# Seismic Behavior of Masonry Buildings

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Masonry is a typical composite construction material which consists of:

- Masonry units,
- Mortar,
- Concrete infill and/or concrete, and
- Reinforcing steel.

**Fig. 1.4.** Regular brickwork.

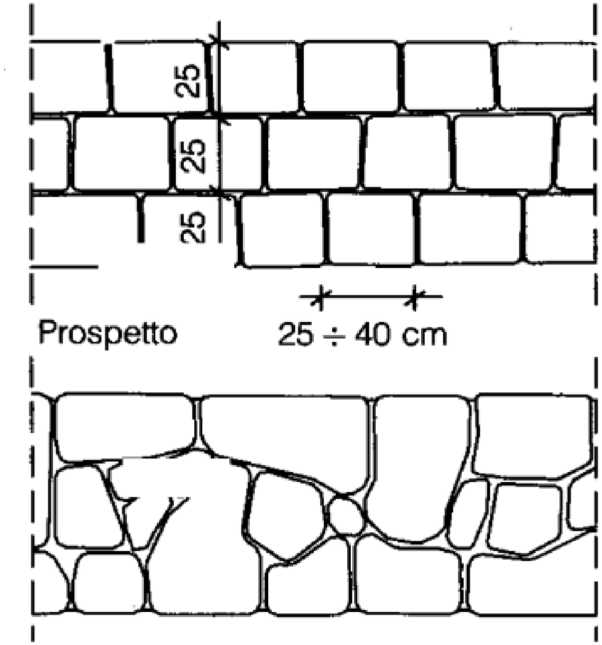


**Fig. 1.5.** Masonry built with tuff blocks.

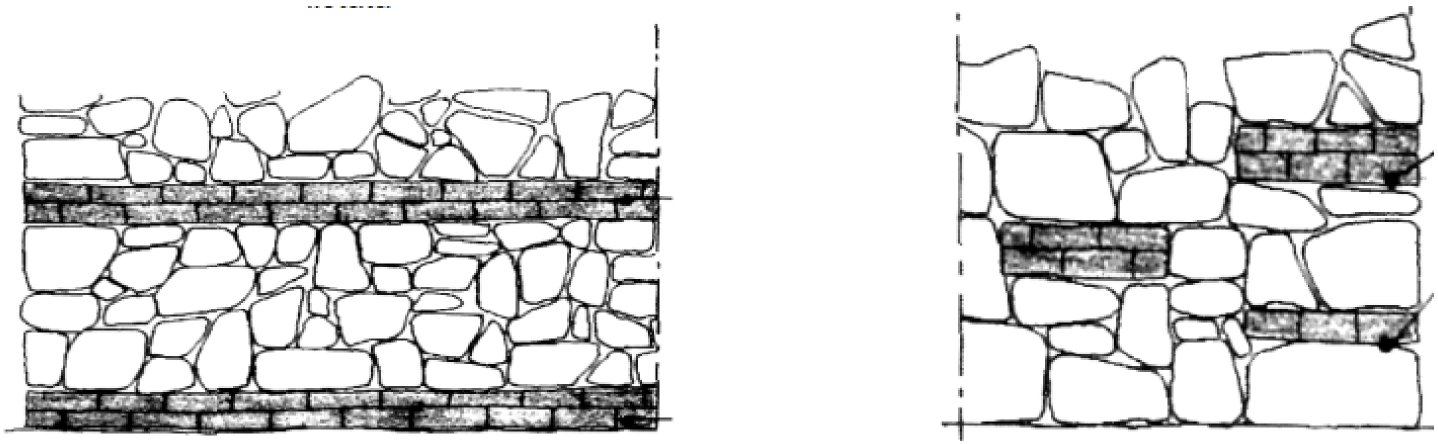

**Fig. 1.6.** Two examples of masonry with a mix of stones and bricks. *a*) edged masonry; *b*) mixed masonry with bricks.

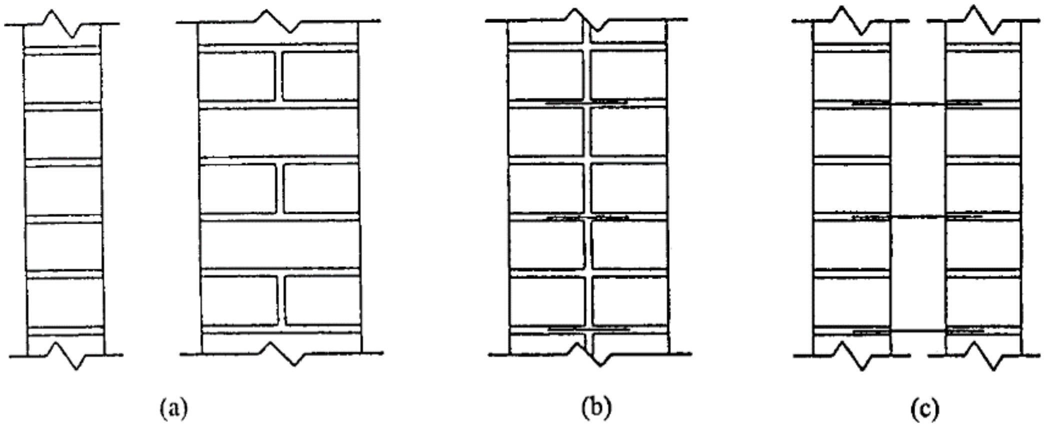


Figure 3.11. Cross-section of a (a) single-leaf, (b) double-leaf and (c) cavity wall (EC6).

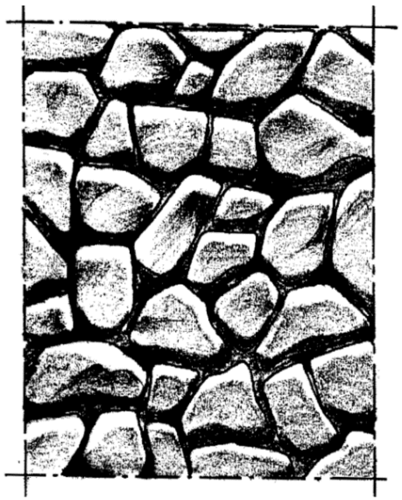

**Fig. 1.7.** Masonry built with huddled stones and mortar.

**Table 1.1.** Classification of stones according to compression strength $f_c$.

| Class | Strength | fc [MPa] |
|---|---|---|
| A | Very high | > 225 |
| B | High | 225÷112 |
| C | Mean | 112÷56 |
| D | Low | 56÷28 |
| E | Very low | < 28 |

**Table 1.2.** Density, Elastic Modulus, and compression strength of some rocks.

| | *Density* ($g/cm^3$) | *compression strength* ($kg/cm^2$) | *Elastic Modulus* ($kg/cm^2 \times 10^5$) |
|---|---|---|---|
| *Igneous rocks* | | | |
| Granite, Syenite | 2.6–2.8 | 1600–2400 | 5–6 |
| Diorite, gabbroid | 2.8–3.0 | 1700–3000 | 8–10 |
| Porphyry, quartz | 2.6–2.8 | 1800–3000 | 5–7 |
| Basalt | 2.9–3.0 | 2000–4000 | 9–12 |
| Pumice | 0.5–1.1 | 50–200 | 1–3 |
| *Sedimentary Rocks* | | | |
| Soft limestone | 1.7–.6 | 200–900 | 3–6 |
| Compact limestone | 2.7–2.9 | 800–1900 | 4–7 |
| Dolomite | 2.3–2.8 | 200–600 | 2–5 |
| *Metamorphic Rocks* | | | |
| Gneiss | 2.6–3.0 | 1600–2800 | 3–4 |
| Shale | 2.7–2.8 | 900–1000 | 2–6 |
| Marble | 2.7–2.8 | 1000–1800 | 4–7 |
| Quartzite | 2.6–2.7 | 1500–3000 | 5–7 |

## 1.4 Mortars

Mortar is a workable paste used to bind masonry blocks together and fill the gaps between them. Mortar becomes hard when it sets, resulting in a rigid aggregate structure. Modern mortars are typically made from a mixture of sand, a binder such as cement or lime, and water.

### *1.4.1 Binders*

Binders used in mortar preparation are:

- gypsum;
- lime;
- hydraulic lime;
- cement.

Table 10.2. Mechanical properties of existing masonry (characteristic values).

| | Stone-masonry | Brick-masonry |
|---|---|---|
| Compressive strength, $f_k$ (MPa) | 0.3 - 0.9 | 1.5 - 10.0 |
| Tensile strength, $f_{tk}$ (MPa) | 0.08 - 0.21 | 0.10 - 0.70 |
| Modulus of elasticity, E (MPa) | 200 - 1000 | 1500 - 3800 |
| Shear modulus, G (MPa) | 70 - 90 | 60 - 165 |

the absence of a value of E determined tests, the value to be taken into consideration in the structural analysis can be assessed to be equal to

$$E = 1000\,f_k. \qquad (3.4)$$

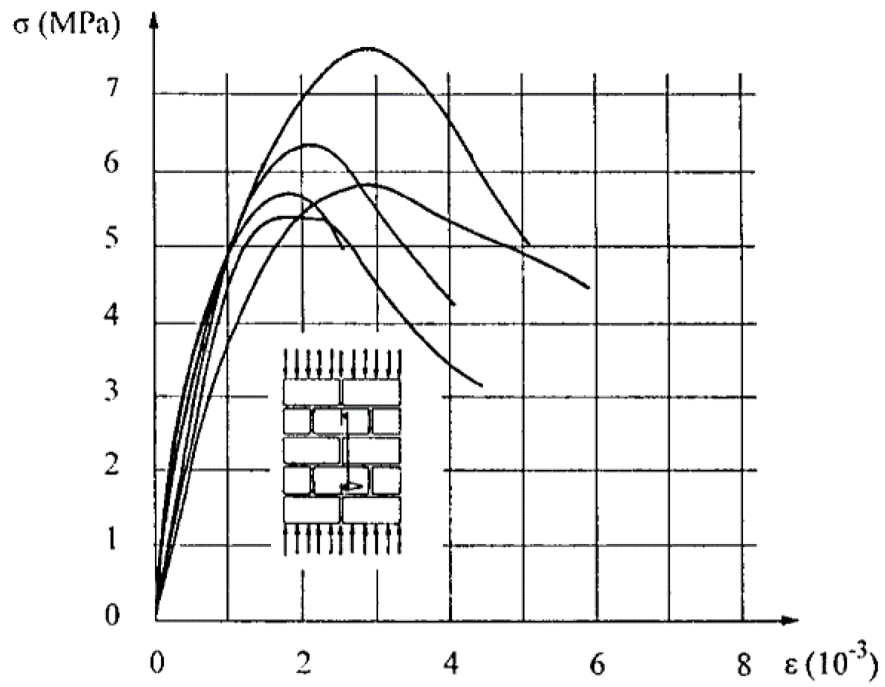


Figure 3.9. Typical experimental stress-strain relationships of masonry at compression [5].

- Unreinforced (plain) masonry, consisting of mortar and masonry units.
- Confined masonry, consisting of masonry units, mortar, reinforcing steel and concrete, and
- Reinforced masonry, consisting of masonry units, mortar, reinforcing steel and concrete infill.

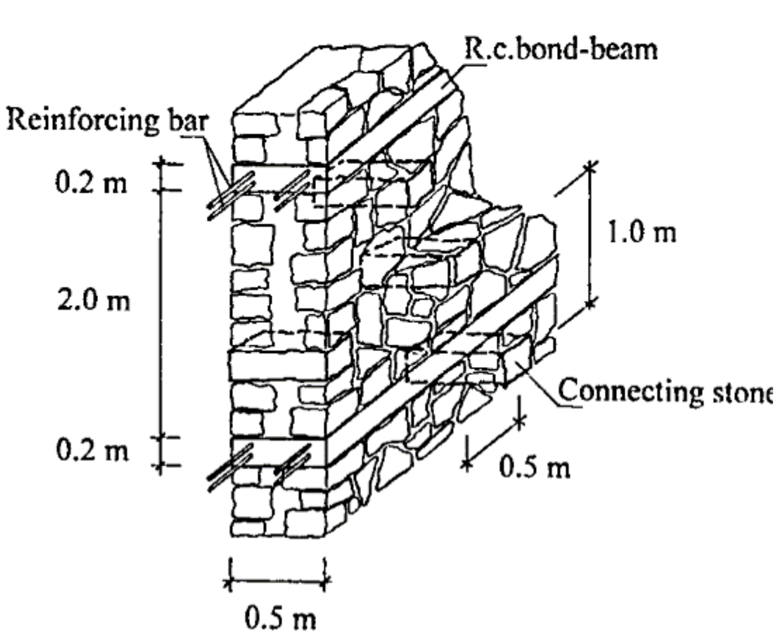


Figure 3.12. Construction of earthquake-resistant traditional stone-masonry wall.

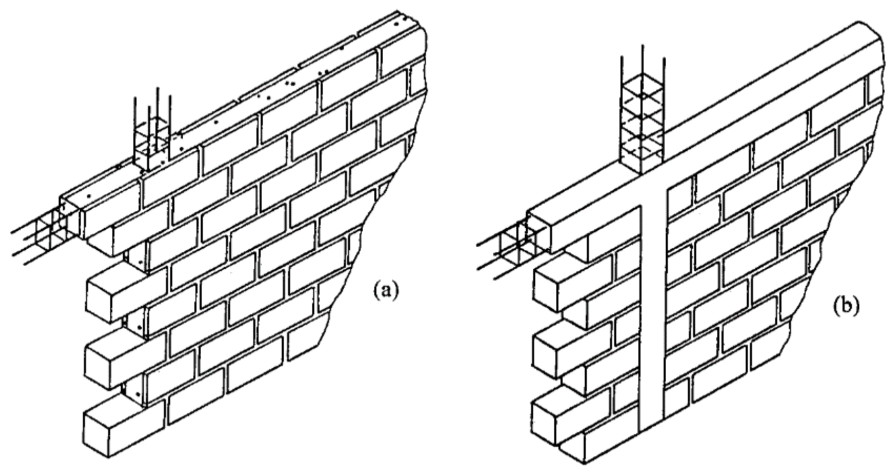


Figure 3.15. Masonry confined within (a) reinforced masonry and (b) reinforced concrete bond-beams and column.

According to the results of earthquake damage analysis and subsequent experiments, three types of mechanism and failure modes define the seismic behaviour of structural masonry walls when subjected to in-plane seismic loads. The mechanisms depend on the geometry of the wall (height/width ratio) and quality of materials, but also on boundary restraints and loads acting on the wall (Fig. 7.1).

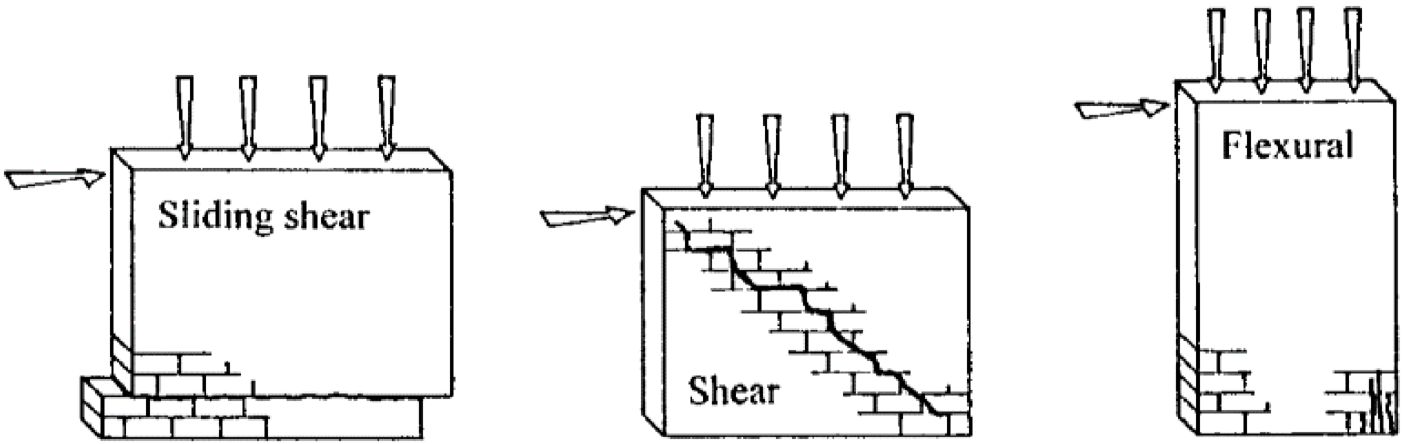


Figure 7.1. Typical failure modes of masonry walls, subjected to in-plane seismic load.

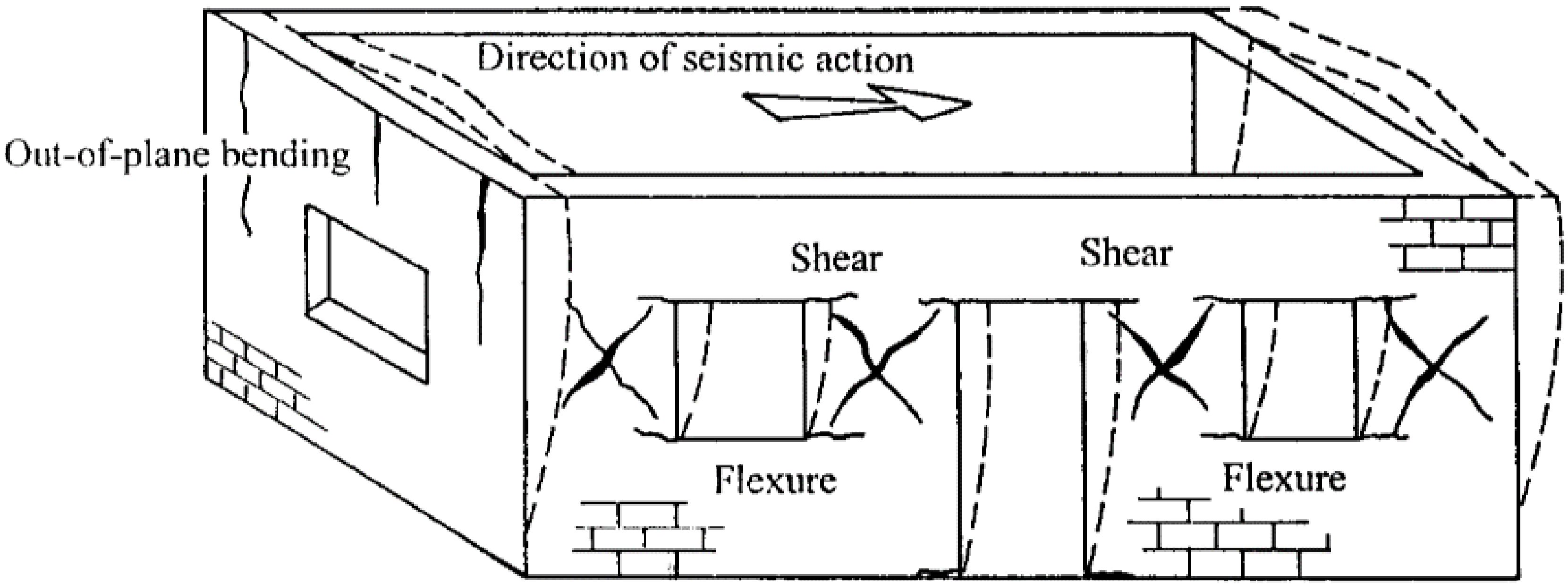


Figure 2.19. Deformation of the building and typical damage to structural wall.

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# INFORMATION FOR STRUCTURAL ASSESSMENT

**TO CARRY OUT THE STRUCTURAL ANALYSES, IT IS NECESSARY TO GAIN PROPER KNOWLEDGE BY MEANS OF SURVEYS, HISTORICAL RESEARCHES, IN-SITU AND LABORATORY TESTS:**

**BUILDING GEOMETRY** →

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

- by means of surveys

**CONSTRUCTIVE 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**

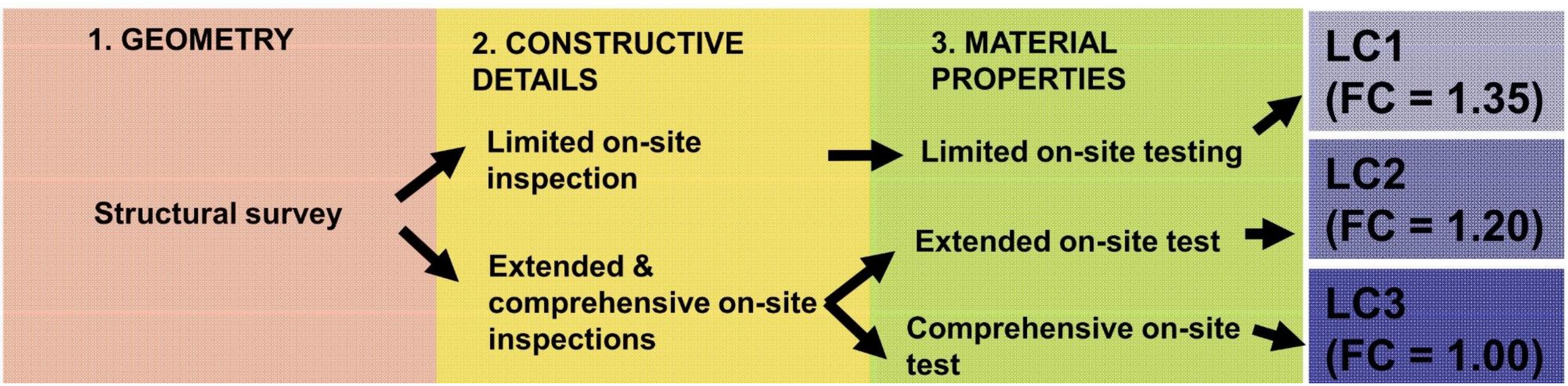
- limited *in situ testing* (inspections)
- extended *in situ testing* (MDT & NDT)
- comprehensive *in situ testing* (DT)

# 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

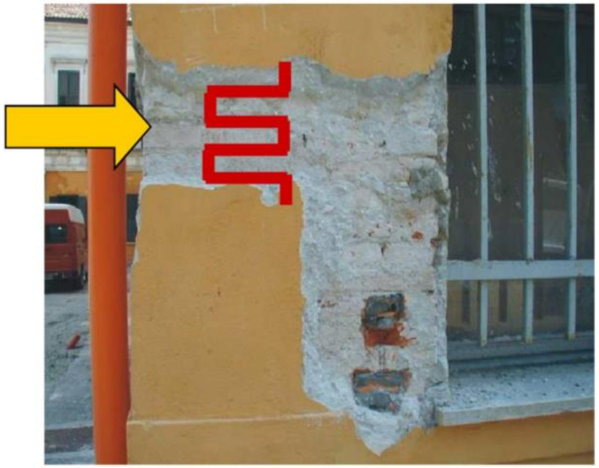
- **Survey and following rendering of the state of the art are the first steps for every knowledge level of the structure.**

- **The further request of the code concerns the critical analysis of the existing crack outline, relative to the structural history of the building. This has to be taken into account during the evaluation of the possibility of the arising of possible local mechanisms.**

**…It is evaluated how the knowledge of the "structural history" of the building is a source of considerable importance with design definition purposes**

# 2. CONSTRUCTION DETAILS

**The critical analysis continues with the evaluation of the execution of the construction details, in the definition of the presence and efficacy/inefficacy of structural elements/links.**
**In practice it is required to conduct an analysis with reference to possible sources of vulnerability and/or methods for its reduction**

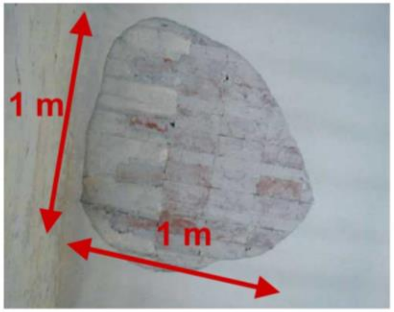


***Limited on-site verifications**: based on sight surveys, usually through tests on the masonry that lead to superficial examination*

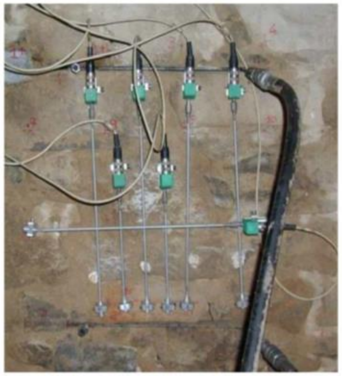
***Extended and exhaustive on-site verifications:** based on sight surveys, usually through tests on the masonry that lead to <u>both</u> superficial and deep examination, and of the anchoring between orthogonal walls.*

# 3. MATERIAL PROPERTIES

***Limited on-site investigations:***
***Information on the material properties, in order to determine the masonry typology. They are based on sight examinations on the masonry surface.***



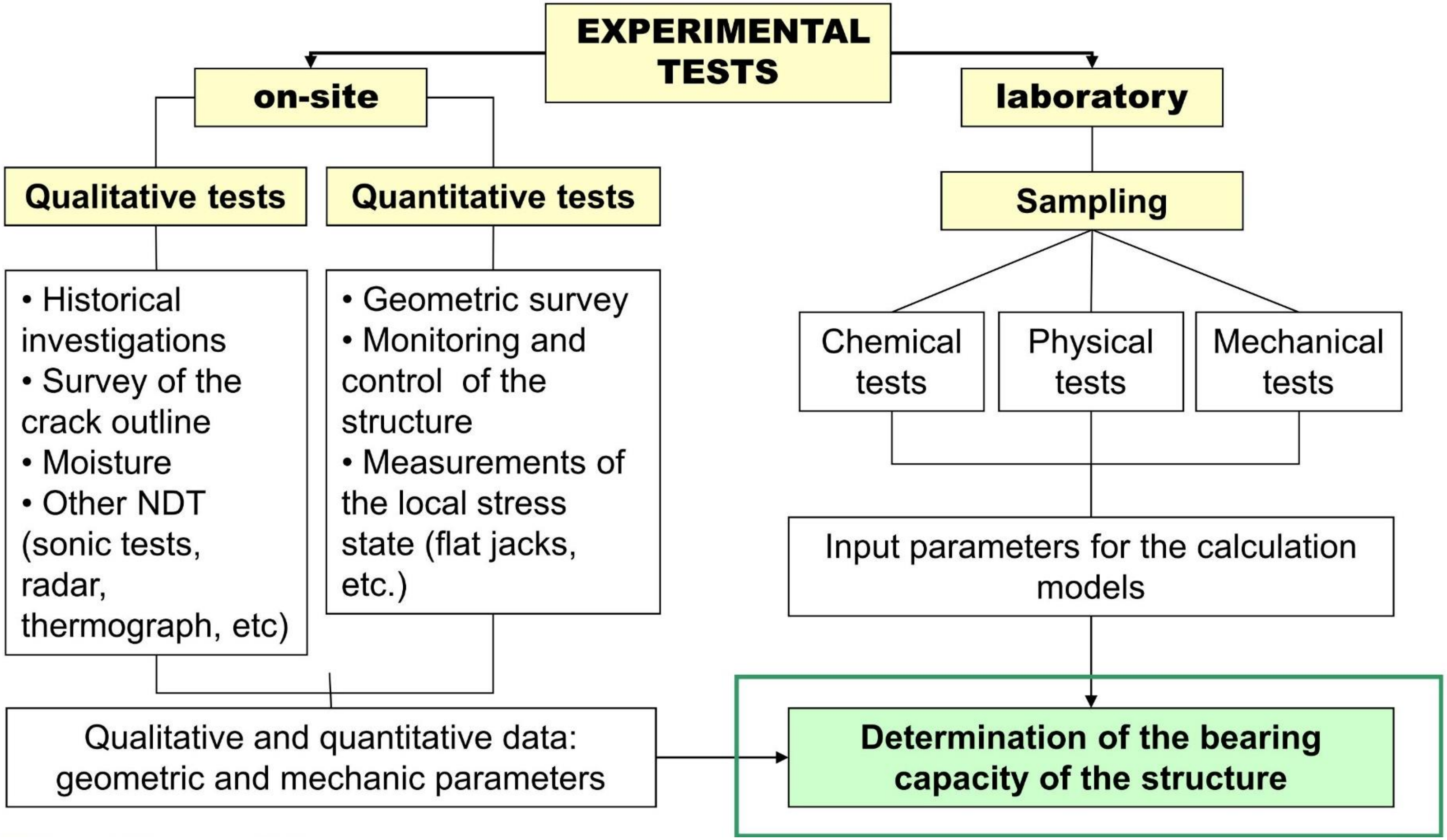

***Extended on-site investigations:***
***Tests with double flat jack and characterization tests of the mortar and of stones or bricks. Non-destructive tests (sonic tests, etc…).***



***Exhaustive 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 EVALUATIONA OF THE BEARING CAPACITY

*(Binda, 1994)*



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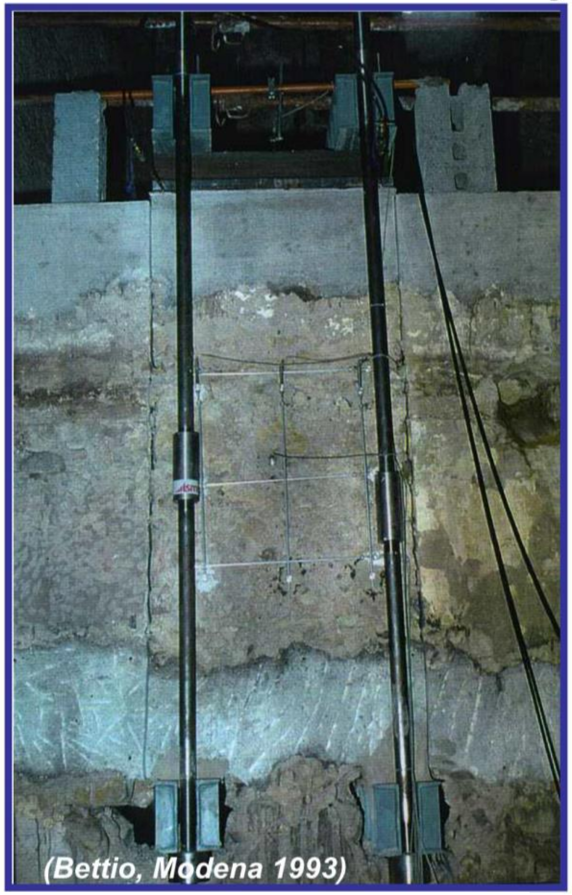
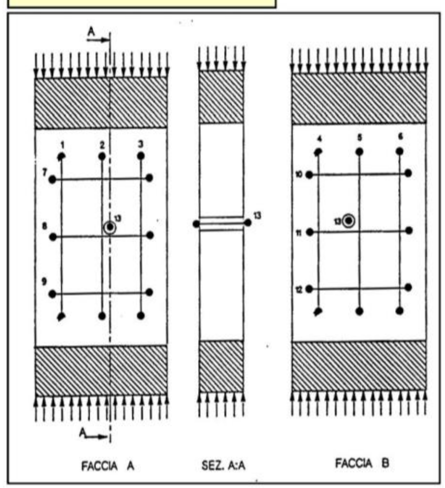
## Resistance of the masonry walls: compression



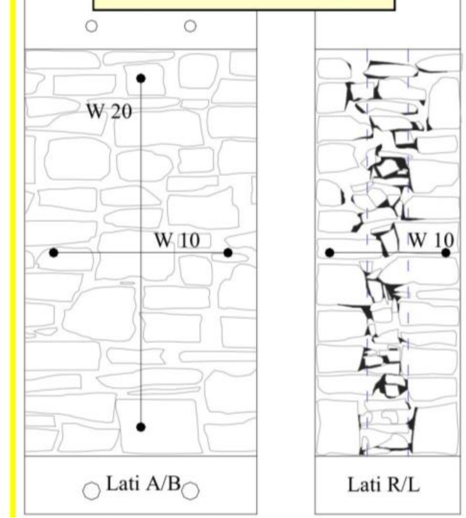
(Bettio, Modena 1993)

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

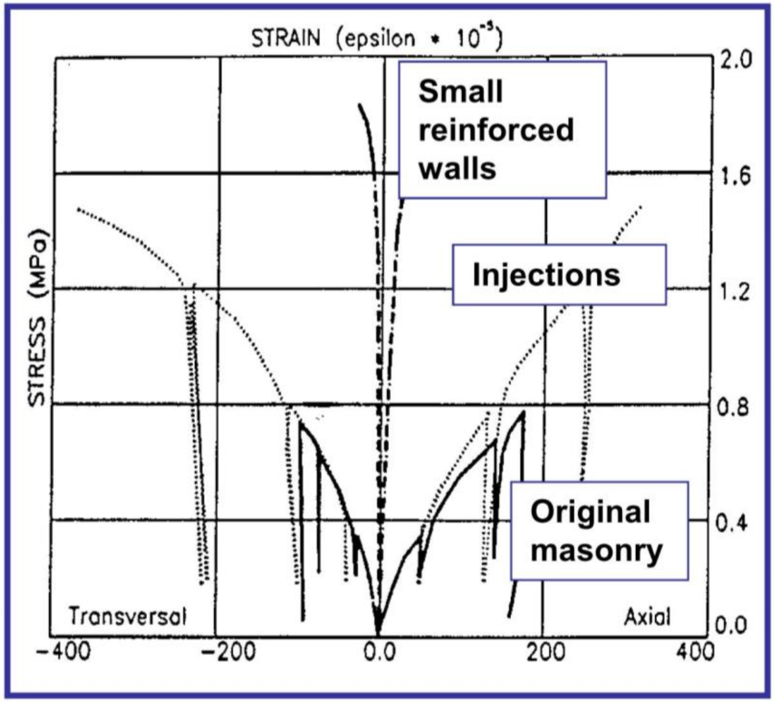
**On-site**




**laboratory**



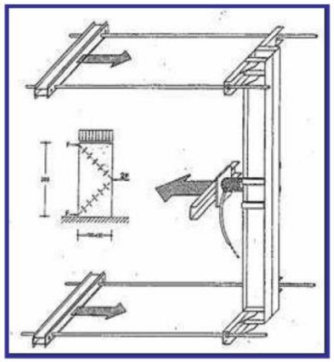
## Resistance of the masonry walls: compression

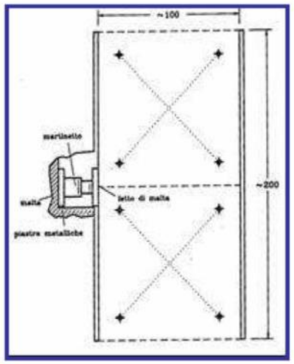




**The compression behavior underlines the differences in terms of resistances and stiffness brought from different kinds of intervention.**

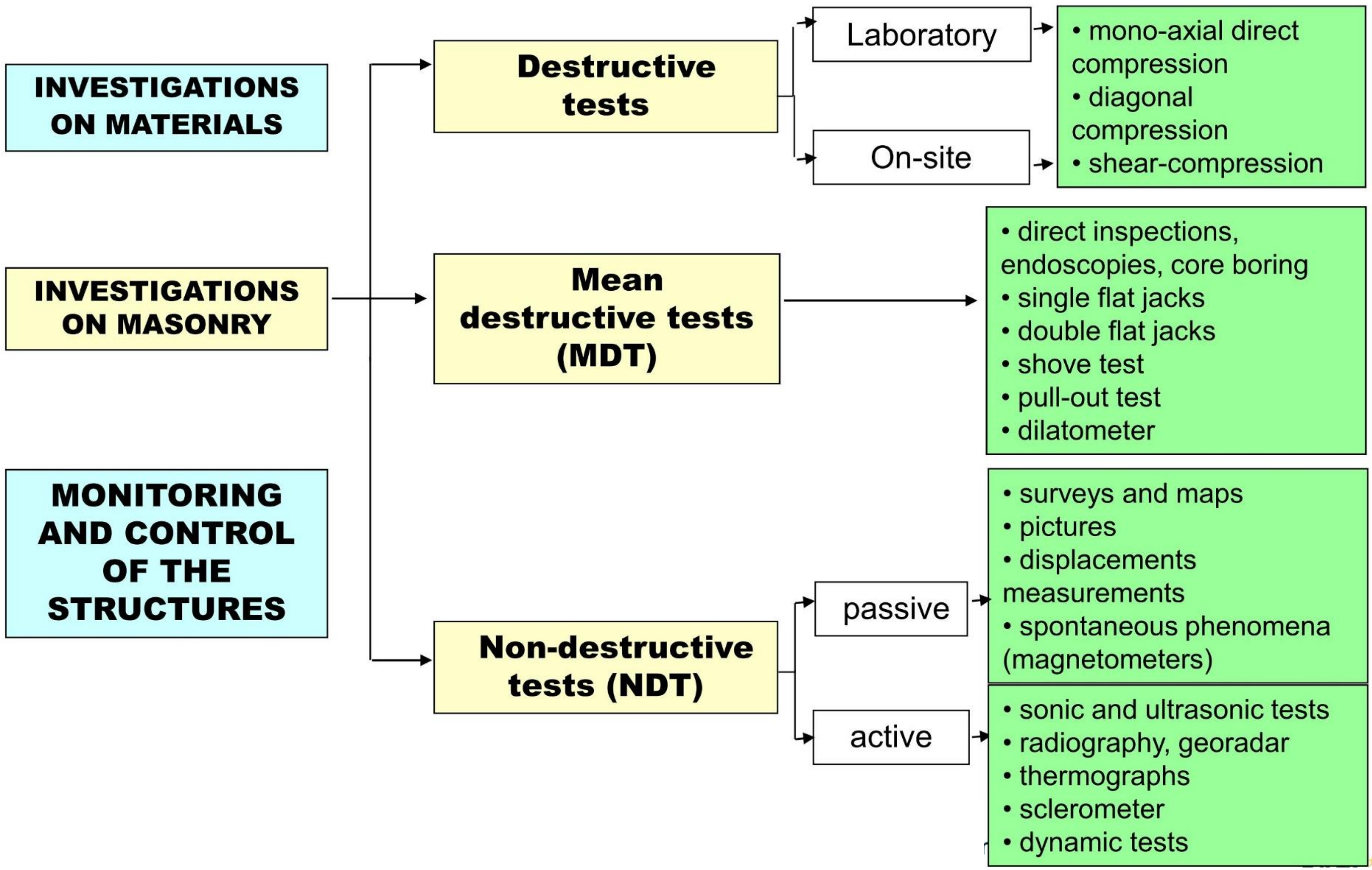
## Mechanical properties of the original masonry and after the consolidation intervention ($\tau_0$, G) through experimental tests

**Shear and compression**






# OTHER INVESTIGATION METHODS ON MASONRY BUILDINGS



# CONSOLIDATION INTERVENTIONS: CODE

**UPGRADING**

*Complex of works that makes the building able to resist to the seismic actions (adopting the increasing of the resistance and/or the reduction of the effects of the seismic action), so as it represents a single and organic technical action with the upgrading intervention*

**IMPROVEMENT**

*Execution of one or more works that concerns the single structural elements of the building with the purpose of achieving a greater safety grade without modifying in a substantial way the global behavior*

# UPGRADING/IMPROVEMENT:

- The difference between upgrading and improvement is maintained, possible when the intervention is on single factory elements and always possible for cultural goods.
- In case of improvement, even if standard analysis and verifications are developed, it is mandatory to quantify the benefits, in terms of reduction of seismic vulnerability, of the applied intervention, even for cultural goods.
- The controlled improvement is introduced: the Regions, given the specific construction typologies, can allow a reduction of the seismic protection levels up to 65% for the upgrading interventions.

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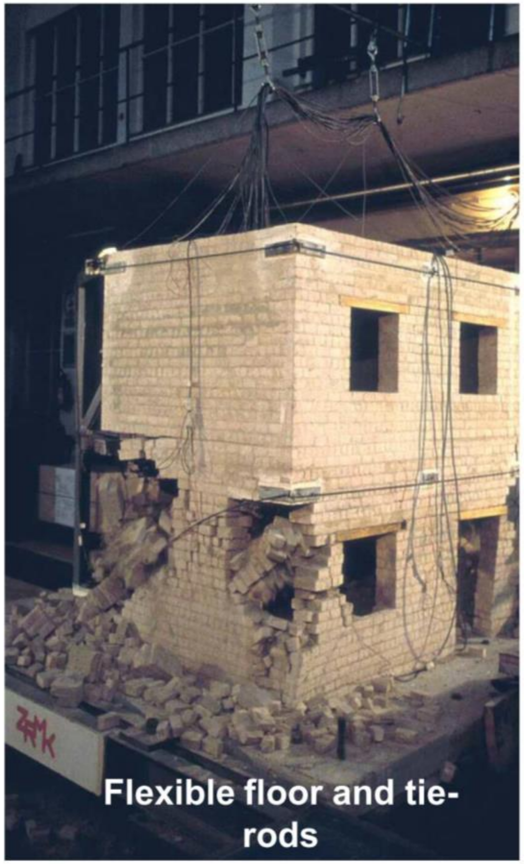
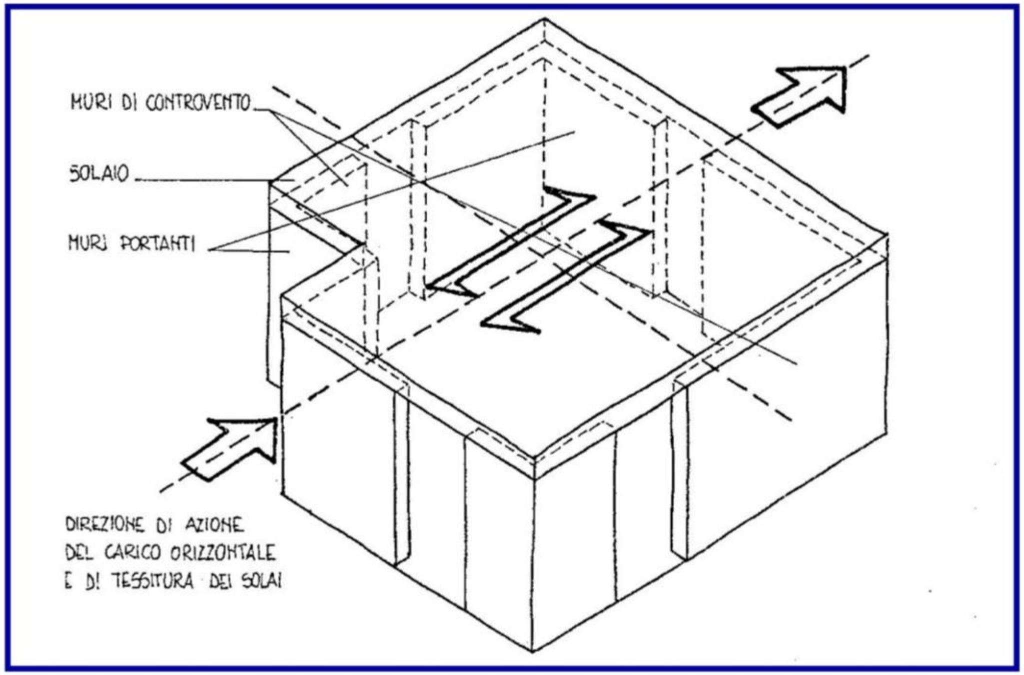
# SEISMIC BEHAVIOR OF MASONRY BUILDINGS (1)

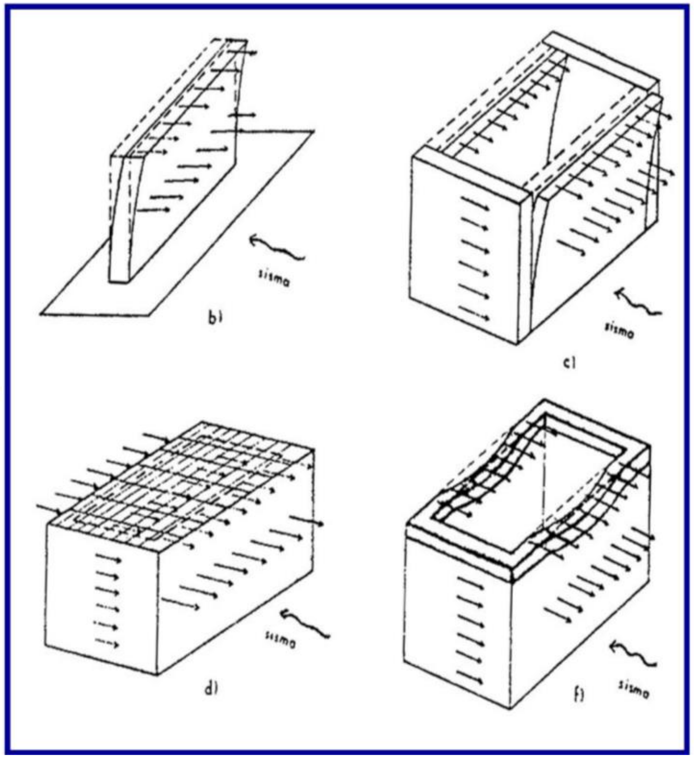


**Brick masonry building models after shaking table tests**

# SEISMIC BEHAVIOR OF MASONRY BUILDINGS (2)




- Disconnected walls (isolated wall)
- High stiffness floor
- Link wall-wall and wall-floor with tie-beam




**BOX BEHAVIOR**:

Horizontal forces absorbed by the walls in their plane

- Sufficiently rigid deck
- Adequate connection between walls
- Link wall-floor and wall-roof

# SEISMIC BEHAVIOR OF MASONRY BUILDINGS (3)

The relevant damage that affected the masonry structures after the recent earthquakes, in particular the Umbria Marche 1997-98 earthquake, according to several experimental and theoretical studies managed in the last years, demonstrated how is necessary the revaluation of the structural behavior models for these structures with reference to the previous approaches.

The essential aspect that comes out from the developed analysis concerns the consideration of a series of information, deduced from the observation, that in most of the cases provides determinant information for the evaluation of the seismic response.

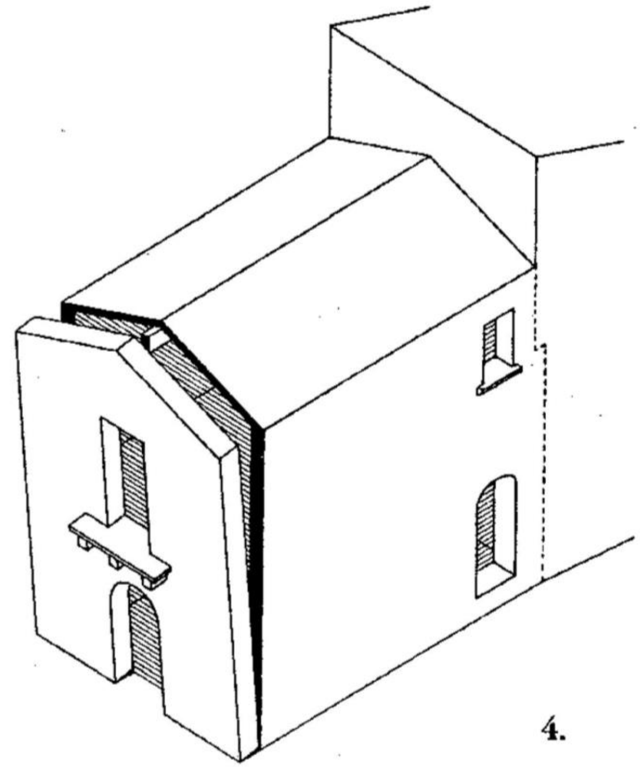
- Historical information
- Geometrical aspects and crack outline
- Material characteristics
- Construction technology
- Construction phases
- …

# SEISMIC BEHAVIOR OF MASONRY BUILDINGS (4)

A wide work of classification, concerning the mentioned aspects, was developed for several study cases, and in particular an "abacus" of the collapse mechanisms was formulated, relative to the different "local" modalities of lose of equilibrium of portions of structure that for several reasons was not able to develop a "global" response.

For example, the rotation of a wall out of its plane suggests its impossibility of transmitting the seismic force which acts on it to the bracing walls through suitable devices (rigid floors, chains…). The wall has to face an action to which it is not able to resist, and it collapses.

These crisis modalities elude a global model.



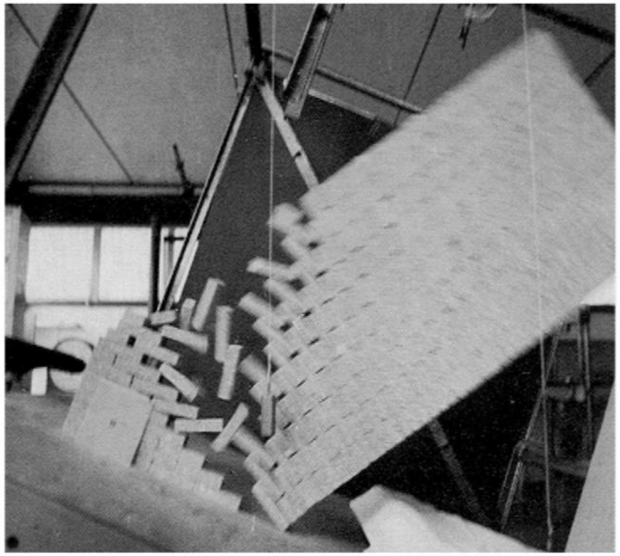
4.

# SEISMIC BEHAVIOR OF MASONRY BUILDINGS (5)

Therefore, the limits of some calculation methodologies are outlined, which consider the masonry structure as a box whose resistance is linked to the material resistance.
The main recorded collapse modalities are:

1. Rotation out-of-plane of bearing masonry (lacking of orthogonal connection)
2. Rotation out-of-plane of the top part of the walls (beating of the roof)
3. Masonry disconnections, masonry expulsion (masonry typology and material quality)
4. In-plane mechanisms for shear stresses with diagonal cracks (presence of openings, thin walls)

Through this point of view the requests of the Ordinance can be better understood, as it requests the joined application of global and local analysis.



# SEISMIC BEHAVIOR OF MASONRY BUILDINGS (6)

**Considering the chapter of the code relative to the seismic improvement:**

***"If there is the intention of the application of structural interventions on single factory elements or improving interventions, intending with them the execution of a complex of works sufficient for the achievement of a greater safety grade of the building for seismic actions, it is allowed to proceed without applying analysis and verifications of the previous chapter, with the condition that is demonstrated that the set of the scheduled works is anyhow capable to give to the building a greater safety grade regarding to the seismic actions".***

**For some typologies of interventions on existing masonry structures, defined as "seismic improvement", it is assumed that the analysis of the local mechanisms (pre and post intervention) can provide the data relative to the quantification of the improvements brought by the intervention**

**In fact, in terms of global analysis often the benefit deriving from the single improving intervention is not directly quantifiable**

# SAFETY EVALUATION OF MASONRY BUILDINGS

For safety evaluation is intended a quantitative procedure focused on establishing if an existing building is able to resist to the design seismic combination.

The code provides the tools for the evaluation of single buildings, and the results cannot be extended to different buildings, even if they belong to the same typology.

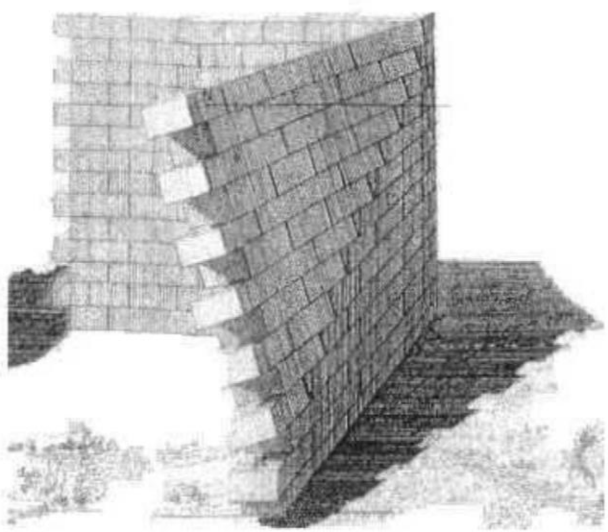
For the evaluation of the existing buildings, besides the global seismic analysis, that has to be effectuated with the methods provided by the code rules for new constructions, also the analysis of the local mechanisms has to be considered.

In the evaluation the experience, if available, has to be taken into account, coming from the examination of the behavior of similar buildings that were affected in the past the effect of seismic events.

# LOCAL COLLAPSE MECHANISMS

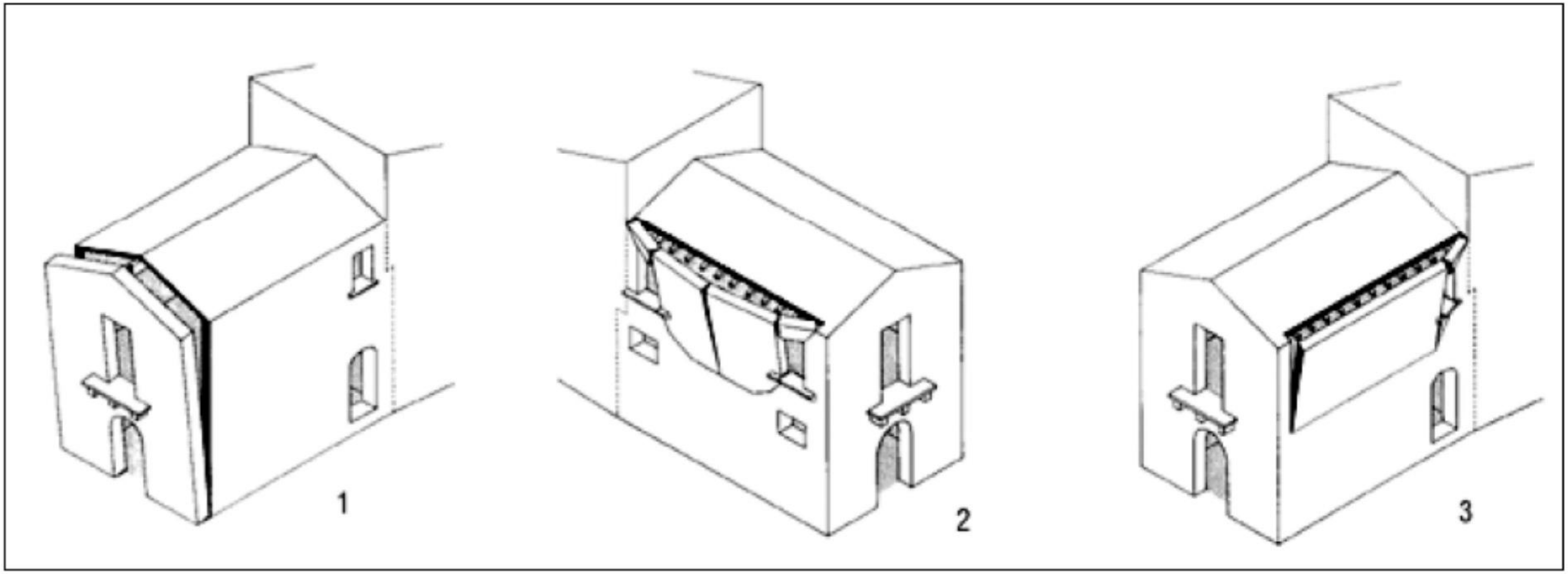
The Hypothesis of multi-connected box is, for what seen above, very often far form the reality of the considered structure.

In many cases the single walls “work” separately, therefore the bear themselves and the portion of load that acts on them.



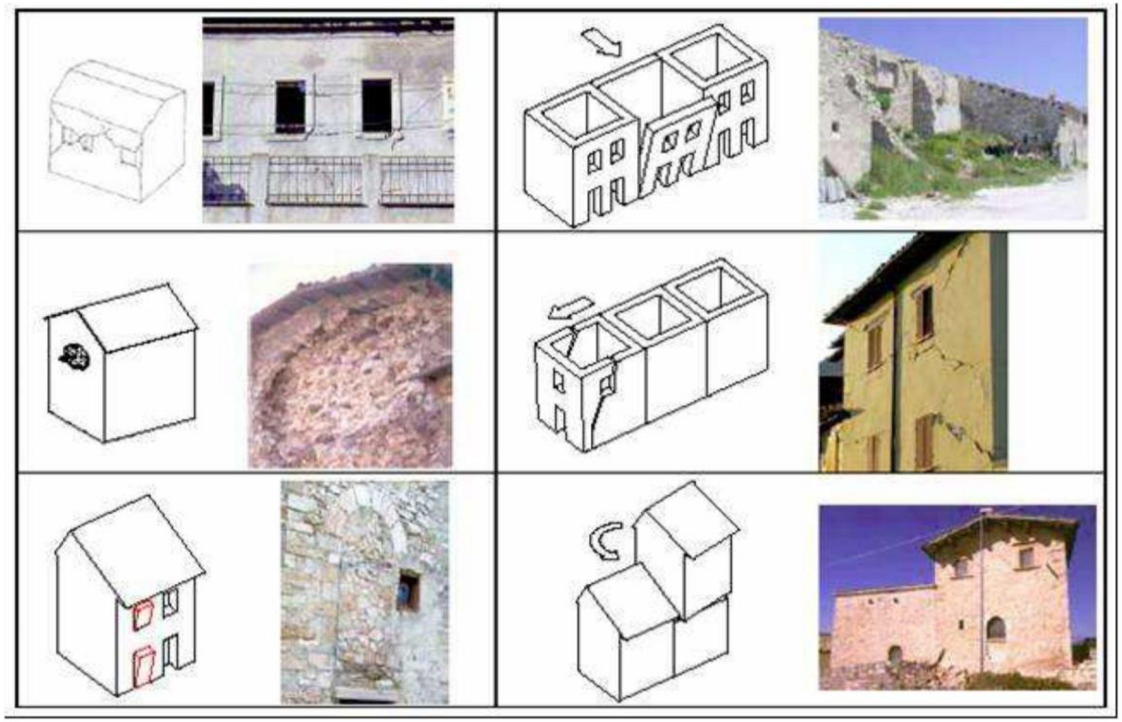
The a-critically committing of the structure response to a standard calculation model (for example POR) can misinterpret the results in terms of actions and ultimate response of the structure, and bring to consolidation interventions of walls that are marginally invested by the seismic actions, rather than others to which a secondary role is assigned by the model.

# SOME EXAMPLES OF LOCAL DAMAGE MECHANISMS



# ANALYSIS WITH KINEMATIC MODELS (1)

**BESIDES THE GLOBAL SEISMIC BEHAVIOUR OF THE BUILINDG UNDER ANALYSIS, IT IS NECESSARY TO MODEL THE INTERACTION WITH OTHER BUILDINGS OR THE EFFECT OF MIXED STRUCTURAL TYPES AND THE POSSIBILITY THAT LOCAL COLLAPSE MECHANISMS TAKE PLACE HAS TO BE TAKEN INTO ACCOUNT**



- BUILDINGS WITH PERIMETRAL LOAD BEARING MASONRY WALLS AND INTERNAL R.C. OR STEEL PILLARS;

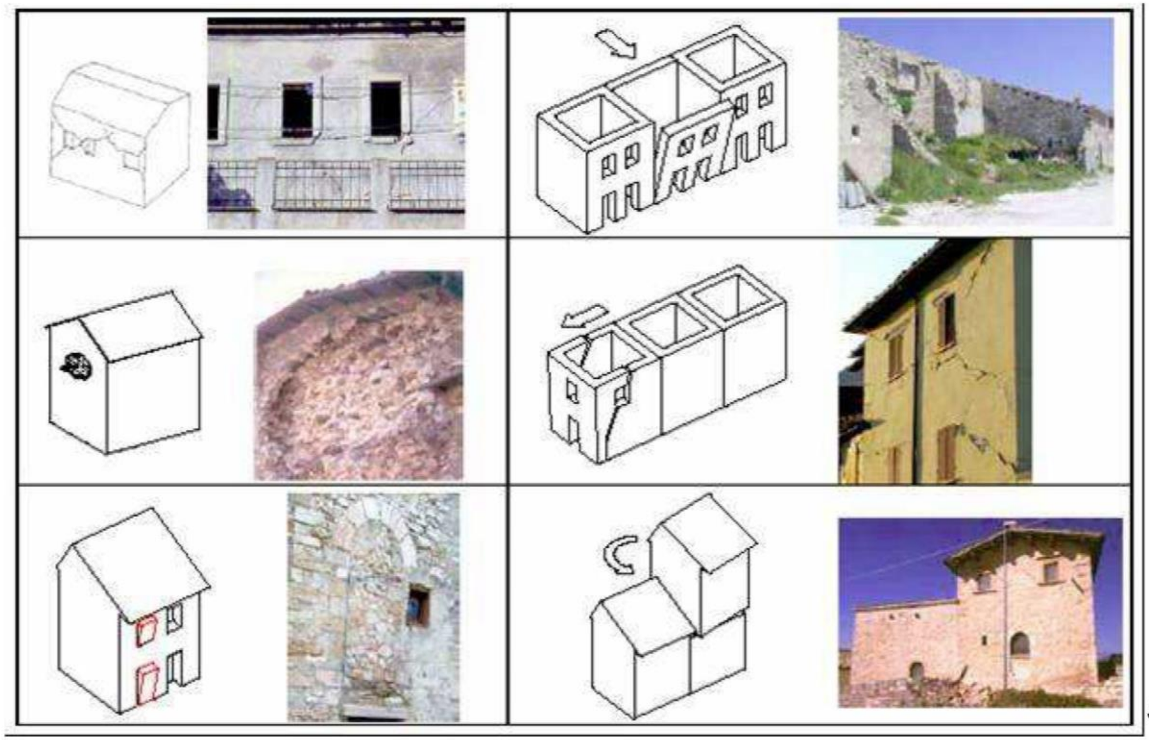
- MASONRY BUILDINGS WITH R.C. OR STEEL ADDED STOREYS;

- MASONRY BUILDINGS WITH OTHER INTERCONNECTED R.C. OR STEEL STRUCTURES

**Local mechanisms** | **Aggregate buildings** | **Mixed structural types**

# ANALYSIS WITH KINEMATIC MODELS (2)

1- The typical collapse mechanisms are determined, on the base of the observation of the collapse modalities of the existing buildings, collected in abacuses divided depending on different construction typologies (isolated buildings, array of buildings, churches…)



*SOURCE: Binda et al. (2004)*

2- The determined mechanisms are schematized with kinematic models, based on equilibrium conditions, which provide a collapse coefficient C=a/g for the elementary mechanism, i.e. the seismic mass multiplier that leads the element to failure

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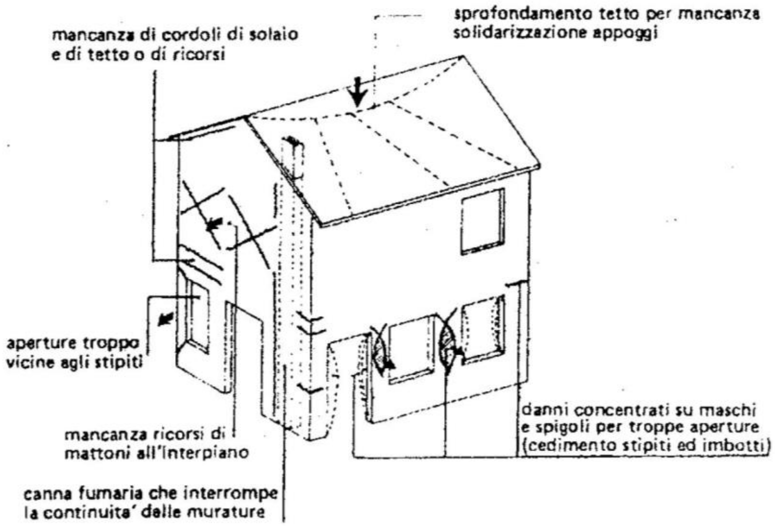
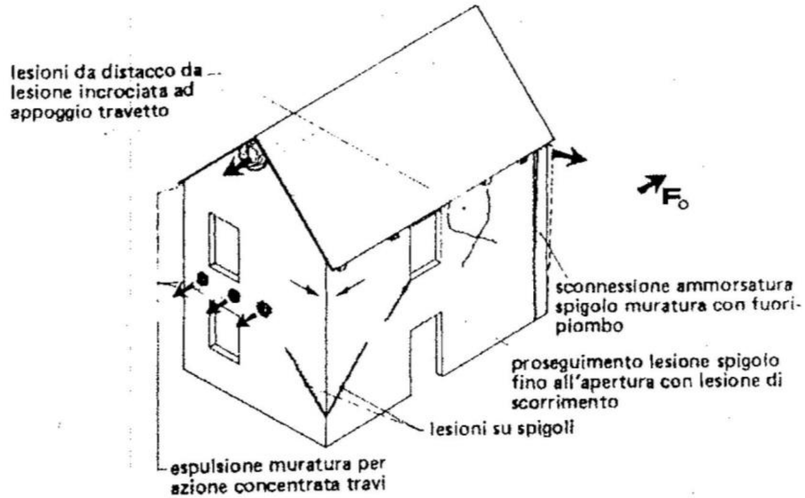
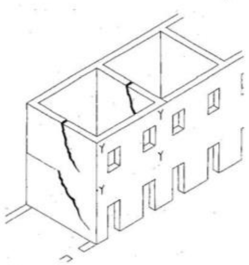
# COLLAPSE MODALITIES FOR EXISTING BUILDINGS (1)

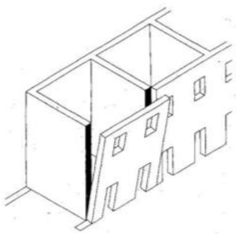



## In-plane wall failure



## Out-of-plane wall failure



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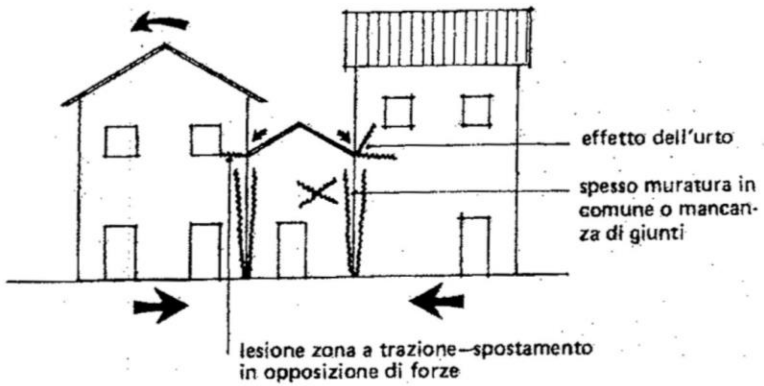
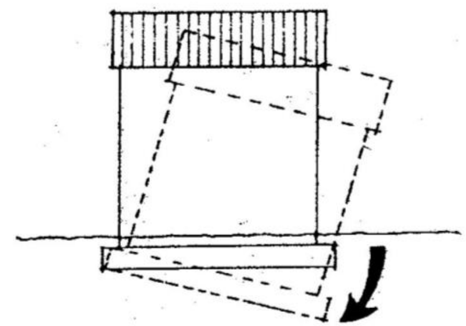
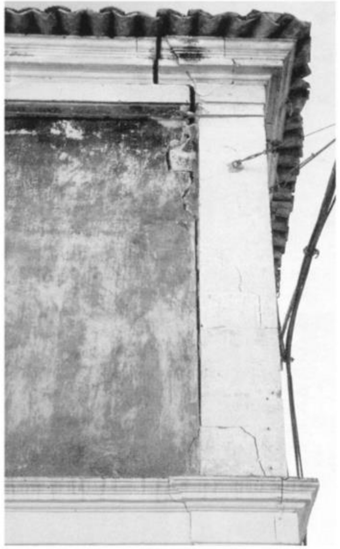
# COLLAPSE MODALITIES FOR EXISTING BUILDINGS (2)

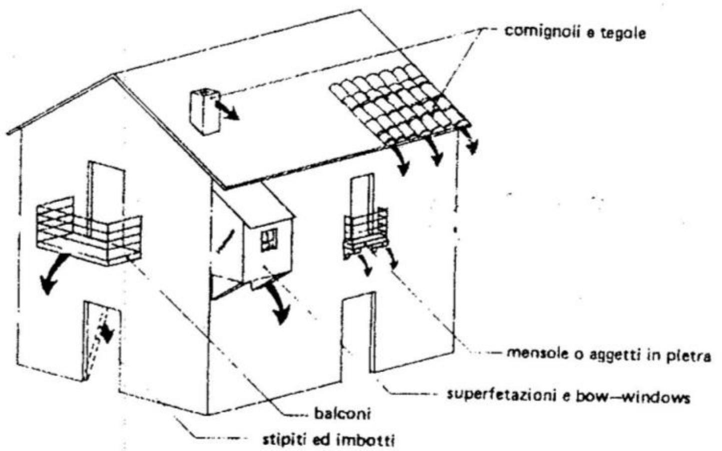



Adjacent buildings beating



Foundation settlement






Non-structural elements failure

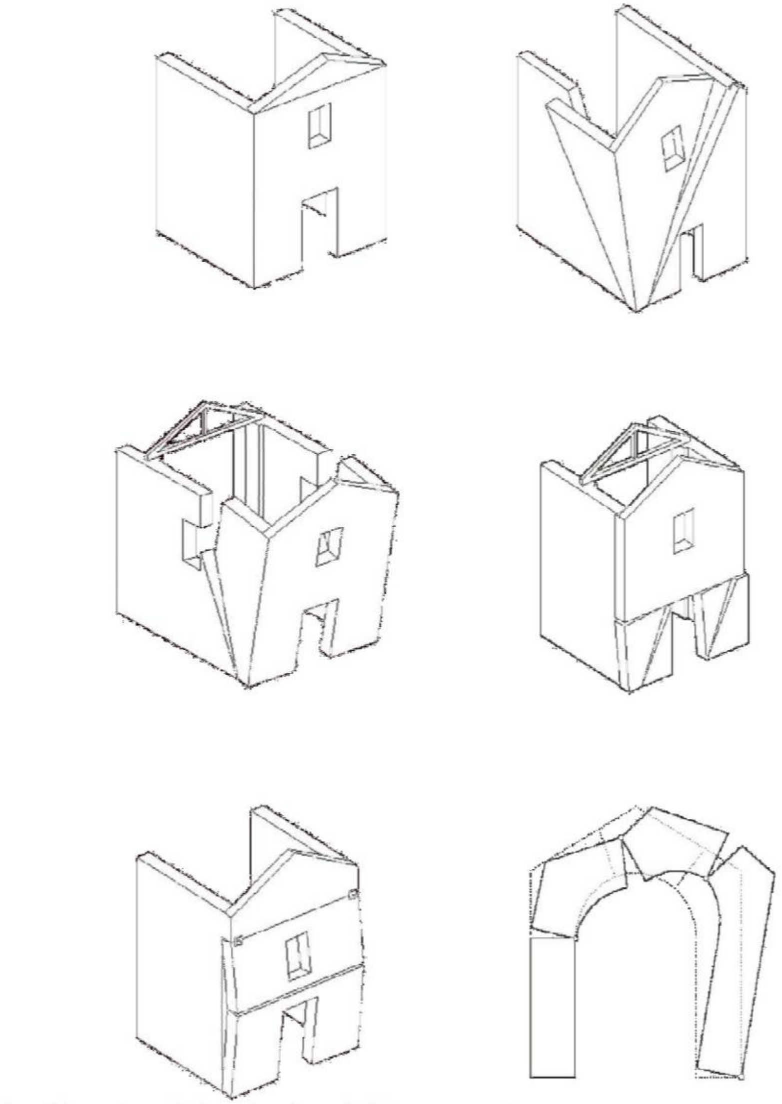
# MACROELEMENTS

**MACROELEMENT: portion of the building with homogeneous constructive characteristics and structural behavior.**

**It can coincide with a portion identifiable even under the architectural and functional point of view.**

The macroelements interact each others underlining lesions in correspondence of the contact zone (influence band).

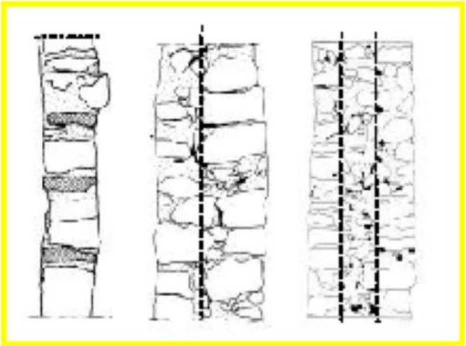
The influence bands are determined by lacking or missing connections or by damage effects (lesions).



# MASONRY TYPOLOGIES: IRREGULAR MASONRY

- Irregular weaving

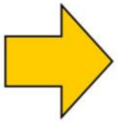
- Irregular sections (multilayer)



- Heterogeneous and of mediocre mechanical characteristics materials

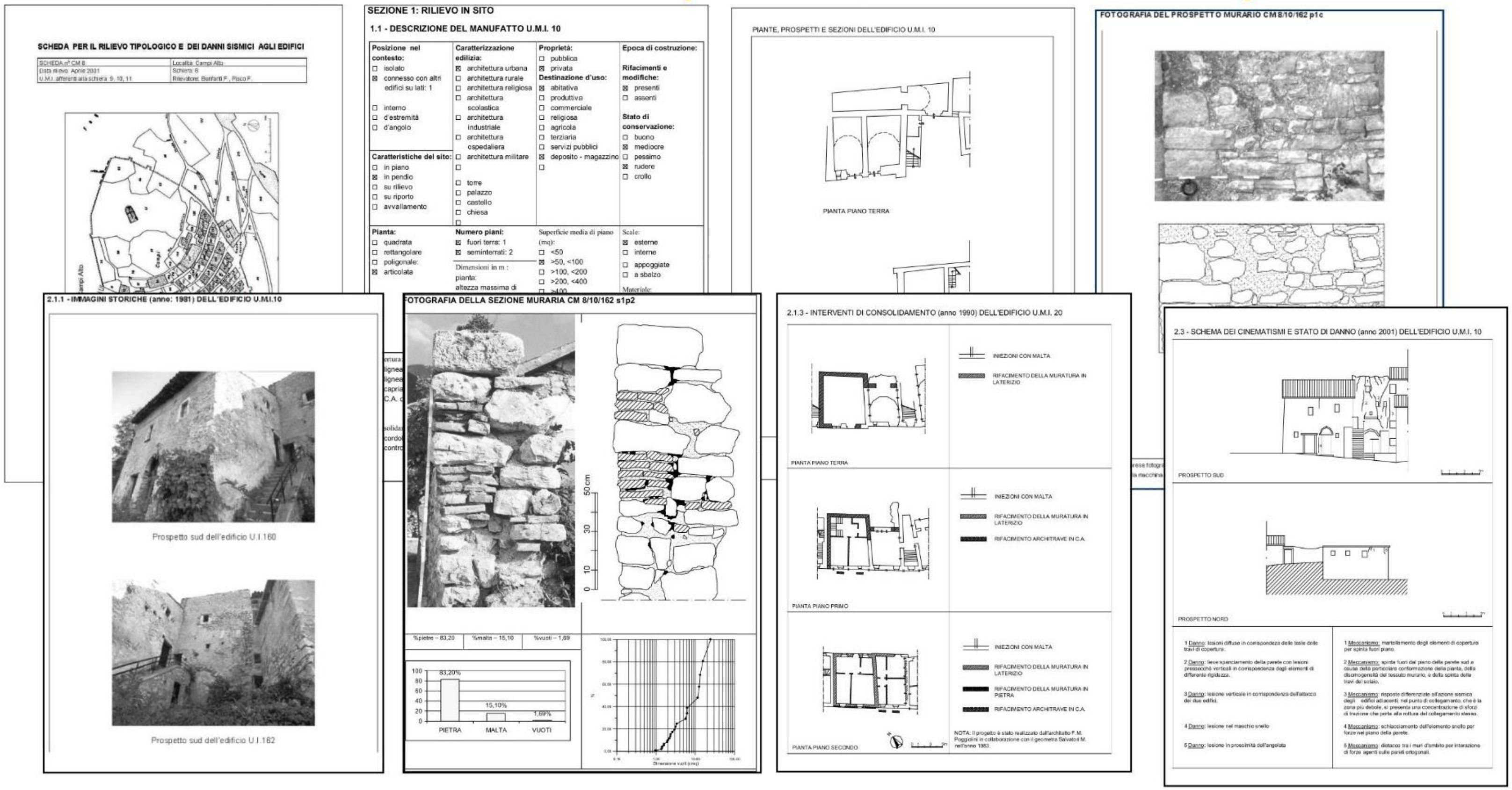
- Various stones
- Tile
- Mortar of different kinds
- Sand
- Fine elements (clay and soil)
- Voids

- lacking of connection between faces
- Not adequate connection between walls and floors



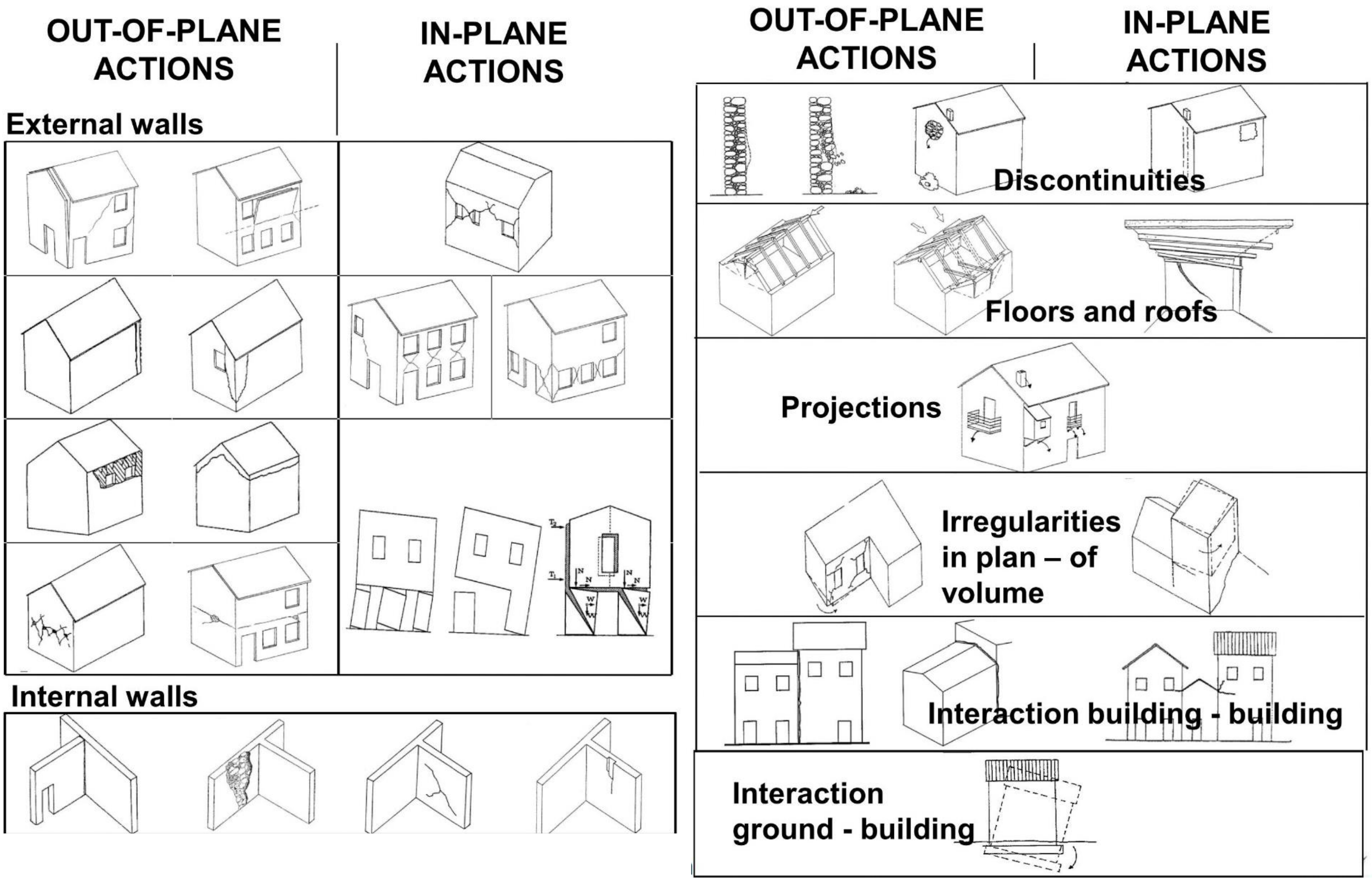
**"anticipated" failures out-of-plane**

# SURVEY FORM (Politecnico di Milano)




***a)*** general survey with plans, sections and photos; ***b)*** characteristics of the masonry structure and typology; ***c)*** past intervention projects and ***d)*** damage survey with crack pattern and evaluation of the possible collapse mechanisms.

# ABACUS OF THE DAMAGE MECHANISMS FOR BUILDINGS



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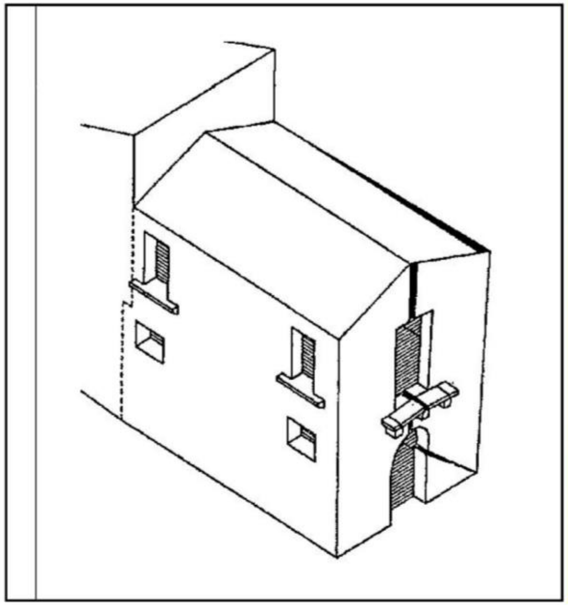
# OUT-OF-PLANE MECHANISMS OF PORTIONS OF THE BUILDING

Damage:
- inclined lesions of considerable width
- vertical lesions in the floor bands, in correspondence to the openings

Mechanism:
- overturning out-of-plane of portions of the building

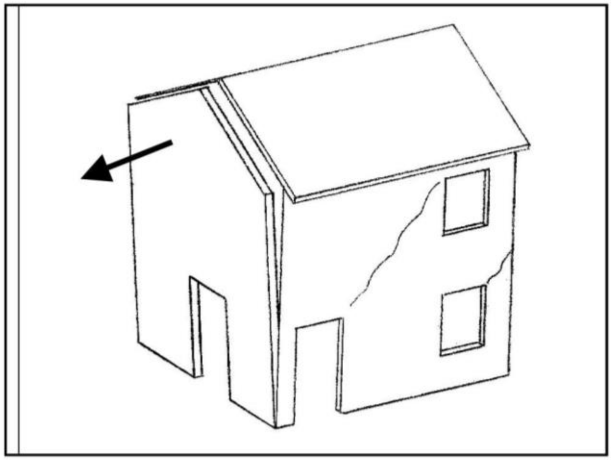


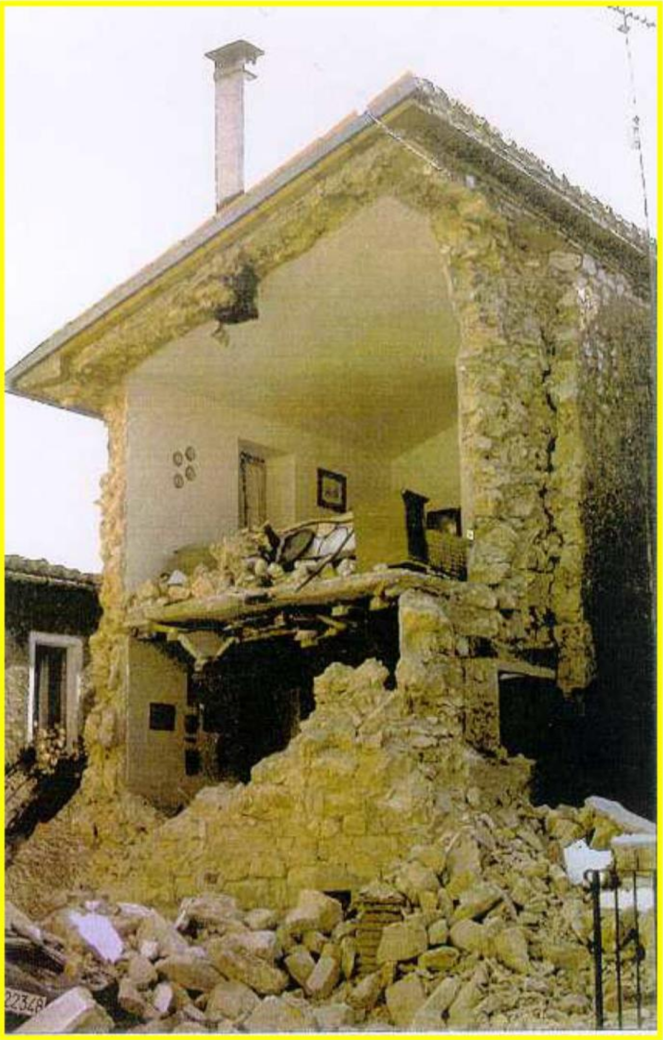
# EXTERNAL WALLS: OUT-OF-PLANE MECHANISMS

Damage:
- total collapse of the facade

Mechanism:
- rotation out-of-plane of the facade with formation of a cylindrical hinge, with horizontal axes, in correspondence to the ground level of the foundations

Structural causes:
- lacking of connection of the orthogonal walls
- lacking of chains or tie-beam which allows the box behavior of the masonry structure



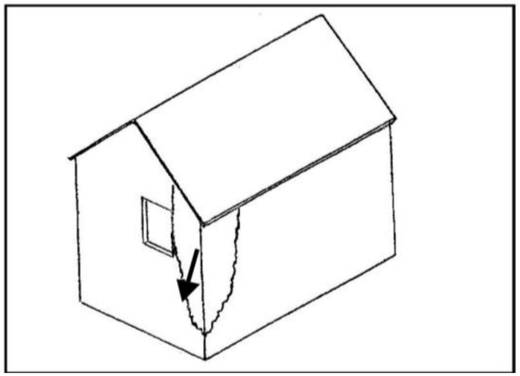


# EXTERNAL WALLS: OUT-OF-PLANE MECHANISMS

Damage:
- collapse of the corner

Mechanism:
- rotation out-of-plane of the corner for the interaction of forces acting on the orthogonal walls

Structural causes:
- ineffective connection between external walls
- insufficient anchoring of the floors to the perimeter walls
- presence of openings near the edges (the crack line often follow the distribution of the facade openings)

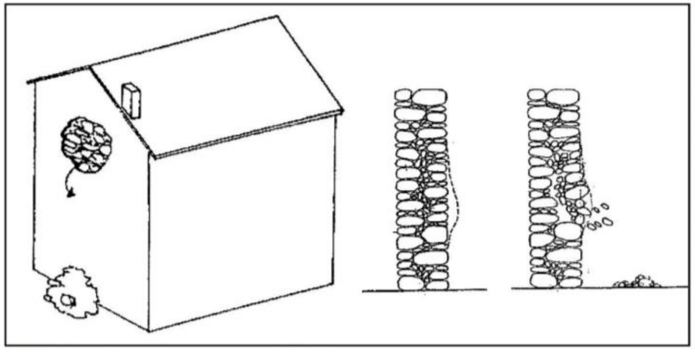


# EXTERNAL WALLS: MASONRY DISCONTINUITIES

**Damage:**
- ungluing between the masonry faces
- local collapses and material expulsions

**Mechanism:**
- overturning out-out-plane of vast portions of the external face

**Structural causes:**
- mediocre quality of masonry for materials, composition and construction characteristics;
- masonry with many pull-over faces (lacking of transversal anchoring, absence of diatonic walls, lacking of adhesion and cohesion of mortar, presence of voids)
- degraded masonry

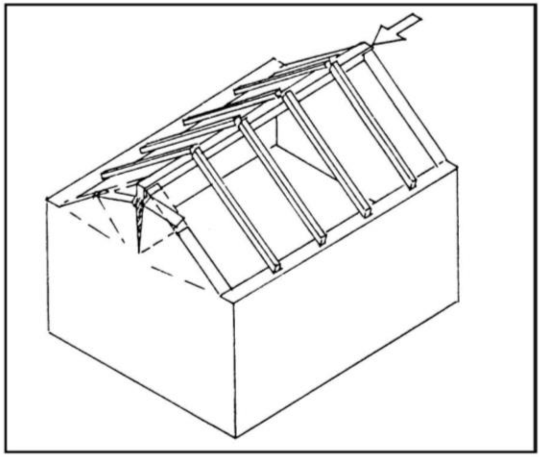


# EXTERNAL WALLS: OUT-OF-PLANE MECHANISMS CAUSED BY THE ROOFS

Damage:
- local collapse in the top of the tympanum wall
- isolated collapses of the cornice

Mechanism:
- rotation out-of-plane of part of the facade, due to the beating of the top beam, on which the seismic action is concentrated

Structural causes:
- roof not effectively connected to the masonry



# SUBSTITUTION INTERVENTIONS OF FLOORS AND ROOFS

- Stiffening of the floors not coupled with adequate consolidation of the walls

Expulsion of the facade

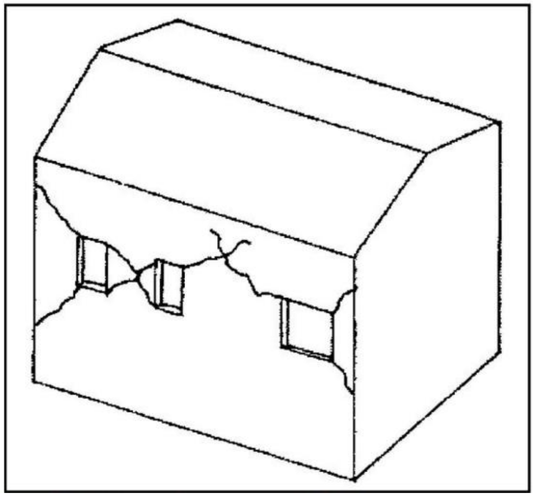
Rigid slipping of the roof

# EXTERNAL WALLS: IN-PLANE MECHANISMS – SHEAR OF THE WHOLE FACADE

Damage:
- diffused lesions inclined or cross shaped

Mechanism:
- shear failure of the whole facade

Structural causes:
- in presence of openings, the lesions starts from their edges, where a greater concentration of stress is present
- masonry of lacking quality or in presence of discontinuities

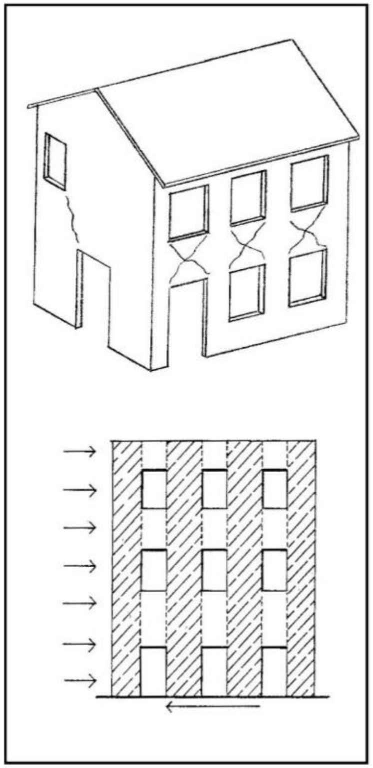


# EXTERNAL WALLS: IN-PLANE MECHANISMS – SHEAR OF THE FLOOR BANDS

Damage:
• crossed or diffused lesions in the area over the lintels of the openings

Mechanism:
• shear failure of the floor bands, for bending stress in the plane of the wall. (The floor bands divide the seismic force between the masonry walls, until the crisis of the system "floor band – masonry wall". The wall reacts then like a set of independent cantilever beams, blocked at the base

Structural causes:
• presence of weak lintels;
• masonry band between the openings reduced in height and depth

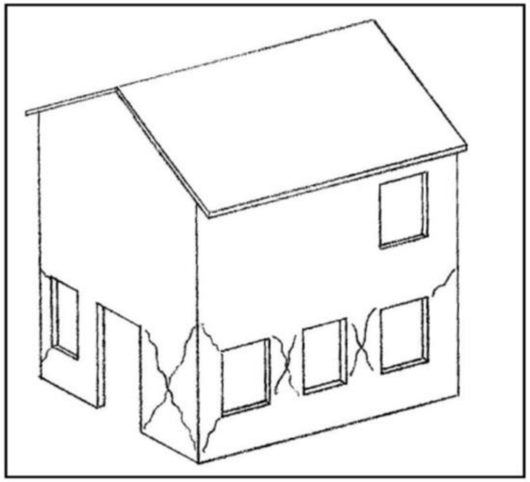


# EXTERNAL WALLS: IN-PLANE MECHANISMS – SHEAR IN THE MASONRY WALLS

Damage:
- lesions in the short walls (inclined in the edge panels, and in case crossed in the central panels)

Mechanism:
- shear failure in the wall stressed in its plane

Structural causes:
- presence of many openings
- mediocre masonry or in presence of discontinuities

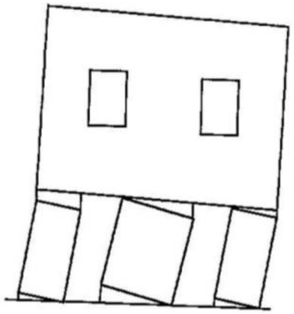


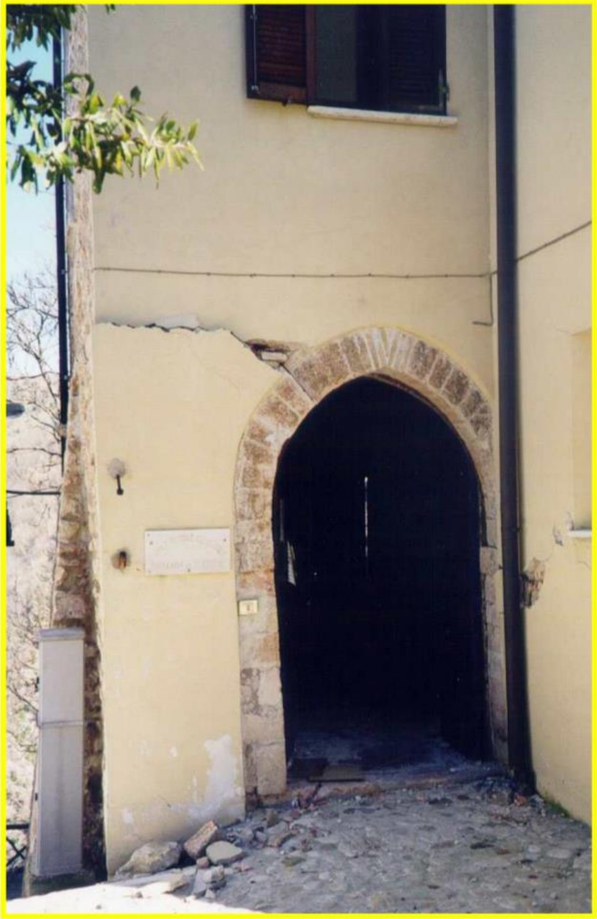
# EXTERNAL WALLS: IN-PLANE MECHANISMS - OVERTURNING OF THE MASONRY WALLS

Damage:
- lesions nearly horizontal even of considerable width (tensioned tail), localized mostly in the walls at the base of the building
- possible crushing of the edge (compressed tail) for reaching of the break value of the masonry

Mechanism:
- overturning of the masonry walls for rotation in their plane

Structural causes:
- excessive slenderness of the masonry walls, due to the presence of too many openings or of excessive dimensions





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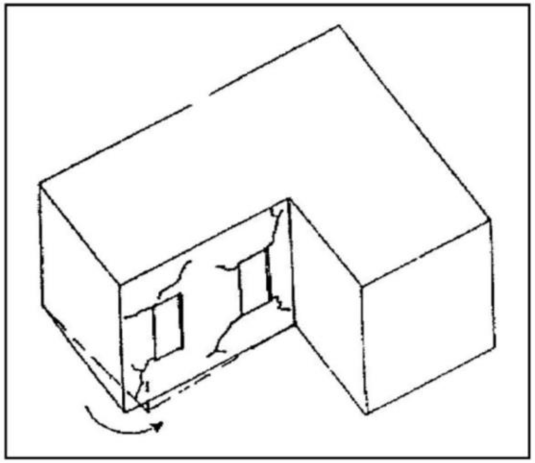
# PLAN-VOLUME CONFIGURATION: PLAN IRREGULARITIES

Damage:
• shear lesions concentrated on the walls of a wing of the building

Mechanism:
• rotation of the building in its complex, or relative rotation between its parts

Structural causes:
• lacking of shape regularity in plan (different absorption of the seismic forces for the eccentricity of the mass center with relation to the stiffness center).

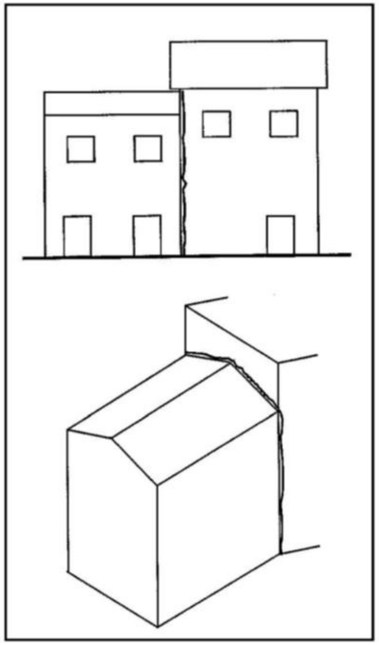


# BUILDING-BUILDING INTERACTION

Damage:
- vertical lesions in correspondence to the attach between different buildings

Mechanism:
- differential responses to the seismic action of adjacent buildings; in the connecting points, characterized by modest mechanic efficacy, a tension stress concentration is present, that brings to failure of the connection itself

Structural causes:
- mediocre connection between contact bodies
- different stiffness of the bodies

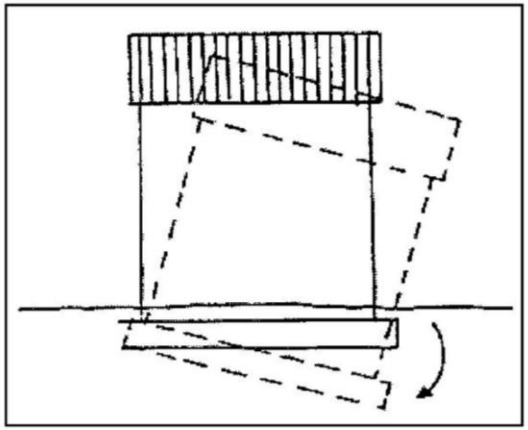


# BUILDING-GROUND INTERACTION: SETTLEMENT OF THE FOUNDATION GROUND

Damage:
- generalized lesions (vertical or inclined), even of considerable width
- slipping, collapse

Mechanism:
- out-of plane rotations and/or slipping of part or of the whole building

Structural causes:
- non homogeneity in the ground lift
- excessive ground slope



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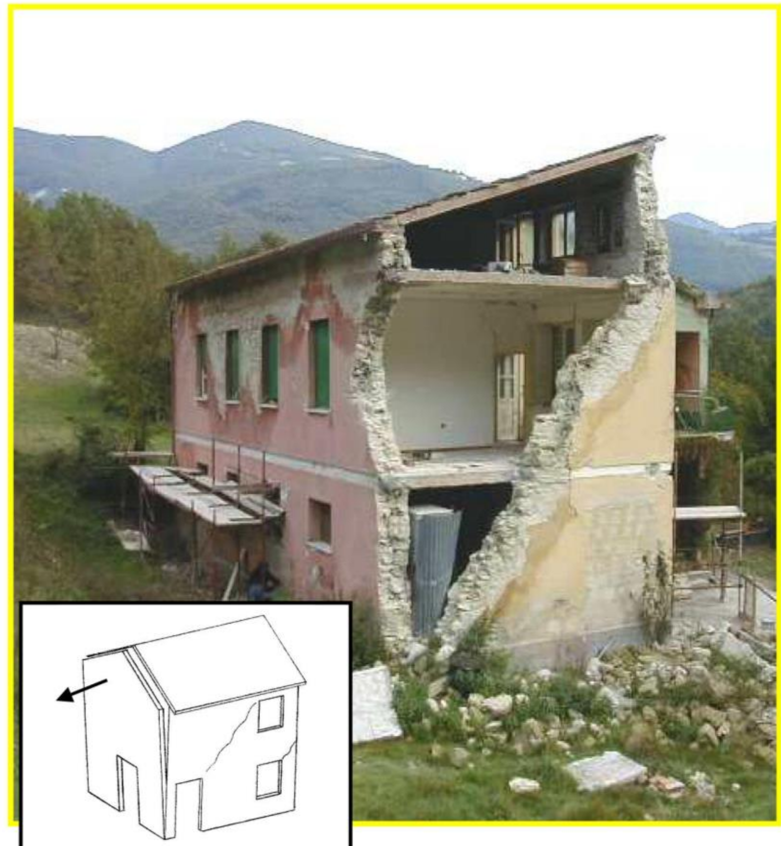
# SYNTESIS OF THE OUT-OF-PLANE MECHANISMS

- Lacking link between masonry faces
- Inadequate connection between walls and between walls and floors

→

- Expulsion of the external face
- Global overturning of the facade or of building portions



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# SYNTESIS OF THE IN-PLANE MECHANISMS

- Mediocre quality of the masonry and presence of openings and discontinuities

- Shear collapse of the walls
- Rotation and in-plane overturning

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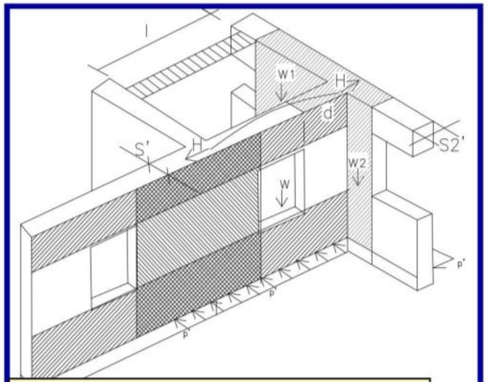
# KINEMATIC MODELS: collapse for the overgoing of the equilibrium conditions




**OUT-OF-PLANE MECHANISMS**

## Vertical bands:

- Global overturning:
  - Simply supported monolithic wall (*)
  - Simply supported double curtain wall
  - Two or more superposed monolithic walls not connected to the internal wall (*)
  - Wall connected to an orthogonal mediocre wall
- Local overturning*:
  - Wall held on the top by a tie-rod
  - Double-height wall held by tie-rod
  - Wall held by a tie-beam
- Local bending:
  - Wall held by high retaining forces (bending beam behavior)

## Horizontal bands:

- Arch mechanisms (overturning of imposts and crushing)
- Fixed beam behavior
- Detachment of the transversal wall

**IN-PLANE MECHANISMS**

- Formation of kinematic chains in portions of walls individuated by the particular geometric and boundary conditions

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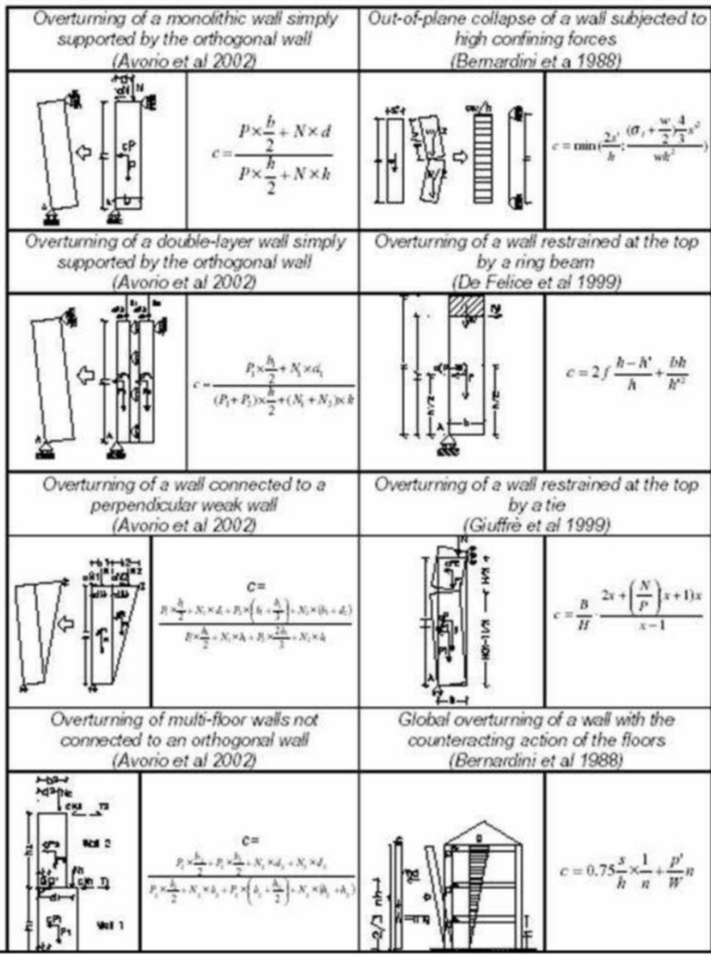
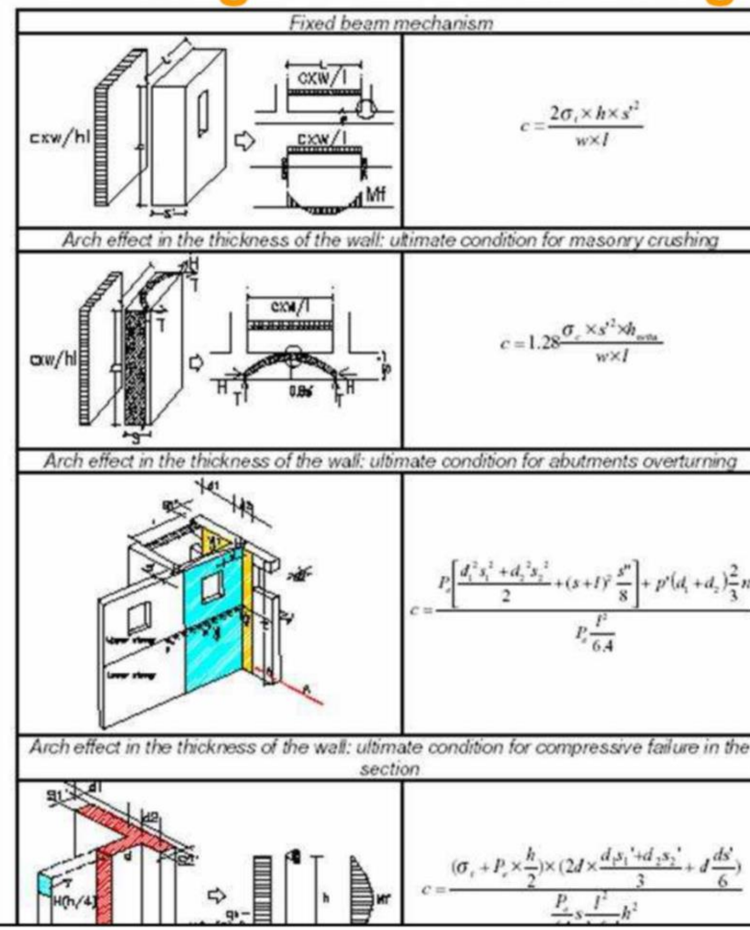
# OUT-OF-PLANE KINEMATIC MODELS: global overturning




Kinematic models for out-of-plane mechanisms: vertical bands [Valluzzi et al. 2004].




Kinematic models for out-of-plane mechanisms: horizontal bands ([Valluzzi et al. 2001; references for the mechanisms: [Bernardini et al. 1988]).

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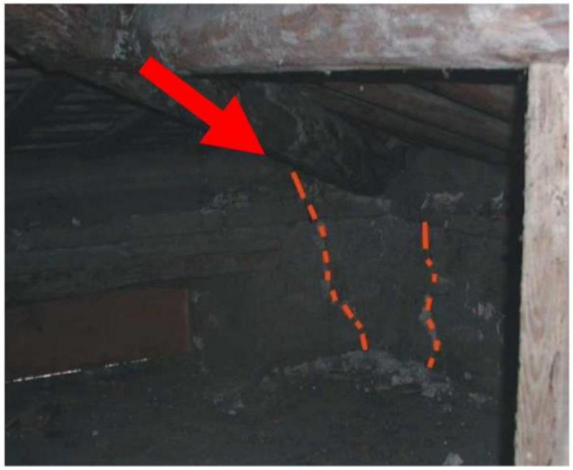
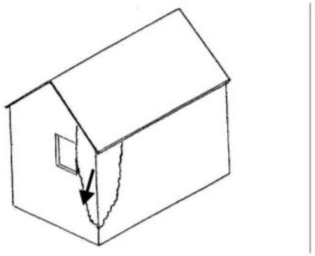
# EXAMPLE: SALO' EARTHQUAKE (2)

Salò – Private house

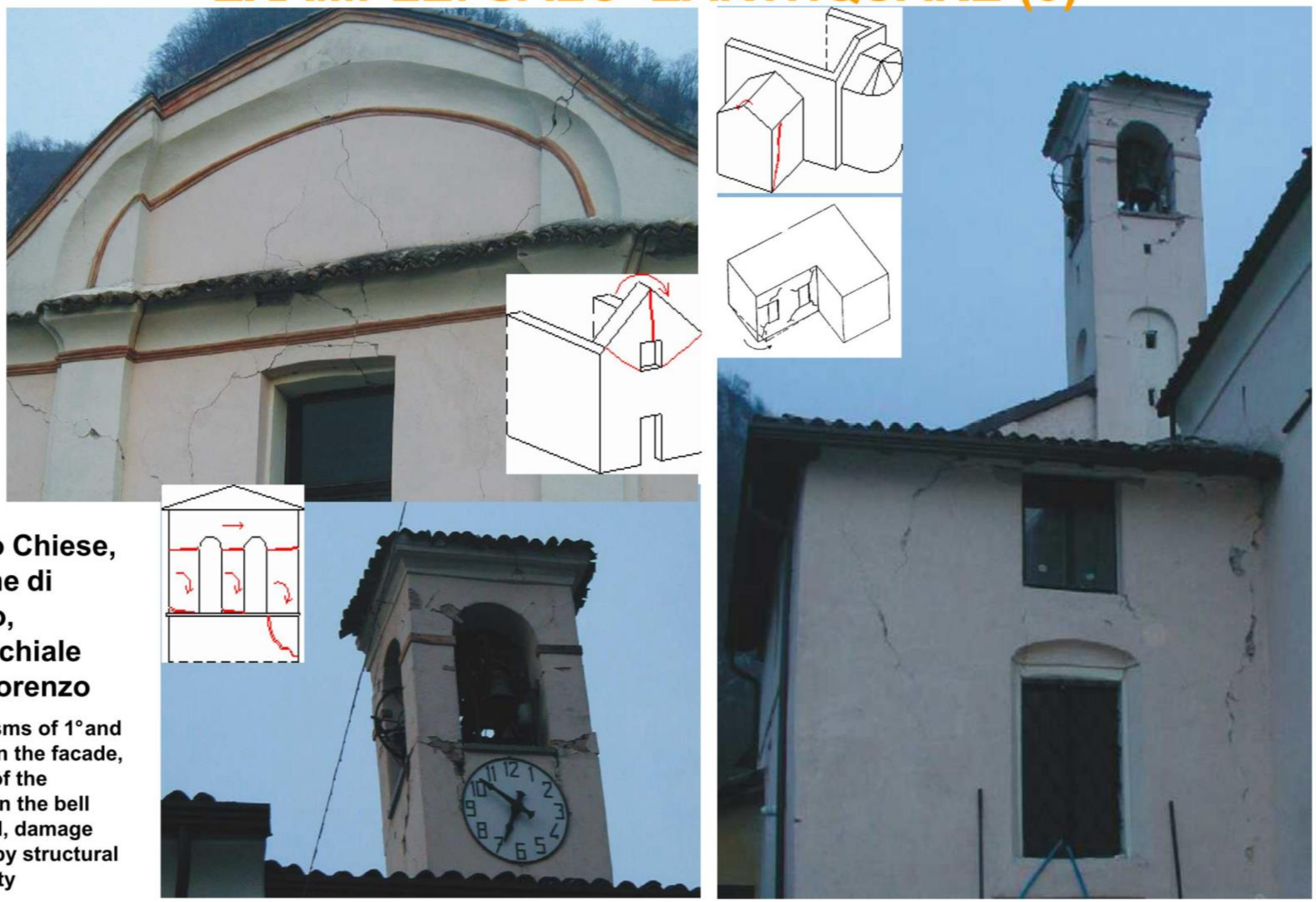
Local effects of damaging of the corner for beating of the roof / absence of top tying

Sabbio Chiese – Town building





# EXAMPLE: SALO' EARTHQUAKE (3)



**Sabbio Chiese, frazione di Clibbio, parrocchiale di S. Lorenzo**

**Mechanisms of 1°and 2°mode in the facade, rotation of the imposts in the bell tower cell, damage induced by structural irregularity**

Ministry of Public Works and Settlement Government of Republic of Turkey

SPECIFICATION FOR BUILDINGS TO BE BUILT IN SEISMIC ZONES

*Issued on 06.03.2007*

**CHAPTER 5 – EARTHQUAKE RESISTANT DESIGN REQUIREMENTS FOR MASONRY BUILDINGS**

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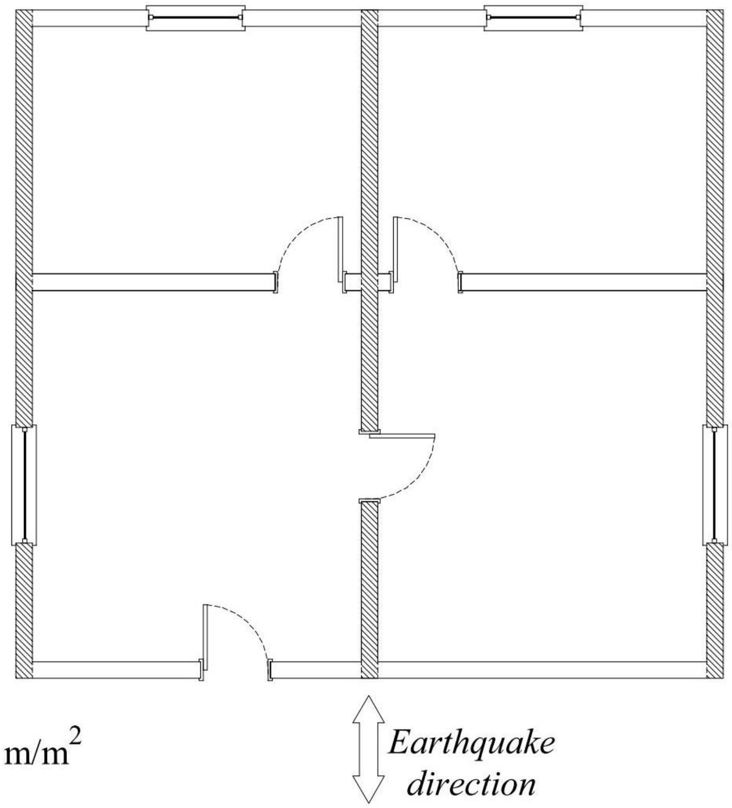
### 10.3.4. Maximum Unsupported Length of Load-Bearing Walls

**10.3.4.1** - Unsupported length of a load-bearing wall between the connecting wall axes in the perpendicular direction shall not exceed 5.5 m. in the first seismic zone and 7.0 m in other seismic zones.

**TABLE 10.2 - MINIMUM THICKNESSES OF LOAD-BEARING WALLS**

| *Seismic Zone* | *Stories Permitted* | *Natural Stone (cm)* | *Concrete (cm)* | *Brick (thickness)* | *Others (cm)* |
|---|---|---|---|---|---|
| 1, 2, 3, 4 | Basement | 50 | 25 | 1 | 20 |
| | Ground storey | 50 | – | 1 | 20 |
| 1, 2, 3, 4 | Basement | 50 | 25 | 1.5 | 30 |
| | Ground storey | 50 | – | 1 | 20 |
| | First storey | – | – | 1 | 20 |
| 2, 3, 4 | Basement | 50 | 25 | 1.5 | 30 |
| | Ground storey | 50 | – | 1.5 | 30 |
| | First storey | – | – | 1 | 20 |
| | Second storey | – | – | 1 | 20 |
| 4 | Basement | 50 | 25 | 1.5 | 30 |
| | Ground storey | 50 | – | 1.5 | 30 |
| | First storey | – | – | 1.5 | 30 |
| | Second storey | – | – | 1 | 20 |
| | Third storey | – | – | 1 | 20 |




$\ell_d$ / A ≥ 0.25 I m/m$^2$

$\ell_d$ : *Length of hatched area* (m)
**A** : *Gross floor area* (m$^2$)
**I** : *Building Importance Factor* (**Chapter 6**)

**Figure 10.1**

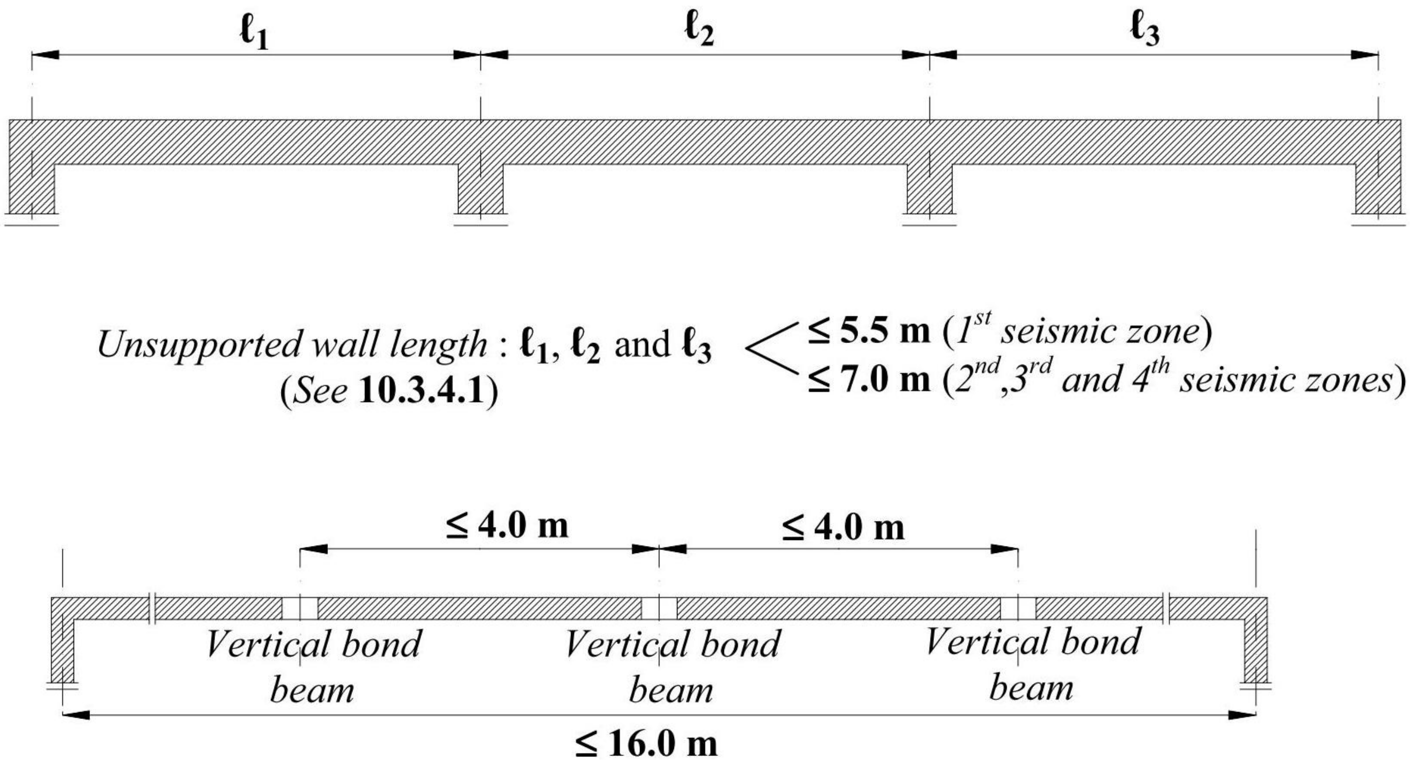

ℓ1
ℓ2
ℓ3
Unsupported wall length : ℓ1, ℓ2 and ℓ3
(See 10.3.4.1)
≤ 5.5 m (1st seismic zone)
≤ 7.0 m (2nd,3rd and 4th seismic zones)
≤ 4.0 m
≤ 4.0 m
Vertical bond beam
Vertical bond beam
Vertical bond beam
≤ 16.0 m

**Figure 10.2**

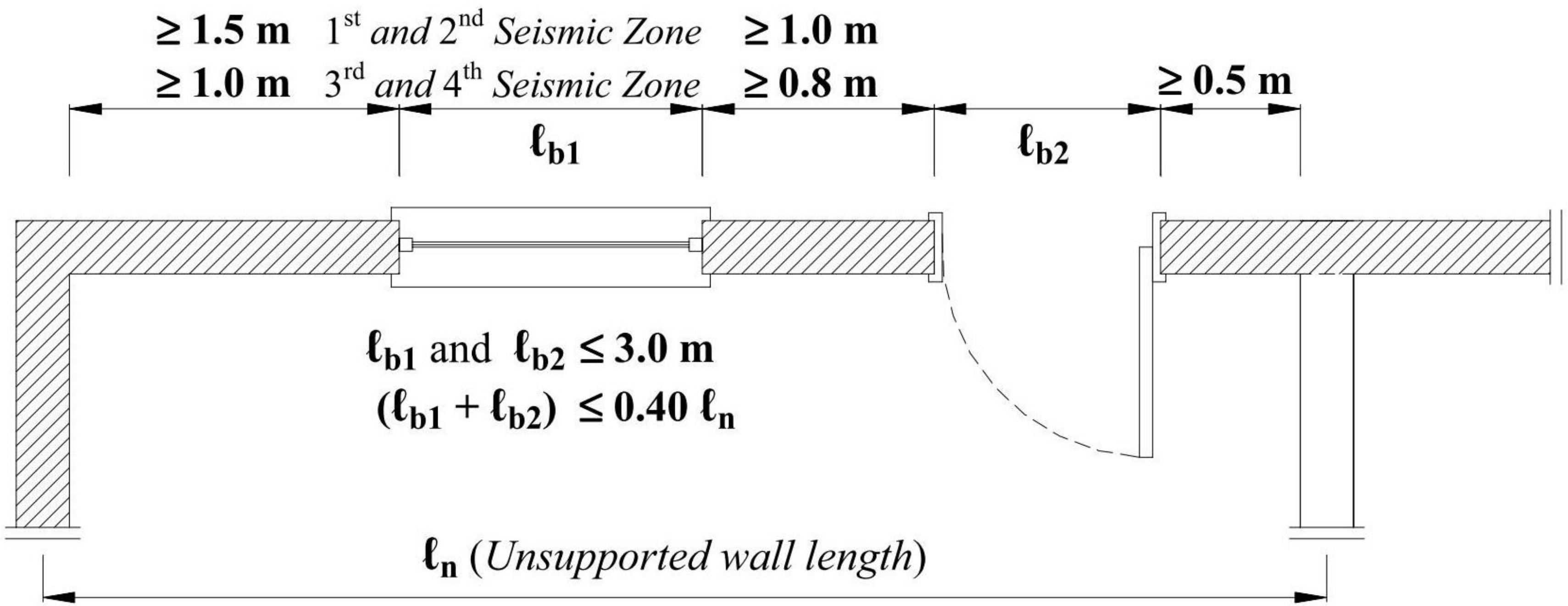

≥ 1.5 m 1st and 2nd Seismic Zone ≥ 1.0 m
≥ 1.0 m 3rd and 4th Seismic Zone ≥ 0.8 m
≥ 0.5 m
ℓb1
ℓb2
ℓb1 and ℓb2 ≤ 3.0 m
(ℓb1 + ℓb2) ≤ 0.40 ℓn
ℓn (Unsupported wall length)

Figure 10.3

## 10.4. LINTELS AND BOND BEAMS

### 10.4.1. Lintels

**10.4.1.1** – Each of seating lengths of window and door lintels on the walls shall not be less than 15% of lintel clear span nor shall it be less than 20 cm.

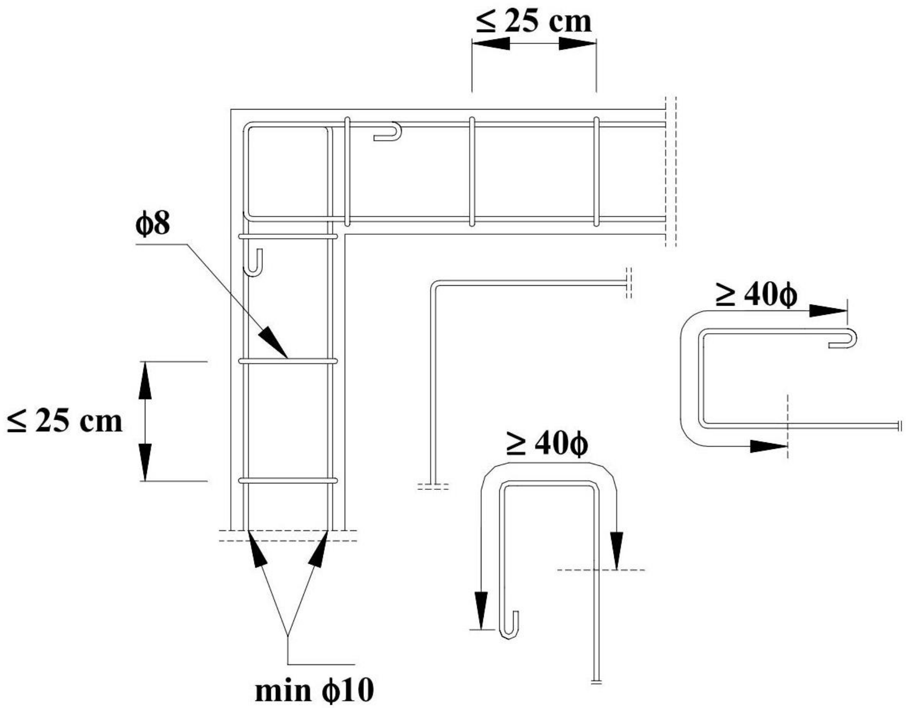
**10.4.1.2** – Cross sections dimensions of lintels as well as longitudinal transverse reinforcement shall not be less than those given in **10.4.2.1** for horizontal bond beams.

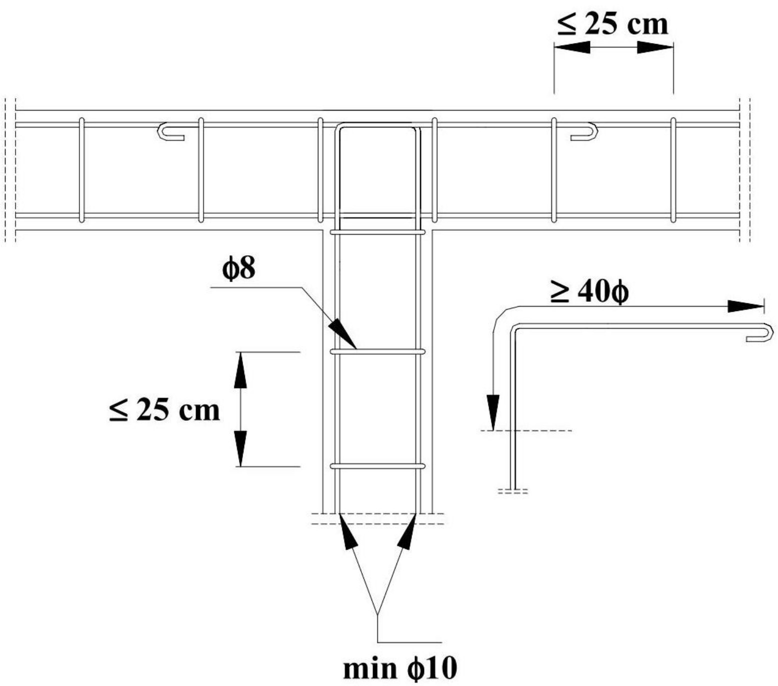
### 10.4.2. Horizontal Bond Beams

**10.4.2.1** – Reinforced concrete horizontal bond beams satisfying the following conditions shall be made at places where slabs, including stair landings, are supported by walls such that they shall be cast monolithically with the reinforced concrete slabs.

**(a)** Width of horizontal bond beams shall be equal to the width of wall, and their height shall not be less than 20 cm.

**(b)** Concrete quality for bond beams shall be at least **C16** (**BS16**). Longitudinal reinforcement shall be at least **6∅10** on stone walls with three at the bottom and three at the top, whereas it shall be at least **4∅10** on other load-bearing walls with **∅8** hoops with a maximum spacing of 25 cm. Longitudinal rebars shall be appropriately overlapped at the corners and intersections to achieve continuity (**Fig. 10.4**).


≤ 25 cm
ϕ8
≤ 25 cm
≥ 40ϕ
≥ 40ϕ
min ϕ10


≤ 25 cm
ϕ8
≥ 40ϕ
≤ 25 cm
min ϕ10

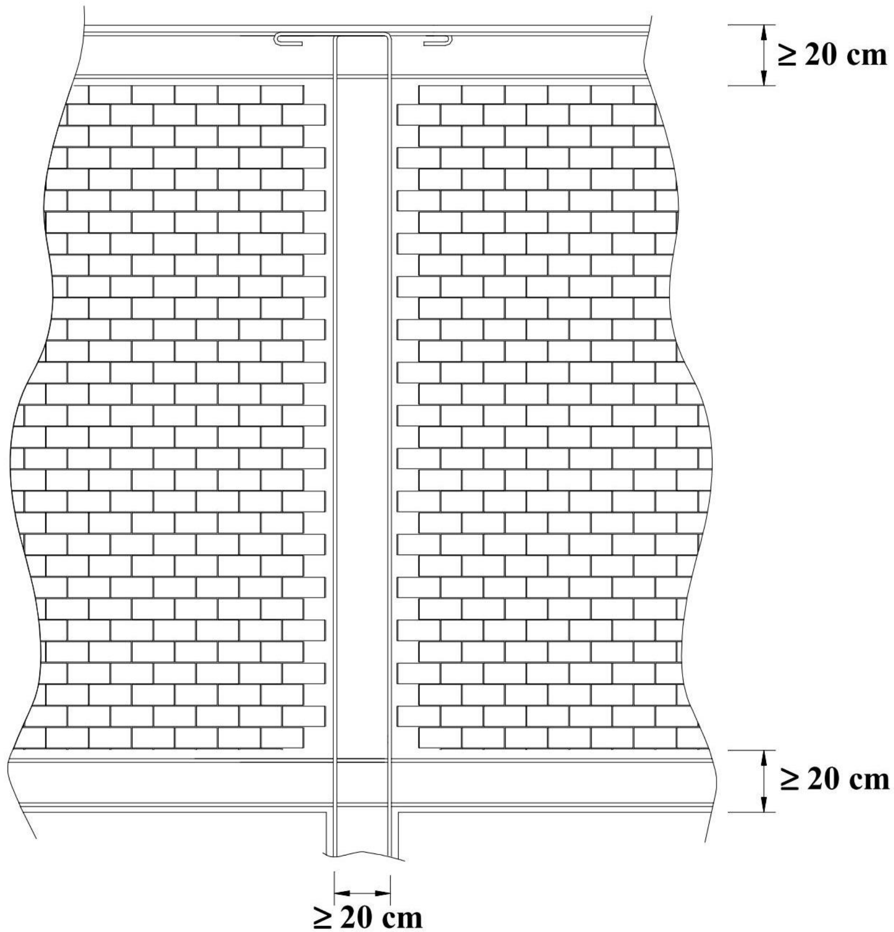



Figure 10.5

## 10.6. ROOFS

**10.6.1** – Roofs of the masonry buildings may be constructed as reinforced concrete terrace roof, timber or steel truss roof bearing on roof slab.

**10.6.2** – Connections of the timber roof elements to the roof slabs or to horizontal bond beams on bearing walls shall be made in accordance with the rules given in TS-2510.

**10.6.3** – In the case where the height of the end wall resting on the horizontal bond beam at the top storey exceeds 2 m, vertical and inclined bond beams shall be constructed (**Fig. 10.6**).

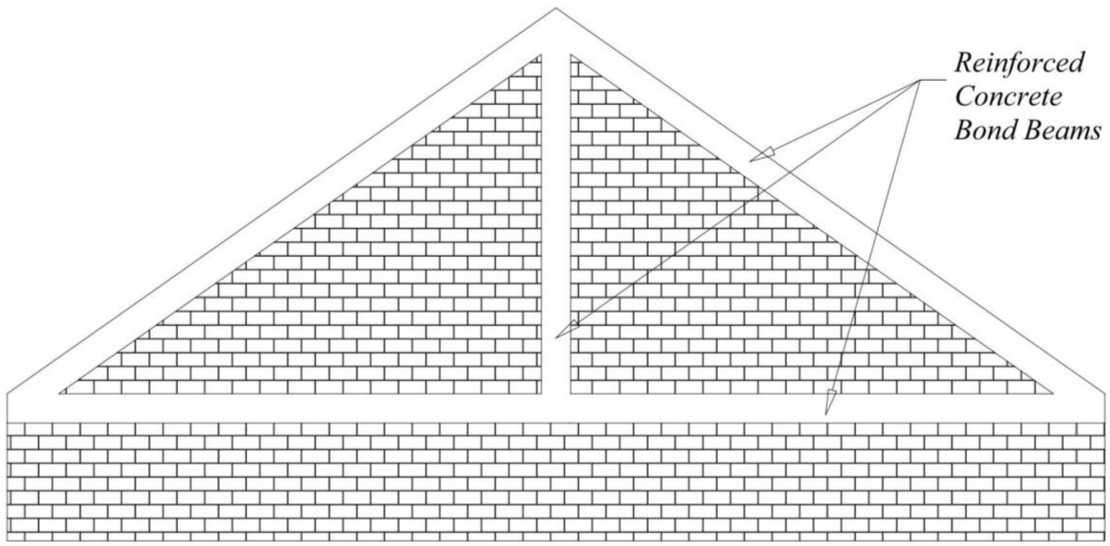



**Figure 10.6**