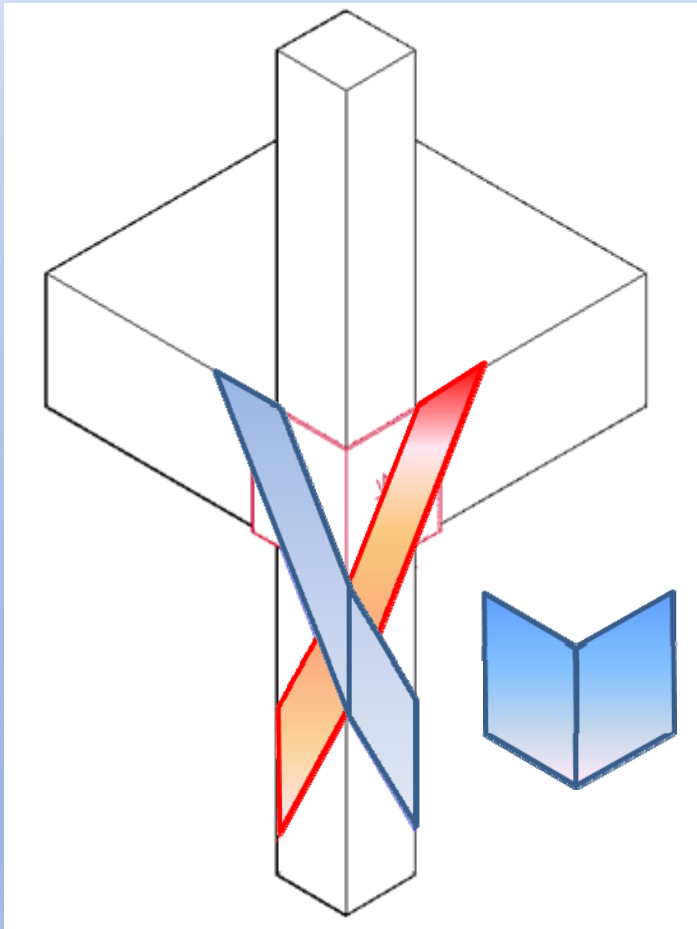




# RECONSTRUCTION PROCESS: ReLUIS CHECKS

“Ligth” Reconstruction – **BUILDINGS “B” – “C”**

**Structural Damages (Repair or Local Interventions)**



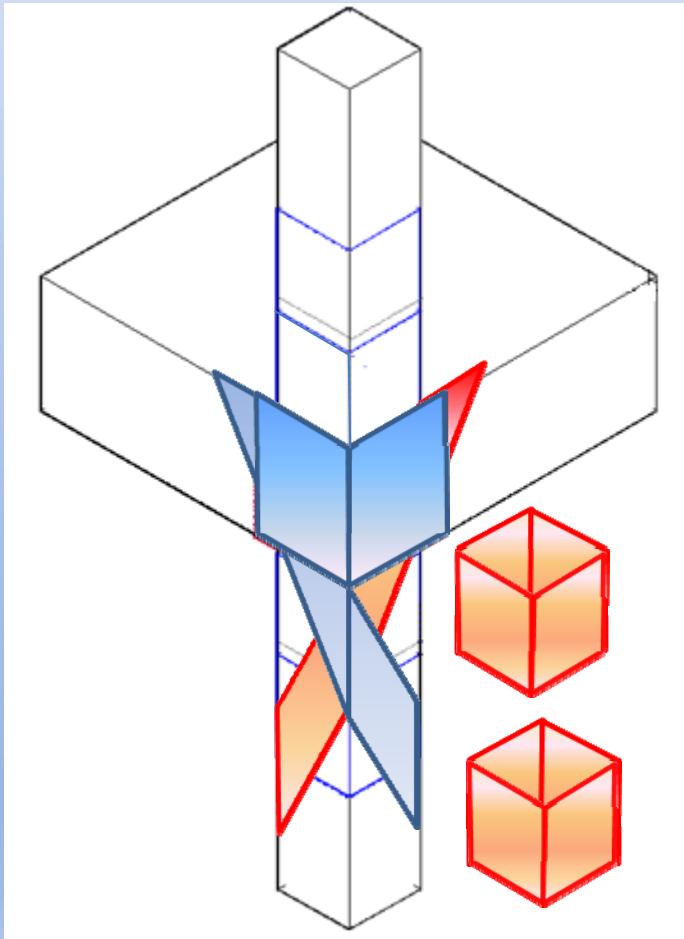
**2.QUADRAXIAL CFRP SHEETON ON THE JOINT PANEL: Shear strength increase.**



# RECONSTRUCTION PROCESS: ReLUIS CHECKS

“Ligth” Reconstruction – **BUILDINGS “B” – “C”**

**Structural Damages (Repair or Local Interventions)**



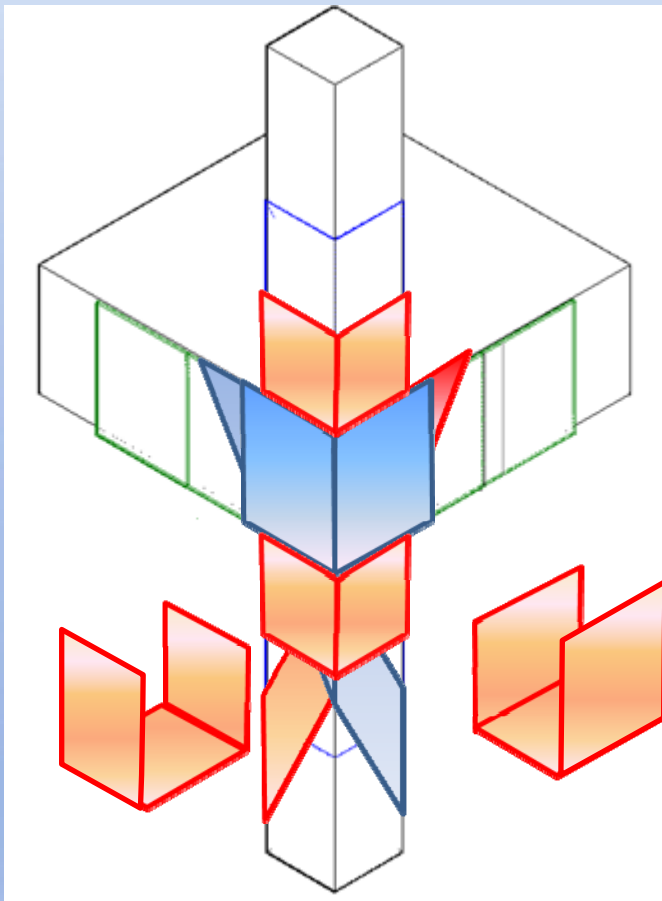
**3. COLUMNS' ENDS CONFINEMENT BY USING CRP UNIAXIAL SHEETS:** Concrete ultimate strain increase  $\epsilon_c$  and thus curvature and rotational capacity increase



# RECONSTRUCTION PROCESS: ReLUIS CHECKS

“Ligth” Reconstruction – **BUILDINGS “B” – “C”**

**Structural Damages (Repair or Local Interventions)**



**4. U-SHAPED UNINAXIAL CFRP SHEETS** : Shear strength increase of beams' ends



# RECONSTRUCTION PROCESS: ReLUIS CHECKS

“Ligh” Reconstruction – **BUILDINGS “B” – “C”**

**MASONRY STRUCTURES**

**Out of plane mechanisms**



**DAMAGES**  
**OVERTURNING**

# RECONSTRUCTION PROCESS: ReLUIS CHECKS

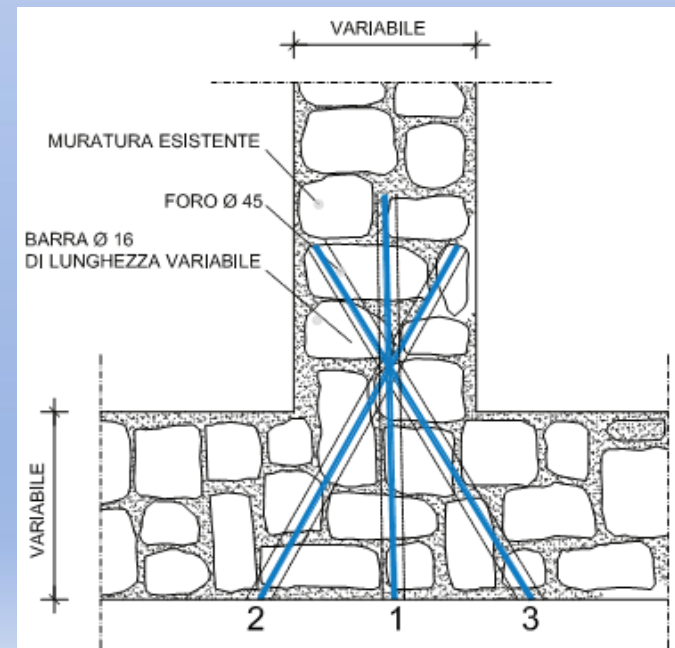
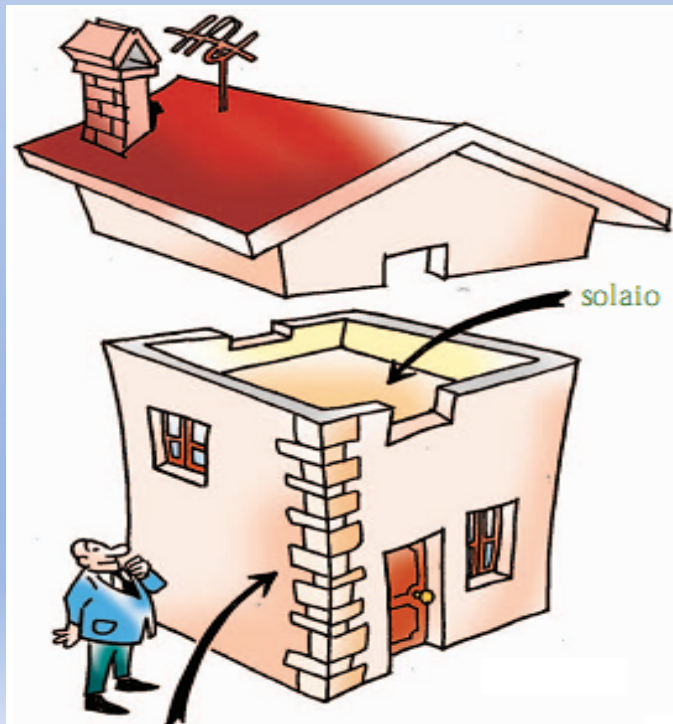
“Ligh” Reconstruction – **BUILDINGS “B” – “C”**

## MASONRY STRUCTURES

### Repair and Strengthening Interventions

**TO AVOID OVERTURNING:**

#### CORNER JOINTS STRENGTHENING



# RECONSTRUCTION PROCESS: ReLUIS CHECKS

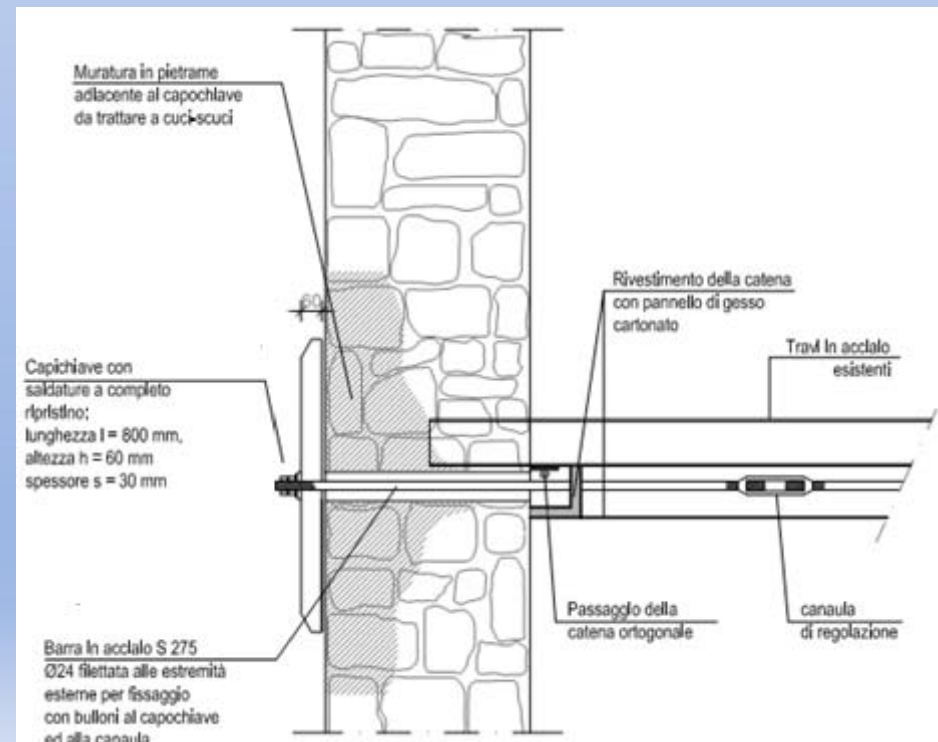
“Ligh” Reconstruction – **BUILDINGS “B” – “C”**

## MASONRY STRUCTURES

### Repair and Strengthening Interventions

**TO AVOID OVERTURNING:**

#### CHAINS



# RECONSTRUCTION PROCESS: ReLUIS CHECKS

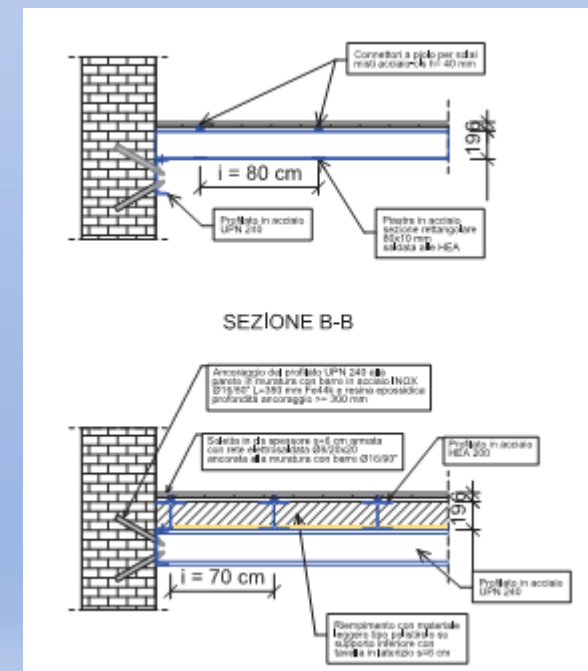
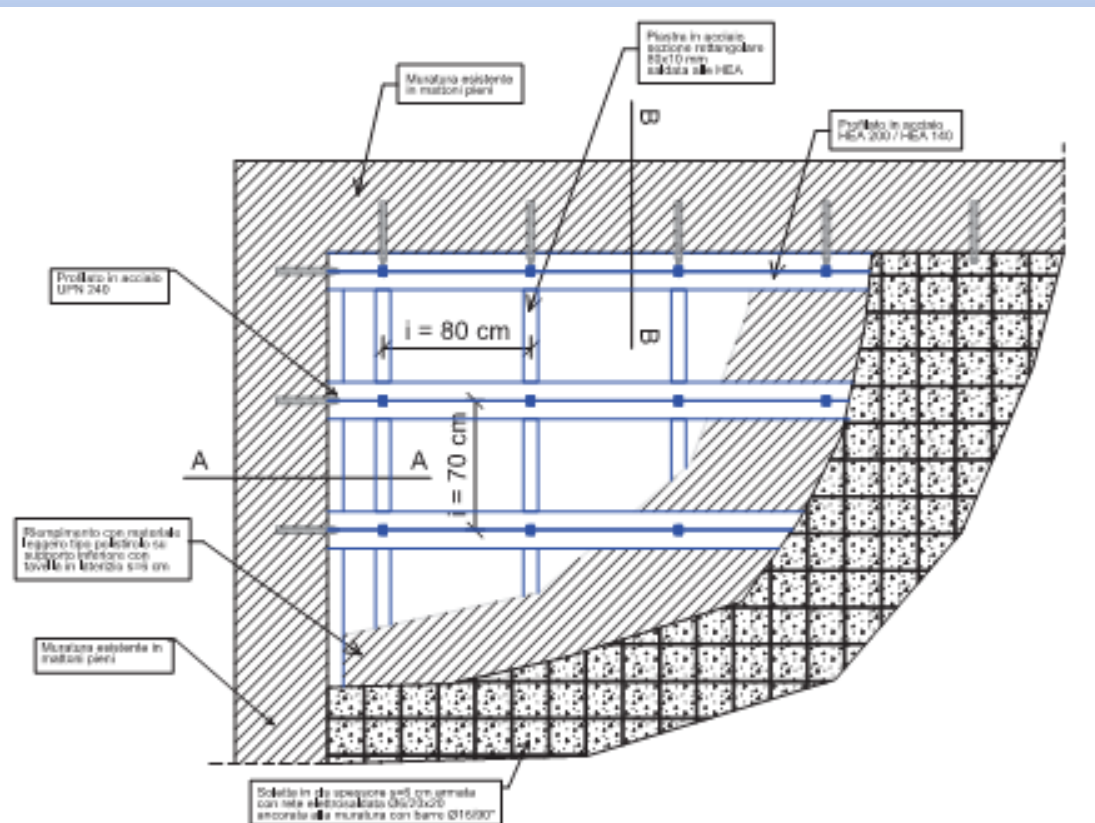
## “Ligh” Reconstruction – BUILDINGS “B” – “C”

### MASONRY STRUCTURES

## Repair and Strengthening Interventions

TO AVOID OVERTURNING:

CONNECTION BETWEEN HORIZONTAL SLAB AND PERIMETER MASONRY WALLS



# RECONSTRUCTION PROCESS: ReLUIS CHECKS

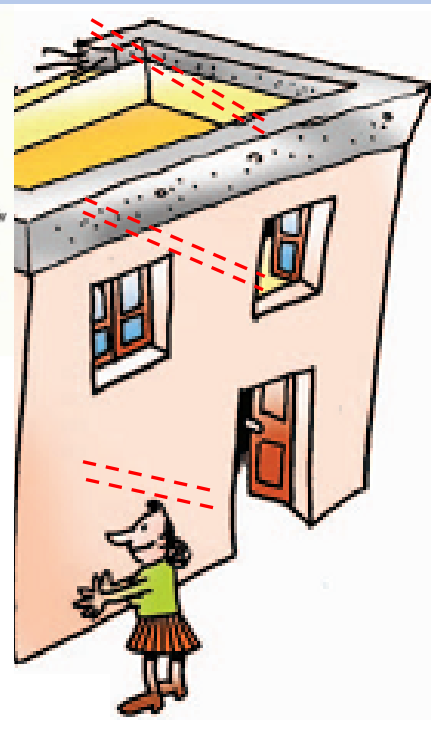
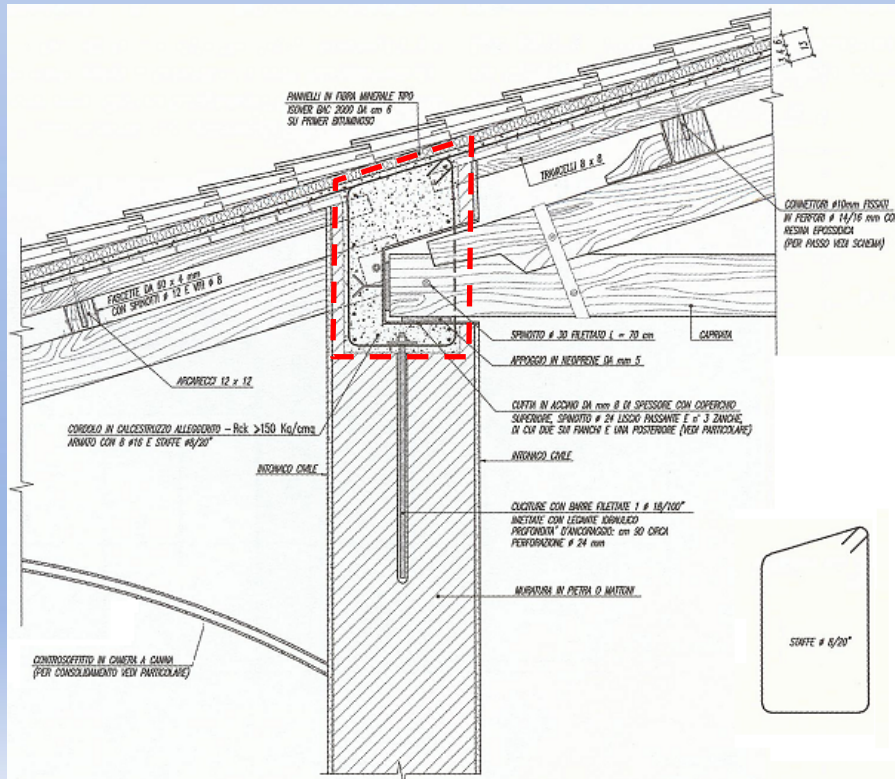
“Ligh” Reconstruction – BUILDINGS “B” – “C”

## MASONRY STRUCTURES

### Repair and Strengthening Interventions

TO AVOID OVERTURNING:

#### RC TIE BEAMS





# RECONSTRUCTION PROCESS: ReLUIS CHECKS

## “Ligh” Reconstruction – BUILDINGS “B” – “C”

### MASONRY STRUCTURES

### In plane mechanisms

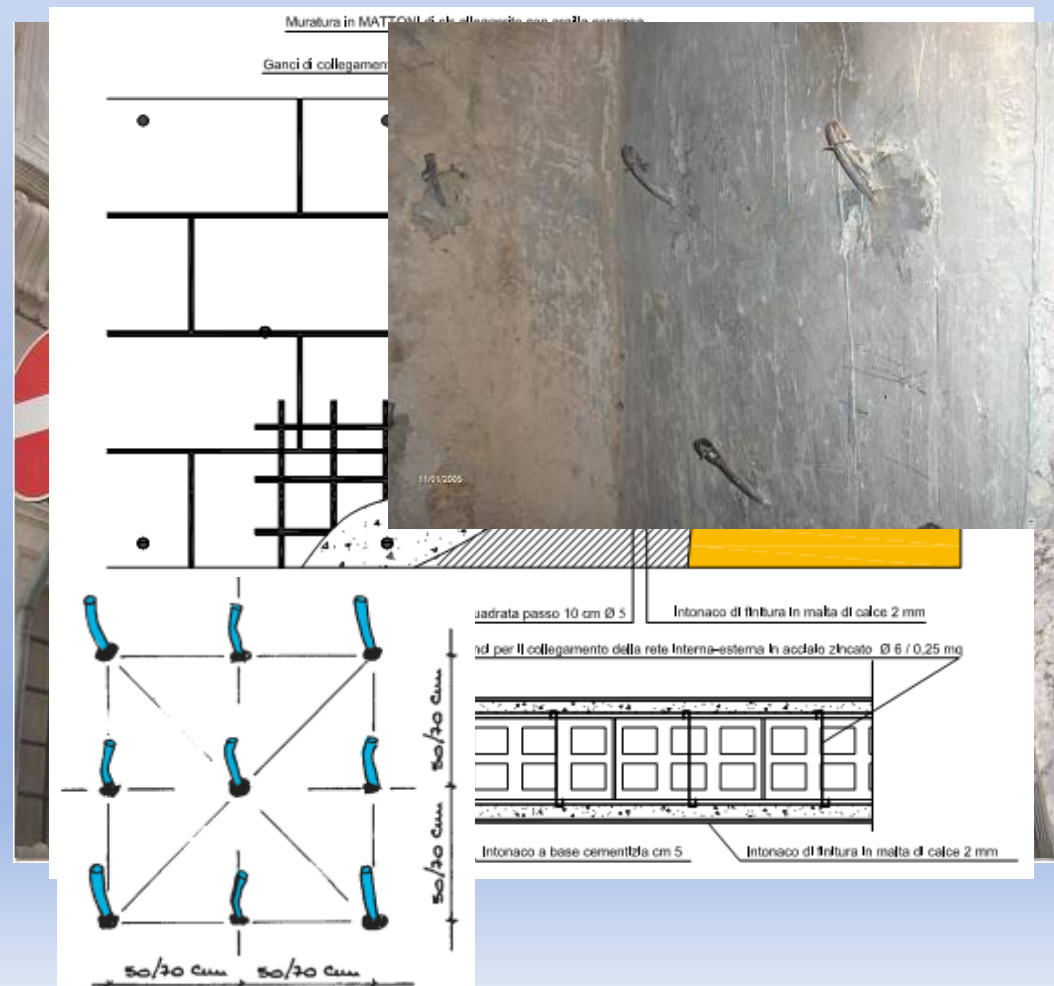
#### DAMAGES

In plane Shear Diagonal Cracks  
on the masonry walls

#### INTERVENTIONS

To increase the mechanical  
characteristics of masonry  
panels

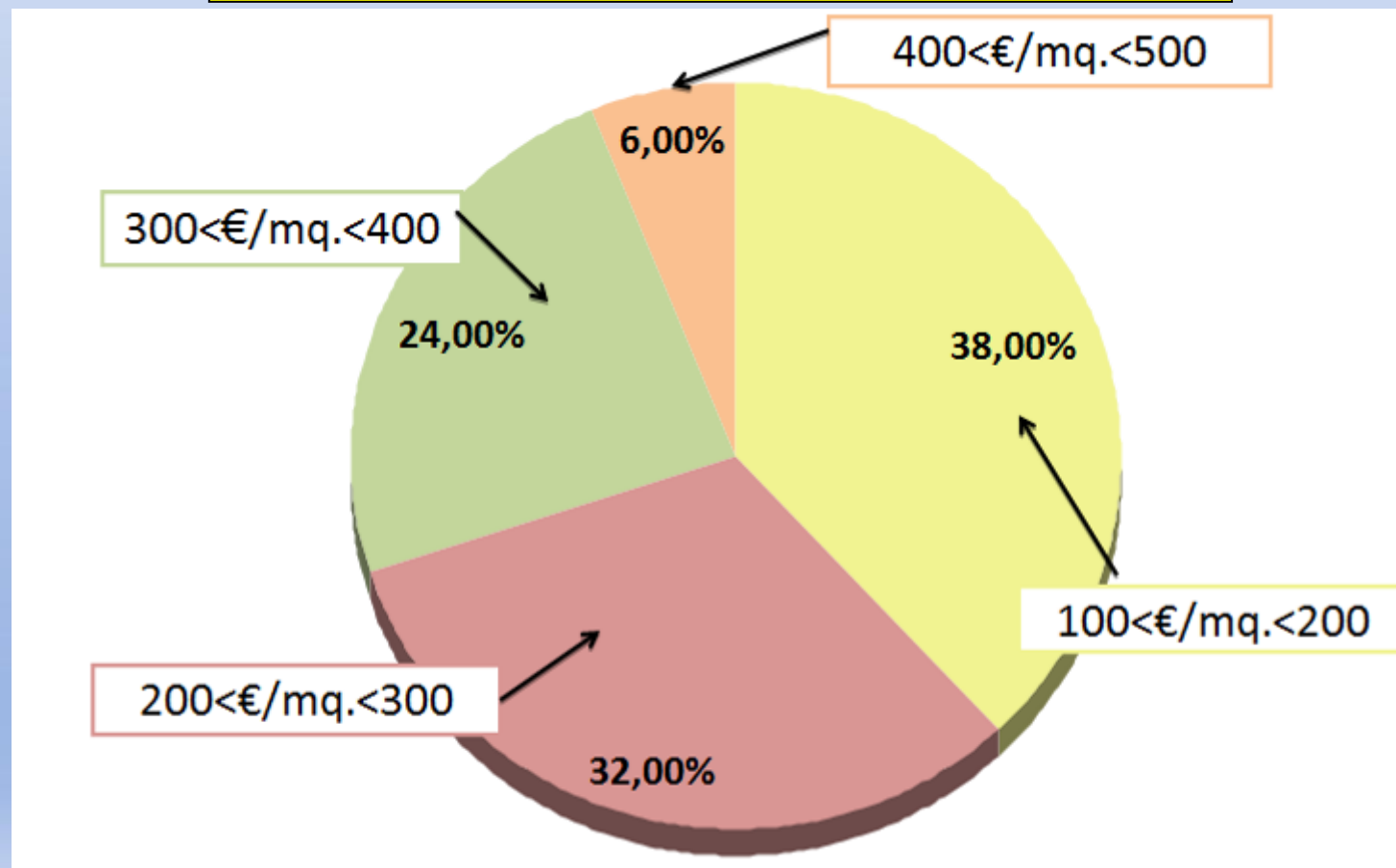
1. Steel or Glass Fibre  
Reinforced plaster
2. Iniections



# RECONSTRUCTION PROCESS:

## "Light Reconstruction" - Buildings "B", "C"

### COSTS ON RC BUILDINGS

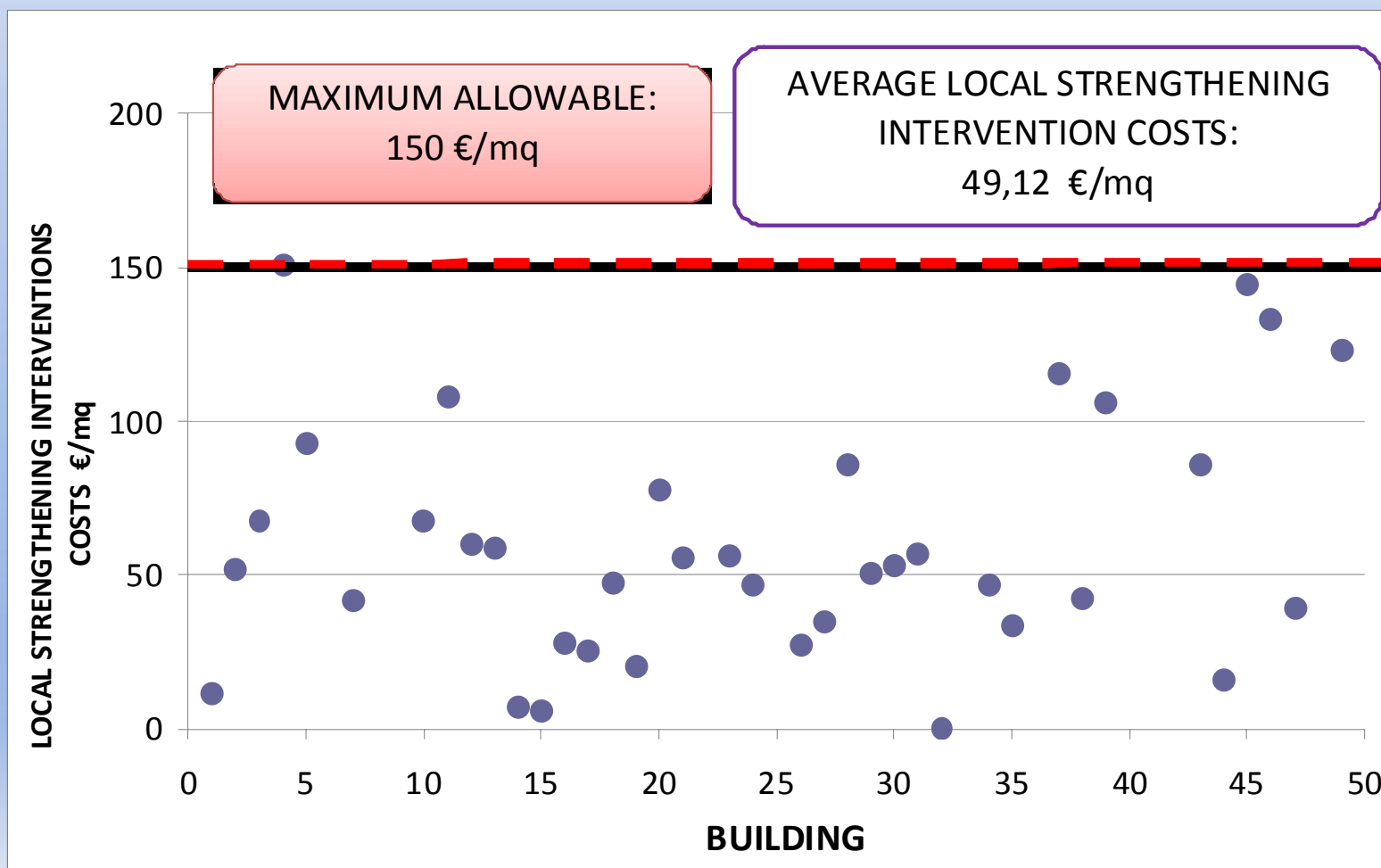


**REPAIR COSTS ON APARTMENTS**

# RECONSTRUCTION PROCESS:

## "Light Reconstruction" - Buildings "B", "C"

### COSTS ON RC BUILDINGS



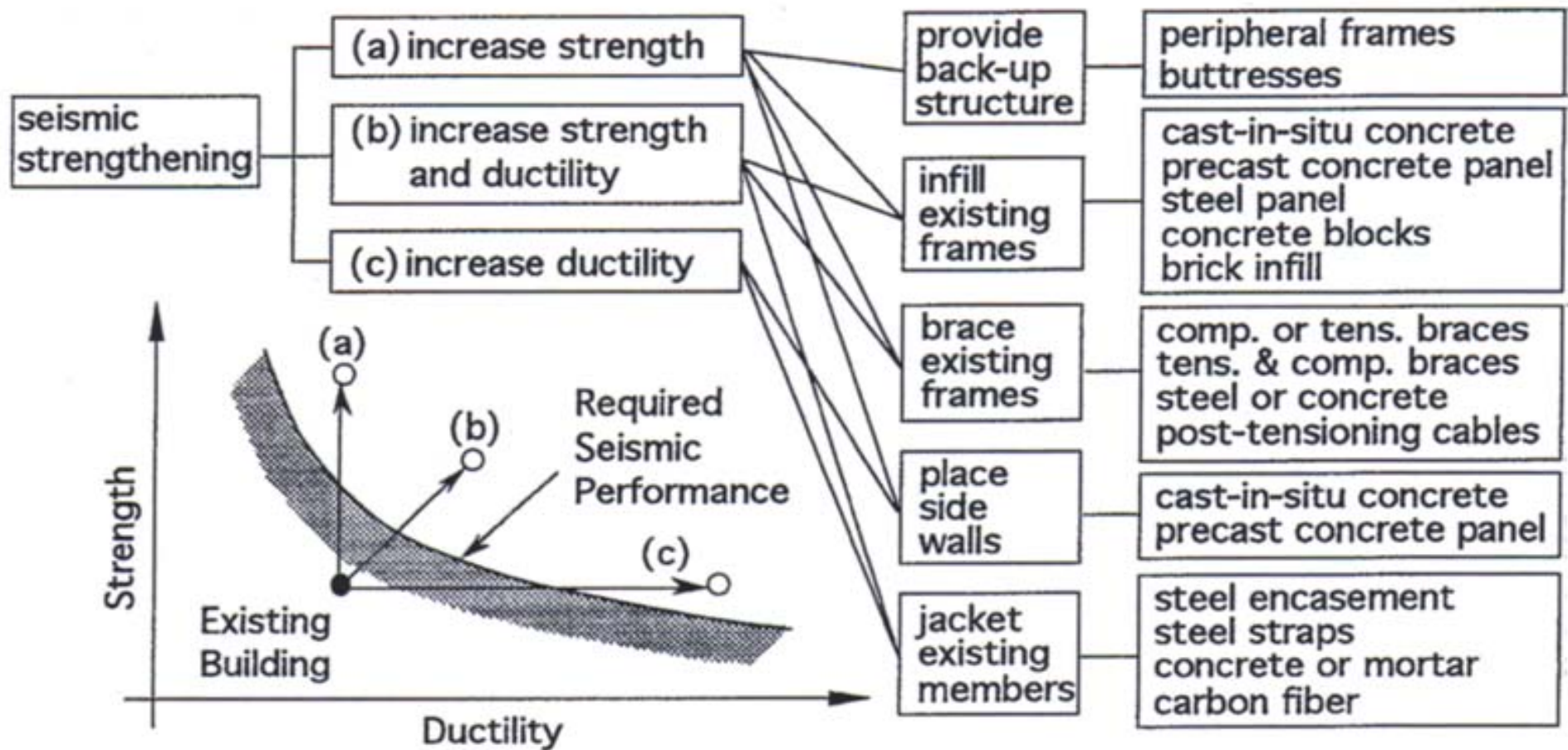
# RECONSTRUCTION PROCESS:

ReLUIS ACTIVITY



**“Heavy Reconstruction” - Buildings “E”**

# Seismic Rehabilitation Strategies



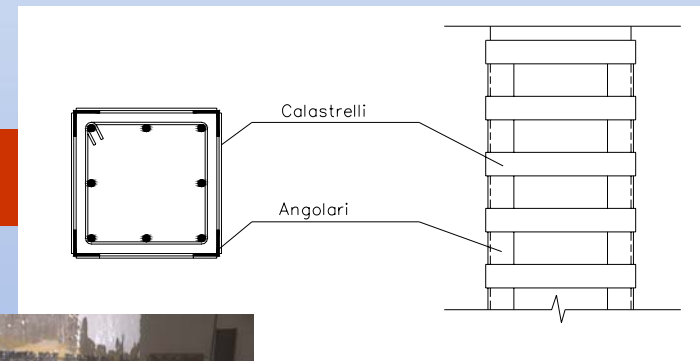
# Seismic Rehabilitation Strategies

## Local Strengthening Techniques

RC Jacketing

Steel Jacketing

FRP Confinement



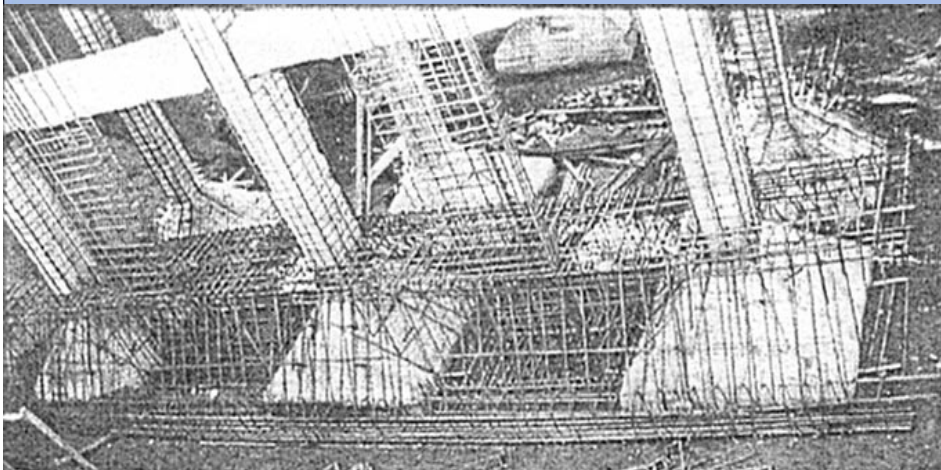
# Seismic Rehabilitation Strategies

## Global Strengthening Techniques

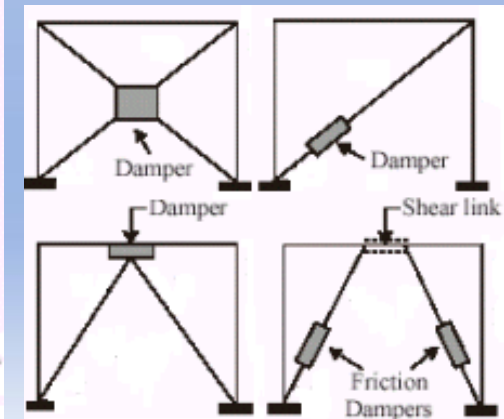
Steel bracing



RC Shear Walls

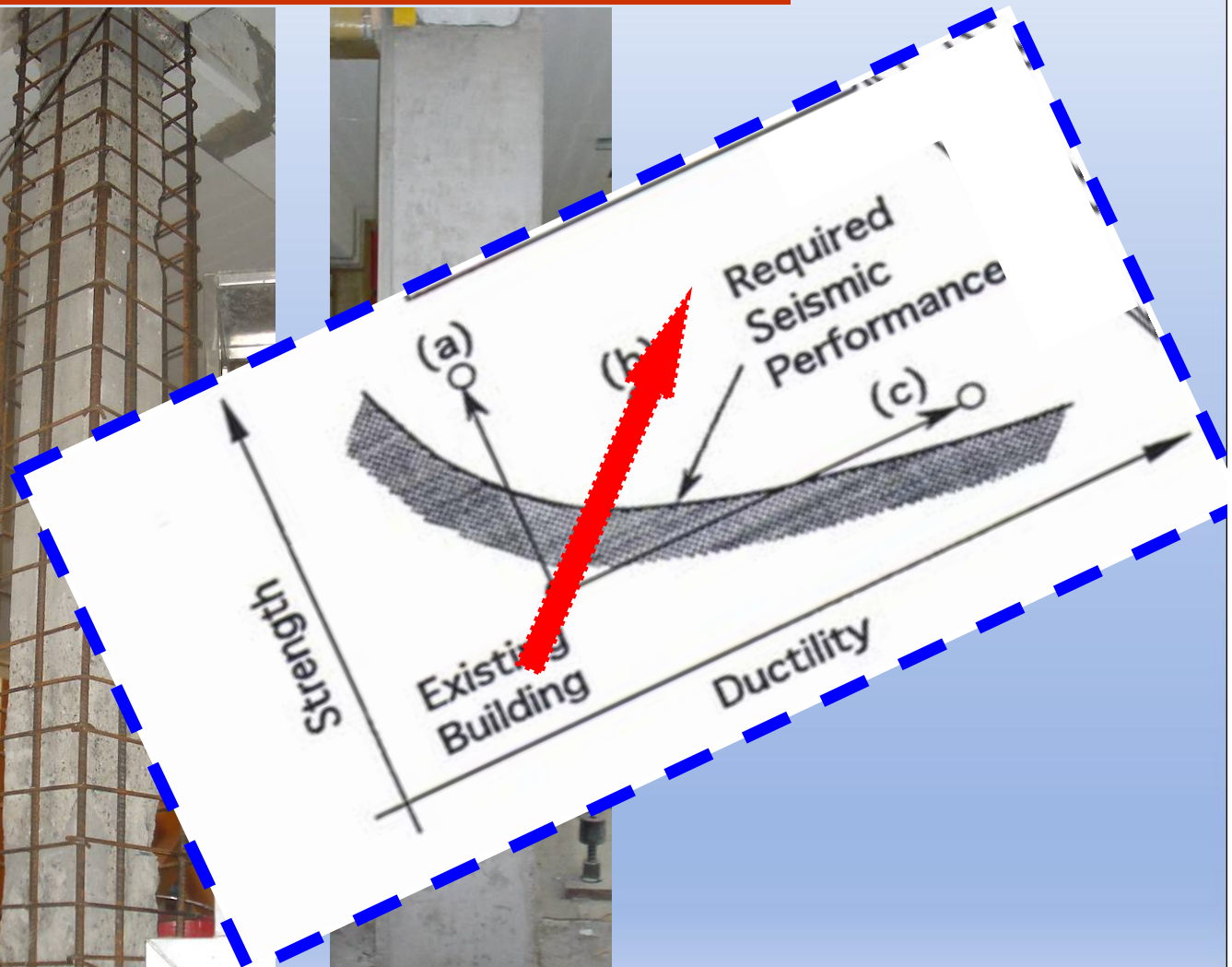
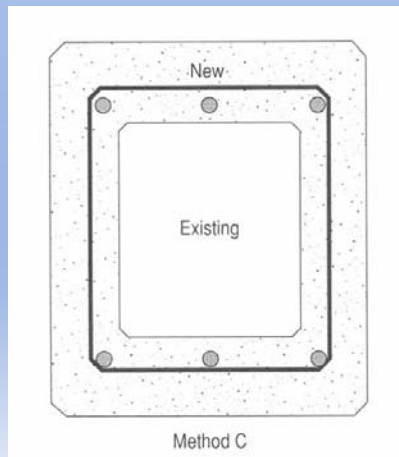
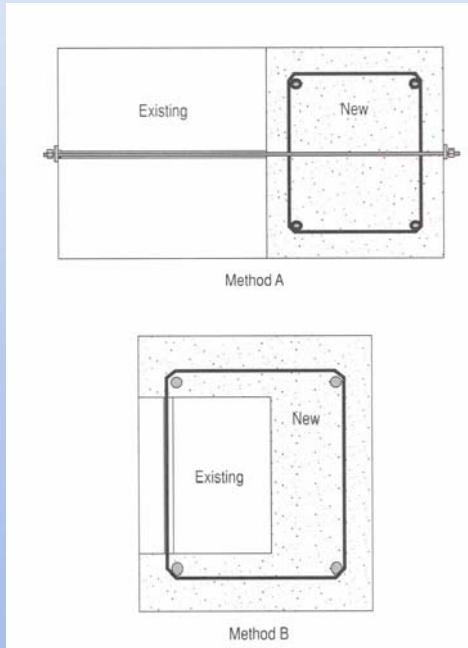


Base Isolators and  
dissipative bracing system



# Local Strengthening Techniques

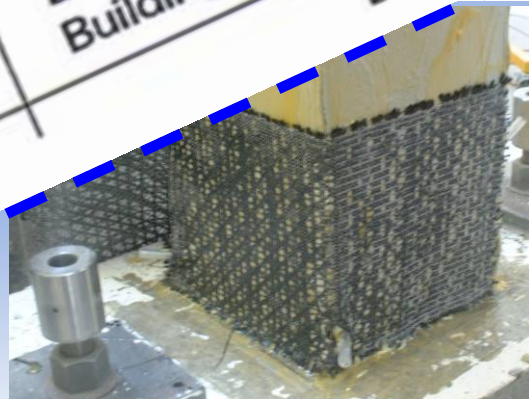
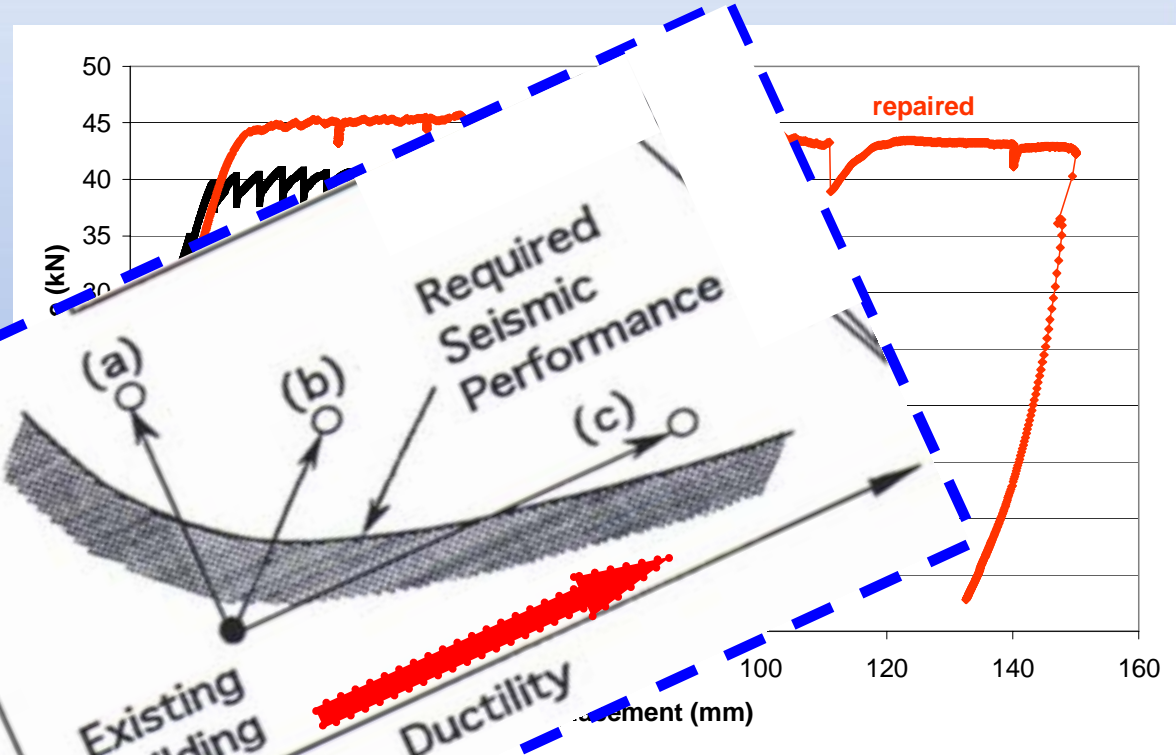
## RC Jacketing





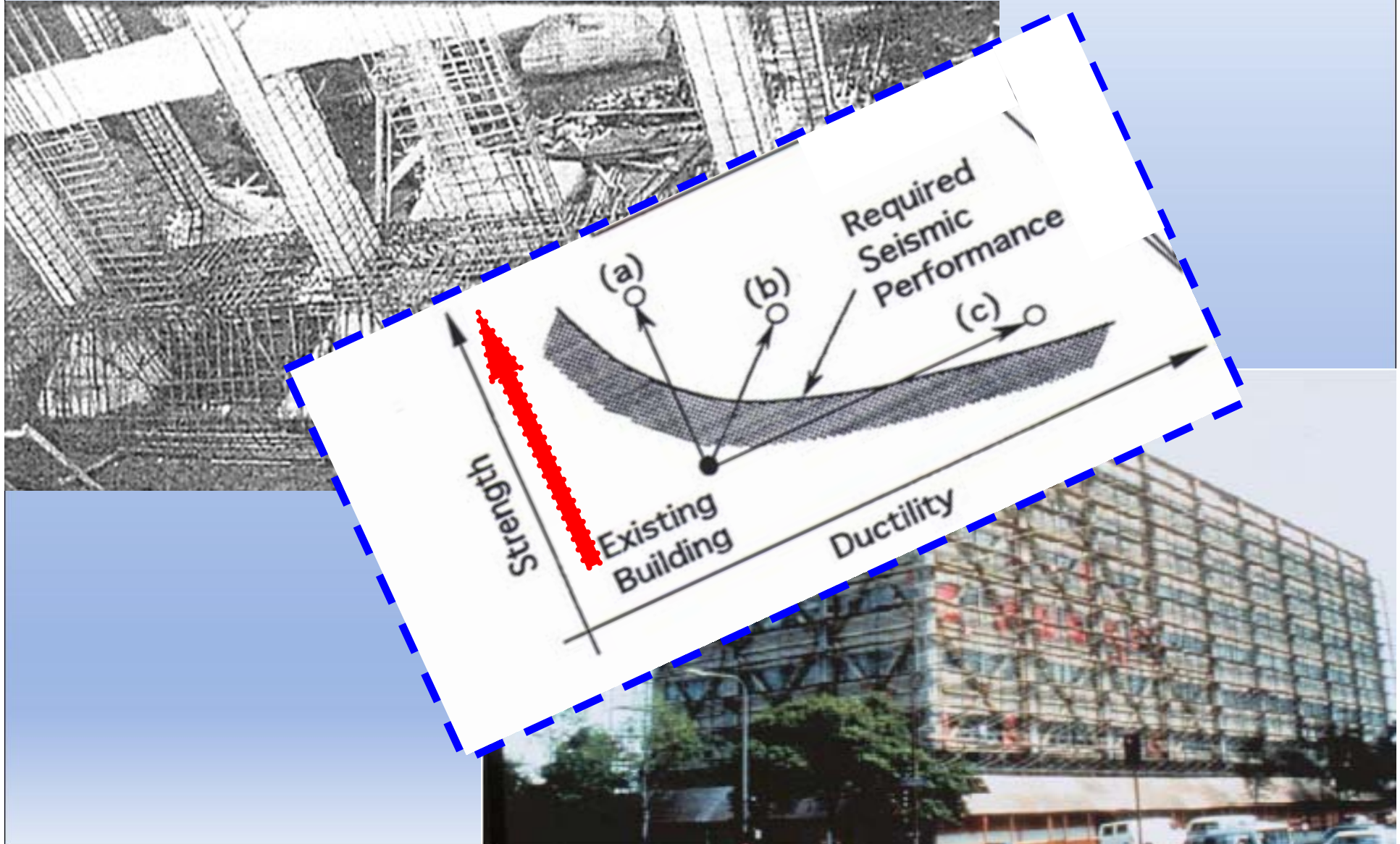
# Local Strengthening Techniques

## FRP Confinement



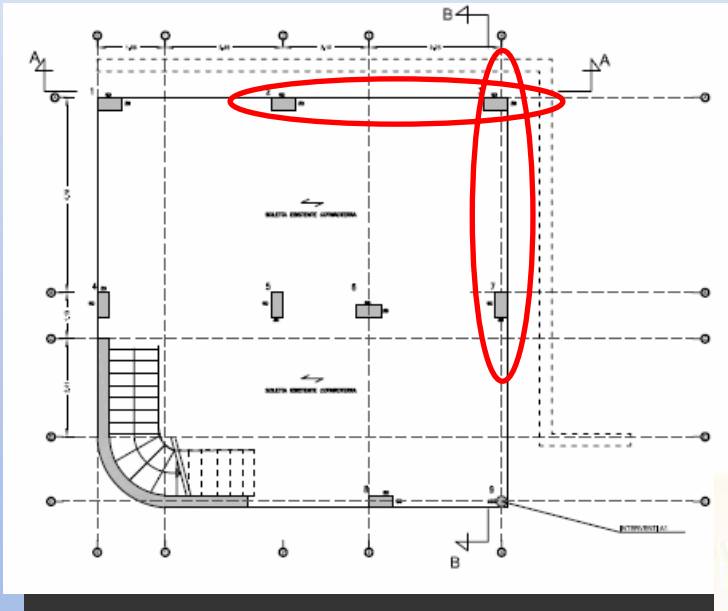
# Global Strengthening Techniques

## Shear walls/Steel bracing

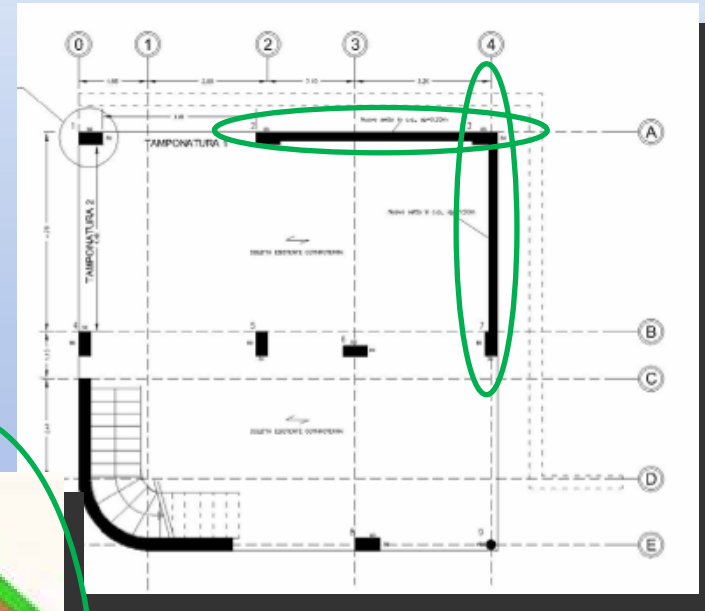


# RECONSTRUCTION PROCESS: ReLUIS CHECKS

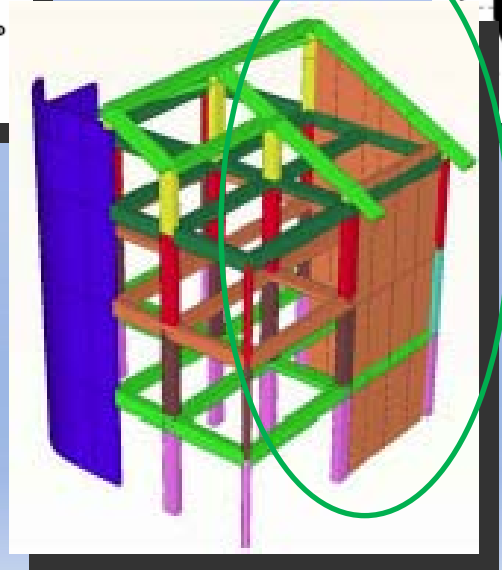
## RC Shear Walls



Ante – Operam

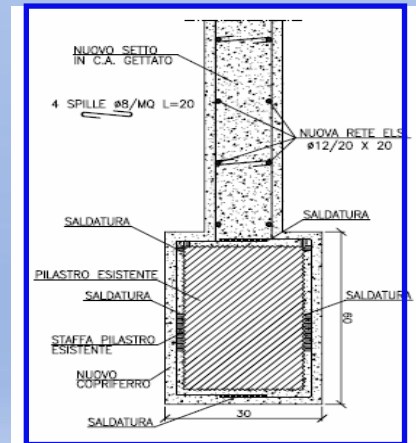
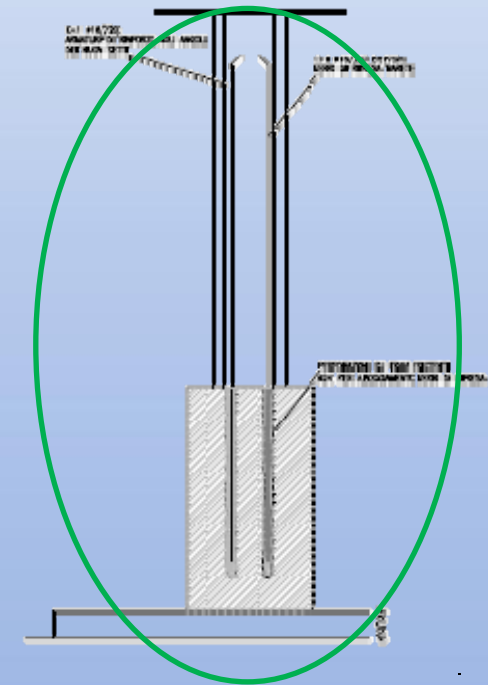
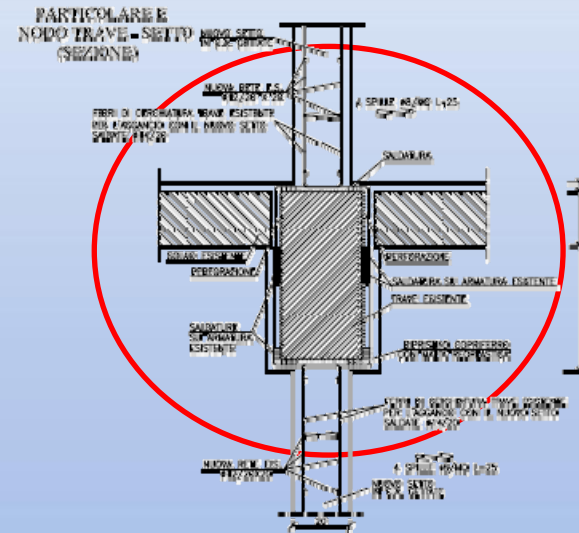
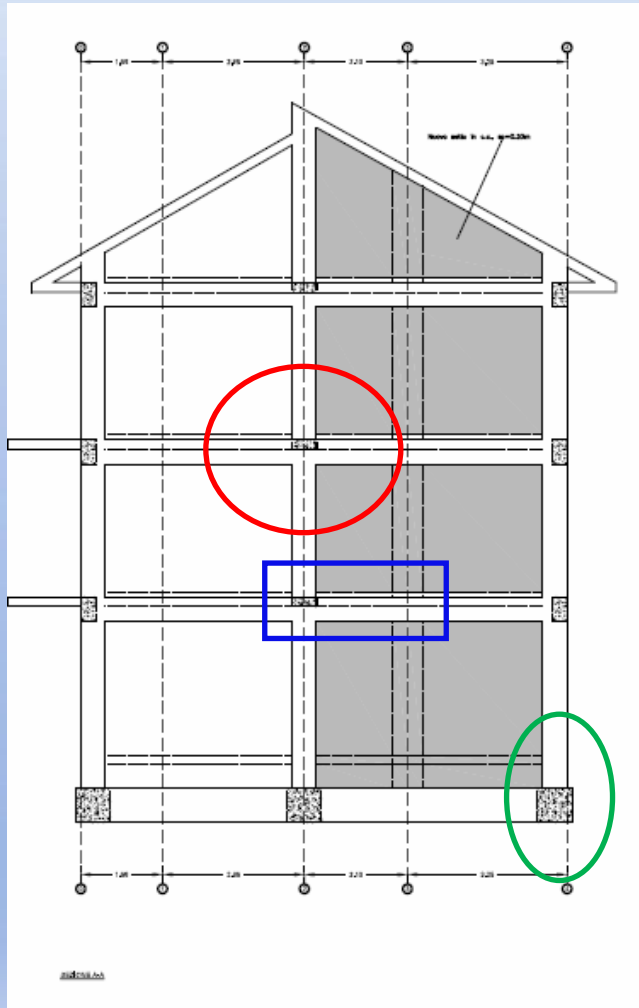


Post – Operam



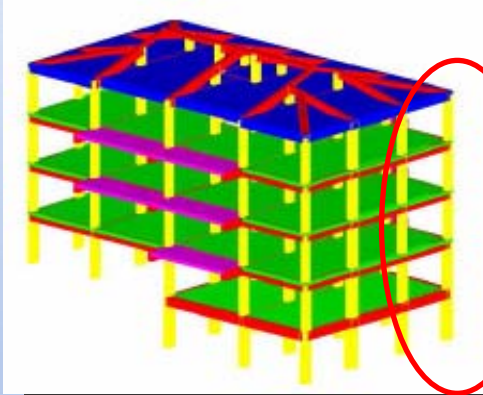
# RECONSTRUCTION PROCESS: ReLUIS CHECKS

## RC Shear Walls

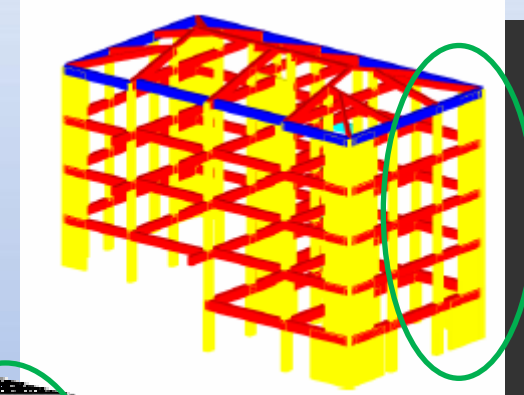


# RECONSTRUCTION PROCESS: ReLUIS CHECKS

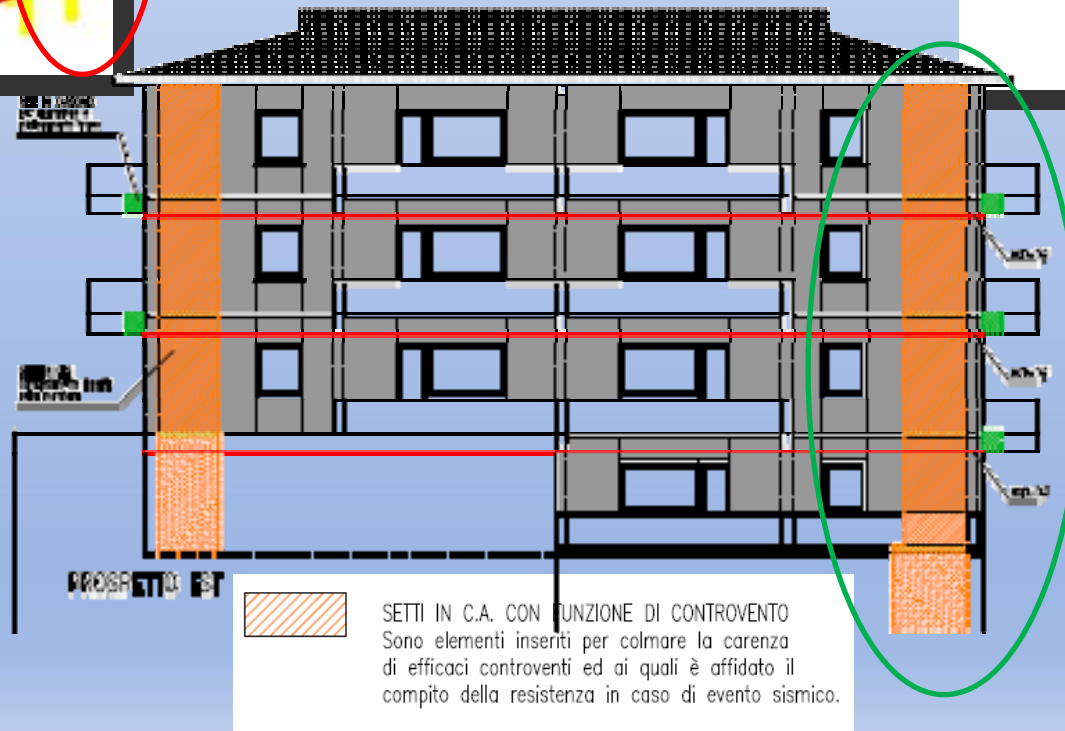
## RC Jacketing



Ante – Operam



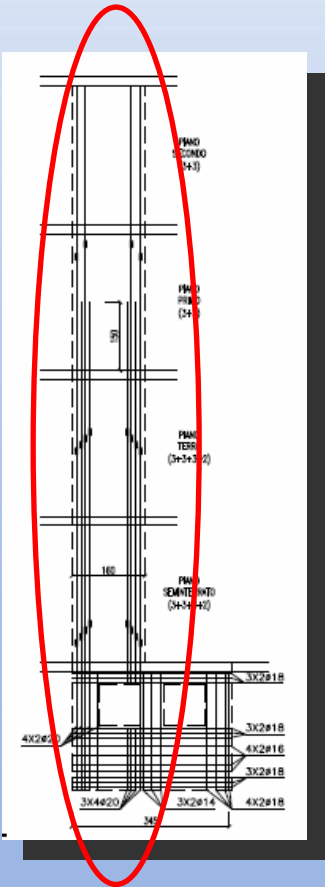
Post – Operam



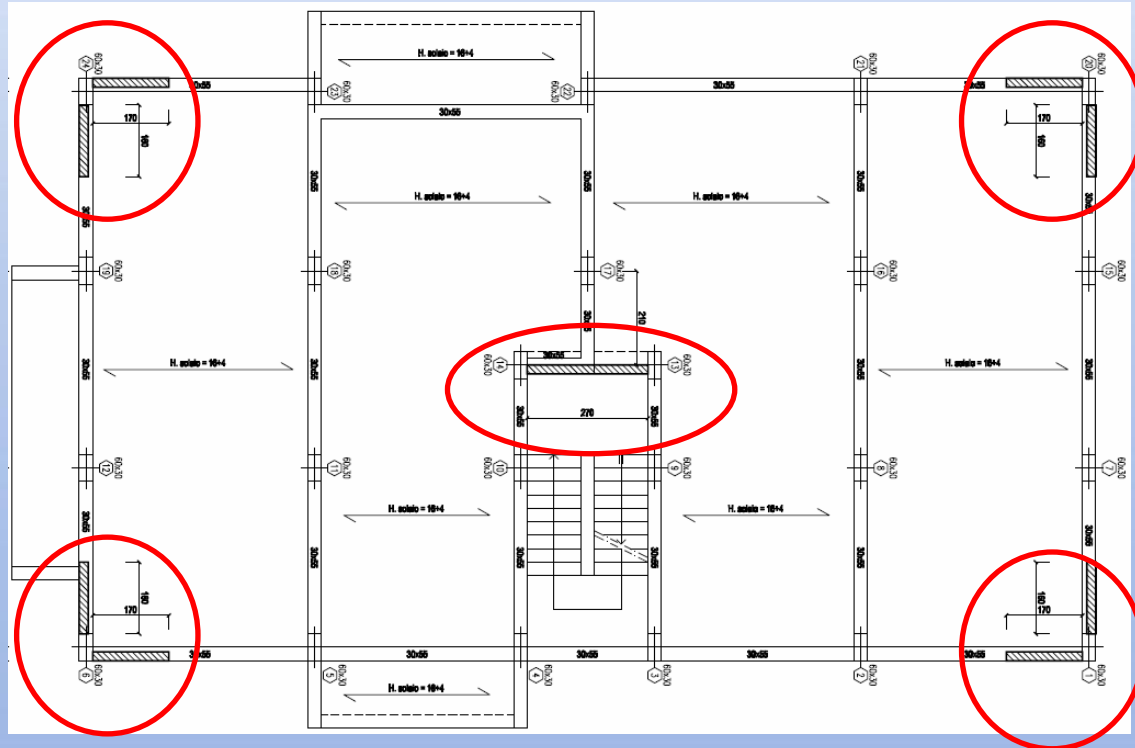
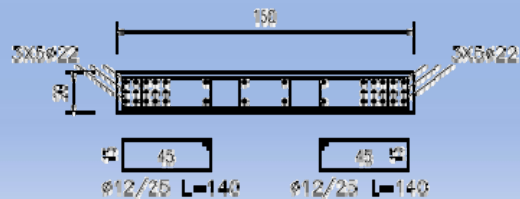
SETTI IN C.A. CON FUNZIONE DI CONTROVENTO  
Sono elementi inseriti per colmare la carenza di efficaci controventi ed ai quali è affidato il compito della resistenza in caso di evento sismico.

# RECONSTRUCTION PROCESS: ReLUIS CHECKS

## RC Jacketing



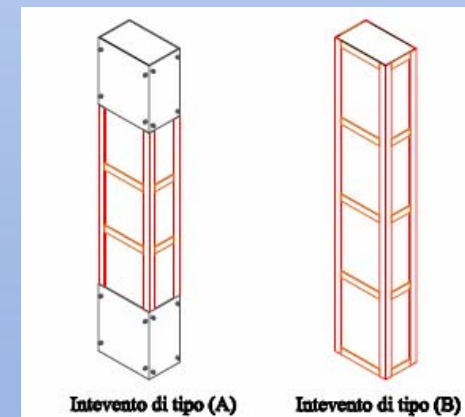
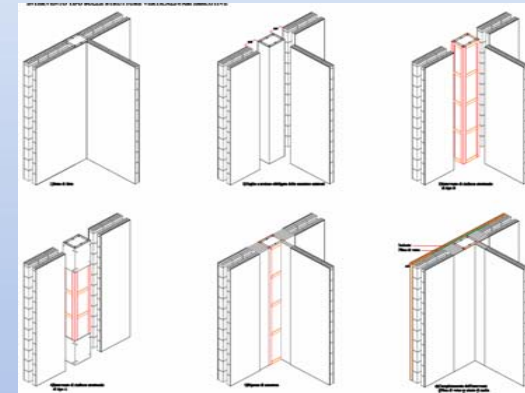
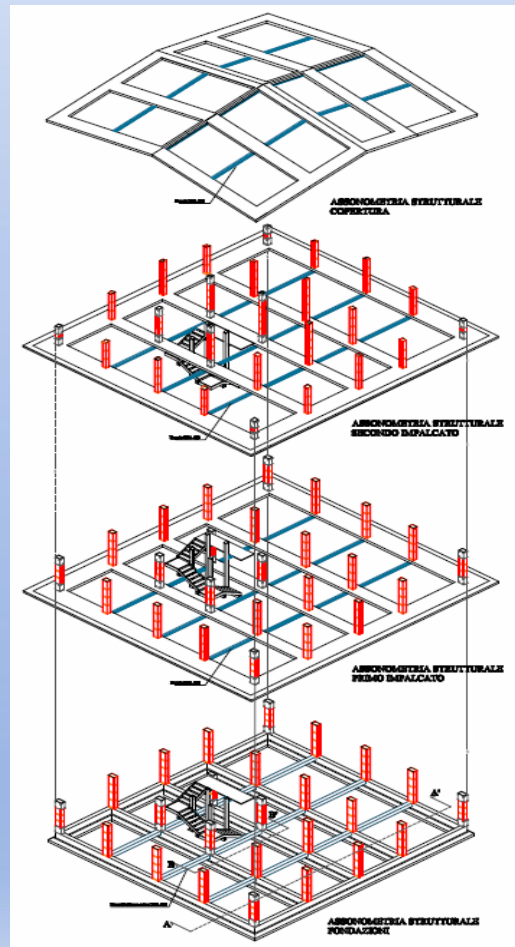
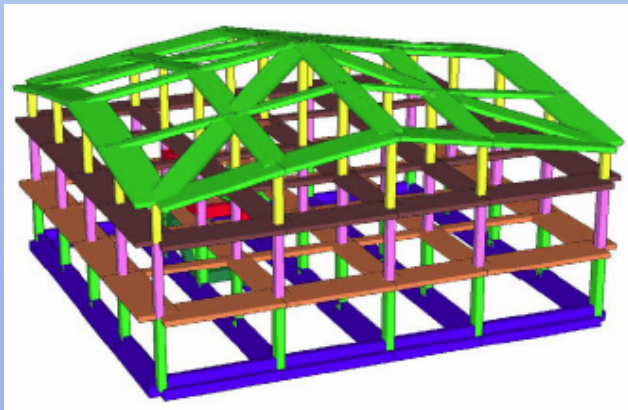
Details



Plan

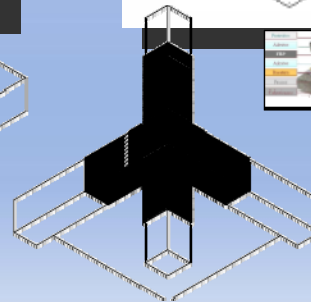
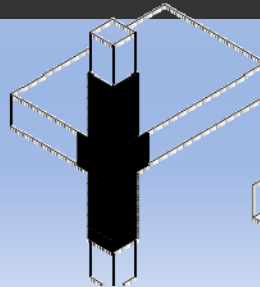
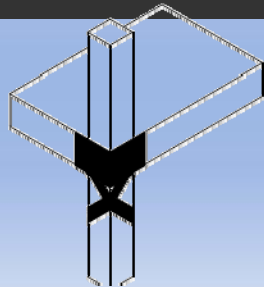
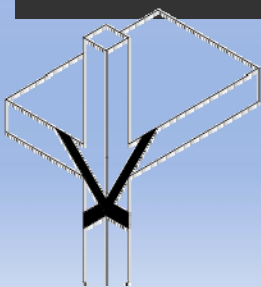
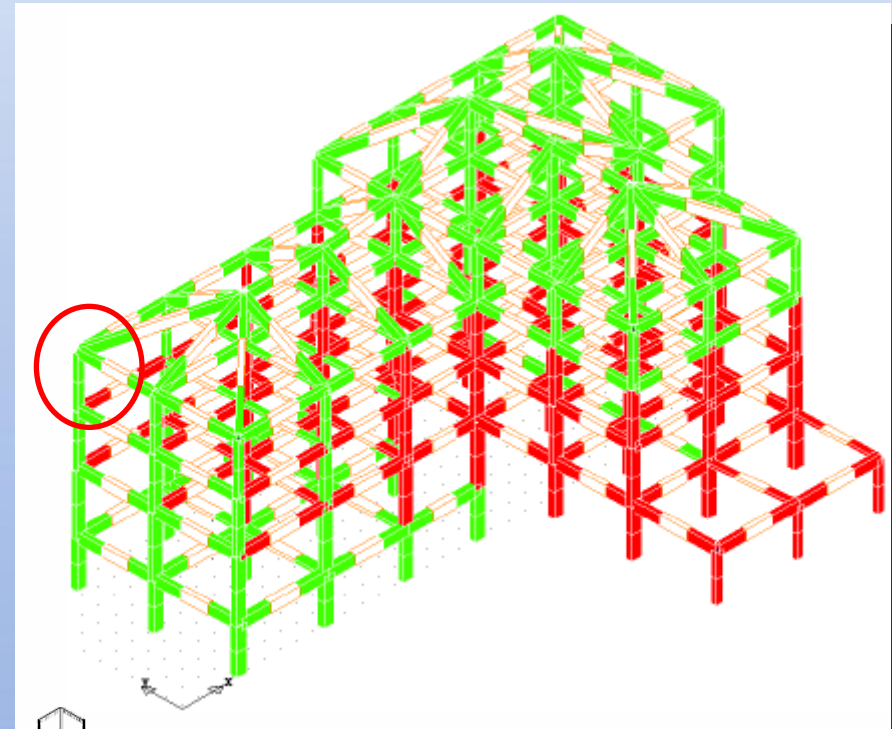
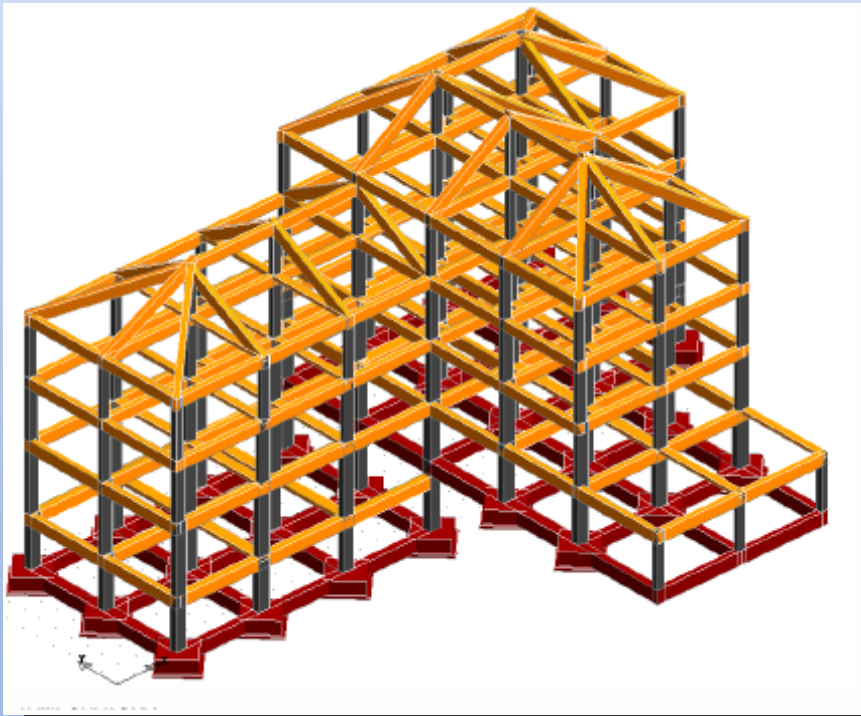
# RECONSTRUCTION PROCESS: ReLUIS CHECKS

## Steel Jacketing



# RECONSTRUCTION PROCESS: ReLUIS CHECKS

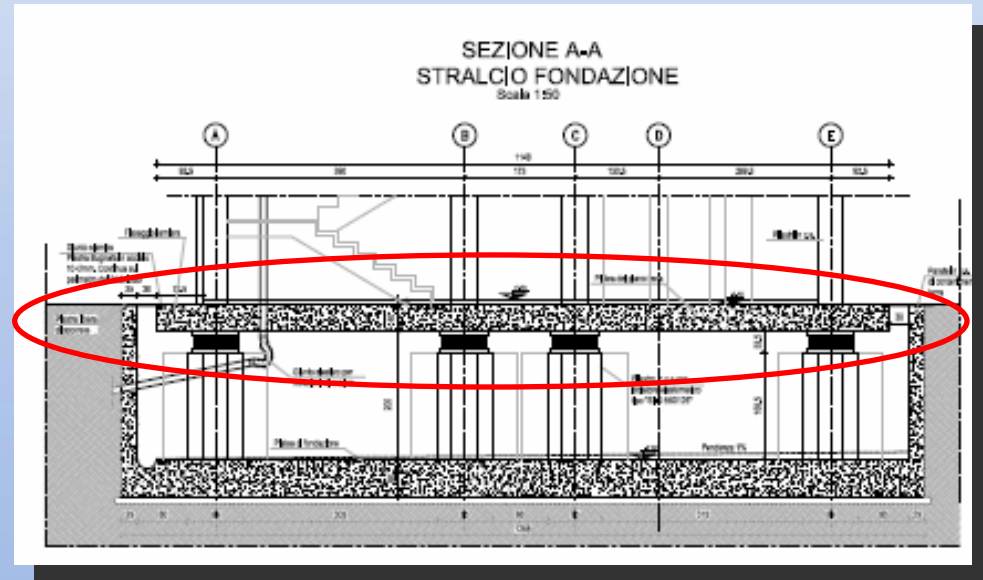
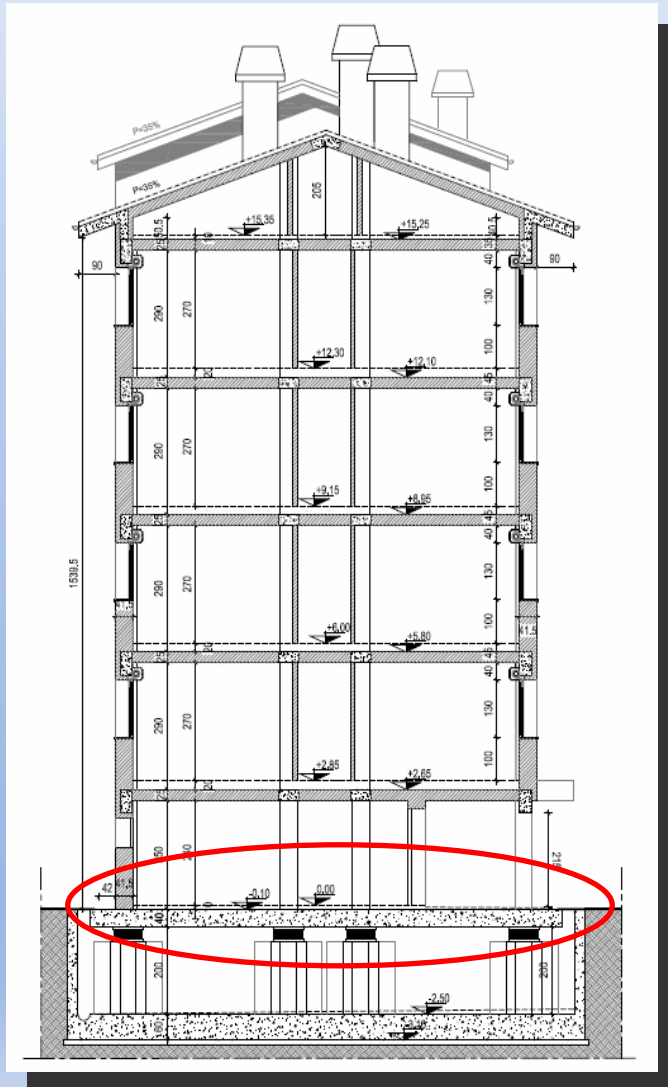
## FRP Strengthening - Global analysis and details





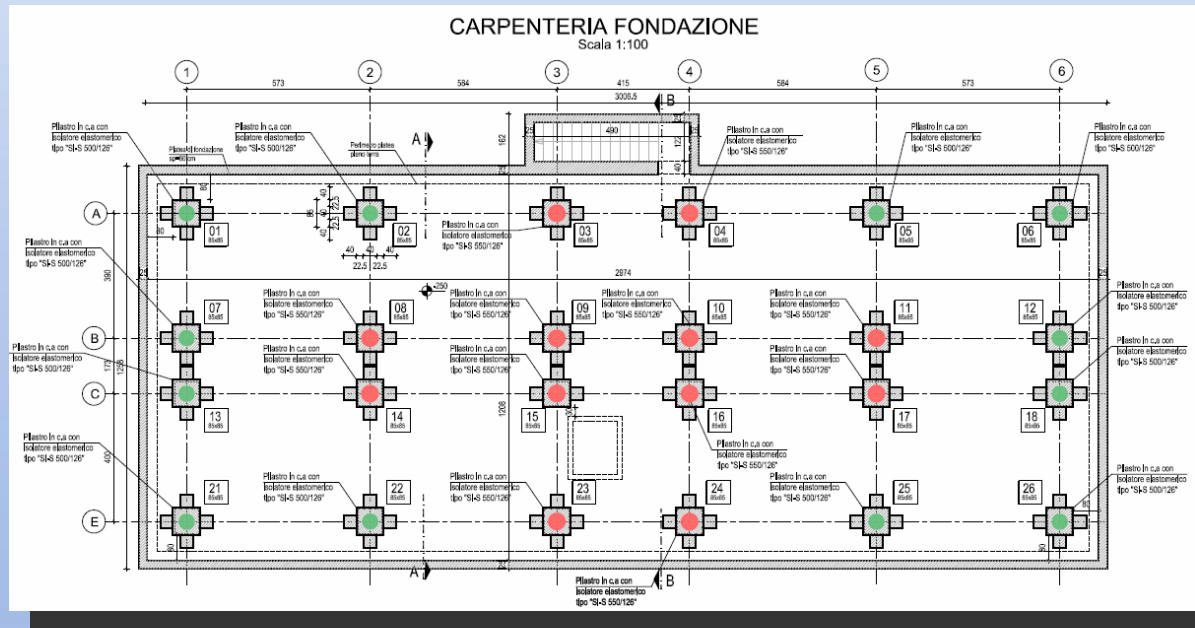
# RECONSTRUCTION PROCESS: ReLUIS CHECKS

## Base Isolation – Case A





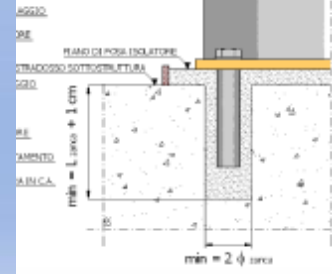
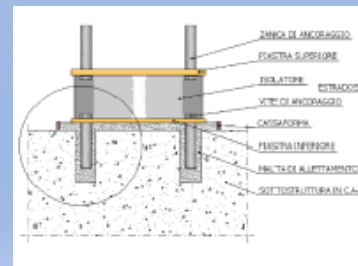
# RECONSTRUCTION PROCESS: ReLUIS CHECKS

## Base Isolation –Case A



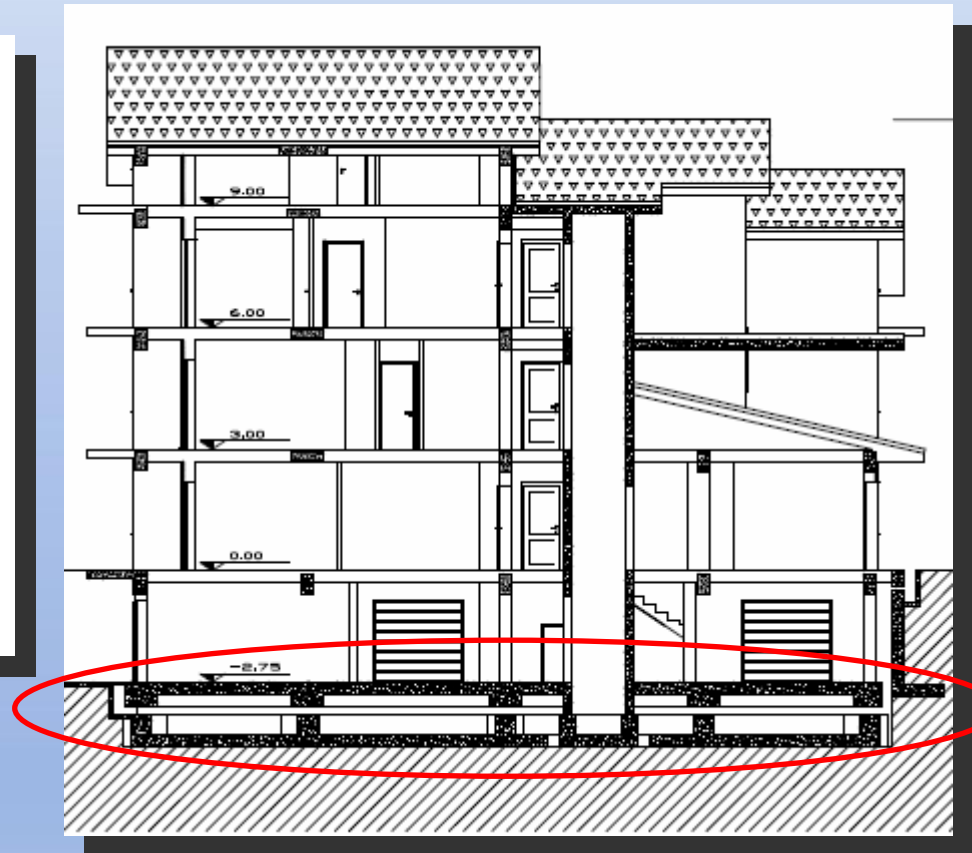
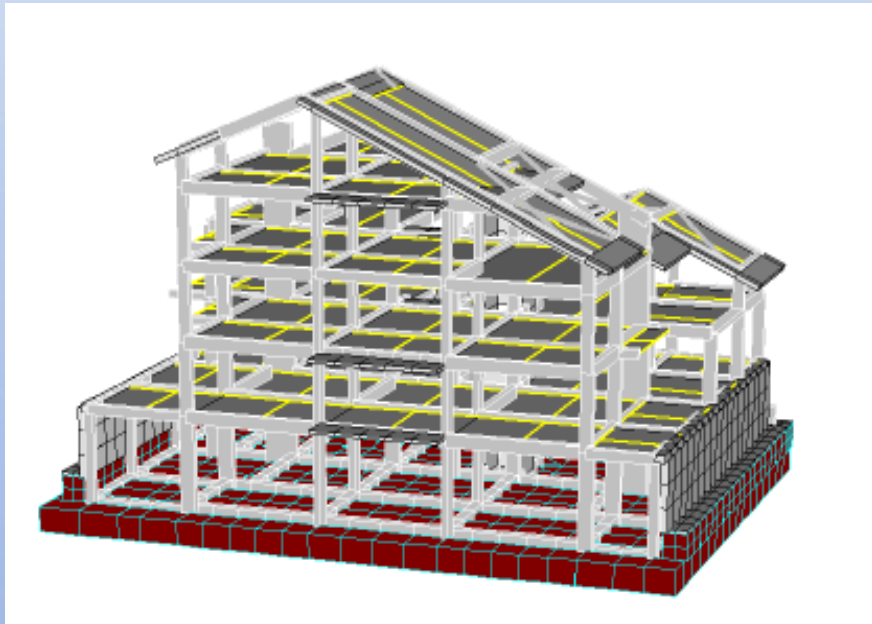
### LEGENDA [ISOLATORI]

-  Isolatore elastomerico tipo "SIS 550/126"
-  Isolatore elastomerico tipo "SIS 500/126"



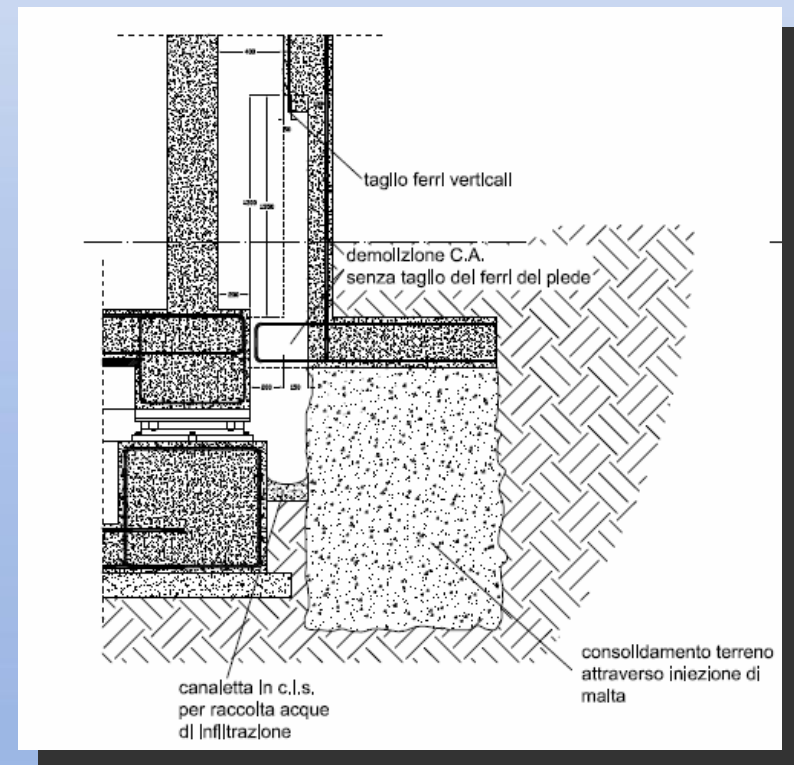
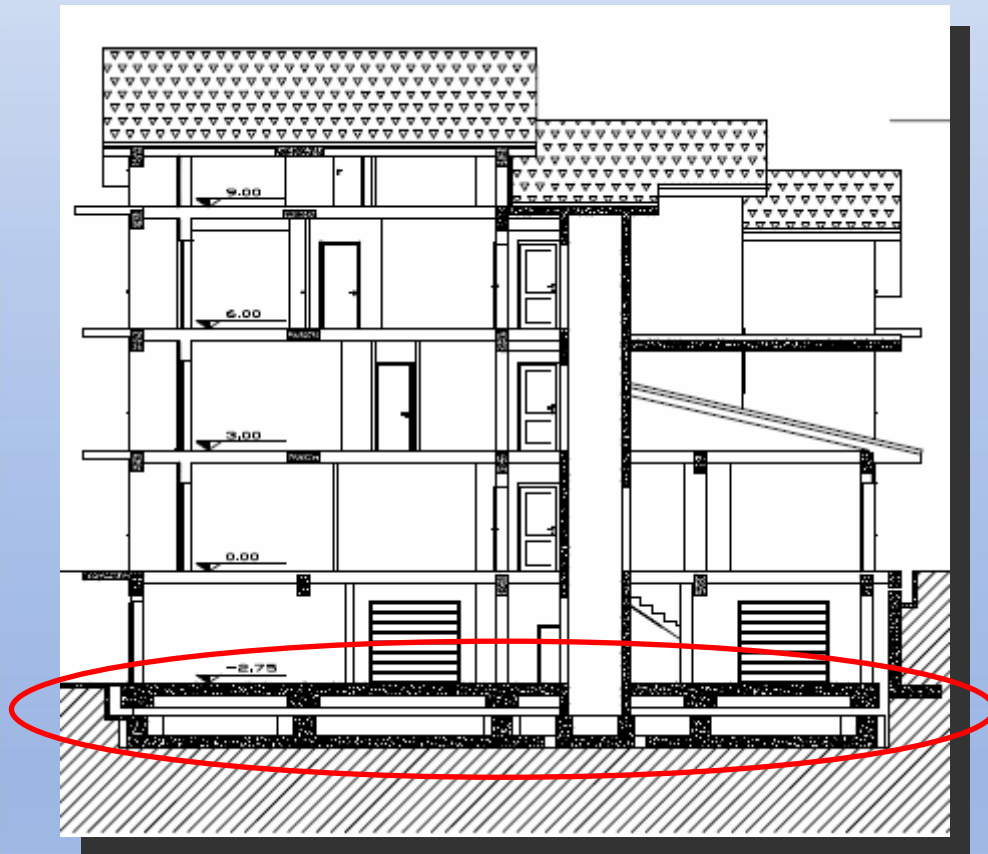
# RECONSTRUCTION PROCESS: ReLUIS CHECKS

## Base Isolation –Case B



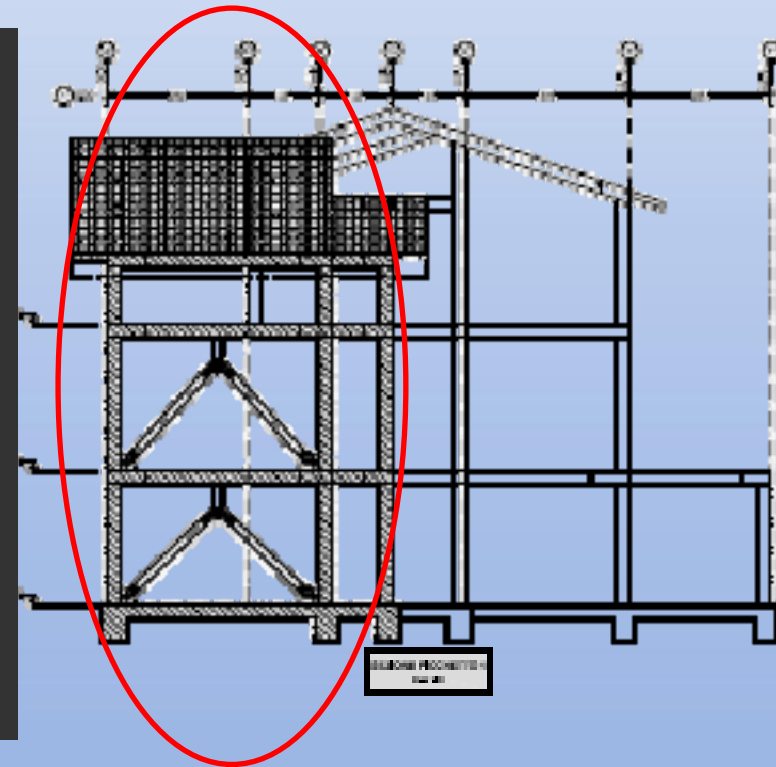
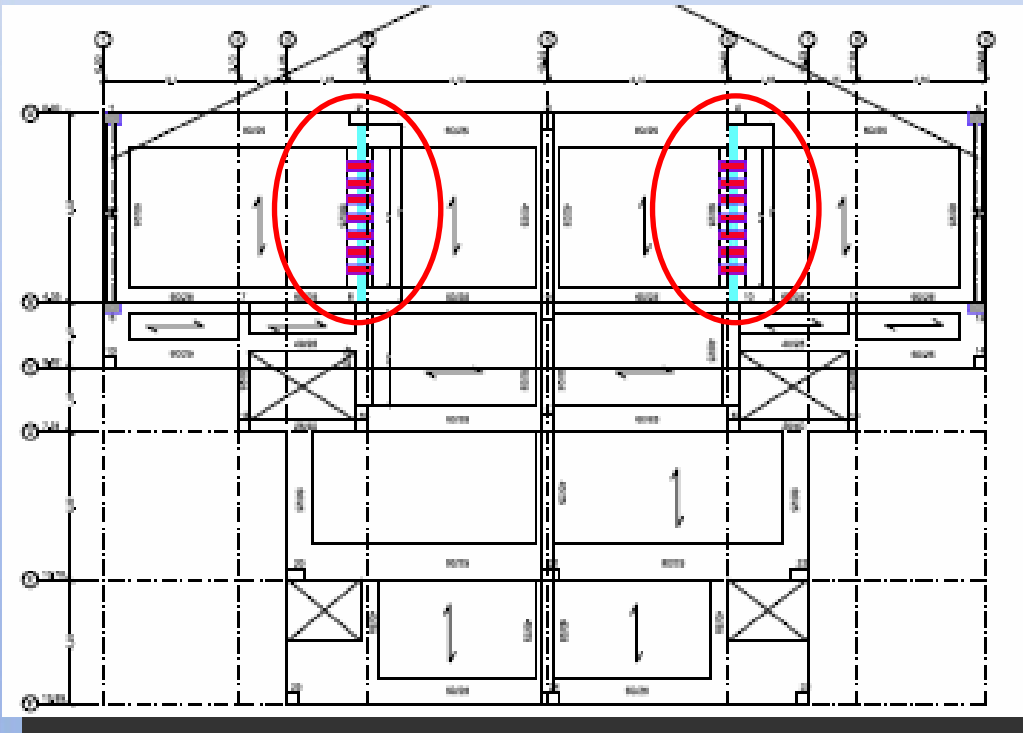
# RECONSTRUCTION PROCESS: ReLUIS CHECKS

## Base Isolation –Case B



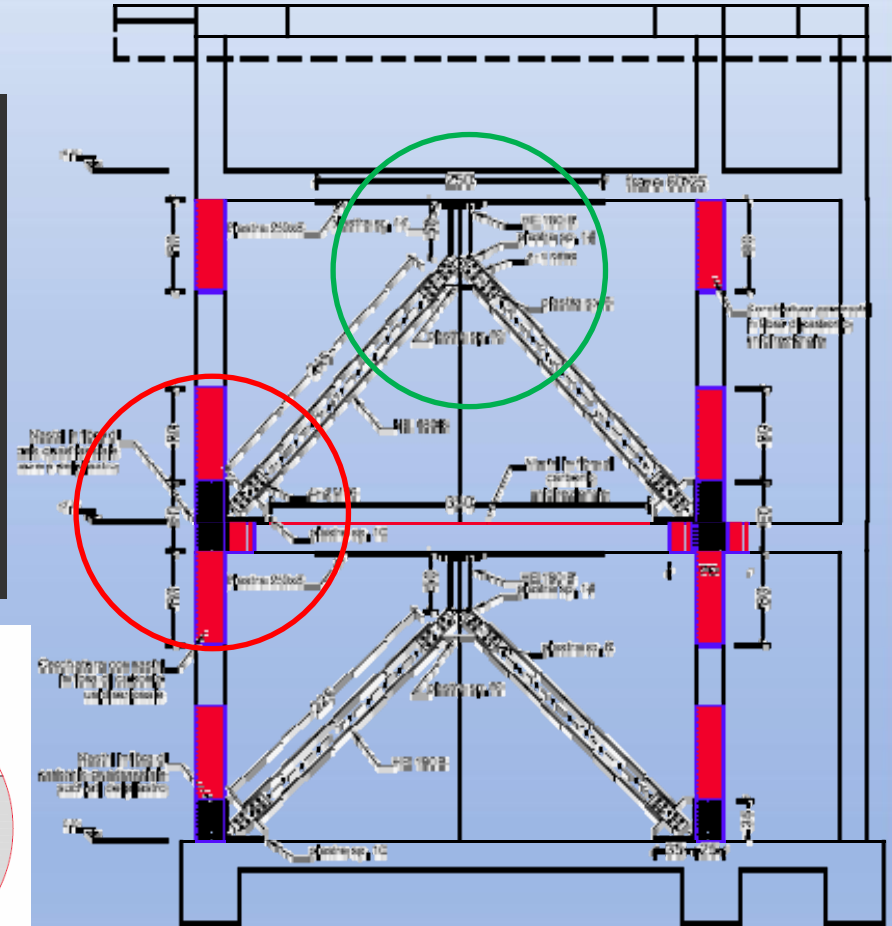
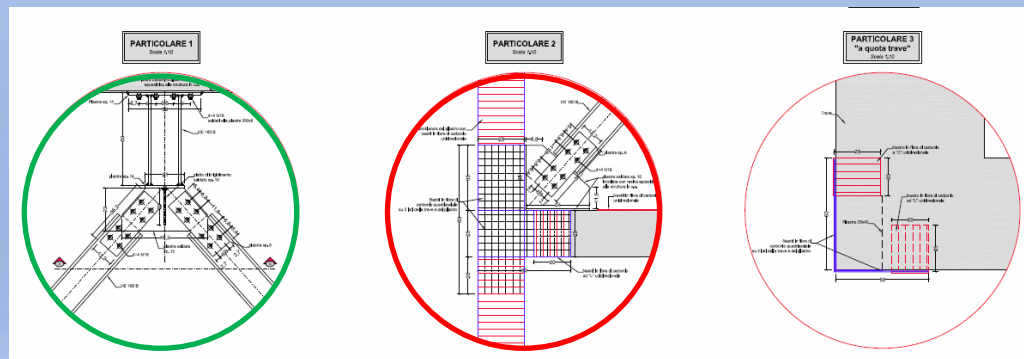
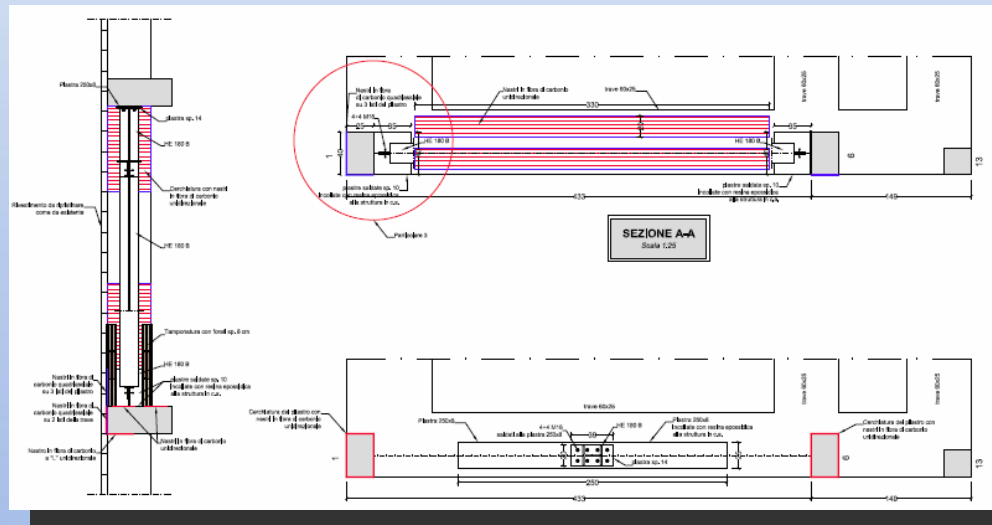
# RECONSTRUCTION PROCESS: ReLUIS CHECKS

## Dissipative Bracing Systems



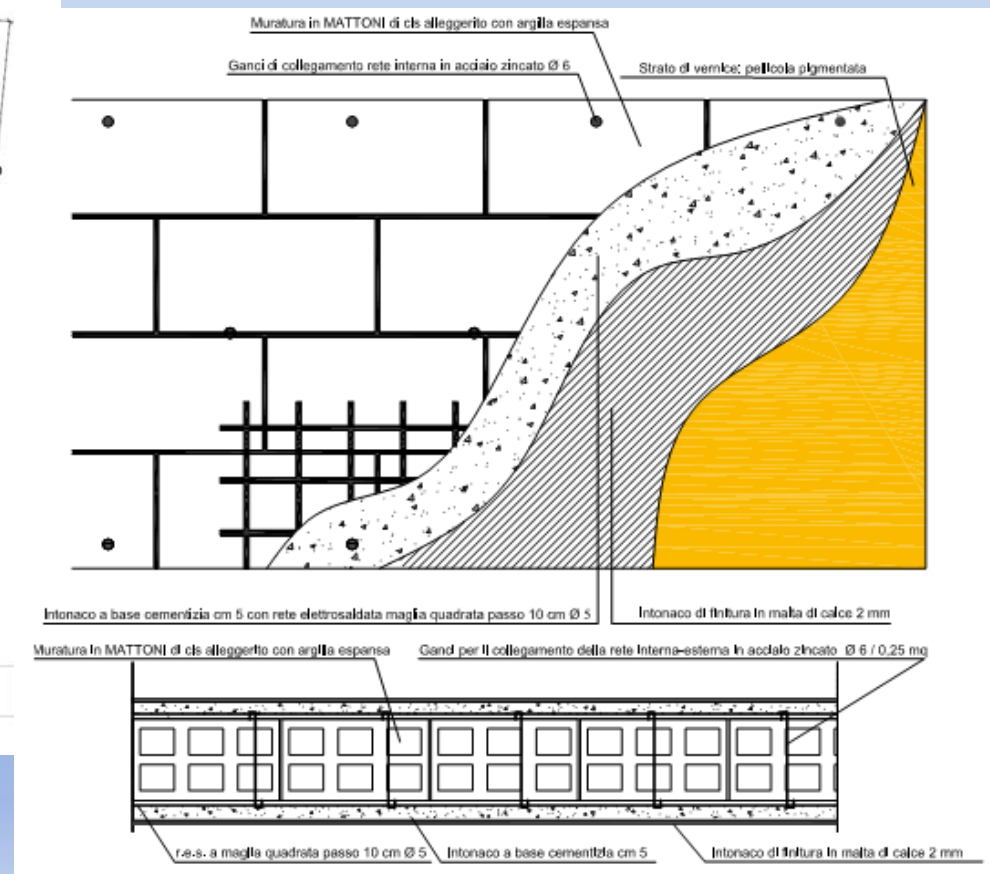
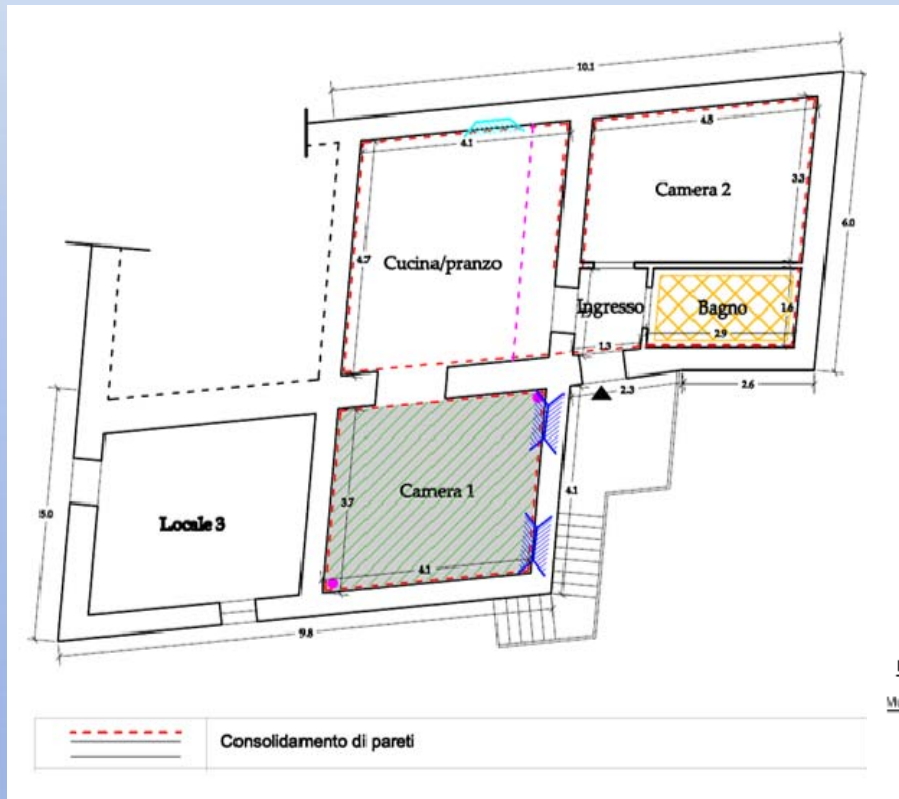
# RECONSTRUCTION PROCESS: ReLUIS CHECKS

## Dissipative Bracing Systems



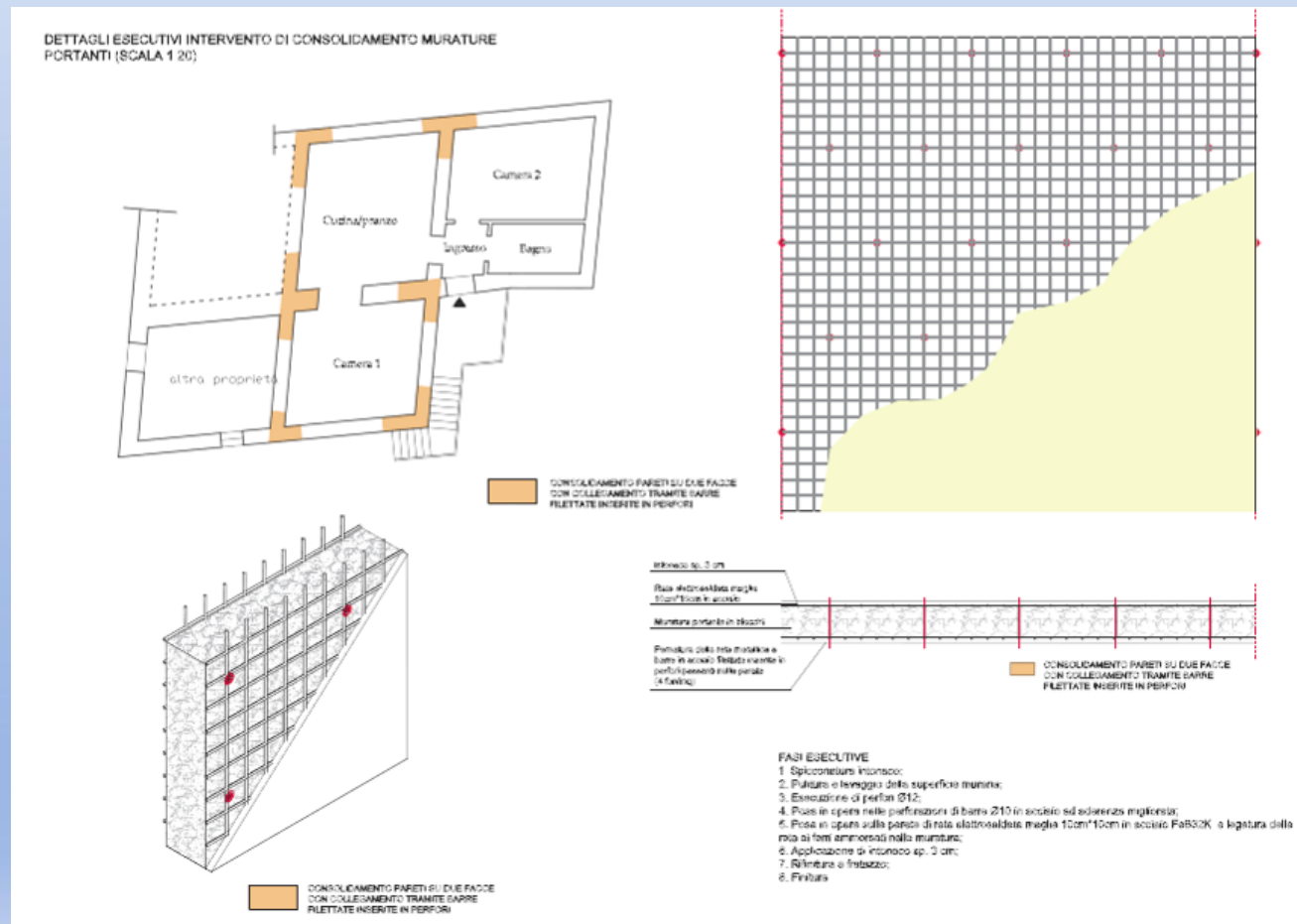
# RECONSTRUCTION PROCESS: ReLUIS CHECKS

## Steel Reinforced plaster



# RECONSTRUCTION PROCESS: ReLUIS CHECKS

## Localized Steel or Glass Fibre Reinforced plaster

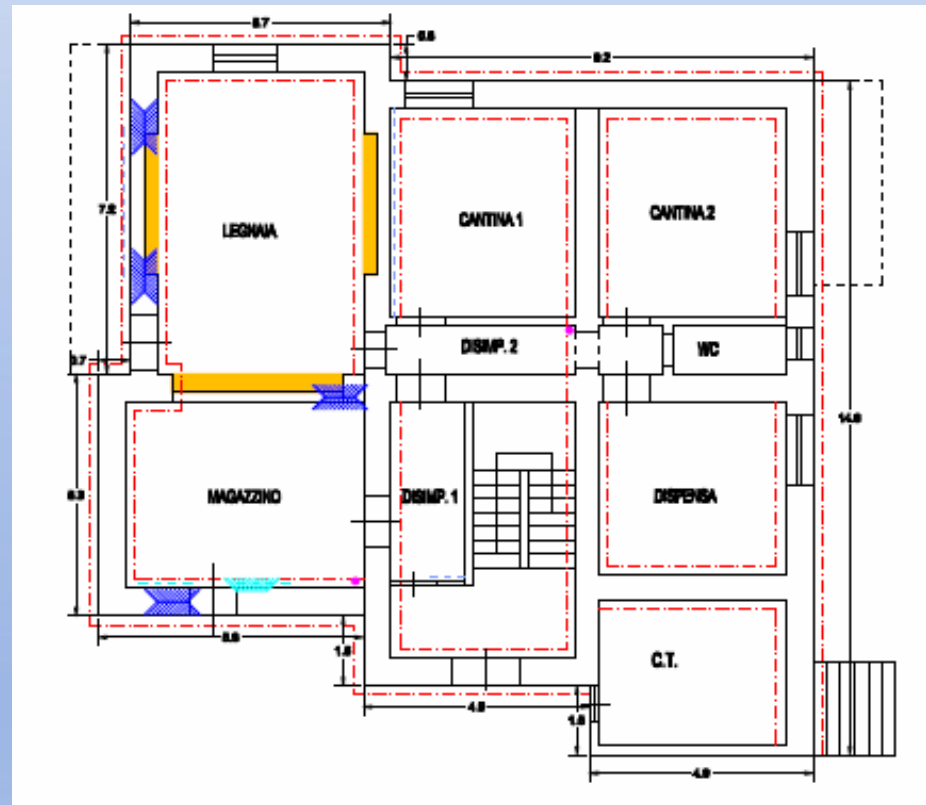




# RECONSTRUCTION PROCESS: ReLUIS CHECKS

Diffused Steel or Glass Fibre Reinforced plaster

Global Analysis is needed



# RESTARTING FROM L'AQUILA

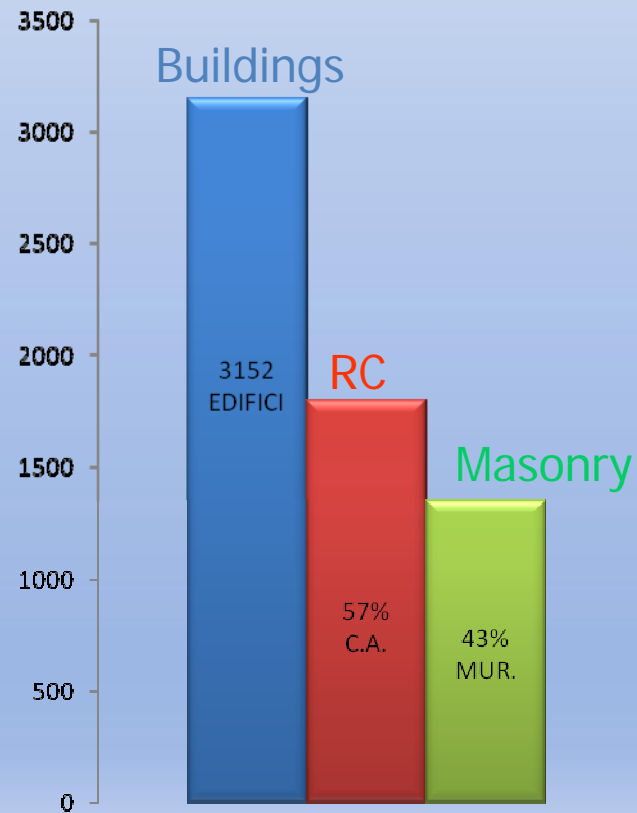


**REte dei Laboratori Universitari di Ingegneria Sismica**

# RECONSTRUCTION PROCESS: ReLUIS CHECKS

## Summary of ReLUIS Checks

**3152** PROJECTS INVESTIGATED OF  
**BUILDINGS RATING B-C-E (L'Aquila)**





# The reconstruction of hystoric centre of L'Aquila



**“PIAZZA della  
PREFETTURA”:  
A PILOT PROJECT**

---

# METHODOLOGY OF STUDY

1. ARCHITECTURAL SURVEY
2. STUDY OF MASONRY BUILDINGS' AGGREGATE AND ARCHITECTURAL CHARACTERISTICS
3. STRUCTURAL SURVEY
4. DAMAGE AND CRACKS ANALYSIS
5. IN SITU TESTS
6. SEISMIC ANALYSIS
7. RETROFIT INTERVENTIONS
8. STRUCTURAL CAPACITY INCREASE

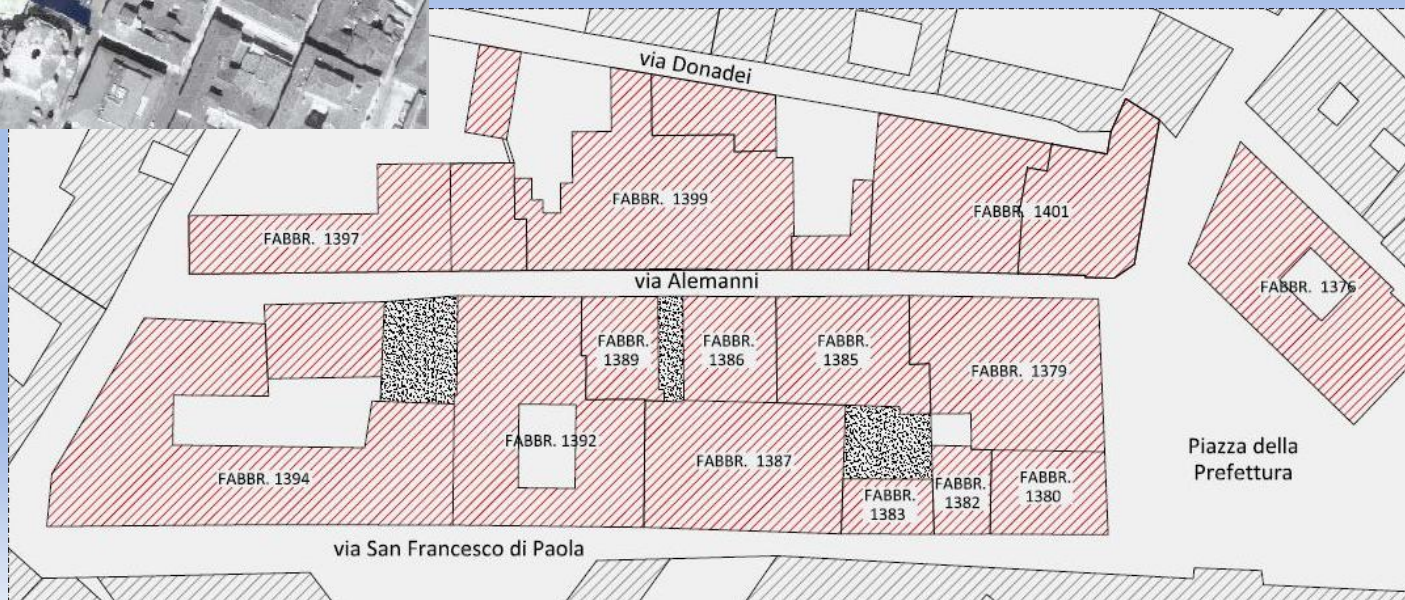


**DEFINITION OF GUIDELINES FOR THE SURVEY, ANALYSIS AND RETROFIT INTERVENTIONS ON MASONRY BUILDINGS' AGGREGATE IN SEISMIC ZONES**



# ARCHITECTURAL SURVEY

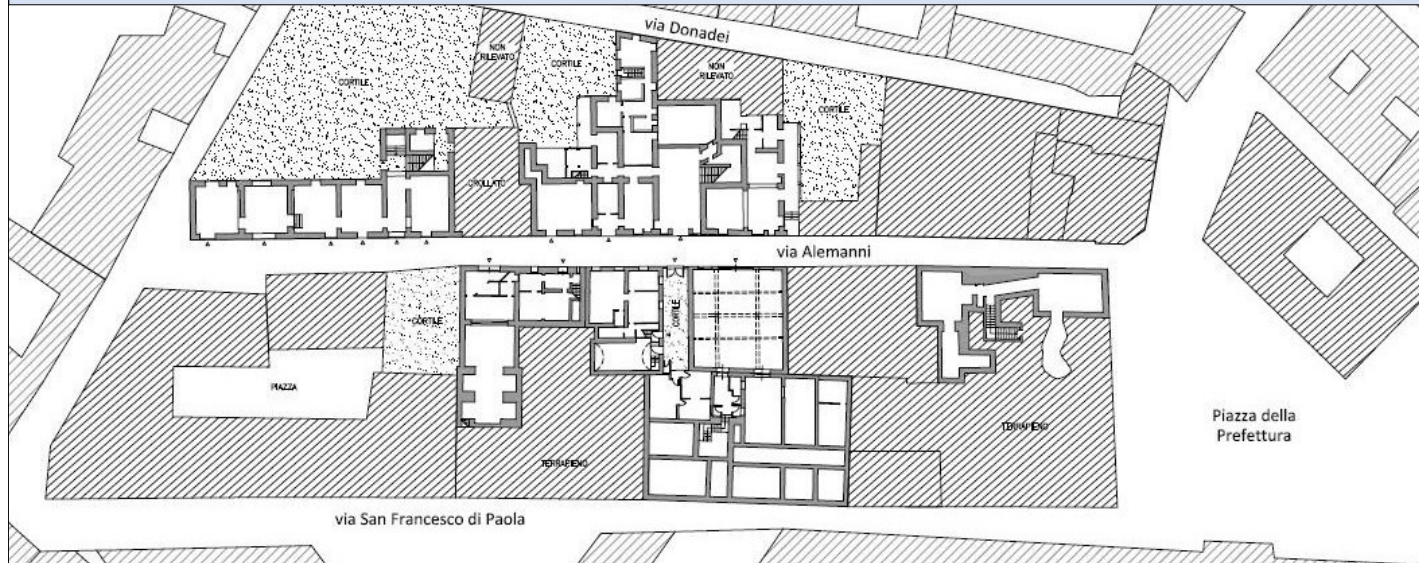
## “BLOCK “PIAZZA della PREFETTURA”



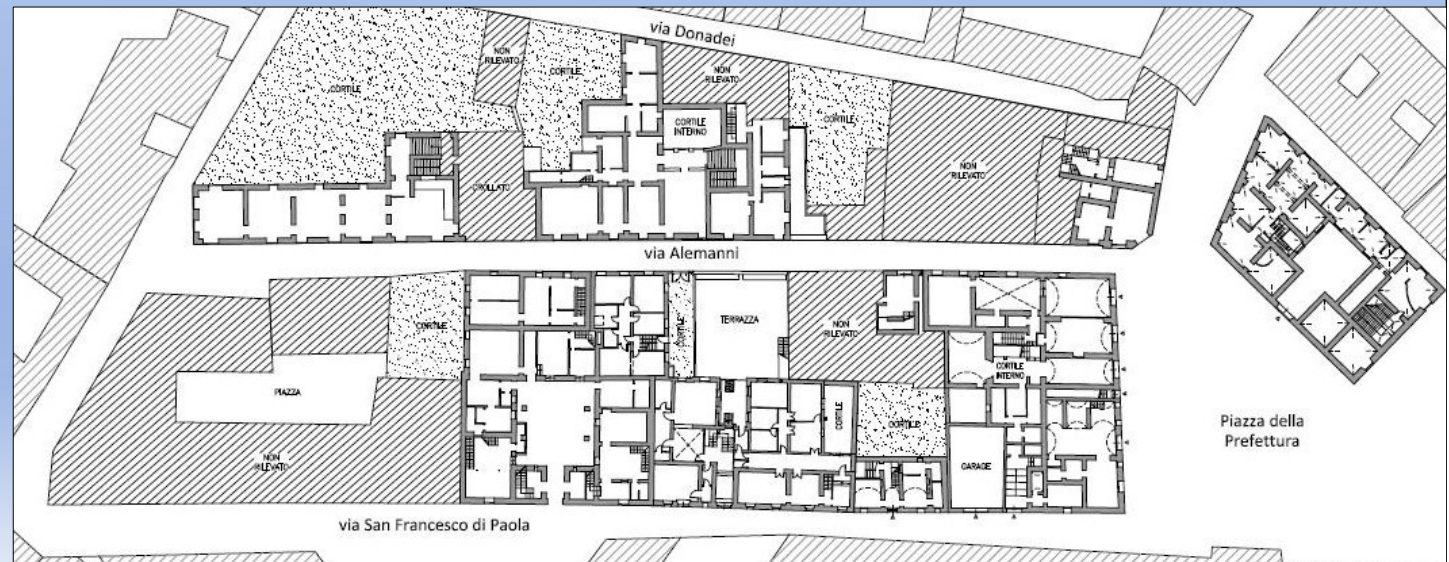
BLOCK PLAN VIEW

# ARCHITECTURAL SURVEY

## BLOCK "PIAZZA della PREFETTURA"



PLAN LEVEL "-1"

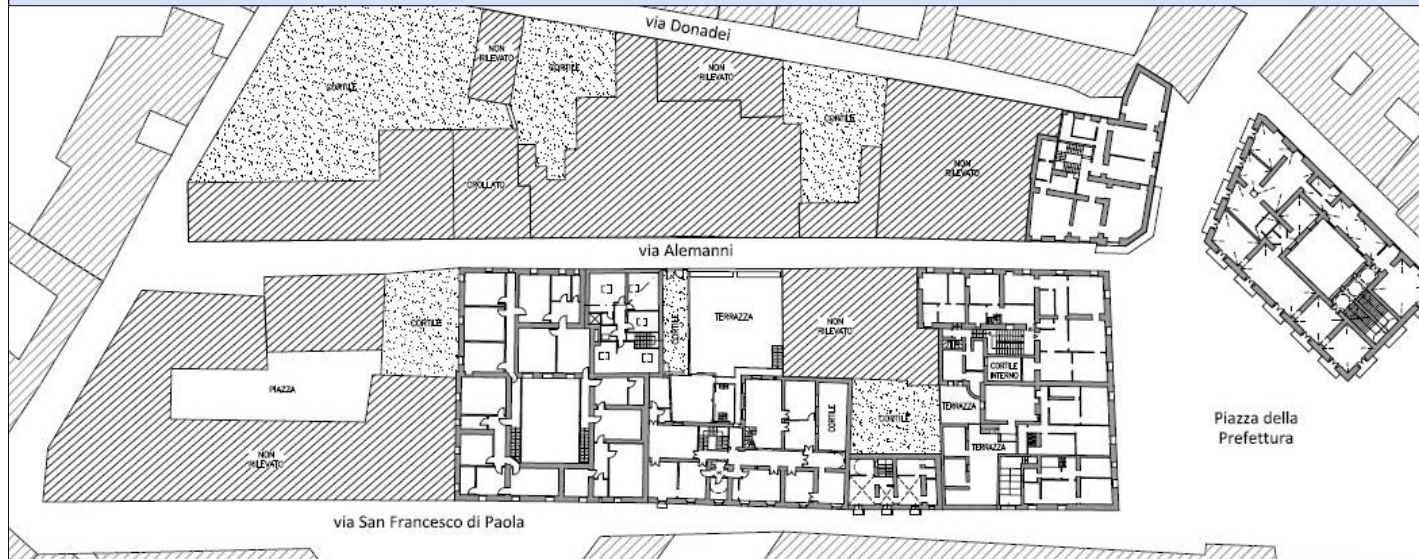


PLAN LEVEL "0"

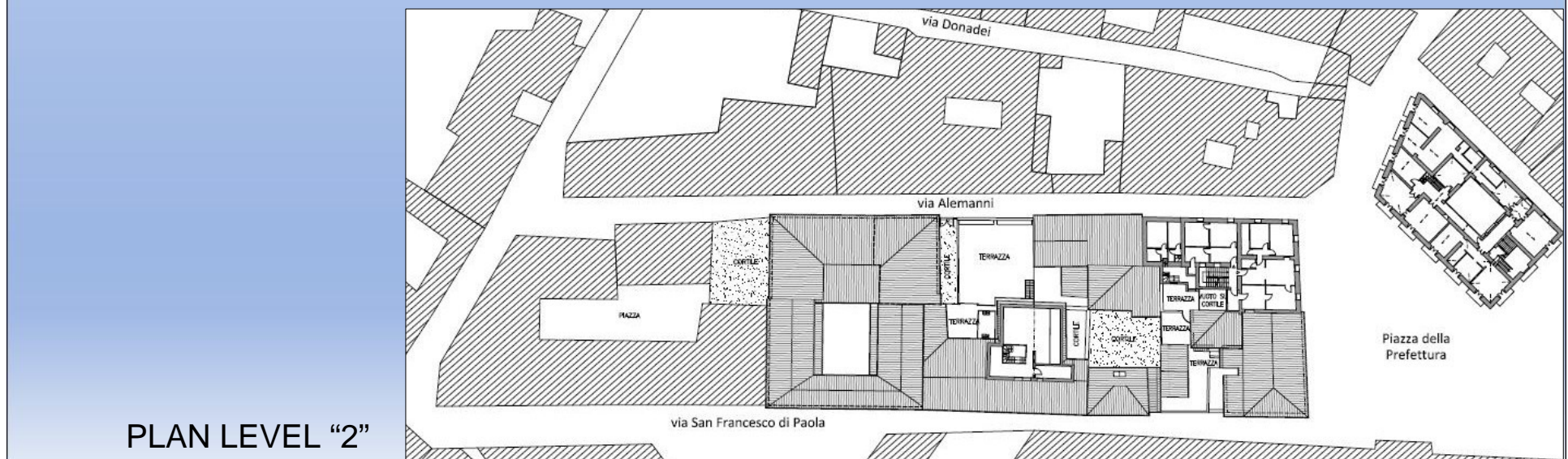


# ARCHITECTURAL SURVEY

## BLOCK "PIAZZA della PREFETTURA"



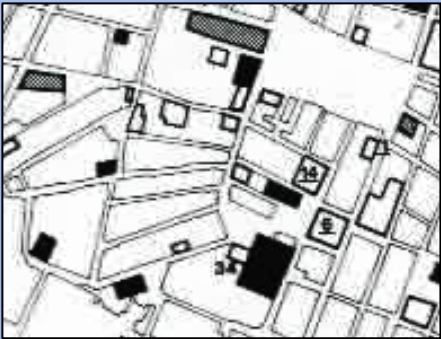
PLAN LEVEL "1"



PLAN LEVEL "2"

# MASONRY BUILDINGS' AGGREGATE

## BLOCK "PIAZZA della PREFETTURA"



Historic view: I 1500.

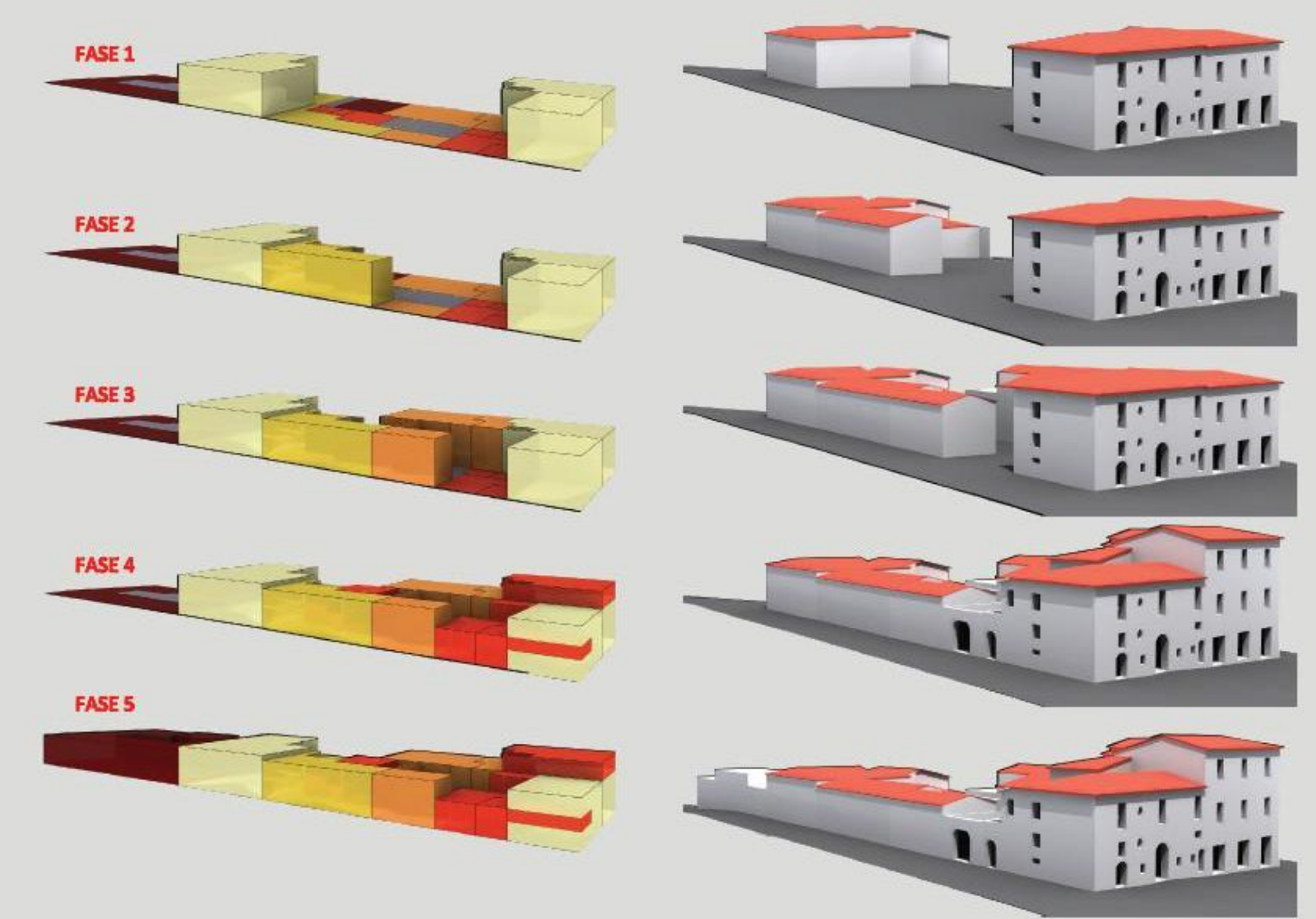
Historic view: I 1700.

Historic View: I 1703.  
Damages due to seismic event

Historic View: 1858.

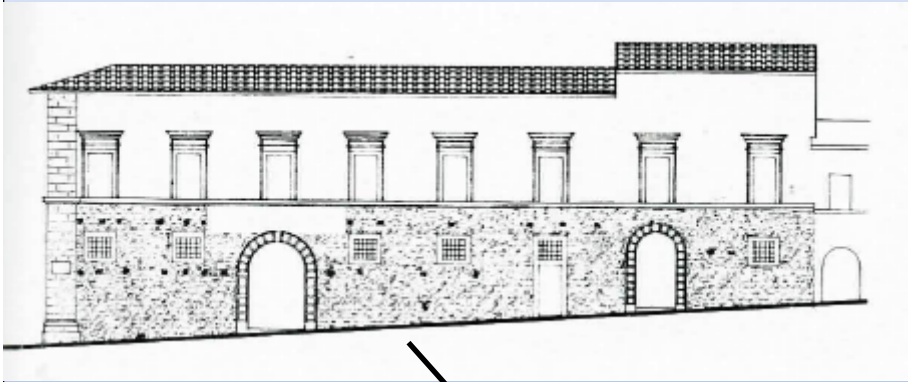
# MASONRY BUILDINGS' AGGREGATE

## BLOCK "PIAZZA della PREFETTURA"



# MASONRY BUILDINGS' AGGREGATE

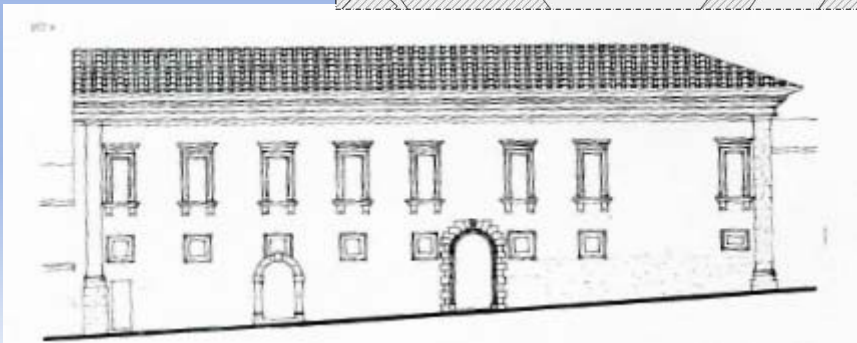
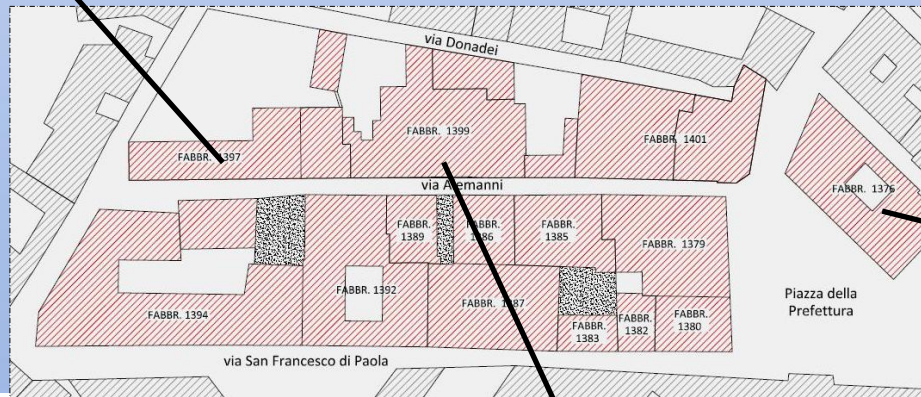
## BLOCK "PIAZZA della PREFETTURA"



**Palazzo Bonomo**  
Via degli Alemanni  
- end of '500 -



**Palazzo in Piazza della Prefettura** – middle century XIX



**Casa Nardis**  
Via degli Alemanni  
- End of '500 and '700 -

# ARCHITECTURAL SURVEY AND BLOCK STUDY

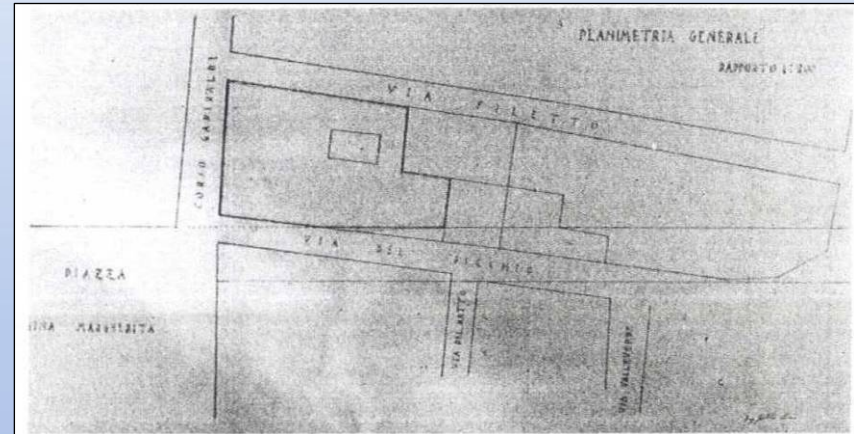
## “BLOCK via VITTORIO EMANUELE II”



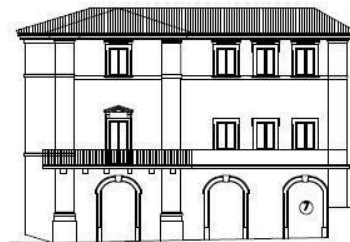
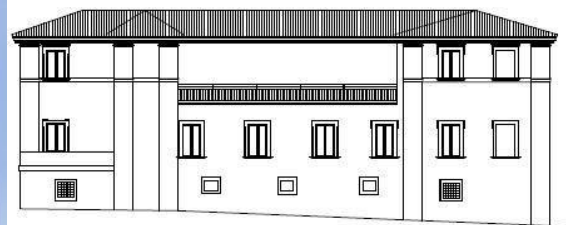
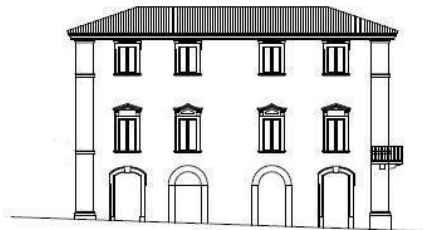
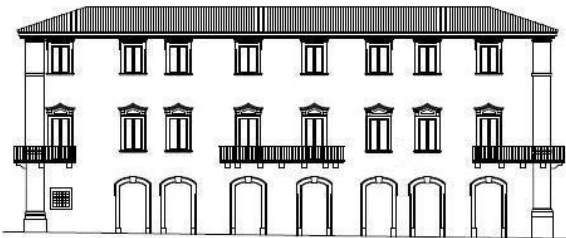
Original building

Portion demolished and re-built with rc frame

New part



Designer Ing. Lisi (1930) extension “via Vittorio Emanuele II”

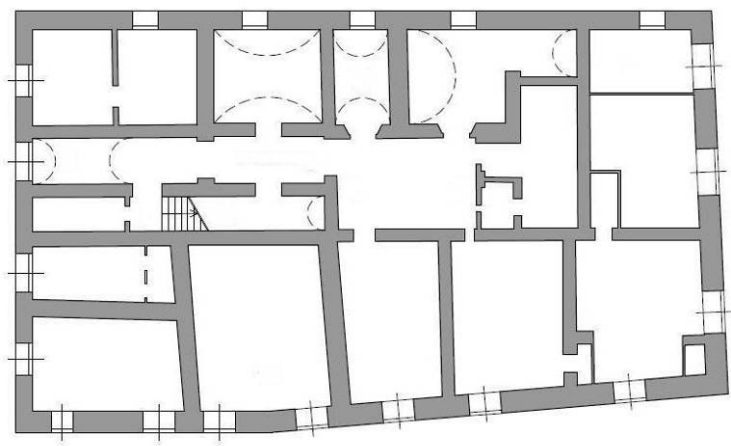


PROSPETTI



# ARCHITECTURAL SURVEY AND BLOCK STUDY

## “BLOCK via VITTORIO EMANUELE II”



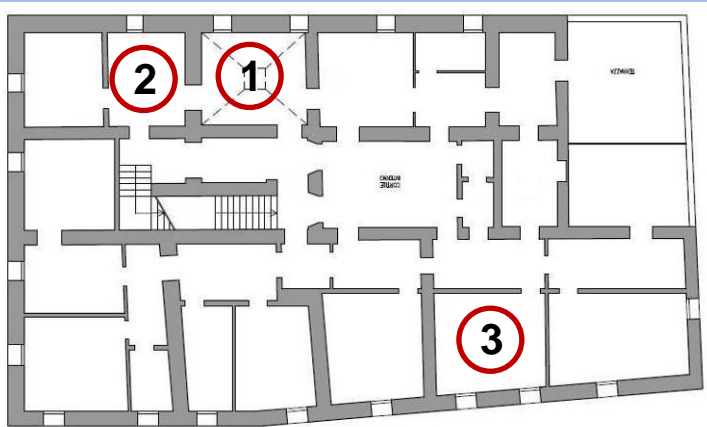
LEVEL 0



1



2



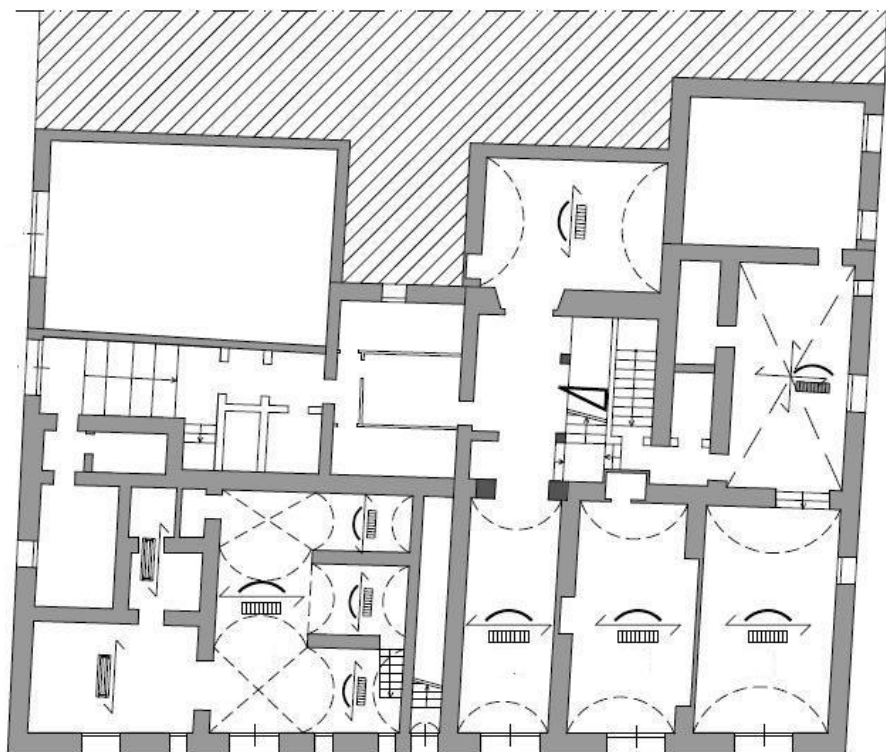
LEVEL 1











3

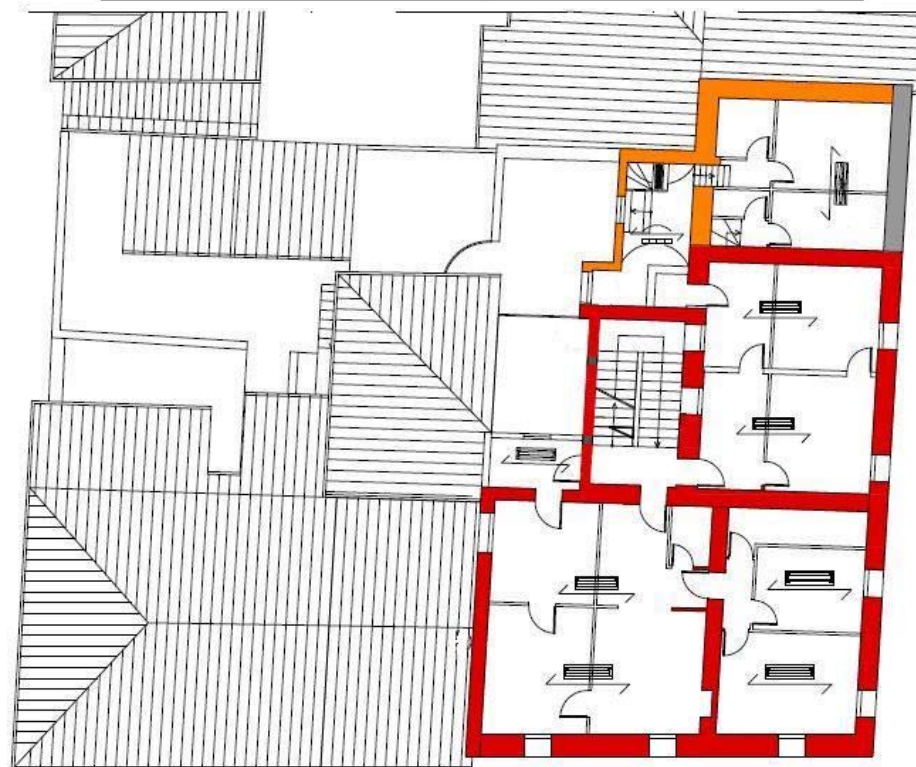


# STRUCTURAL SURVEY



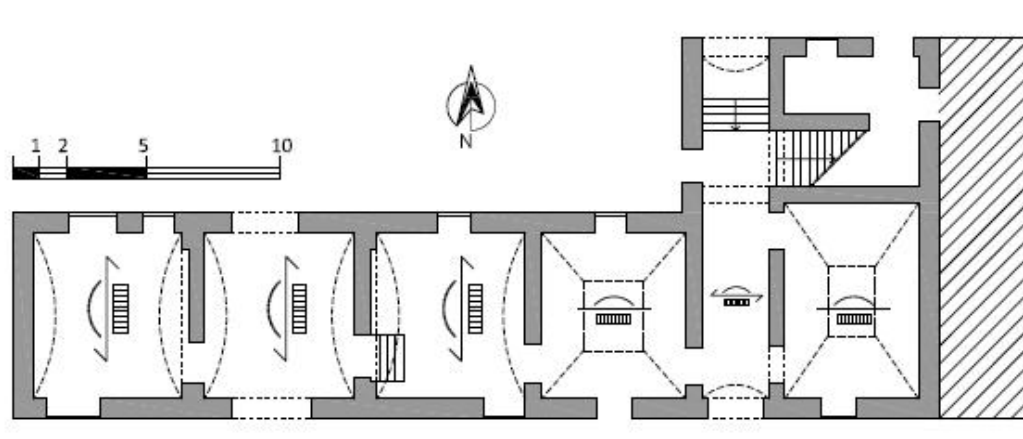
PIANTA PIANO TERRA

STRUTTURE IN ELEVAZIONE	ORIZZONTAMENTI
 struttura portante in pietra irregolare	 solaio in legno
 struttura portante in pietra mista	 solaio in putrelle e tavelloni
 struttura portante in pietra squadrata	 solaio in putrelle e voltine
 struttura portante in laterizio	 volta in spessore
 struttura portante in c.a.	 volta in foglio

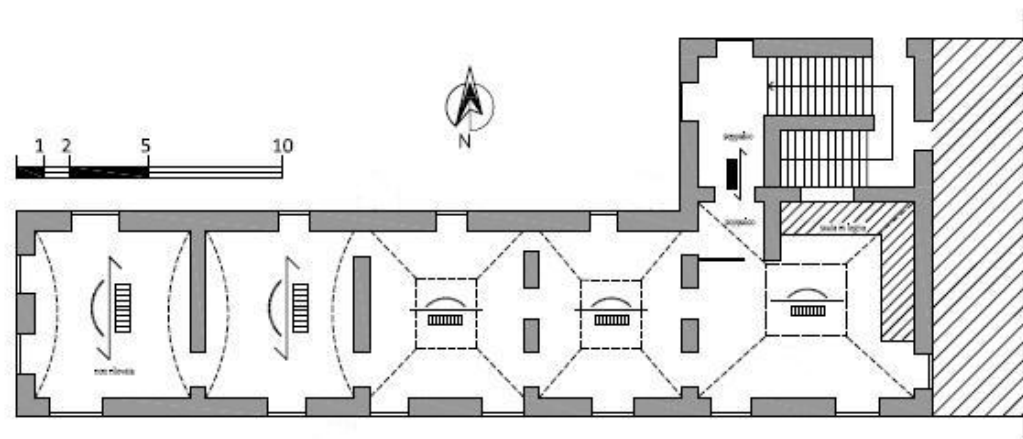


PIANTA PIANO SECONDO





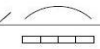
# STRUCTURAL SURVEY



PLAN – LEVEL 0



PLAN – LEVEL 1

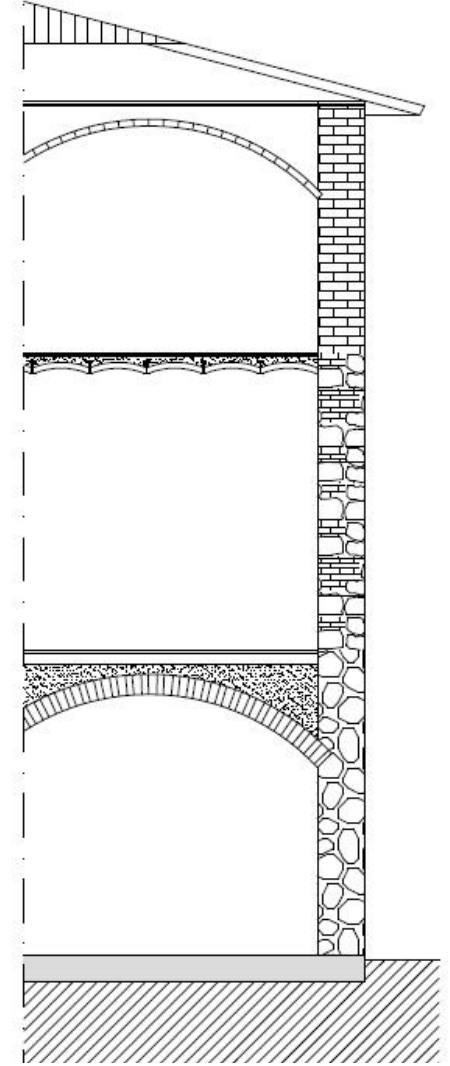
STRUTTURE IN ELEVAZIONE	ORIZZONTAMENTI
 struttura portante in pietra irregolare	 solaio in legno
 struttura portante in pietra mista	 solaio in putrelle e tavelloni
 struttura portante in pietra squadrata	 solaio in putrelle e voltine
 struttura portante in laterizio	 volta in spessore
 struttura portante in c.a.	 volta in foglio





# STRUCTURAL SURVEY

## MASONRY TYPE



BRICK MASONRY



MIXED RUBBLE MASONRY

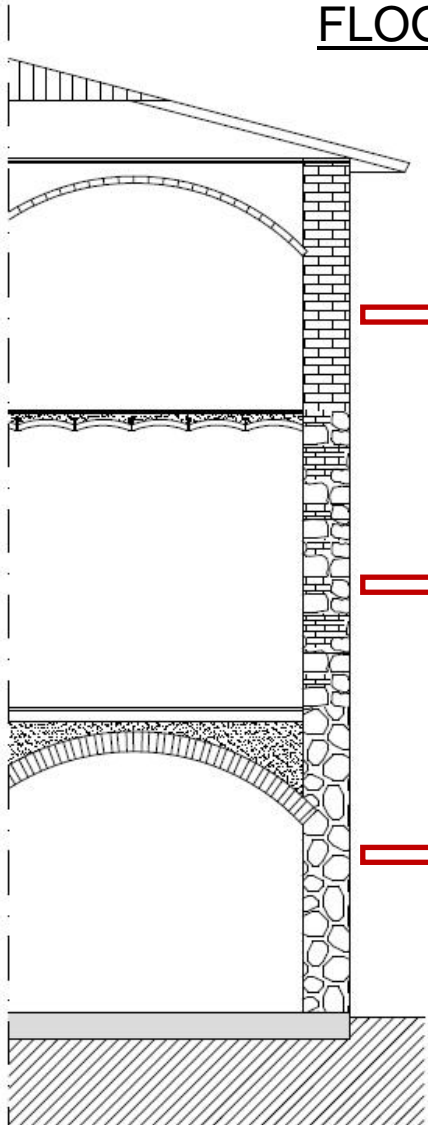


IRREGULAR RUBBLE MASONRY



# STRUCTURAL SURVEY

## FLOOR SLAB



THIN VAULT



THIN VAULT



THIN VAULT



MIXED BEAM-VAULT  
FLOOR SLAB



MIXED BEAM-VAULT  
FLOOR SLAB



MIXED BEAM-VAULT  
FLOOR SLAB



CLOISTER VAULT



BARREL VAULT

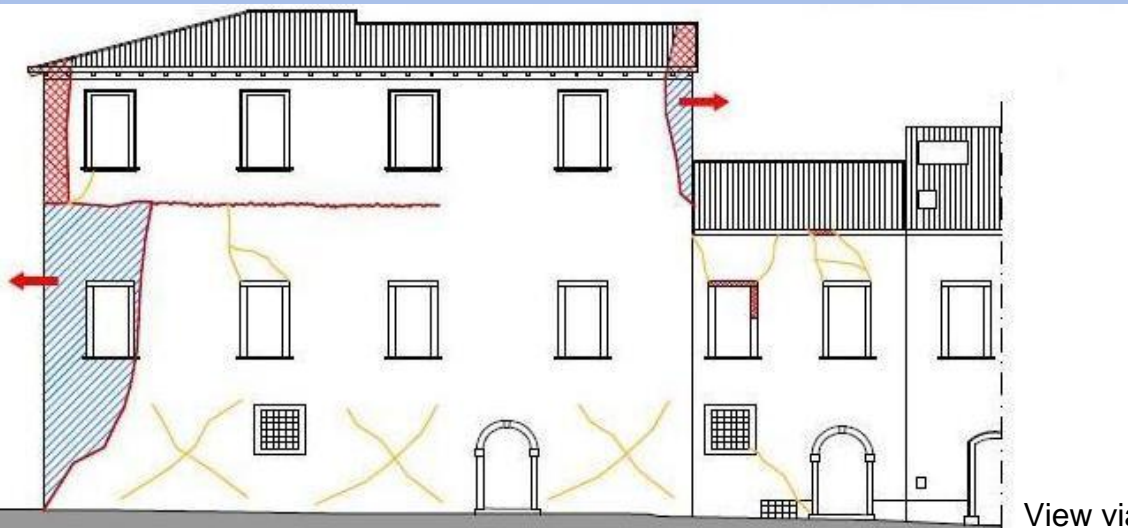


BARREL VAULT

# DAMAGES ANALYSIS



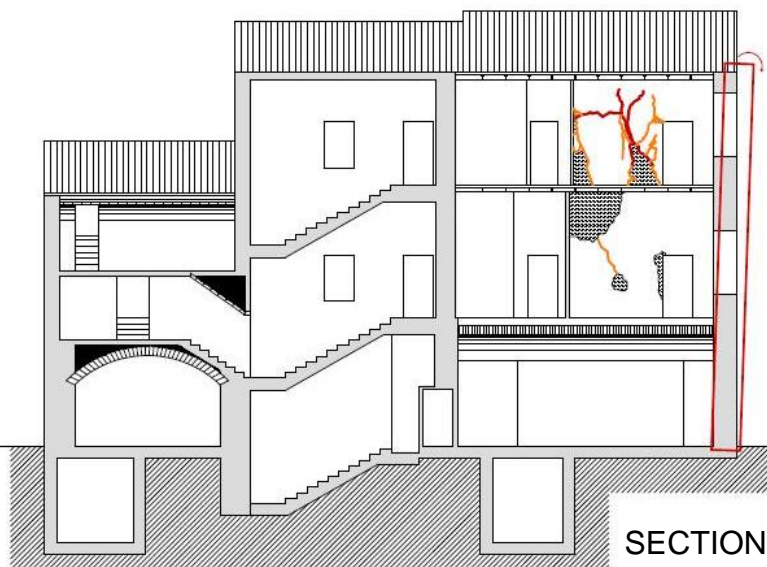
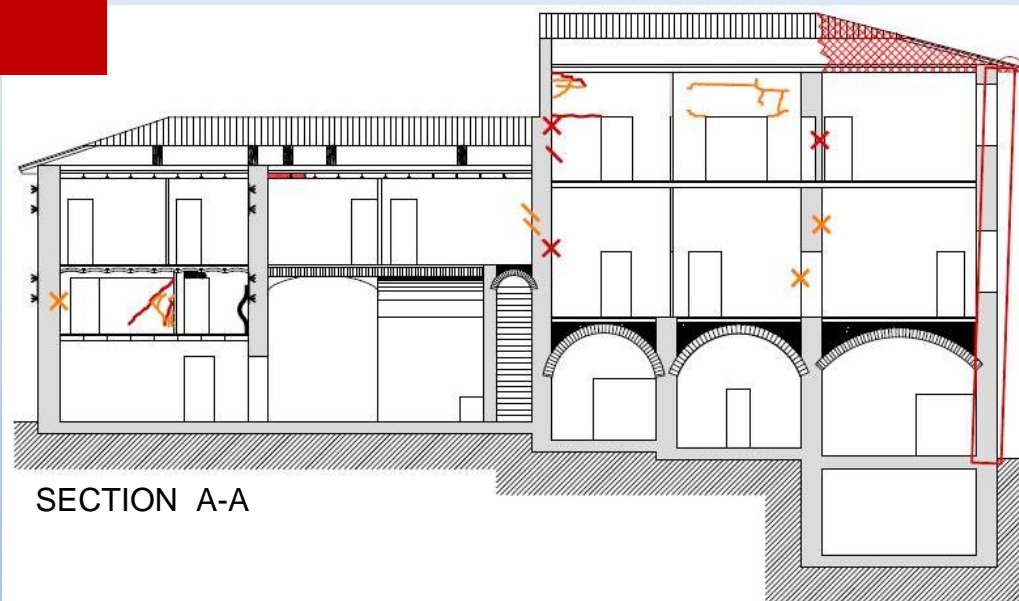
View p.zza Prefettura



View via Alemanni

	lesione passante
	lesione non passante
	collo
	meccanismo fuori piano attivato
	distacco dell'intonaco
	tiranti pre-esistenti

# DAMAGES ANALYSIS



	spanciamiento		crollo		fessure su pavimenti e volte
	lesione non passante		lesione al cantonale	TIRANTI	
	lesione passante		martello		
	lesione diffusa		incrocio		
	lesione a croce		lesione all'architrave		

# DAMAGES ANALYSIS



REINFORCED PLASTER



MASONRY WALLS



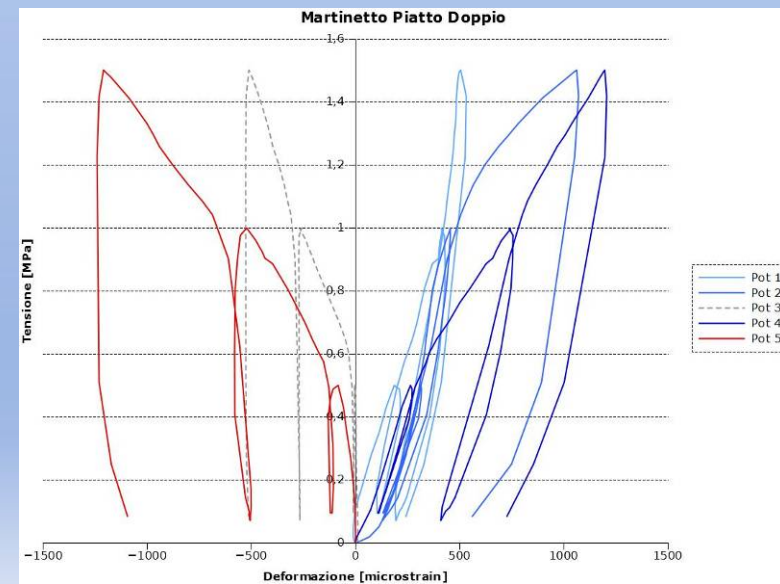
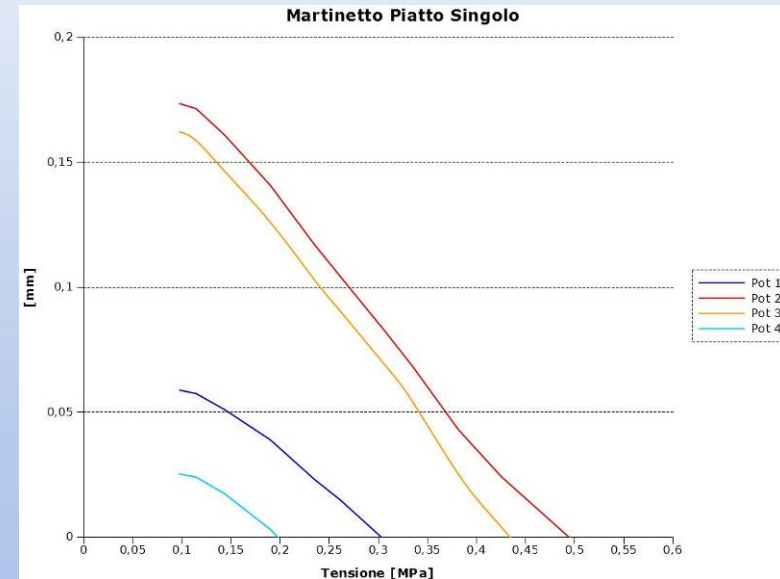
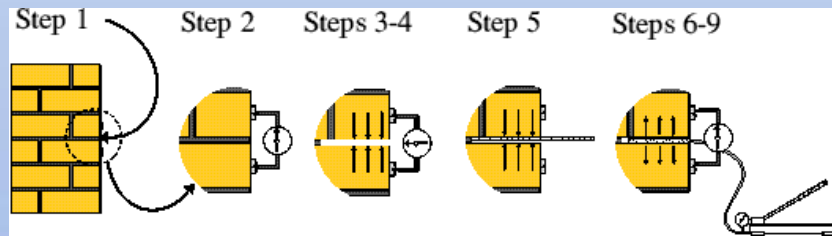
TIE RC BEAMS INSERTION



# IN SITU TESTS

## FLAT JACKS

- SINGLE: stress in the masonry
- DOUBLE: elastic properties



# STRUCTURAL BEHAVIOR ANALYSIS

## ANALYSIS OF LOCAL MECHANISM

Assessment of masonry building vulnerability.



Calcolo indici I1 e I2 - v\_1

Caratteristiche e risultati parziali di  edifici

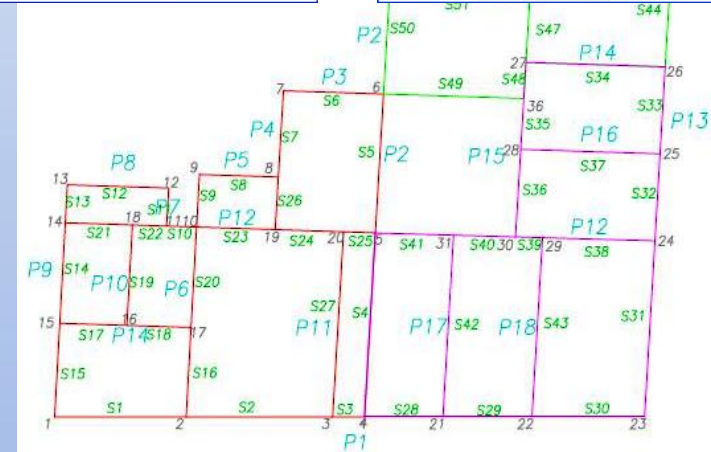
Campione:

Edificio:  Numero

Materiale pareti:   
Conservazione:   
Resistenza a compressione:  MPa  
Resistenza a trazione:  MPa  
Densità specifica equivalente (PSI = 0):  kg/mc  
Numero piani:   
Solai:   
Pianta:   
Altezza alla gronda:  m  
Numero incatenamenti su prospetto // X:   
Numero incatenamenti su prospetto // Y:   
Numero cordoli perimetrali:   
Contenimento pareti // X:  kN/m  
Contenimento pareti // Y:  kN/m

Indice 1 (Vet) direzione X:   
Indice 1 (Vet) direzione Y:   
**Indice 2 min:  Parete:  Setto:**   
Indice 2' + indice 2" min:  +   
Indice 2 max:  Parete:  Setto:   
Indice 2' + indice 2" max:  +   
Indice 2 valore medio:

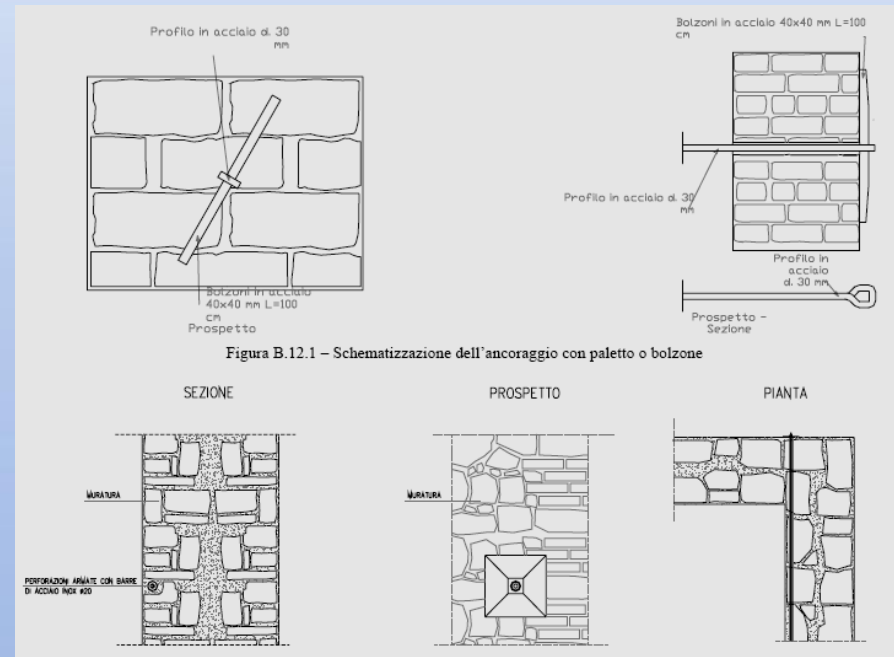
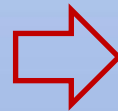
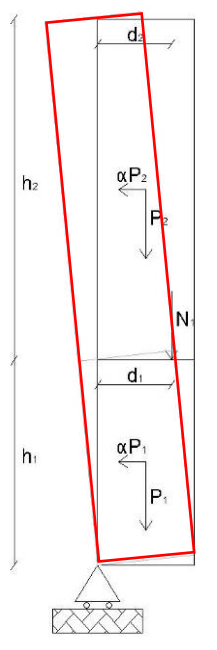
Calcola indici per ciascun setto  
Salva / Stampa Risultati  
< Indietro  >  
Chiudi



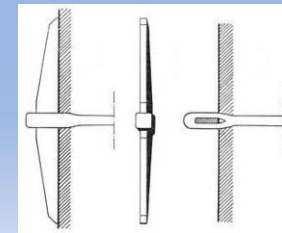
# INTERVENTIONS

## VERTICAL MEMBERS

### OUT OF PLANE MECHANISMS: Facades' Overturning



### INSERTION OF TIES



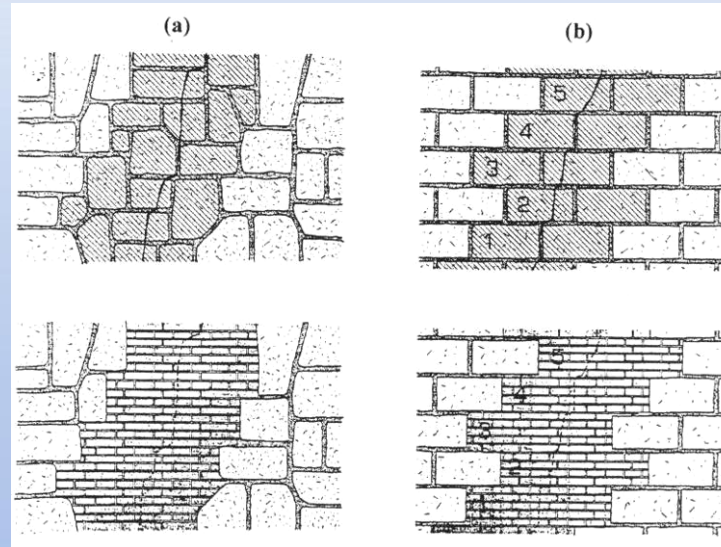


# INTERVENTIONS

## SHEAR CRACKS

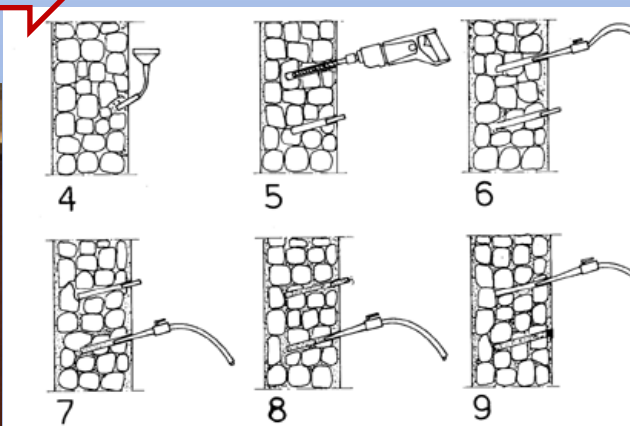


## VERTICAL MEMBERS

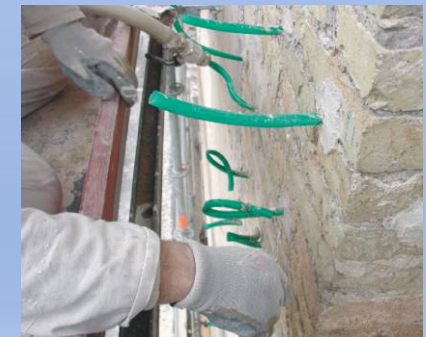


## MASONRY SUBSTITUTION WITH INTERLOCKING

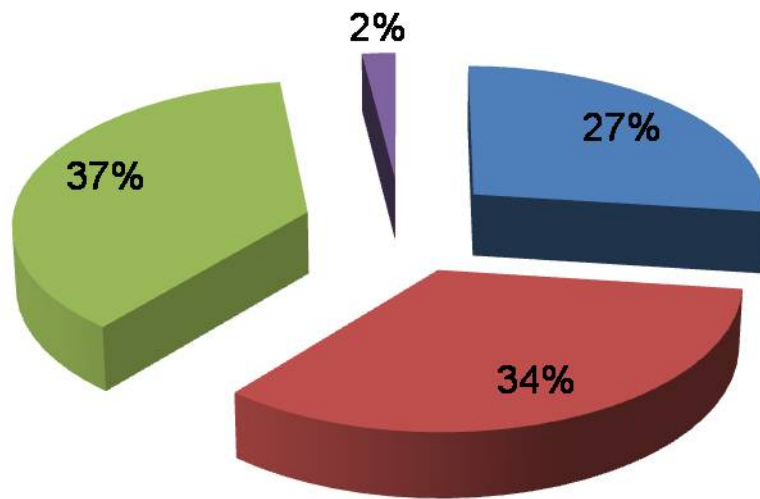
## LOW QUALITY OF RESISTING WALL



## INJECTIONS

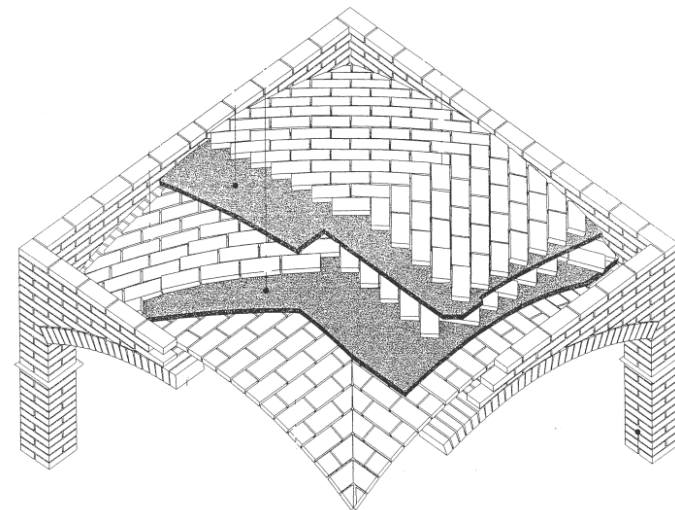
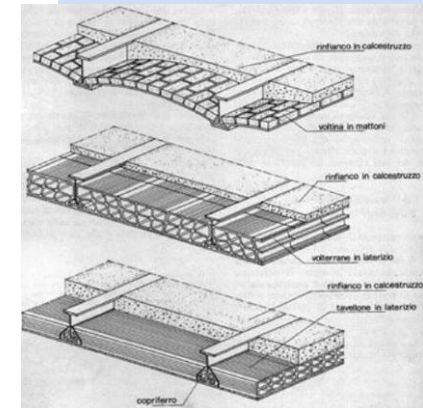
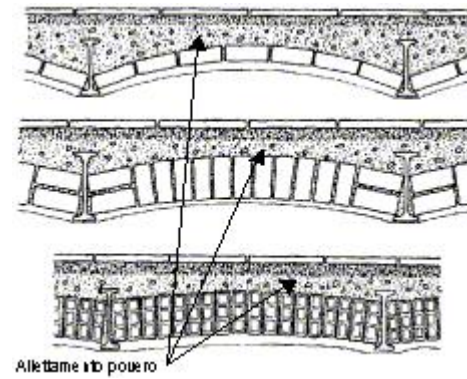


# INTERVENTIONS



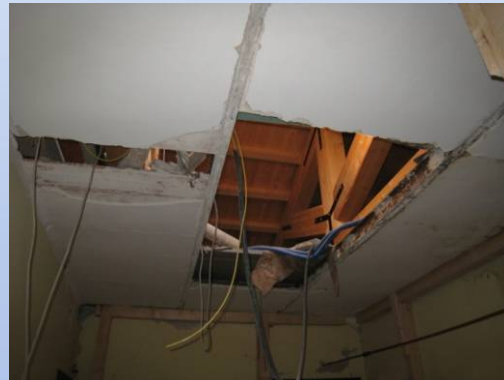
- DEEP VAULTS
- THIN VAULTS
- MIXED STEEL BEAMS FLOOR SLAB
- MIXED BEAM-VAULT FLOOR SLAB

## FLOOR SLABS

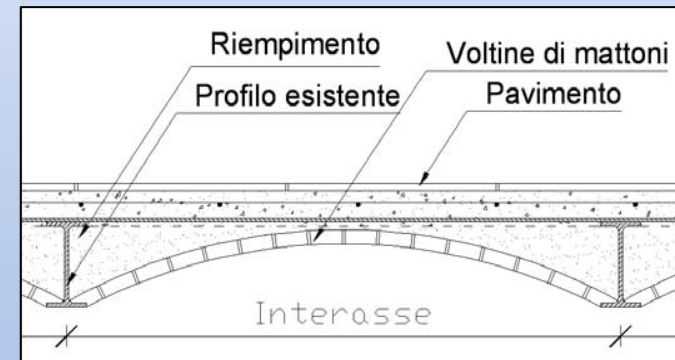


# INTERVENTIONS

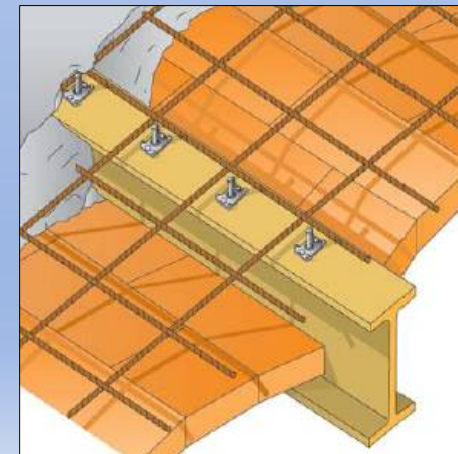
CRACKS AND PARTIAL OR TOTAL FLOOR SLABS COLLAPSE



## FLOOR SLABS



**Floor slab strengthening with reinforced concrete slab**



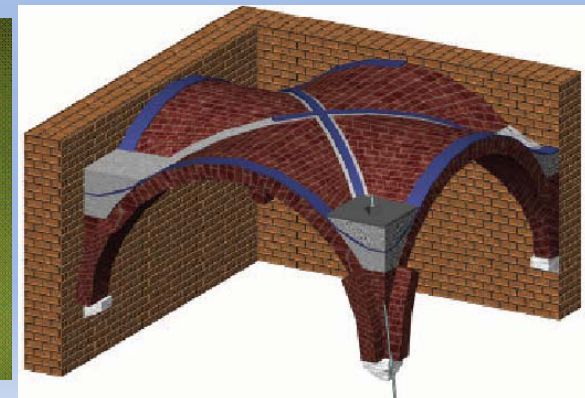
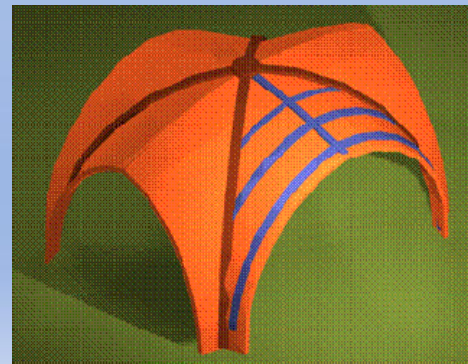
# INTERVENTIONS

## FLOOR SLABS

CRACKS OR PARTIAL COLLAPSE OF VAULTS



**Strengthening with composites (FRP)**



# INTERVENTIONS

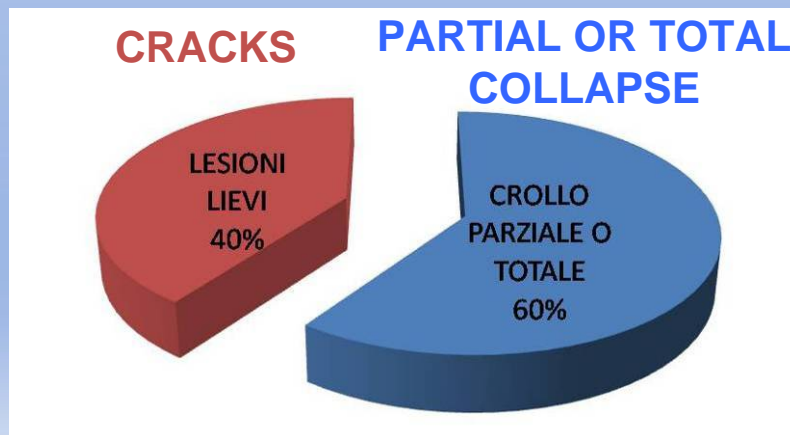
## FLOOR SLABS

### TOTAL COLLAPSE OF VAULTS



### THIN VAULTS

### DEEP VAULTS



# RESTARTING FROM L'AQUILA



**REte dei Laboratori Universitari di Ingegneria Sismica**