CHAPTER 4: METHODOLOGIES

This chapter was divided into two main sections. In the first section; the qualitative methods for evaluating the bath's masonry walls were explained in a detailed way. These methodologies were used in case study structures. In addition each case study's historical values, functional and structural specifications of were examined.

In the second section; description of damage and collapse analysis method was determined with statements, table of graphic descriptions. This art of science was used in case study bath structures.

4.1. Definition of the qualitative methodology for defining the masonry walls of bath structures (Methodological application A)

In this methodology, there is an investigation of the seismic vulnerability of the building, damage altitude and how it harms the quality of structural damage. This essentially means simplified methods based on observation, degradation and collapse put in evidence various structural deficiencies, giving them a 'weight' in qualitative assessment. These simplified methods are:

1. The acquisition of specific indicators to measure vulnerability.
2. Determination of effectiveness and quality of the walls.
3. Identification of kinematic chains in the absence of signs, indicative of the potential damage mechanism.

The scope of this research is; qualitative criteria for defining the structural safety analysis of quality walls by basic assumption rules.

The basic assumption rules of the methodology:

- Good behavior and ensure the compactness and the monolithic structure.
- Mortar regulates contact between the stones.
- Transmit and distributes uniform way.
- Good quality makes some resistance to the nature of the wall.
- The resistance of the mortar can become important if they lack the other parameters of the rule of the art able to ensure the monolithic wall.
- Presence of diatones which passing through the whole thickness of the wall.
  - Prevent the breakdown of the wall hangings.
  - Load distribution whole thickness of the wall.
- Shape of the elements. The presence of two faces flat enough.
  - The size of the elements. Resistant elements larger size. Well meshed together and difficult to move.
  - Presence of offset between the vertical joints. 'Chain effect' provides a certain tensile strength of the masonry. Even if the stones are not square.
- Horizontal rows become important during seismic action 'Horizontal bricks'.
- Acquisition of indicators of vulnerability specification: The index of quality walls.

Object of study is the wall panel considered isolated and homogenous *(Borri, 2011).*

4.1.1. Parameters of the rule of methodology

In the following steps, the parameters of the methodology are clarified.

Parameters of the rule of methodology;

Q.M. - Quality of the mortar

P.D. - Presence of diatones

F.R.E. - Shape of the elements resistant

S.R.E. - Size of the resistance elements

S.V.J. - Stagger vertical joints

P.H.R. - Horizontally of the rows

Q.R.E. - Resistance of the elements

In the following paragraph description of parameters of the rule of art are clarified *(Borri, 2011).*

- The quality of mortar, effective contact between elements – (QM)

Respected: Mortar in good condition and well maintained, the joint size is not excessive in relation to the stones or bricks. Mortar joints are large and excellent quality. Masonry walls are formed by large square elements with a thin layer of mortar. If all these specifications are found in the same case, it means the quality of the mortar is 'respected' and there is effective contact between the stones *(Borri, 2011).*

Partially respected: The quality of the mortar is rated in intermediate level. And mortar joints are not excessively eroded. Masonry walls are formed with irregular elements. Wedges are inserted into the spaces between the stones *(Borri, 2011).*

Not respected: The mortar is poor, degraded or powdery. The mortar is completely devoid of cohesion. The mortar joints are overly thick in comparison to the stones of the wall. The masonry of the porous elements, for instance tuff stone has got poor adhesion between the mortar. However, in some cases masonry with large squared elements that has thin layers of mortar meet this parameter *(Borri, 2011).*

- Presence of cross diatone-meshing - (PD)

Respected: Diatones confer sufficient monolithic behavior. The approximate measurement of the $1m^2$ wall surfaces is 5 to 6 diatones. The visibility on the surface of the masonry wall, LMT (minimal path) must be greater than 155cm *(Borri, 2011).*

Partially respected: There are approximately 3 to 4 diatones in each $1m^2$ wall surface. The visibility on the surface of the masonry wall, LMT (minimal path) must be between 125cm to 155cm. The front facing surface of the masonry wall is well organized on one side. The thickness of the wall is not excessive in relation to the size of the stones. This category may include the walls with diatones that do not extend from side to side, but are still be able to join the masonry wall structure together *(Borri, 2011).*

Not respected: Diatones are insufficient in number to ensure the monolithic wall stability. Approximate indication: in a $1m^2$ wall surface if there are less than three diatones, this wall goes into the category of 'not respected'. The visibility on the surface of the masonry wall, the LMT (minimal path) is less than 125cm. The stones are smaller in dimension compared to the thickness of the masonry wall *(Borri, 2011).*

- Form of the element that was resisted – (F.R.E.)

Respected: Prevalence of square shaped elements or outlined square shapes or square shaped tiles which form parallels on both wall faces. Also the dominance of the ratio of square shaped elements is at least ¾ of the surface of the masonry wall and at least ¾ of the thickness of the wall *(Borri, 2011).*

Partially respected: The presence of elements inside the masonry are irregularly shaped or rounded. There are pebbles and blocks of square shaped elements or bricks on the masonry walls formed with irregular shaped stones or bricks. The percentages of pebbles on the wall surface are between ¼ and ½. On the thickness of the wall the presence of pebbles are between ¼ and ½ *(Borri, 2011).*

Not respected: The stones which are used on the masonry walls are irregularly shaped and rounded. The percentages of the pebbles are at least ½ according to the wall surface. The pebbles are used on both surfaces of the wall *(Borri, 2011).*

- Size of resistant elements - (S.R.E.)

Respected: The masonry wall is composed of blocks of stones based on the following dimensions. The prevalent size of the masonry elements is greater than 40cm. In these types of walls the blocks are usually so large as to affect the thickness of the wall; they function as diatones *(Borri, 2011).*

Partially respected: The masonry wall is composed of blocks of stones based on the following dimensions. There is a prevalence of elements whose size is greater than 20cm on one side and 40 cm on the other side *(Borri, 2011).*

Not respected: Wall blocks, chips of stone and minute dimensions of stones exist inside the masonry. Inside the masonry wall there is a general prevalence of elements whose largest dimensions is below 20cm *(Borri, 2011).*

- Stagger the vertical joints between the meshing in the plan - (S.V.J.)

Respected: Method for quantitative analysis; on the wall face the minimum line of the track is greater than 160cm. And method for qualitative analysis; the vertical joints generally correspond to the central area of the lower masonry element *(Borri, 2011).*

Partially respected: Method for quantitative analysis; on the surface of the wall the line of the track is between 140cm and 160cm. Method for qualitative analysis; the vertical joint of the mortar is in an intermediate position between the central area of the lower element and its edge *(Borri, 2011).*

Not respected: Method for quantitative analysis; on the surface of the wall the line of the track is below 140cm. For a double wall, the line track is lower than 140cm on one side and lower than 160cm on the other side. Method for qualitative analysis; there is also an apparent lack of meshing of one or more vertical lines of the wall *(Borri, 2011).*

- Presence of horizontal rows – (P.H.R.)

Respected: The staggering of the horizontal rows mostly affects the width of the wall. In this category masonry horizontal rows are lined up without interrupting the continuity of the rows and they are present on both faces of the wall. Horizontal row intervals are less than 60cm *(Borri, 2011).*

Partially respected: The diffusion of the horizontal rows length is approximately less than ¾ of the entire width of the wall *(Borri, 2011).*

Not respected: The horizontal rows are continually interrupted or do not have clear offsets throughout the entire masonry wall *(Borri, 2011).*

- Quality resistant elements – (Q.R.E.)

Respected: Stones are not degraded or only slightly degraded. The masonry has approximately less than 10% of the elements degraded. Masonry elements are of hard tuff (volcanic). Brick elements with holes are approximately less than 45% *(Borri, 2011).*

Partially respected: The degraded masonry elements are approximately between 10% and 50% relatively to total elements on the wall surface. Brick elements have been drilled between 45% and 70%. In addition the masonry walls are composed of soft tuff (limestone) *(Borri, 2011).*

Not respected: A total of 50% of the elements are damaged. For the brick elements the drilling percentage is lower than 70%. Also the masonry walls are composed of mud bricks or unbaked clay. In general, the elements are clearly unable to resist any form of stress *(Borri, 2011).*

4.1.2. Determination of the scores and their contribution to the masonry wall categories

Determination of the scores and their contribution to the masonry wall categories are done with the use of Table 4.1 and Table 4.2. The main requirements for evaluating the quality of the walls are:

- The possibility of separate evaluations based on the type of actions that enforces the masonry structure. The schematic descriptions of these actions are shown in (Fig 4.1, 4.2 and 4.3) *(Borri, 2011).*

-Analysis of the requirements of the methodology will have differing weights depending on the action causing stress on the wall and depending on the presence of other equivalent requirements *(Borri, 2011).*

-The final result is expressed by a 'category' belonging to wall type 'A, B or C'.
-Ease of application and intuitiveness of the proceedings.
-Possibility of being modified and adapted to wall typologies not covered in this phase.
-Calibration and tests carried out in large numbers. The proposed methodology called the 'Method of scoring' requires an assessment of the degree of respect.
-For each parameter of the rule of methodology; the end result is a 'Quality index wall' (IQM) for each of the three stress actions considered *(Borri, 2011).*

There are three possible categories:
Category A, which corresponds to the good quality and stability of the masonry.
Category B, which corresponds to the average quality of the masonry.
Category C, which corresponds to the insufficient quality of the masonry *(Borri, 2011).*

4.1.3. Method of scoring of the parameters

The primary evaluation of the parameters:

-For each type of action, if Q.R.E. is not respected then the masonry is for the category C.

-If the diatones are arranged on the longer side of the wall, then the wall is in category C *(Borri, 2011).*

In Table 4.1; type of the masonry walls and type of the plane actions with the coefficient of the parameters were seen.

Table 4.1. Type of action on a plane surface with the coefficient parameters *(Borri, 2011).*

	Vertical action			Out of plane action			In plane action		
	N R	P R	R	N R	P R	R	N R	P R	R
PD	0	1	1	0	1,5	3	0	1	2
QM	0	0,5	2	0	0,5	1	0	1	2
FRE	0	1,5	3	0	1	2	0	1	2
SVJ	0	0,5	1	0	0,5	1	0	1	2
QRE	0,3	0,7	1	0,5	0,7	1	0,3	0,7	1
PHR	0	1	2	0	1	2	0	0.5	1
SRE	0	0,5	1	0	0,5	1	0	0,5	1

In Table 4.2; type of actions and IQM ratios related to the category of the masonry are seen.

Table 4.2. Type of action on a plane surface and the IQM ratios related to the category of the masonry *(Borri, 2011).*

Type of Action	Category of the Masonry		
	C	B	A
Vertical Action	0≤IQ<2,5	2,5≤IQ<5	5≤IQ≤10
Out of plane action	0≤IQ≤4	4<IQ<7	7≤IQ≤10
In plane action	0≤IQ<3	3<IQ<5	5≤IQ≤10

Criterion used to differentiate the behavior of masonry against the three types of actions considered consists in attributing to the various parameters of the rule of methodology in different weights. Therefore, one aspect of the rule of the parameter can be more or less important depending on the type of stress considered *(Borri, 2011).*

As mentioned, the element to be analyzed is the single wall panel. For its quality; wall is evaluated for each of the three possible different types of actions: vertical loads, horizontal actions that engage the wall panel in his mid-plane (such as, for example, seismic actions on the walls of buildings in box-like behavior and hard floor), actions that engage the wall panel at right angles to its plane medium (for example, states that stress due to eccentric loads or forces of vaults and arches, seismic actions on buildings). The parameters of the rule of the methodology in a different way affect the response of the wall depending on the type of action *(Borri, 2011).*

4.1.4. Loads that affect the masonry wall structure

The loads which applied to the stone masonry wall are clarified on the following steps.

- Vertical Loads

A wall submitted to a vertical load could have break up for two reasons: instability or breakup by compression. Breakup happens by compression, if the resistant element is weak, at least for the ordinary loads of the traditional buildings, or the masonry is strongly degraded for instance because masonry subjected to weather or to moisture. If one of them verified of these two conditions, then the parameter Q.R.E. equals to not respected. It comes directly to a category C without performing further evaluations *(Borri, 2011).*

Otherwise, it is excluded the possibility of breakage by compression and analyzes the possibility of a break for instability. The instability is facilitated by the presence of strong vertical tensions within the masonry wall *(Borri, 2011).*

The schematic description of this action is shown in (Fig 4.1 and 4.2).

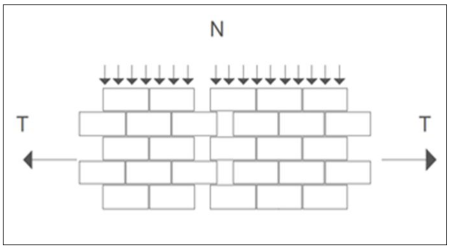


Fig 4.1: Vertical action *(Borri, 2011).*

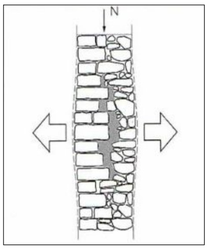


Fig 4.2: Vertical action on section of the masonry wall *(Borri, 2011).*

The parameters more than others prevent the circulation of incorrect data's in the presence of solid walls are square blocks (F.R.E.), the horizontality of the rows (P.H.R.) and the mortar of good quality (Q.M.).

Therefore, in principle, it can be said that for vertical actions:

- A masonry category A, hardly suffers injury or bulging and can be considered of good quality.

- A masonry category B, has low probability of collapse due to instability but it can get damaged or at least swell therefore it is an average quality.

-A masonry category C, has a high probability of buckling and bulging suffer, especially if thickness of the wall is very limited and if placed under the loaded condition, it also almost, particularly at compliance of concentrated loads. In extreme conditions, it is possible to collapse. This category of masonry should be considered of poor quality *(Borri, 2011).*

- Horizontal out of plane actions

A wall subjected to horizontal actions that tend to deform out of its plane has the limited portions of the masonry that are subject to strong compressive stresses. For example, consider the case of a wall which reverses and the tensions that tend to crush the stones positioned close to the horizontal hinge. For this reason, we come immediately to a category C if the wall has degraded resistant elements or weakly resistant to compression *(Borri, 2011).*

Otherwise, the aspect considered essential for the response of the walls to plan out actions, namely their monolithic due to the presence of diatones (P.D.). In this parameter has the greatest weight in this type of actions *(Borri, 2011).*

Other parameters which have been assigned a higher weight are: the presence of horizontal rows (P.H.R.), which promote the oscillation of the wall around a horizontal hinges and shape of resistant elements (F.R.E.). The schematic description of this action is shown in (Fig 4.3) *(Borri, 2011).*

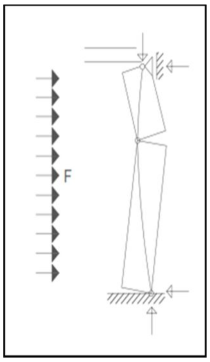


Fig 4.3: Out of plane action *(Borri, 2011).*

Therefore, in principle, it can be said that for horizontal actions out of plane:

- A masonry category A; is able to maintain a monolithic behavior. It has a very low probability of collapse or get damaged from out of plane actions if the walls are well connected to each other and well connected to the floors, the walls of category A is considered to be of good quality *(Borri, 2011).*

- A masonry of category B; is not able to maintain a monolithic behavior but even breaks down when subjected to horizontal plane actions. For this category of masonry, it is likely to have damages or bulging behavior in the event of an earthquake, but it is unlikely that they will collapse if they are well connected to the walls and horizontal elements, and the walls of category B is considered to be average quality *(Borri, 2011).*

- A masonry of category C; disintegrates in case of an earthquake, for it is very likely to collapse, even in the presence of effective connections. The walls of category C is considered to be poor quality *(Borri, 2011).*

- o Horizontal plane actions

Even in the case of shares stressing horizontal plane actions to the wall which is non-resistant to compression, or highly degraded, leading directly to category C. If the resistant elements of the masonry are adequate, and if it is not included in the case of masonry of only composed by diatones leading category C. The schematic description of this action is shown in (Fig 4.4) *(Borri, 2011).*

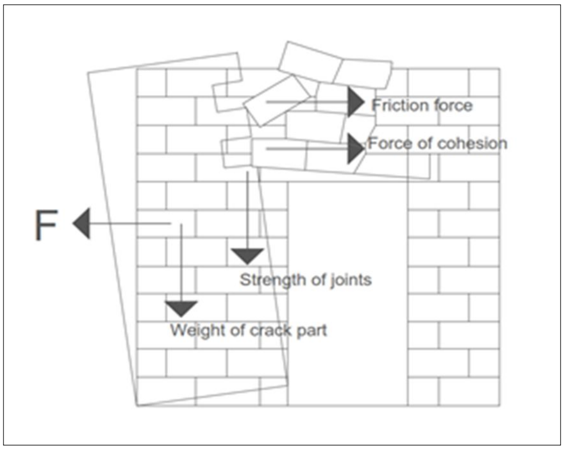


Fig 4.4: In plane action *(Borri, 2011).*

The resistance of a wall in horizontal plane actions is due to:
-Cohesion, appearance to the wall by a mortar of good quality (Q.M.) *(Borri, 2011).*

-Friction, it is carried on horizontal surfaces (due to the verticality of the load) of resistant elements in contact with each other, hence the importance of the parameter (F.R.E.). But not enough: it is also necessary that the vertical joints are staggered so that the friction between them cannot occur, so for this reason it gives importance to the parameter (S.V.J.) *(Borri, 2011).*

-Meshing and interlocking the blocks, and this aspect can even define the slope of the lesion that will form in case of an earthquake. The joint between the blocks is essential for this aspect if square blocks are present (F.R.E.) and vertical joints staggered (S.V.J.) *(Borri, 2011).*

Three parameters of the methodology considered essential to prevent the wall a good resistance actions without square blocks or staggered vertical joints and the quality of the mortar (F.R.E., S.V.J, and Q.M.) *(Borri, 2011).*

It has been given increased weight to the presence of diatones (P.D.), which are important because the wall present reaction to horizontal plane effect of the entire thickness of the wall *(Borri, 2011).*

Therefore, in principle, it can be said that for horizontal plane actions:

- A masonry category A; has low chances of getting damaged, it can be defined as a masonry of good quality.

- A masonry category B; in case of earthquake, it is likely to get damaged, especially if the walls are thin or if they are small relative to the area covered by the building. However those damages will be relatively minor, this category defines the walls average quality.

- A masonry category C; is most likely to get damaged in the horizontal plane actions. Therefore this type of poor quality walls fall into the category C *(Borri, 2011).*

4.1.5. Scores and calculations

The scores obtained from Table 1 are inserted in a formula. The overall score of IQM is obtained for each type of action that the masonry walls are subjected *(Borri, 2011).*

IQM = Q.R.E. x (P.H.R. + P.D. + F.R.E. + S.V.J. + S.R.E. + Q.M.). The results of the observations made are summarized in a form of immediate use which provides the numerical value of IQM. These parameters are examined according to the type of walls and the direction of the stresses *(Borri, 2011).*

The applied loads indications are important for these parameters for a good response of the wall against the type of stress that is considered.

There is a correlation between the quality index and mechanical parameters of the walls. By using the Quality Index (I.Q.M.) is possible to obtain an estimate of the mechanical parameters of masonry needed to carry out the verification of safety. Using the index IQM, an estimation of the numerical values of the following parameters could be found:

- Correlation of IQM vertical with fm (compressive strength of masonry);

- Correlation of IQM in the plan with To (shear strength of the masonry);

- IQM vertical correlation with E (value of the modulus of elasticity of the masonry) *(Borri, 2011).*

Each correlation is represented on a graph with IQM, and their minimum, maximum and average mechanical parameters of (fm, To or E). In this diagram, for each of the 36 virtual walls is given a point, that point has the coordinates identified IQM of the masonry and the virtual value (minimum, medium or maximum) of the mechanical parameters of the same masonry *(Borri, 2011).*

In addition, the diagram represents the correlation which presented by the exponential curve of these virtual walls. The equation of the curve is below the diagram, along with some parameters of statistical. Besides that, correlation curves (minimum and maximum) identify a zone that represents the range of possible variation of the mechanical parameters consideration for each value of IQM *(Borri, 2011).*

On the tables below, the IQM and the mechanical parameter graphs were shown.

Table 4.3: Curve of Correlation between fm (min, max values) and vertical IQM *(Borri, 2011).*

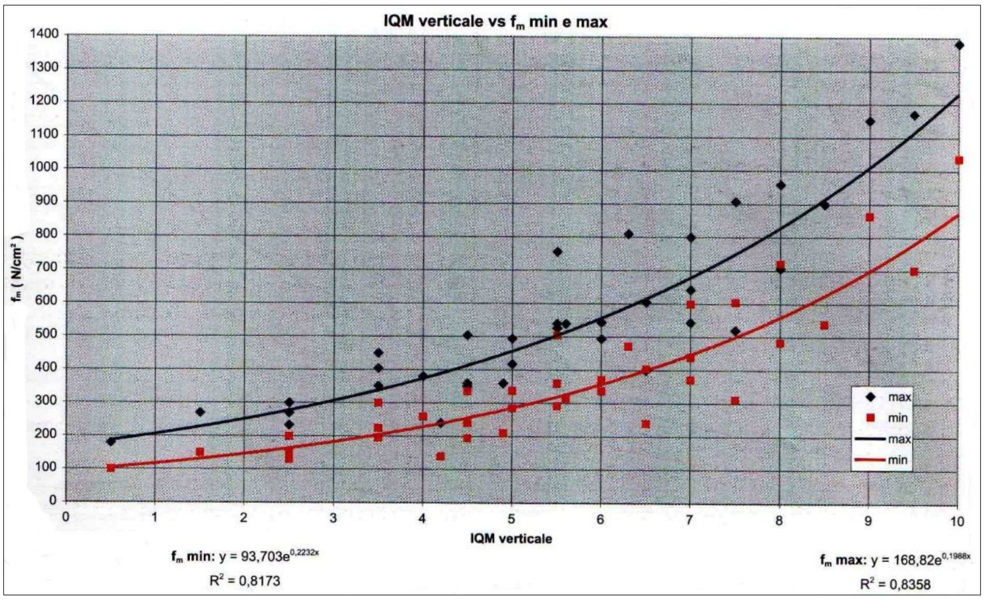


Table 4.4: Curve of Correlation between fm (average value) and vertical IQM *(Borri, 2011).*

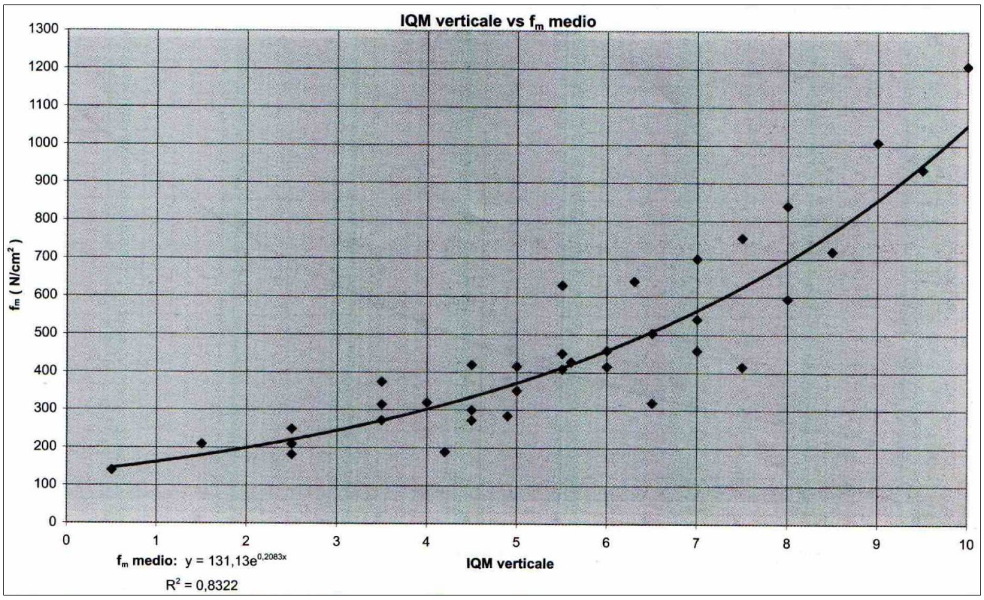


Table 4.5: Curve of Correlation between To (min and max value) and vertical IQM *(Borri, 2011).*

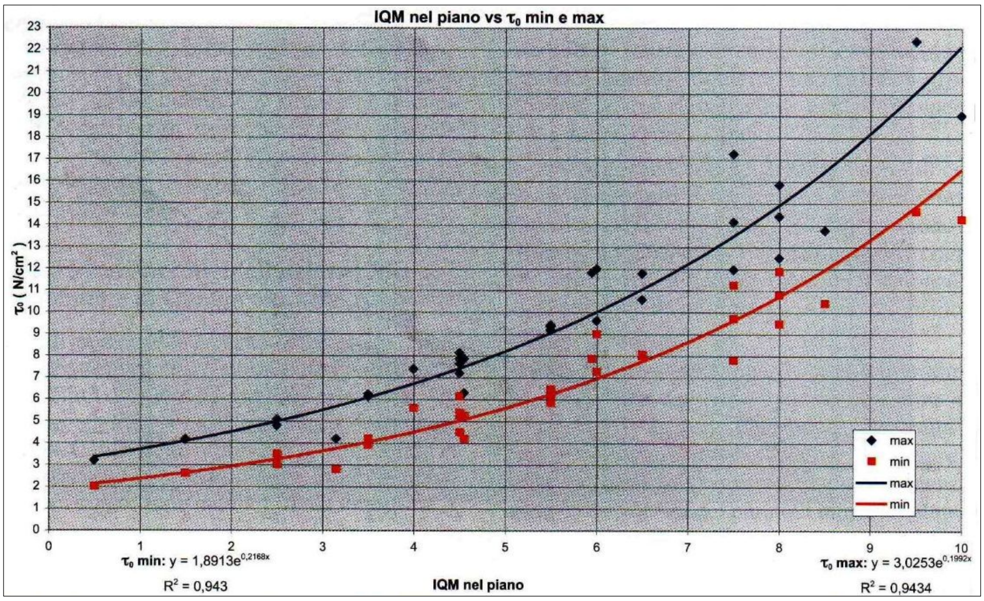


Table 4.6: Curve of Correlation between To (average value) and vertical IQM *(Borri, 2011).*

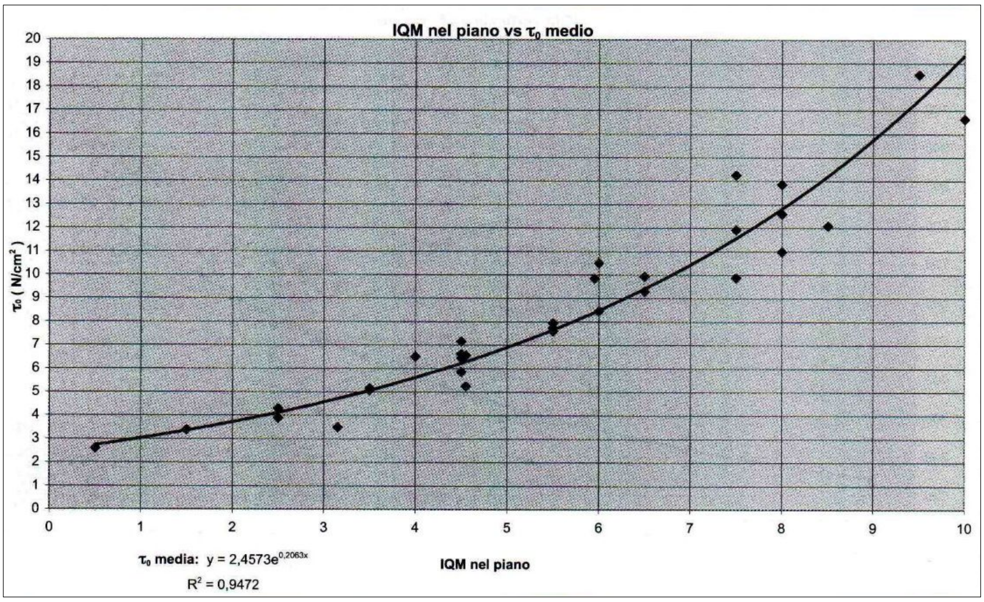


Table 4.7: Curve of Correlation between E (min and max value) and vertical IQM *(Borri, 2011).*

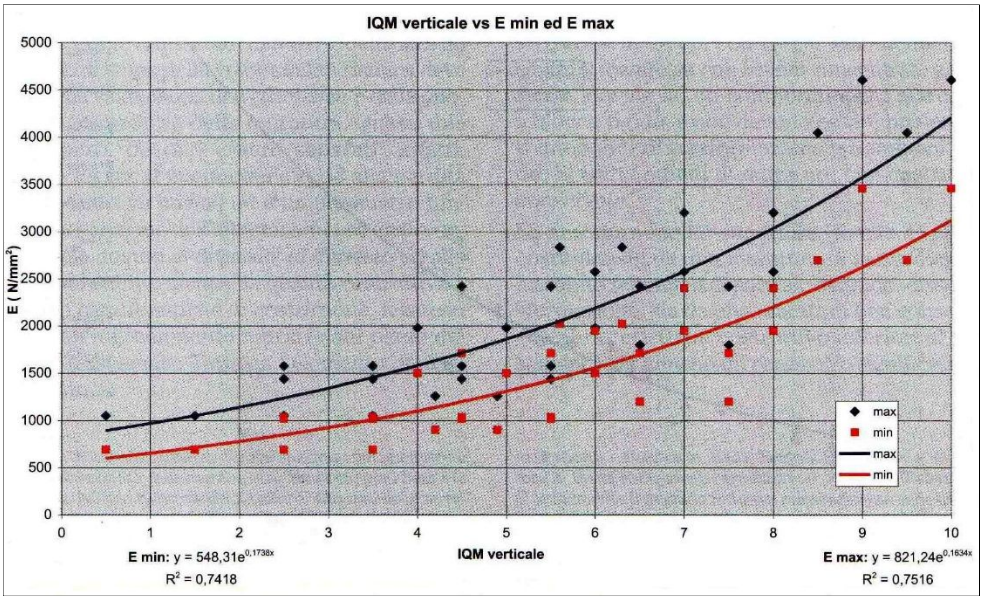
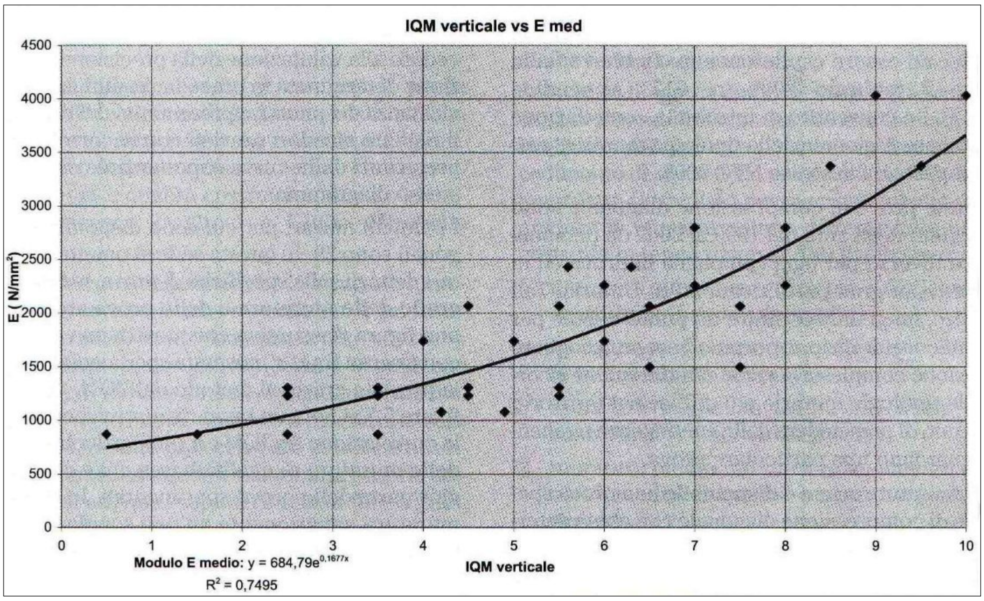


Table 4.8: Curve of Correlation between E (average value) and vertical IQM *(Borri, 2011).*



The methodology here in proposed to estimate quality index and mechanical parameters of the masonry is based, essentially, on the correlation that was observed between the quality index and the values of the IQM *(Borri, 2011).*

According to the book 'Manuale Delle Murature Storiche, Analisi E Valutazione Del Comportamento Strutturale, Volume 1', limited types of masonry were given to analyze. However the methodology allows change some features of the masonry and to derive other possible methodology types.

4.2. Definition of damage and collapse analysis method (Methodological application B)

Damage analysis and collapse mechanism (analysis) of the case study baths in İznik, Bilecik and Edirne is a wide research subject. Therefore description of the methodology is crucial for understanding following steps.

Some ideas that are supported the methodological approach of this study. Therefore qualitative methodology is the main method that is used to research to this subject. According to Gustavo Giovannoni who was an engineer and affectionate of restoration also he consider the calculations of science construction: Theories of resistance are in fact for buildings which were constructed for the last century. However these calculations were not account for the poor constructions or disintegration of the structures like historical existing buildings. There were huge margin between loads of safety and breaking loads of the new and existing historical buildings. Historical buildings are on the line of margin in safety loads. Therefore for the historical and old buildings are mainly in the respect of static empirical methods, they were stick to qualitative assessments rather than conventional tests *(Borri, 2011).*

The uncertainties about the strength of the structure are affected by the resistance values of its materials. The mathematical model of the structure may be close to the reality. However it is never in the reality. Uncertainties arise from this fact that the model provides the response to the actions of stresses. To take into account all possible uncertainties are affecting the modelling of structures, materials and possible used actions and stresses. The characteristic values of the actions and response values of the materials under the stress have to be defined *(Borri, 2011).*

Several problems are arisen in the field of existing buildings. Especially if they are masonry structure and located in the seismic zones. The obvious difficulties are arisen from the test values of the characteristic of resistance of the masonry. It is not always possible to do tests because of the building’s historic and artistic interests. It is not uncommon experience that the type of walls changes from one point to another building. Thus specifications are limiting the values that found from the tests on the parts of the buildings *(Borri, 2011).*

Nevertheless there is another problem that has to take into consideration even more important than the data’s of the masonry that were not similar to each other. The characteristic resistance of the masonry is differentiated to some of the parts. The tension of one part of the masonry could prevent collapse. Under the crisis in some cases high strength parts of the masonry buildings can take place not only for overcoming the resistance to compression or shear force but also they behave a triggering mechanism of kinematic chain of collapse *(Borri, 2011).*

In any existing masonry buildings, a security check based on stress on the structures and it could not put away from other destructive failure modes. These failure modes are illustrated in the text depended in part by the minimum resistance of the masonry. Most of the other parts of the masonry are affected by the other factors such as the texture of the masonry and the presence of effective connections between the walls and floors or between the orthogonal walls *(Borri, 2011).*

Construction should ensure certain performance against certain action that occurs the cause of the earthquake. If the structure could not ensure that performance, the structure could be collapsed *(Borri, 2011).*

Safety factor in construction field is the measure for safety. The ability of resistance is expressed as the value of action that causes the “crisis” of the structure. The term “crisis” refers to events which would affect public safety which refers to the collapse of the building. However “crisis” also be defined by events that do not result in the collapse of the work. For instance the simple cracks or damages are the formation of “crisis” *(Borri, 2011).*

The “structural problems” of the masonry are part of a methodological approach for the analysis and design of interventions. Illustration this route is parallel in the field of medical science, “pathology” of a building namely a state of suffering or instability of the masonry structure. It is necessary to proceed to its analysis using the “diagnostic process”, which is a collection of information through examination the building with survey, investigations and the analysis of the cracks. In “diagnostic process” or formulation of the hypothesis about the causes of the instability of the building, this hypothesis directly related to the information gathered during the diagnosis process. Second step is to implement a “therapy” a series of measures aimed at eliminating the disease, both in its “symptoms” and in the cause’s vulnerable elements *(Borri, 2011).*

Examination of the structure is similar to the typical operations of the physical examination of the patient. Detection of walls and assess the actual texture of a lesion. This operation is done percussion to the leaves of the masonry. Especially this examination is done to the neighborhood of cracks in search of areas of stress concentration. Visual examination by types of cracking is also essential for examining the neighborhood cracks *(Borri, 2011).*

Particular importance is given by the observation of the damages that are in the form of cracks. In both formation; damages or cracks, they represent the physical traces of the mechanisms of instability of structure. The relief of the cracks and their organic and systematic way of evaluation provided an important contribution to the identification of the failure mechanisms which must be carried out in the process of diagnosis *(Borri, 2011).*

In the evaluation of structural situations is to be considered inherently weak or structural conditions is clearly outside the norm of construction. Walls constructed with small stones and poorly connected or double hanging leaves without connecting elements. Roof struts or domes push the piers for the failure of the ridge. These are the first measures that have to be taken first *(Borri, 2011).*

It is possible to examine the failure mechanisms which have been or may be triggered by earthquake. Outer leafs of the masonry wall structures which are started to tipping, have to take into account for uncertainty introduced by tampering. In these situations separations are possible on leafs of the masonry wall structure. The presence of resistance elements are needed for this kind of seismic activity *(Borri, 2011).*

The instrumental investigations are not only qualitative but also quantitative. They could obtainable from the analysis of the resistant mechanism from observed in diagnostic phase. These assessments are much closer to reality than any physical well-colored output of programs. They are very sophisticated but inadequate to deal with the behavior of historic masonry conservation *(Borri, 2011).*

Structural deficiencies in the quality walls, the investigation methodology is strictly necessary for reconstitution for the resistant mechanisms if they are impaired *(Borri, 2011).*

The design of structural detailing is directly from the analysis of the mechanisms of detachment. The detachments could be accrued by the earthquake activity. In masonry construction due to the earthquake, in addition to the vertical loads, horizontal loads are caused most common failure modes according to following steps *(Borri, 2011).*

-Solid wall is dividing into portions which were considered in itself rigid behavior monolithic element.

-The formation of one or more kinematic motion in which the various portions of walls move reciprocally.

4.2.1. Analysis of the Quality of Walls

Most important results of the diagnostic process are understanding and classification of the quality of the building walls. The quality of the masonry depends on the possibility of a mechanical behavior of appropriate planed actions *(Borri, 2011).*

Moreover to predict the mechanical behavior of construction of the masonry building, the information that was gain in diagnostic process was provides little ideas about this structure.

In fact differently from the types of structural materials, the wall structures changes to a wide spectrum of possibilities. It is not possible to condense into a single assessment of "quality wall" like all the characteristics that influence the mechanical response. However, it is possible to consider this brief characterization of the masonry in three different areas depending on the action concerned *(Borri, 2011).*

a) Vertical loads

b) Horizontal loads in plane action

c) Horizontal loads out of plane action

To examine the quality of a stone or brick, it can be referenced to some of the elements that constitute the effect of the mechanical behavior. They can be summarized schematically by the following points.

-Size and shape of resistant elements.

-Type of binder.

-Presence or absence of diatones.

-Type and textual characteristics.

One of the most important qualities for masonry is to respond to the actions in a monolithic behavior. In principle this can be distinguished in two different patting on the masonry wall structure.

a) The meshing of the blocks. It is based on arranging of the stones or bricks. Mortar has a sole purpose of creating regular contact between them. The optimal situation of masonry is square blocks and using diatones *(Borri, 2011).*

b) The strength of the mortar. If the mortar with high mechanical characteristics even with small stone walls and improper installation could be behave like monolithic. Masonry walls constructed as opus and constructed with small aggregates and strong mortar happened in extreme cases *(Borri, 2011).*

4.2.2. Introductory points for "the rule of art"

The satisfactory seismic response of the masonry structures is; tied the blocks to each other and exchanged the stresses.

Rule of art, means "art of building" which contains and brings together all the experiences that characterize the history of the building masonry wall. The idea of this is; ensuring the building appears at the same time robust and secures the structure *(Borri, 2011).*

As already mentioned there are problems of recognition of the mechanical qualities of the old walls which forms the rule of art and it includes:

- The comparison and organization of the wall structure with presence or absence of elements such as cross connections of diatones, geometry, shape, type and size of the elements, horizontality of joints and offset of joints, the quality and consistency of the mortar, the presence of wedges and chips, the characteristics of possible inner core and the homogeneity of materials *(Borri, 2011).*

- The concept of slenderness of the building elements is considered proportional relationship of the building structures *(Borri, 2011).*

- The rule of art is given with the structural geometric dimensioning compliance and the technical nature of the constructive elements. The parameters are defining the quality *(Borri, 2011).*

Studying with masonry stones are difficult than studying with bricks. In fact the technical quality of the masonry has been primarily affected the nature of the base material that available locally. This situation determines also profound differences in the mechanical properties. “The rule of art” differs from types of stones depending on square blocks of hewn stones in masonry walls *(Borri, 2011).*

In important buildings, the masonry walls are made up of perfectly squared stones which are very close to the ideal of the perfectness. Mortar only performs to function for regularizing contacts between the stones. When the mortar becomes powdery, it is not the fundamental behavior of the masonry *(Borri, 2011).*

The rule of art in stone masonry is lasted until the beginning of this century. According to this art between the stones, rows must be horizontal. The top and the bottom of the walls must be sufficiently flat. In the joints of the stones they use lime mortar, in larger cavities they use chips of stone or brick. Particularly decisive for the resistance to outside plane action is the presence of diatones which is connected two curtain walls of the masonry. The vertical joints are staggered appropriately *(Borri, 2011).*

The effectiveness of the actions in stone masonry structures reflected both in static and dynamic conditions. In the first case masonry wall is stabilizing the effect of the applied loads, and in the second case masonry wall rotated according to the horizontal axes of the applied loads. The intensity of the seismic activity and constrains of the structure, prevent tipping of the masonry walls and returning the initial conditions of the structure. In absence of horizontal layers, it is impossible to format the axes of rotation, recurrence of the oscillations and disintegrate the masonry wall in chaotic manner *(Borri, 2011).*

Masonry stone walls constructed with small elements have got excellent mechanical characteristics. The tensile strength of the mortar allows certain limits. The mortar is good for distributing the loads in a continuous elastic form *(Borri, 2011).*

If the masonry wall construction is mostly standing with the support of physical, chemical and mechanical properties of the mortar, the masonry wall construction cannot attributed to the reliability behavior of the masonry wall structure. In this type of masonry structure, inside of the masonry wall filled with disorderly pebbles without following the rules of masonry wall construction. If the mortar is not effective this types of masonry structure will be collapsed under the seismic activity *(Borri, 2011).*

- Interpretation of quality through the cracks of the walls

The pictures of the damages are highly indicative for the quality of the walls. A wall which has irregular fractures that were spread everywhere is an indication that a wall is not connected. Small stones arranged in a chaotic manner without keeping the horizontality of the rows. The isolated damages occurred because of the wall of the masonry is divided into parts and it is related to monolithic behavior of the wall. The disruption of the wall that produced damages and these damages must be sought overall functioning and assemblies and connections *(Borri, 2011).*

The crack on the plasters provides valuable insights into the causes of the collapse of the structure. They must be taken into care that the interpreting of their damage based solely related to the structure. The cracks on the plastered walls must take into account and the judgment on the crack and the masonry walls have to be done in two different way. Behavior of the masonry and the behavior of the cracks were particularly differentiated according to the thickness of the cement plasters *(Borri, 2011).*

Damage of the plasters occurred in stone masonry walls because of their considerable thickness. The hanging cement has got a great rigidity in the plane and it absorbing much of the initial stress. The mutual movement between the walls is a phenomenon that is observed frequently during the earthquake. And in many cases displacement between the joints of the masonry wall causes the breakage of the thin plate of the plaster *(Borri, 2011).*

The buckling on the face of the stone masonry is a sign of separation between core and two outer leafs of the masonry. If there is not any buckling on leafs of the masonry it is indicating a good quality of masonry wall *(Borri, 2011).*

- Peculiarities of the masonry walls

The evaluation of the structural efficiency of masonry cannot be only on the values of mechanical strength. The purpose is to be a reference for behavior of structural models. This assessment must instead go through the examination the state of the mortars and the quality of the resistant elements. Therefore a comparison made with reference to different masonry types and their structural characteristics *(Borri, 2011).*

- Construction and Structure

Behavior of stress and strain within the walls deserves a special study. It is a function not only of the loads but also engagement and the size of the segments *(Borri, 2011).*

The loads are diffused inside of the masonry and they were affecting well defined areas. The load applied to masonry leads to a separation within the elements of walls between leafs. For keeping the structure for distinction of its parts, there is a purpose for analysis and understanding of cracking phenomena *(Borri, 2011).*

- Previous data synthesis for masonry wall structures material qualitative synthesis and “rule of art”

Various masonry types are detected in Marmara region and their quality analysis is done in other chapter. The masonry types and their objective parameters are the part of the “rule of art” which is determined the quality of the walls and their response that can be expected from masonry wall for different types of actions. These actions are summarized as in plane, out of plane and vertical actions of the masonry wall.

4.2.3. Steps that have to considered for the “the rule of art”

1-Resistance of the masonry elements; the data’s are received from qualitative analysis of the masonry wall in previous chapters.

The intrinsic resistance of the elements forming the wall is a fundamental parameter, even if it is not part of the "rule of the art" in the traditional sense.

2-Behaviour of the masonry wall according to the actions

The behavior of the masonry wall structures are divided into three actions

a- Vertical loads
b- Horizontal loads out of plane action
c- Horizontal loads in plane action

o Vertical loads

Behavior of masonry wall to vertical actions is subjected to, the state of compression, and the wall determines different situations depending on the stress. For aesthetical reasons or purely economic reasons, most of the walls present non-uniform sections, characterized by leaves of the masonry that differ both for the quality both for the type of material (Fig 4.5, 4.6, 4.7). *(Borri, 2011).*

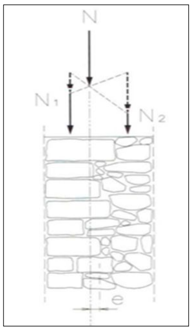


Fig 4.5: Section of wall hangings of stones with uneven dimentions *(Borri, 2011).*

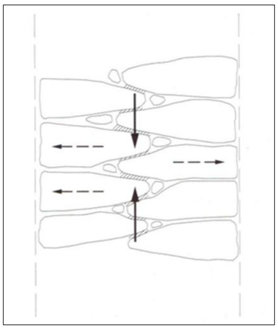


Fig 4.6: Detail of the meshing of the stones and the effect of removal crushing *(Borri, 2011).*

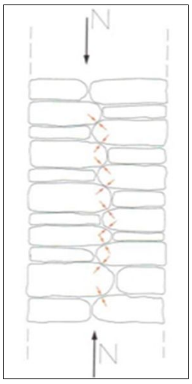


Fig 4.7: Effect pushing the spread between the compressive stresses on inclined surfaces *(Borri, 2011).*

The buildings themselves are in valuable to the risk because of the poor quality of the internal filling material. This made the differences in performance and appearance of the masonry structure. This is going to be a problem for asymmetric distribution of weight transferred from the horizontal elements. Any load acting on the axis of geometric masonry determines an eccentric load affection which intended to generate a buckling very dangerous for the stability of the wall, due to the different distribution of the forces within the wall. In fact the distribution of compressive stresses between the two leaves of the masonry occurs a specific stiffness *(Borri, 2011).*

Irregularity of the stones used for masonry introduces another important aspect, that connected meshing leafs of the masonry that were subjected to a peak load and they were tend to divide the effect of a traction. There is a direct relationship between wall thickness and quality of the masonry *(Borri, 2011).*

There is a possibility of a detachment of leafs of the masonry along mid-plane and the triggering mechanism of swelling to instability of the walls separated.

- Phenomena of swelling to instability of the leaves of the masonry

This aspect requires some in-depth analysis; in particular, attention should assume that the contacts between the stones. The masonry stone walls build up on fine meshed stones that are tend to overlap with laying plans in horizontal (Fig 4.8). However if the stones are touched on their corners, it is generated a pushing effect that is realized by the drawings of the construction and the static scheme that drift represented in (Fig 4.9). In this case the stones are pushed each other and they are tend to expel from the structure of masonry wall. However friction forces with the contribution of binders are contrast of this subtraction *(Borri, 2011).*

This effect could be the triggering effect of serious damage mechanisms. On the following; a useful schematization of the masonry wall and its mechanism of instability are represented.

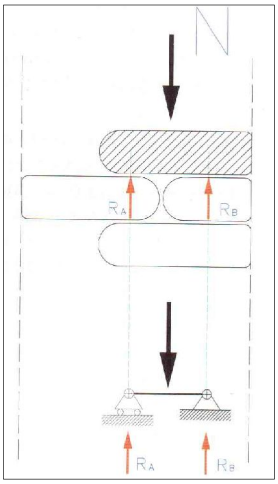


Fig 4.8: Equilibrating forces in the wall hangings with meshed *(Borri, 2011).*

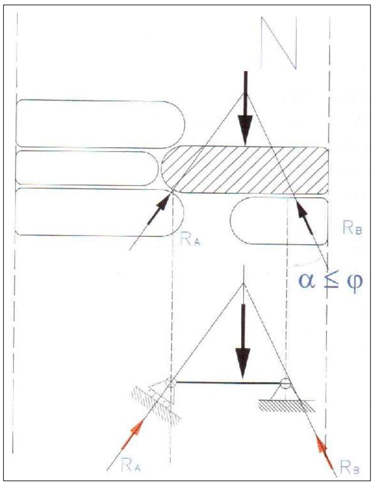


Fig 4.9: Forces balancing in the presence of non-meshed leafs of the masonry: masonry internally pushing *(Borri, 2011).*

In fig 4.10 and fig 4.11 the compressive force is pushed away two masonry leafs from each other. The masonry wall gets into the formation of symmetric bulging.

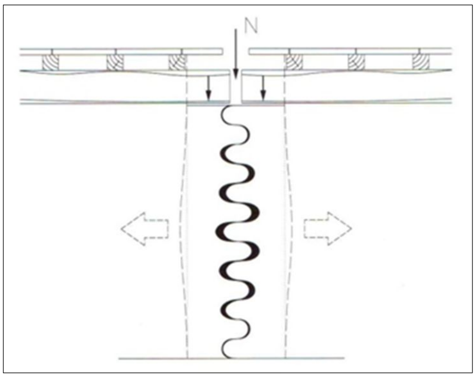


Fig 4.10: Expulsion leafs of walls *(Borri, 2011).*

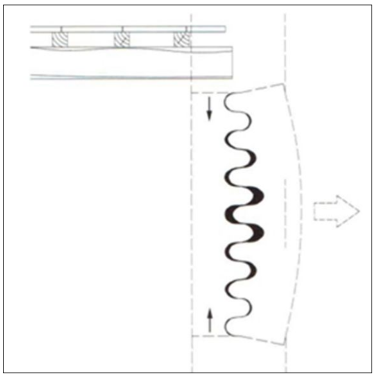


Fig 4.11: Phenomenon expulsion of the external *(Borri, 2011).*

Eccentric loads as they are occurred in the perimeter walls are located on the sides of the masonry. The disruption can produce the expulsion of the leaves of the masonry walls which moreover cannot oppose with an adequate frictional resistance. The rounded shape of the stones and low level of connection along the midplane of the masonry wall construction enable the removal of leafs with the application of critical load on the masonry until it will reach to the configuration of collapse *(Borri, 2011).*

The similar mechanism that makes the masonry pushing internally, therefore the direction for the seismic stress is important.

The meshing between the stones triggers an effective action of friction that prevents cracking in the middle plane, thus guarantees a monolithic behavior of the wall (Fig 4.12, 4.13) *(Borri, 2011).*

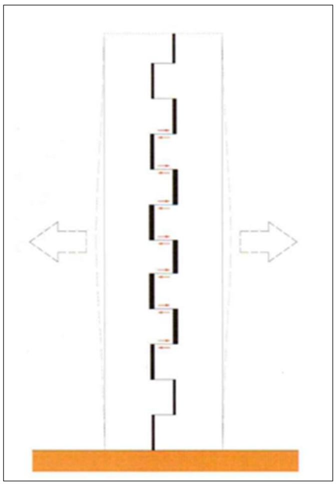


Fig 4.12: Mesh of the leafs masonry and their behavior under the applied forces *(Borri, 2011).*

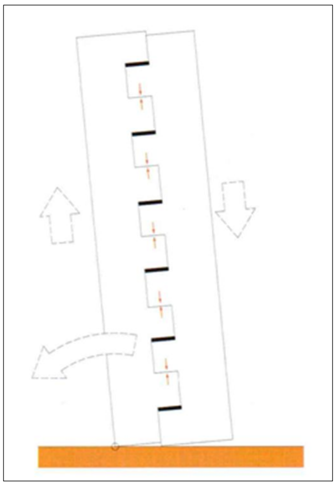


Fig 4.13: Mesh of the leafs masonry and their behavior under the applied forces *(Borri, 2011).*

The bad behavior of the masonry derives essentially from the poor quality of the mortar or aggregates, while in reality the correct placement of the stones make the difference of the strength of the masonry *(Borri, 2011).*

The influence of the mortars for the masonry wall structure is crucial especially for the masonry which is constructed with incoherent little type of stones. In regular stone constructed wall masonry structures the binders are less important even negligible for large blocks *(Borri, 2011).*

The mortar is connected between the stones and it is transmit and distribute the stresses. And also it is contributes to the monolithic body wall *(Borri, 2011).*

Another important aspect that affects the quality wall is represented by the horizontal lines of the rows. The horizontality of the masonry structure is prepared to withstand the vertical loads to carry. The static function is regularizing constraint support *(Borri, 2011).*

Staggering vertical joints; this condition, together with the square shape of the stones, allows "the effect chain" that provides a certain tensile strength to the masonry (Fig 4.14). The staggered joints regularly mobilize another great resource of resistant masonry: the overlap between the resistant elements, sometimes called "joint effect" *(Borri, 2011).*

In the following example, magnitude of the compressive stresses in the wall panel is shown. The separation of the vertical loads has different effect widths of area according to the type of walls. The differences of the spreading of the vertical loads according to the different size texture of the blocks shown on the below (Fig 4.15) *(Borri, 2011).*

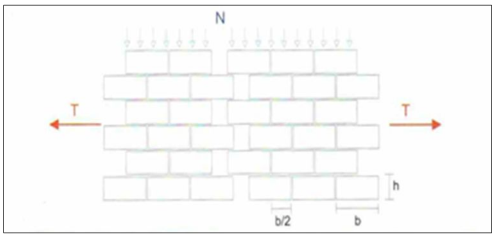


Fig 4.14: Staggering vertical joints *(Borri, 2011).*

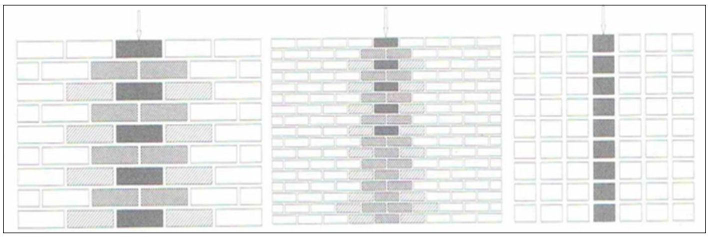


Fig 4.15: The differences of the spreading of the vertical loads according to the different size texture of the blocks *(Borri, 2011).*

According to the (Fig 4.15)

a. Masonry wall, its elements are big sized dimensioned according to the other examples and they are correctly placed.
b. Masonry wall, its elements are small sized dimensioned according to the other examples and they are correctly placed.
c. Masonry wall, its elements are small sized dimensioned according to the other examples and they are incorrect ensambled.

A typical mode of failure for masonry types C, and due to the applied forces which are triggers the thickness of the masonry and plaster relation with seismic orthogonal action. Thinner bricks have got lower diffusion therefore there is higher stress, and also cracks could be on this area (Fig 4.16) *(Borri, 2011).*

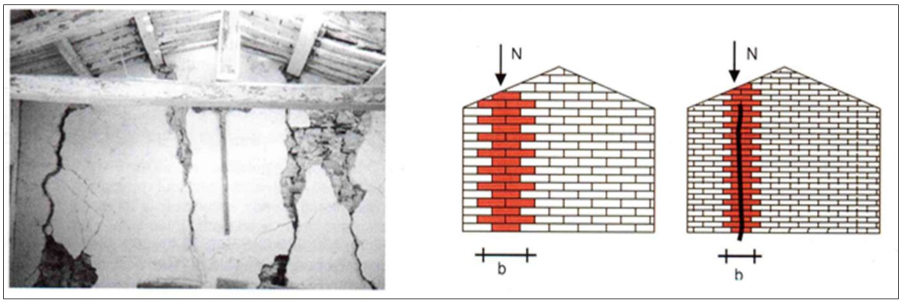
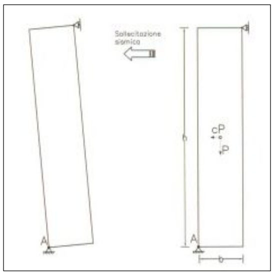


Fig 4.16: A typical mode of failure for masonry types C *(Borri, 2011).*

- Horizontal loads out of plane action

The masonry wall structure behaviors for the out of plane actions are perpendicular to it. The respect of the horizontal loads which were seismic or wind loads are crucial for the for the wall structure. Presence of diatones which connecting two leafs of the masonry wall is important for the behavior of the horizontal loads *(Borri, 2011).*

The behaviors of the stone masonry wall structure against horizontal forces are seen on the following figures. One of the cases the diatones stones connection elements combine two leafs together and the structure works monolithically. However on the other example the lacking of the diatones stones made the structure work as two different leafs and not linked. Therefore mechanism collapses are very different for each of the wall structure (Fig 4.17, 4.18) *(Borri, 2011).*



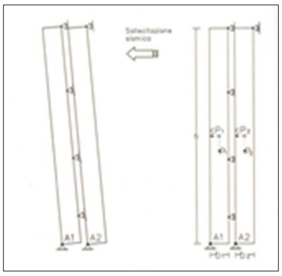


Fig 4.17: Scheme for overturning a monolithic wall *(Borri, 2011).*

Fig 4.18: Scheme for overturning a monolithic wall with two leaves *(Borri, 2011).*

Presences of diatones in masonry wall are essential for out of plane actions that are shown in (Fig 4.19).

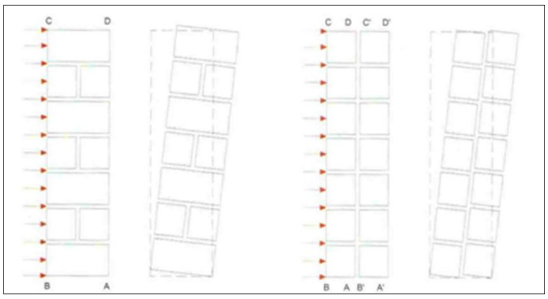


Fig 4.19: Presence and not presence of diatones in two different example of masonry wall *(Borri, 2011).*

The diatones are stones passing through the entire thickness of the wall. They prevent the breakdown of the wall hangings more simply placed against each other. The presence of diatones makes sure that a possible mechanism of tipping involving the entire wall in the rotation, around the edge of the base. Moreover, the diatones allow the distribution of the vertical load on the whole thickness of the wall even in those cases where there is a load on the edge of the wall (Fig 4.19) *(Borri, 2011).*

The types of stone materials used in construction in masonry wall are differentiated the behavior of structure under the out of plane actions. Behavior of masonry wall for out of plane action according to the classification of masonry types are shown in (Fig 4.20) *(Borri, 2011).*

Masonry Category A: the wall maintains a monolithic behavior if subjected to orthogonal actions.

Masonry Category B: the wall tends to separate into two facings each of which is equipped with a good level of monolithic.

Masonry Category C: it is not monolithic. The walls are subject disintegrates, chaotically and not possible to define any macro element.

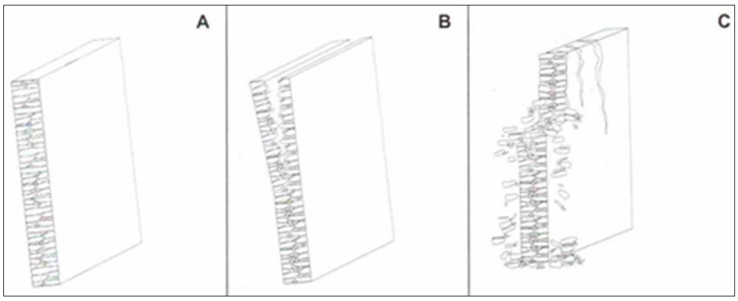


Fig 4.20: Masonry wall category according to the materials *(Borri, 2011).*

Combined compressive and bending stress applied to the masonry wall structure. Masonry walls with category A (Fig 4.21) and category B (Fig 4.22) *(Borri, 2011).*

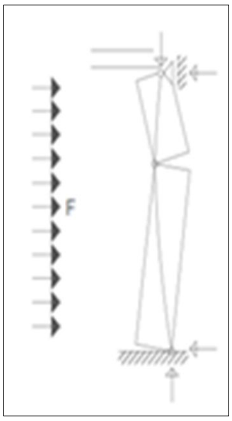


Fig 4.21: Compressive and bending stresses that are applied to masonry wall (Masonry walls with category A) *(Borri, 2011).*

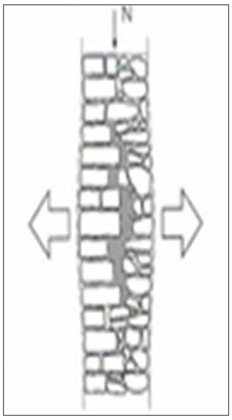


Fig 4.22: Compressive and bending stresses that are applied to masonry wall (Masonry walls with category B) *(Borri, 2011).*

Masonry bag is an extreme case of the absence of "the rule of art". The lacks of diatones are occurred inconsistency of the filling inside the masonry (Fig 4.23).

Fig 4.23: Lack of diatones inside of the masonry *(Borri, 2011).*

Figure, Coefficient "C" is overturning collapse of a wall. It is depending on the thickness of the filling.

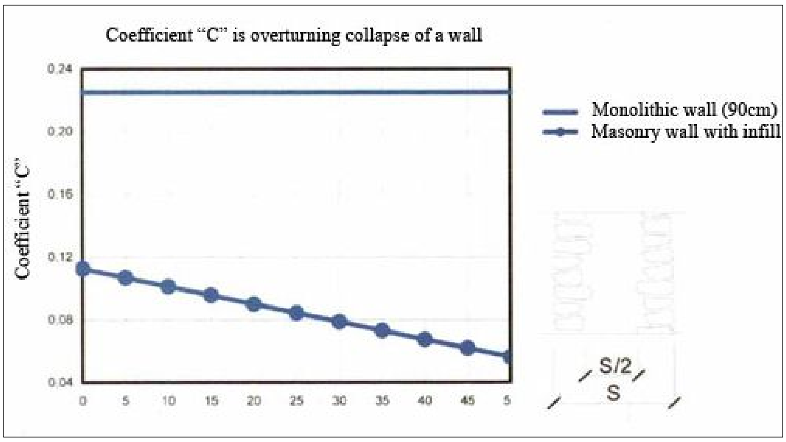


Fig 4.24: "C" coefficient for masonry walls and monolithic walls *(Borri, 2011).*

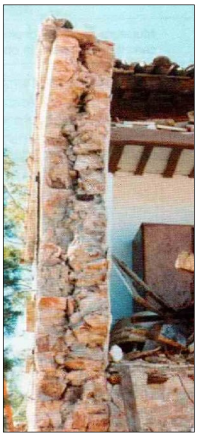


Fig 4.25: Example of overturning double leaf walls *(Borri, 2011).*

The graph shows the value of the coefficient of collapse "C" for tilting mechanisms out of plane action of a wall isolated in function of their percentage of filling. The horizontal line represents the value of "C" assuming that the wall is monolithic. The underlying sloping line represents the value of "C" in the event that there are two distinct and disconnected leafs; it is seen that "C" decreases markedly with the increase in the percentage of fill *(Borri, 2011).*

Overturning of a wall with the percentage of loose fill is shown in (Fig 4.24). In stone masonry structure, damages are arised from poor quality of the masonry (Fig 4.25). Seismic action perpendicular to wall is shown in (Fig 4.26).

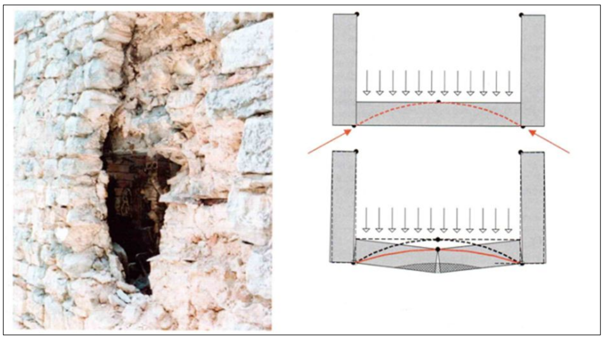


Fig 4.26: Overturning of a wall with the percentage of loose fill *(Borri, 2011).*

The mechanism of damage on a masonry wall structure is induced by isolated seismic action in octagonal direction. The stone masonry behaves as a facade wall devoid of any connections with the orthogonal walls and the floors of the plan; in these conditions, the wall opposes very little resistance to tipping and can be pushed, even by relatively small forces, beyond the limit configuration of equilibrium *(Borri, 2011).*

When the seismic action hits the masonry wall in a direction orthogonal, this tends to make overturn around the base of support. The response of the masonry wall in action of seismic forces orthogonal depends not only on the geometrical dimensions, also by the nature and mechanical quality of the masonry. In fact, become important determinants of resistance mechanisms to ensure that attitude monolithic which is the real source of stability *(Borri, 2011).*

Horizontality of the rows are the requirement leads to a good distribution of the vertical loads as get a bond of regular support. But the horizontality of the rows also assumes importance during the seismic activity because it allows the oscillation around a horizontal cylindrical hinges without damaging the masonry (Fig 4.27). In Fig. is shown the different failure modes of masonry which received two different types of construction, subjected to seismic action in the direction orthogonal. The wall panel “A” made with masonry “chaotic” shatters irreversibly due to oscillation. Behavior of the panel “B” had different behavior according to the “rule of the art”. The upper part, the rigid body rotates around the cylindrical hinge which is formed along one of the horizontal planes while the underlying part can be considered stationary *(Borri, 2011).*

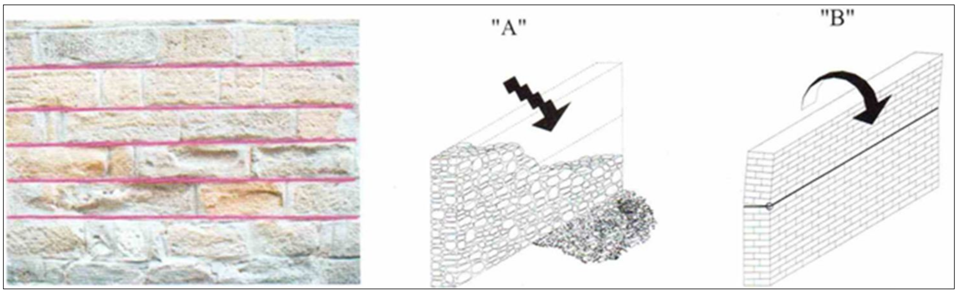


Fig 4.27: Presence of horizontal planes of arrangement allows the occurrence of kinematic mechanisms of the walls (wall "chaotic" and wall in perfectly regular rows with masonry) *(Borri, 2011).*

In the following picture, the kinematic mechanism of the "arch effect" is shown in the figure. The kinematic chain was started for the monolithic masonry with ½ ratio thicknesses which had higher value of "C" rather than masonry with 1 ratio thickness with lower value of "C". As it is seen on the picture thick wall manage to resist trigger mechanism better than the thin one *(Borri, 2011).*

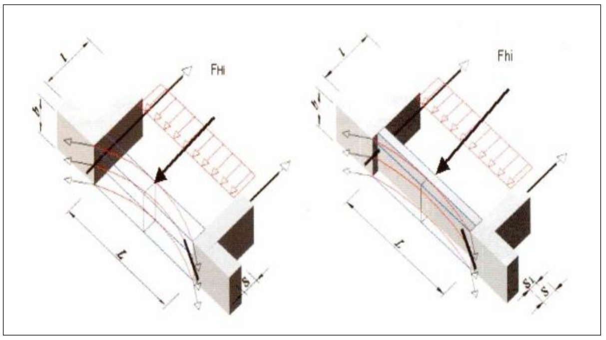


Fig 4.28: Effect of arch masonry*(Borri, 2011).*

- Influence of void in masonry wall structures

The examination of the failure mechanisms shows clearly how there could be important changes in the resistance mechanisms resulting from the presence of voids in the masonry. Two examples are shown in the following schemas (Fig 4.29) *(Borri, 2011).*

In figure, a chimney is formed by exploiting the wall thickness and it's lowering of arrow of the arc discharge and a consequent lowering of the value of coefficient of collapse associated with the horizontal deflection mechanism *(Borri, 2011).*

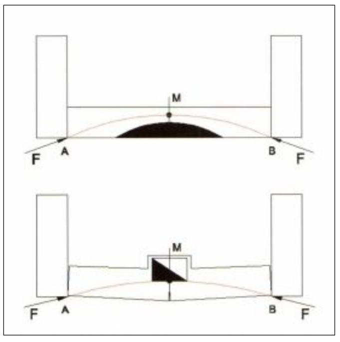


Fig 4.29: Influence of voids on failure mechanisms: the case of a chimney illustrated in a diagram *(Borri, 2011).*

In rotation motion around the base, the wall tends to unload the weight on the outer edge of the section of support, generating a strong shear stress along its middle plane. At this stage, it is put with the tests, the ability of the masonry wall according to the kinematics of the collapse movements, it is supported its integrity *(Borri, 2011).*

A masonry wall that is devoid of diatones or connecting elements, stones or blocks which ensure the meshing between the masonry leafs do not provide a sufficient resistance to shear stress and reaches the collapse. The vulnerability of the building organism is strongly conditioned by these damage mechanisms and their control is the primary goal for intervention (Fig 4.30) *(Borri, 2011).*

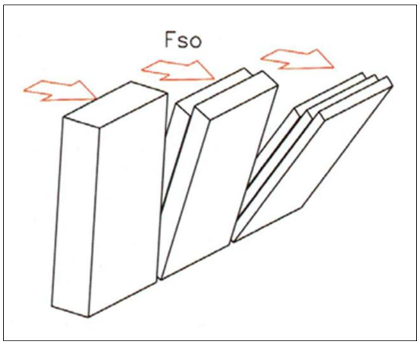


Fig 4.30: Response of masonry walls hit by seismic orthogonal *(Borri, 2011).*

A stone masonry, made up of masonry of leafs and well-connected by square stones arranged in horizontal rows, retains its monolithic structure and is able to follow the movements imposed by the orthogonal actions without disconnecting. Under these conditions, any movement is theoretically reversible. In this way, the wall is able to swing like a pendulum around the equilibrium position, until the attenuation of the seismic forces, the leaves in a position possibly different from the original, but however, allows you to intervene with appropriate rehabilitation work *(Borri, 2011).*

In relation to these mechanisms, very frequent and ruinous responsible for failures and, therefore, the ongoing transformation of the facades of historic centers, already in the past have been developed several anti-seismic techniques. From their analysis it is often possible to reconstruct the history of the local seismicity and the evolution of construction techniques *(Borri, 2011).*

o Horizontal loads in plane action

Horizontal loads are parallel to the masonry wall formed in plane actions. Contributions for the resistant to the actions on masonry wall elevation are shown in fig 4.31 *(Borri, 2011).*

Contributions for the resistant to the actions on elevation

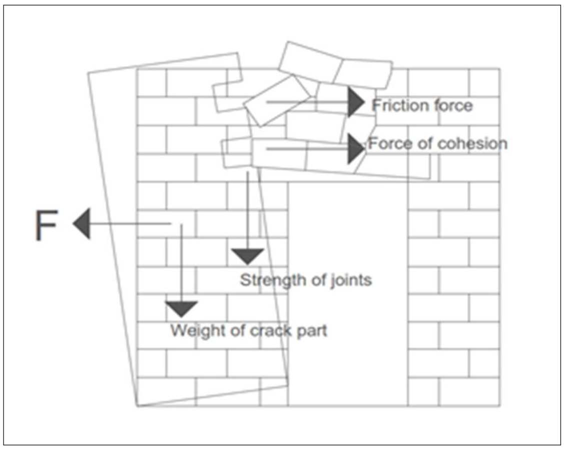


Fig 4.31: Contributions for the resistant to the actions *(Borri, 2011).*

The contributions can oppose to a mechanism of a building masonry wall are on the following:

• F (ATTR) = friction force. It is a horizontal stabilizing force due to sliding between the stones. Increases with the horizontal surface on which it is expressed and the weight acting on these surfaces *(Borri, 2011).*

• Fc (C) = force of cohesion. It is a stabilizing force perpendicular to the surface of separation of the macro-elements. It is due to the tensile strength of the mortar. On historic masonry is good of its contribution *(Borri, 2011).*

• F (IN) = strength of joints. It is the weight (vertical force) of the areas of masonry that are raised to allow the mechanism *(Borri, 2011).*

• P = weight of the macro-element. It is, of course, a strong vertical stabilizer *(Borri, 2011).*

The main factors that counteract the rotation of the wedge are constituted by the shape of the wall portion that detached from the elevation which behaves counterweight for the cutting action of detachment as a resistance. The initial stage of resistance for the detachment of cutting action is constituted by cohesion and friction inside of the masonry. However it is almost never possible rely on strong contribution of cohesion in historical masonry structures. The friction force between the stones continues to play an important role to detachment of solids. Geometric factor counteract the collapse phase with the effect of friction *(Borri, 2011).*

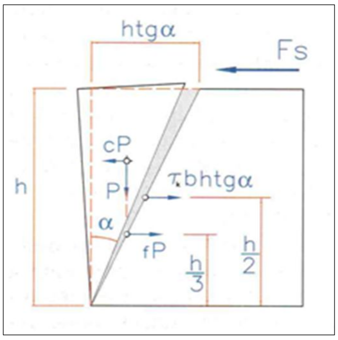


Fig 4.32: Resistant forces inside of the masonry, rotation of the wedge A *(Borri, 2011).*

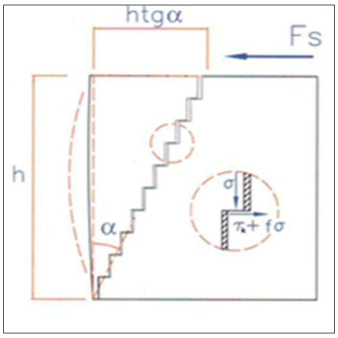


Fig 4.33: Resistant forces inside of the masonry, rotation of the wedge B *(Borri, 2011).*

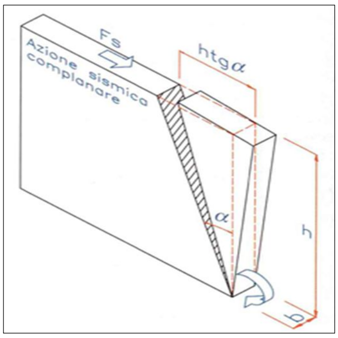


Fig 4.34: Resistant forces inside of the masonry, rotation of the wedge C *(Borri, 2011).*

Cohesion and sliding friction between the blocks are shown on the fig. Cohesion resistant depends on the good quality of the masonry. Sliding friction is a greater force between the surfaces of the block. The weight of the wedge masonry tends to oppose the rotation of the wall. Among the forces that can oppose, there is certainly that due to the so-called "chain effect", favored by a regular staggered vertical joints *(Borri, 2011).*

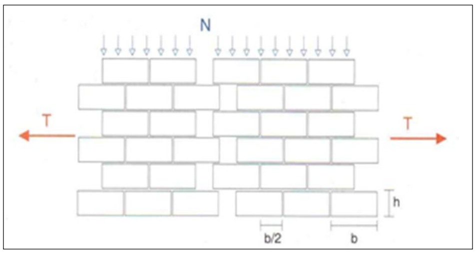


Fig 4.35: Effect "chain" of masonry wall *(Borri, 2011).*

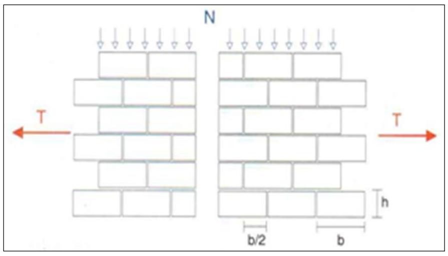


Fig 4.36: Absence of sliding resistance in masonry walls with joints aligned in at least a vertical section *(Borri, 2011).*

Because the vertical load compresses the blocks one against the other along the horizontal support surfaces, it is evident that any action that tends to slide those blocks relative to one another must overcome the friction that raises the compression between these surfaces. The force T, which represents a kind of tensile strength of the masonry, is proportional to the overlap of the joints. Therefore, the greater the offset of the joints, the greater the tensile resistance masonry occurs on leafs. A wall with overlapping joints, the sliding resistance is almost nothing. In the absence of the joints, in fact, the tensile strength is provided only by the cohesion of the mortar. However quality of stone masonry is rather weak in historical structures *(Borri, 2011).*

The multipliers of collapse can be associated to each mechanism of the values dependent on the amount of resistant area of the masonry walls parallel to the seismic action. The presence of openings and the overall geometry of the masonry wall are the parameters that have to take into consideration for the collapse mechanisms *(Borri, 2011).*

- Damage and collapse mechanisms

These mechanisms can be triggered by various seismic intensity of the masonry walls. Condition on the quality of the wall, have a level of ductility that allows avoiding collapse even for earthquakes of high intensity *(Borri, 2011).*

The factors that influence the onset of the mechanism are varied according to the total response of the structure and its mode of damage. The quality of the connections between masonry walls, the type of masonry and the characteristics of the laying of the materials, as well as the thickness and the height of the walls are the parameters that have to be taken into consideration. It is easy to identify the angular width of the wedge of separation. In logic it is likely to match tear line with the slope *(Borri, 2011).*

There is a direct relationship between the geometric shape of the wedge and the direction forces that applied to the structure. However the profile of the tear is associated primarily with the characteristics of the masonry, rather than the intensity of the earthquake *(Borri, 2011).*

The damage of detachment tends to occur along preferential lines defined by the alignment of the joints, that the seismic intensity affects the activation of the mechanism *(Borri, 2011).*

In each wall is possible to identify three areas (Fig 4.37, 4.38), which corresponds to a different tendency to instability, separated by damages of tear (type A) and scroll (type B) *(Borri, 2011).*

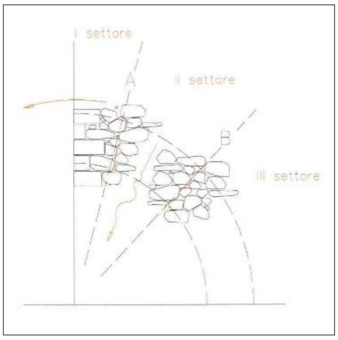


Fig 4.37: Masonry cracks caused by actions coplanar with the wall *(Borri, 2011).*

Fig 4.38: Masonry example of masonry cracks by actions coplanar with the wall *(Borri, 2011).*

The first sector tends to rotate relative to the base; it prevails in the flexural stress that favors the detached tip of the wedge. In the second sector prevails shear action, which is stimulated the sliding mechanism along the second line of separation. The third area covers portions of masonry which, if well implemented, are not affected by the seismic coplanar, which is discharged into the foundation without inducing dangerous kinematic structure *(Borri, 2011).*

For each type of masonry is a critical angle characteristic, represented by the alignment of the mortar joints. These are identifies a weak direction along that tend to be formed in actions coplanar with the masonry wall *(Borri, 2011).*

In general, higher probability of occurrence of the tearing of the wedge masonry dragged and overturning from elevation is under the coplanar action.

The comparison, shown in Fig. and Fig., between a brick masonry well organized and a masonry stones roughly squared, the importance of longitudinal connections made with an appropriate size.

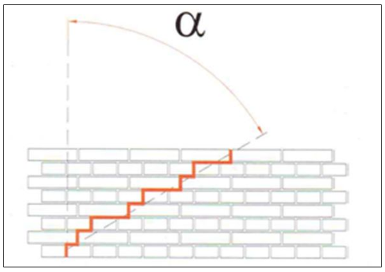


Fig 4.39: The critical angle between the bricks of masonry *(Borri, 2011).*

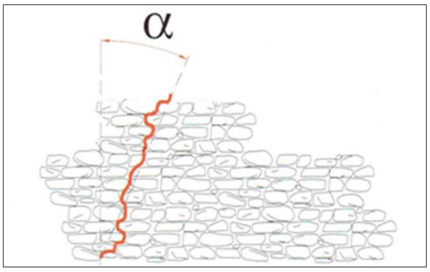


Fig 4.40: The critical angle between the stones of masonry *(Borri, 2011).*

It is important to mesh the masonry wall for creating a proper connection between the facings of the wall, for transverse action. It is equally important to have meshing longitudinal to make the masonry rather homogeneous and suitable to respond either to the actions orthogonal, both to those coplanar *(Borri, 2011).*

The walls made of brick, with a regular alternation assures a good connection in both transverse, longitudinal, however, the provision of only for diatones makes the wall very resistant to one type of stress but vulnerable to the other (Fig 4.41) *(Borri, 2011).*

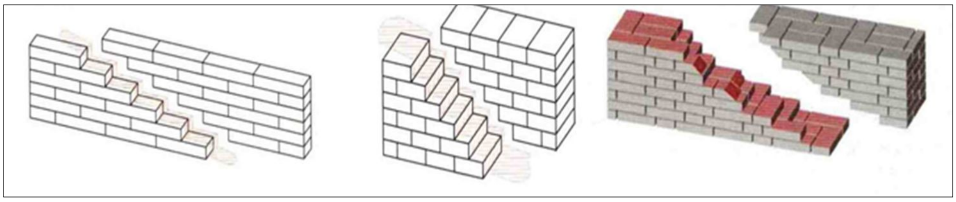


Fig 4.41: Three type of patterned brick masonry wall that have different resistance to in plane actions *(Borri, 2011).*

The importance of the masonry texture for resistance to the seismic forces is on the elevation. On the left example, the solid masonry constructed with bricks on horizontal long side. In this example it is easy to identify a crack passing through the mortar joints with an angle of approximately 45°. An angle able to facilitate emerge of crack under the seismic forces. In the middle example if the masonry wall constructed with bricks on horizontal short side (diatones). The crack angle of the masonry wall joints is higher than the first example. Finally on the right example, masonry wall constructed with three different patterning combinations of brick and the crack line is not straight. In this case, the resistance to the seismic forces is high because of the combination of the bricks. The approximate 45° cutting line have to pass through masonry wall and break the bricks (Fig 4.41) *(Borri, 2011).*

Collapse is due to diagonal cracks of the masonry wall on vertical strips of brick. The spread of the vertical loads is related to the size of the segments and the type of material. The wall made of small bricks, linked by mortars poor, are observed diagonal cracks that turn the masonry wall with more separations and more prone to the collapsed and buckling *(Borri, 2011).*

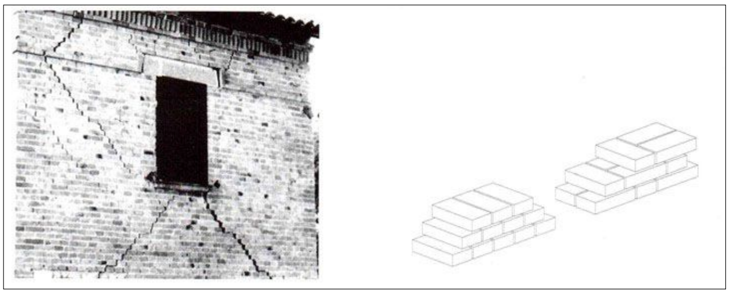


Fig 4.42: Typology of brick masonry pattern and crack analysis *(Borri, 2011).*

The side wall is made of bricks which were placed horizontal short sides on the elevation (diatones). It is a kind of pattering consists of only diatones that shown in left fig 4.42, while lacking the horizontal short sides bricks (orthostates). The behavior of this type of masonry wall for actions in the plan is significantly worse than walls with textures of the type shown in the diagram on the right fig. (Gothic pattern) *(Borri, 2011).*

4.2.4. Crack and damage behavior of the angled masonry walls

Single masonry wall behavior under the three actions and their crack, damage and collapsed analysis is examined in the previous part. In this part, the masonry walls that connected to each other with an angle and their behavior to the seismic activity with an orthogonal direction is examined in variation of collapse types *(Borri, 2011).*

The instability is facilitated by the formation of a cylindrical hinge around the base of the wall occurred by out plane actions, while the other wall is affected by in plane action mechanisms. The wall damaged by out of plane action rotates with respect to a hinge point at the base (Fig 4.43) *(Borri, 2011).*

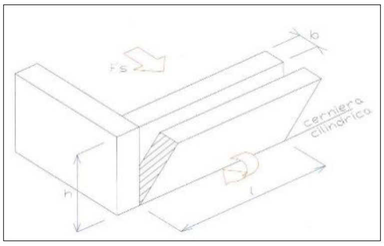


Fig 4.43: Mechanism of damage without connections on corner of masonry wall *(Borri, 2011).*

In second kinematic analyses of the angled masonry walls which are perfect connection on the corners is shown is fig 4.44 *(Borri, 2011).*

In these structures of the masonry wall are well connected and in a good strength. The cylindrical hinge tends to align diagonal on the masonry (Fig 4.44). This mechanisms requires a seismic action (out of plane action) greater than the previous mechanism for activate the phenomenon of tipping *(Borri, 2011).*

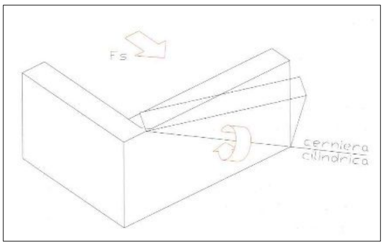


Fig 4.44: Mechanism of diagonal damage *(Borri, 2011).*

Rather frequent and interesting folding mechanism of damage is in third case, which introduces a significant variation represented by the hinge arranged with intermediate inclination compared to the previous cases. The crack effect is occurred between the connections of two walls *(Borri, 2011).*

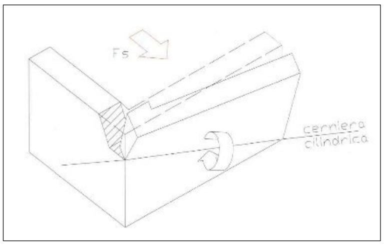


Fig 4.45: Collapse mechanism with formation of an intermediate diagonal hinge *(Borri, 2011).*

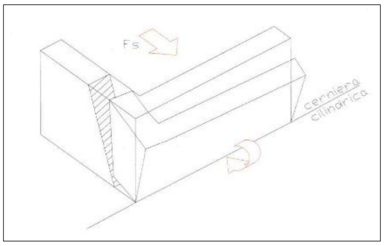


Fig 4.46: Mechanism of damage with well-connected and crack start from diagonal the wall *(Borri, 2011).*

For analyzing the collapse mechanism, the structures have to be divided into parts of masonry walls that are connected to each other. The damage mechanism requires the detachment of a wedge of masonry walls and angular cracks variable in relation to the quality of the masonry. This allows for further analysis of the mechanisms with a view of framework of total instability, with bound least the involvement of the masonry walls with right angles *(Borri, 2011).*

4.2.5. Crack and damage behavior of masonry cells

In this part; damage behavior of masonry cell and its walls, masonry cell closures that are barrel and cross vaults are examined *(Borri, 2011).*

- Behavior of the masonry cell

After doing a critical analysis of the basic damage and collapse mechanisms related to the masonry walls and masonry walls with angled connections, the problem needs a broader view of analyses, by examining the structural behavior of buildings which is more complex. These organisms are characterized by interactions among the various structural elements not detectable in simpler structures *(Borri, 2011).*

The primary cell wall is the first part of building that will be considered. It is bounded by the four walls with a closed perimeter of horizontal ceiling. Each closed cell, where the higher the level of vertical and horizontal connections, interacts with the structure to show a behavior very different from that shown by the masonry wall. However, new mechanisms of damage, if carefully observed, are always related to the elementary schemes from which they are derived *(Borri, 2011).*

The analysis of the behavior of all the elementary cells is a necessary step further for the study of more complex structures. For this purpose is referred to an isolated cell of building which rectangular or square, organized on one floor and walls with no openings. This type of masonry cell is suitable for simplification *(Borri, 2011).*

This case study provides the opportunity to evaluate the relationship that develops between the outer walls and the orientation in various configurations, to be classified into two basic types, characterized by different seismic response offered by other horizontal deformable and rigid examples *(Borri, 2011).*

In order to clarify the various aspects that affect the seismic response of the elementary cell is necessary to analyze some structural configurations that occur frequently in the historical building. The aim of highlighting some structural elements is essential for different seismic situations *(Borri, 2011).*

The increase of loads resulting from the inclusion of the floor involves to damage mechanism of structure in fact increase of a seismic activity that adversely effects on the trigger of kinematic of the structure *(Borri, 2011).*

- Deformation of the cell walls

In the walls of considerable thickness, the profile of the arches and the thrusts of balance have acceptable values, while for the thin walls, pose real problems for stability of the structure *(Borri, 2011).*

The limit equilibrium configuration for the trigger mechanism of collapse corresponds to the formation of hinges in the arches resistant. The evolution of the resistant mechanism also is depended the characteristics of the masonry, as well as by the ability of the side walls to withstand the pressures of the arches, more intense at the top, where the opposing rotation of the solids tends to produce the greater horizontal displacement *(Borri, 2011).*

As a secondary effect, there is the formation of damage of diagonals in the area below the parabolic profile. These damages, represented in Fig 4.47, are determined by the cutting forces generated by the horizontal arcs *(Borri, 2011).*

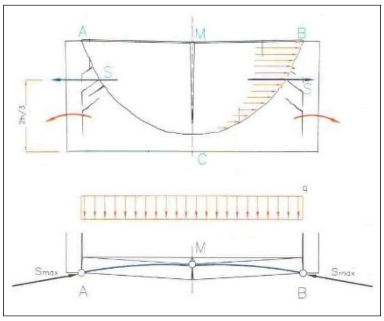


Fig 4.47: Mechanism of bending failure and side effects, plan and elevation *(Borri, 2011).*

- Rigid cell walls with horizontal fixing elements

Reinforced masonry, more flexible and adaptable to different geometric configurations and counter mechanisms with shares distributed to reduce stress on the flexural wedge (Fig 4.48). Instead, the metal chains, if placed in the crown of the wall (Fig 4.48), are likely to be expelled with ease when the wedge begins to rotate *(Borri, 2011).*

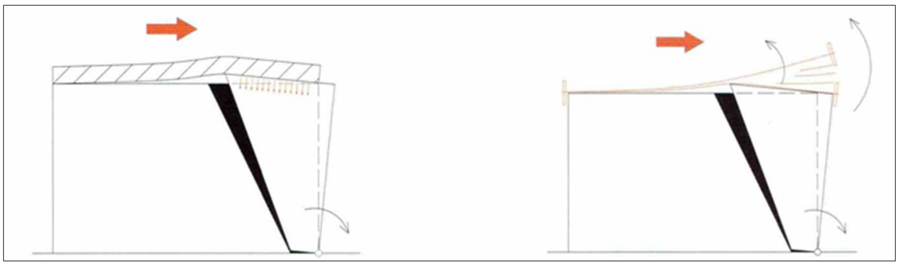


Fig 4.48: Failure mechanism of masonry wall structures with the attachment of concrete or iron chains *(Borri, 2011).*

The walls retained from attics, applied by seismic orthogonal trigger damage mechanisms other than those that are occurred in the configuration console, is certainly less dangerous. The quality of the masonry that makes the difference between the walls capable of ensuring a behavior of monolithic which has a well meshed masonry leaves (fig 4.49) *(Borri, 2011).*

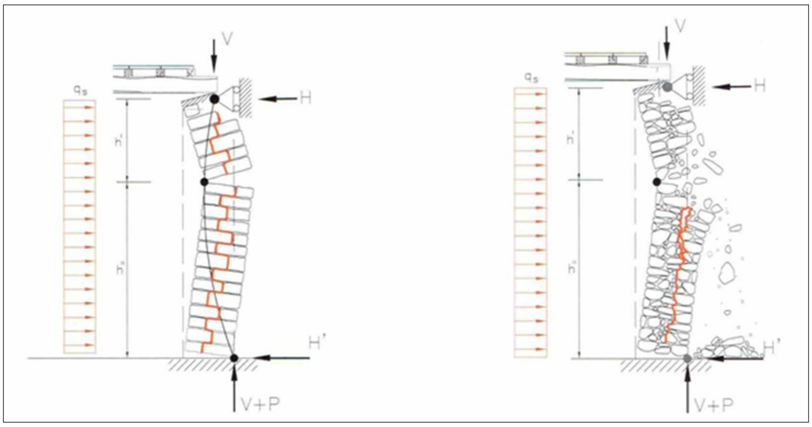


Fig 4.49: Mechanism of wall damage retained in the attic *(Borri, 2011).*

The good quality of the connections between the vertical and horizontal elements, and between the structural elements is the basis of any intervention to improve earthquake-resistant. The insertion of rods, located according to the orientation of the walls along the diagonal functions against the wind designed to counteract the deformations of the masonry walls. It was provided excellent stability of the whole *(Borri, 2011).*

- Masonry cell closures

  - Configuration with vaults

The closures of the cells that are barrel and cross vaults are simple structural profiles. Their balance against the pressure is significant and increases under the seismic action that applied to the structure horizontal or vertical *(Borri, 2011).*

For evolution of the classical mechanism of damage of the masonry vault tipping of its opposite walls, there is a need for create positive collaboration between the vaults. This happens mainly in static conditions, while, under the effect of earthquake that hits the walls in orthogonal sense. Produced on one hand a reduction of thrust, so that stabilizes the upper wall, the other side there is a increase the thrust that leads often to the reversal of the walls not properly sized *(Borri, 2011).*

The damage mechanisms of the masonry cell show a different evolution in relation to the geometry and the direction of the earthquake. The stress in barrel vaults are supported with the perimeter walls. The barrel vaults are not affected by increasing the loads on them. The vaults are work in the principle of arch which are supported by the perimeter walls. On the following fig. the vault thrust on the perimeter walls which were trigger to tipping the side walls and the folding mechanism is started *(Borri, 2011).*

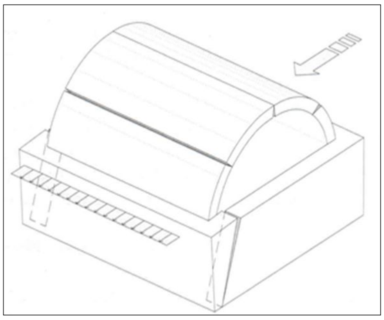


Fig 4.50: Folding mechanism amplified by the thrust distribution of the barrel vault *(Borri, 2011).*

The walls made of excellent quality with good connections that prevent the detachment and dragging the corner wedges, it becomes more likely the kind of bending failure similar like flat or sloping floors.

This is mainly type of bending failure of masonry cell walls which provides maximum thrust at the center of the wall (Fig 4.51) *(Borri, 2011).*

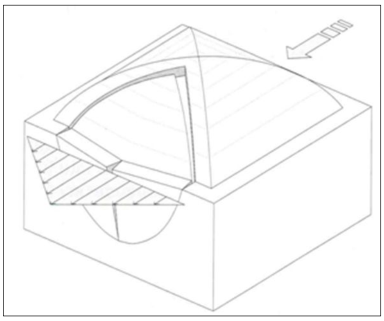


Fig 4.51: Mechanism of rupture in bending out of the plane, amplified by the central thrust of the segment *(Borri, 2011).*

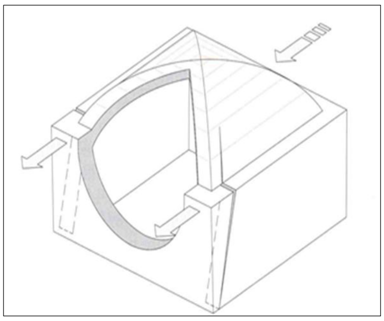


Fig 4.52: Evolution of the mechanism of damage resulting from the collapse of the central segment *(Borri, 2011).*

The mechanism of the moment amplified by the seismic activity and it is changed the equilibrium conditions when a portion of the front flap is detached from the rest of the structure. It reduces the pressure immediately transferred to the center of the wall. The eventual collapse of this portion of the structure involves the formation of a new resistant mechanism *(Borri, 2011).*

In this way the bumpy vault continues to work on three sides, according to the original configuration. At this point, the mechanism evolves as if it were a cross vault *(Borri, 2011).*

In the case of the cross-vaults, it is observed that, the seismic force are discharged at the corners, generally in the cells in isolated or leaning to other structures, the thrust component coplanar with the elevation wall, the load is transferred to the adjacent walls, while the front wall is responsible for the possible overturning *(Borri, 2011).*

In the case of the cross-vaults, as well as for the barrel vaults, there is the possibility to counteract forces acting directly on the walls of the brace, for example through the insertion of rods perpendicular to the elevation *(Borri, 2011).*

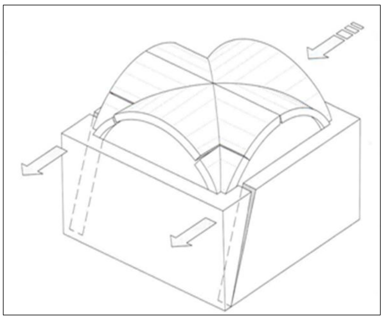


Fig 4.53: Mechanism of breaking or bending of the vault by out of plane action *(Borri, 2011).*

4.2.6. Behavior of mass: “The buildings in a row”

The complicated configuration of whole mass of the row building are formed by the unification of the elementary cells. In particular, the overlap of cells constitutes an obvious step towards the definition of building organisms more complex and introduces a number of variables such as to make difficult a damage or collapsed diagram like the one just performed for the single cell *(Borri, 2011).*

The mass of elementary cells in a composite structure, inevitably vulnerable from the seismic activity, in which all the damage and collapse mechanisms of the cell are found amplified in single cells at the highest levels. The possible combination of horizontal elements of different nature and orientation, define a very large case series and introduces a further element of uncertainty *(Borri, 2011).*

Creation of connections with cells which formed a mutual interaction that contributes to the stability of all structures. This is the criterion; however the formation and evolution of historic buildings thus, even the pre-modern anti-seismic techniques collaboration between the structural parts of the building that can stabilize the whole system *(Borri, 2011).*

The arches made between opposing buildings, are the most obvious example of a technique of preventing seismic activity widespread in the past, wherever they are manifested building against earthquakes *(Borri, 2011).*

The cell structures have a possibility to have a solution of many structural problems however if it is done with the right criteria in an approximate way *(Borri, 2011).*

- Mode of growth of the masonry cells

It is crucial, to reconstruct the mechanisms of growth of the cells with the connections between building elements. Knowledge of building types and conservation status of the buildings is crucial to assume a static scheme with realistic boundary conditions *(Borri, 2011).*

It is often difficult to determine whether a facade wall is connected to the brace. Important information may come from the observation of the crack and the critical historical investigations *(Borri, 2011).*

The consequences for the functioning of the mass structure under seismic conditions are easily predictable for orthogonal actions to the facades and they are tending to disconnect the first cell which is the most vulnerable *(Borri, 2011).*

- Transversal actions

The composed cell walls can give rise to other types of mechanisms that involve simultaneously. It happens that the rotation of the parts turns into a process of disruption that affects the wall common of the two cells (Fig 4.54) *(Borri, 2011).*

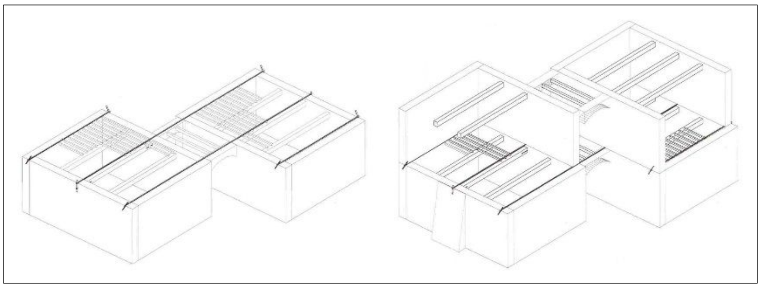


Fig 4.54: Search of structural collaboration between cell walls arranged on one and two levels with arches and iron chains *(Borri, 2011).*

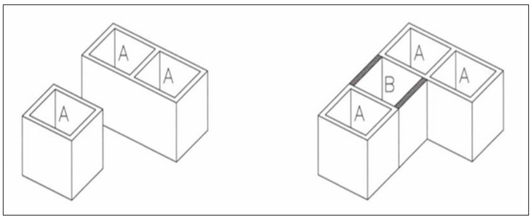


Fig 4.55: Mechanisms of growth of the historical location of the cells in the context of neighboring buildings, A *(Borri, 2011).*

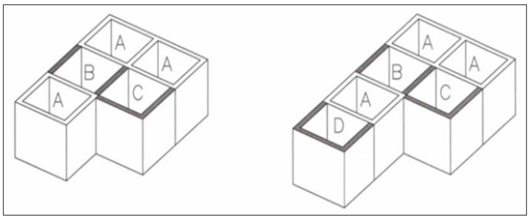


Fig 4.56: Mechanisms of growth of the historical location of the cells in the context of neighboring buildings, B *(Borri, 2011).*

This type of damage is very common practice in the series of masonry cell walls, especially in buildings configuration of the slope. However in these structures it is more difficult to resist the actions perpendicular to the elevation *(Borri, 2011).*

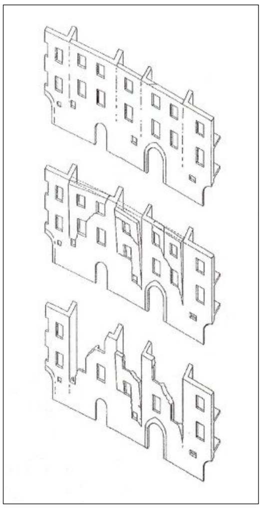


Fig 4.57: Example of tilting mechanisms of facade walls which are not bound to the main structure *(Borri, 2011).*

The factors such masonry walls, corner of the masonry walls and masonry cells as the causes of the mechanism of the damage are elementary. The ideal multiplication of elementary cells is vertically and horizontally. The damage analysis of such a complex situation of the masonry cells is repetitive. It is observed that there is a substantial correspondence between the behaviors of the elementary cells grouped together. And also masonry cells inside of the building organism are much more complex. The overturning of the elevation is among mechanism at greater risk in the context of the masses. This overturning may occur involving the full-height masonry wall or only the portions of the masonry wall. The hinges of rotation are formed preferably at the level of the floors. Each mechanism corresponds to a different collapse multiplier. In general it is inversely proportional to the number of the floors that overturn *(Borri, 2011).*

The wall bracing has an important role for stabilizing the overturning actions. It is counterbalance against the overturning action. The effectiveness is assessed on the basis of the amplitude of the action that dragged the angular sector into the kinematic movement (Fig 4.58) *(Borri, 2011).*

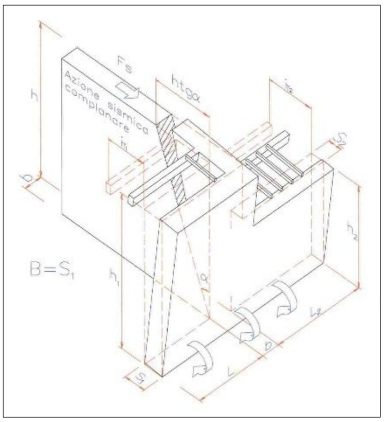


Fig 4.58: Failure mechanism of a masonry wall *(Borri, 2011).*

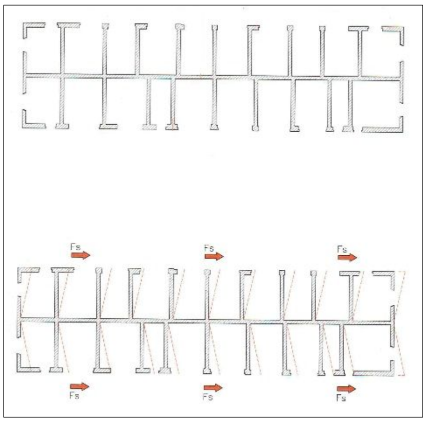


Fig 4.59: State of deformation induced by seismic action on the longitudinal masonry walls coplanar with cellular row building *(Borri, 2011).*

The perimeter walls are the access for the opening for windows for lighting and ventilation. However these masonry walls with openings are less rigid than the other walls *(Borri, 2011).*

To get even clearer picture of the static behavior of building, it is not sufficient to limit the investigation to only the masonry walls of the elevation. However these are the particular vulnerable elements, but it is necessary to extend it to the whole body structure. In particular the central loadbearing walls with masonry walls that are bracing it are constituted the backbone of the building organism. The central wall of the block devoid the opening for windows. The backbone masonry wall statically is stabilized by orthogonal walls (Fig 4.59) *(Borri, 2011).*

The walls are responded to the coplanar actions in a very different way, due to the different stiffness of the longitudinal walls, damage could be experienced to the horizontal elements, especially in the vaulted structures *(Borri, 2011).*

Each cell under the action of the seismic affect can count on the contribution of the adjacent ones that interact with it, producing a mutual stabilizing effect (Fig 4.60) *(Borri, 2011).*

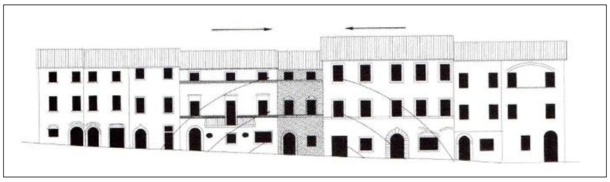


Fig 4.60: Central cells of a block row: law enforcement efforts ensured by the adjacent buildings *(Borri, 2011).*

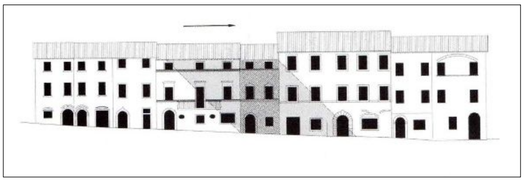


Fig 4.61: Central cells of a block row: diffusion pattern of seismic actions *(Borri, 2011).*

The seismic forces can be easily diverted towards the foundation of the building. However in some cases horizontal components occur extreme tipping and the collapse of the masonry wall elevation is occurred under these seismic forces. Through a simple graphical construction (Fig 4.61), it is understood that how each cell tends to absorb the actions transmitted by the structure and the proper function of the buttresses *(Borri, 2011).*

In masonry cells are under the extreme lack of stability absence of the buttresses. The areas under the most risk of collapse are with presence of holes that for window and door openings and also their positions and sizes essential for the collapse *(Borri, 2011).*

- Front cell masonry wall

The analogy is similar with the single masonry collapse behavior. The collapse behaviors of the plane front wall of the block rotate or slide under the possible kinematic rotation (Fig 4.62) *(Borri, 2011).*

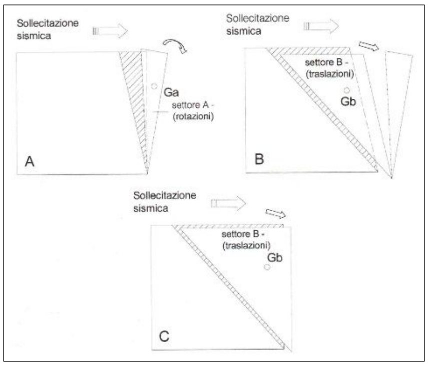


Fig 4.62: Kinematic rotation of the masonry wall *(Borri, 2011).*

The rotation mechanism is activated by horizontal stresses. The broken parts of the masonry structure are identified according to the quality of masonry and the presence of the openings on those walls. The broken parts indicated with the term "sector of rotations". Sector A, is emphasizing the main effect of the kinematic mechanism which essentially consist of a rigid rotation of the broken part. The walls are sensitive to this type of collapses, particular parts are generally top of the masonry cell walls and not confined by other cells *(Borri, 2011).*

The top of the masonry cell could be prevented by pre-modern interventions which have proved very effective in (Fig 4.63). To avoid for the tipping the part of the structure; the perpendicular wall have to be thick enough or these walls supported with buttresses *(Borri, 2011).*

The kinematic horizontal mechanism in sector B is occurred higher values of the seismic effects on the structure *(Borri, 2011).*

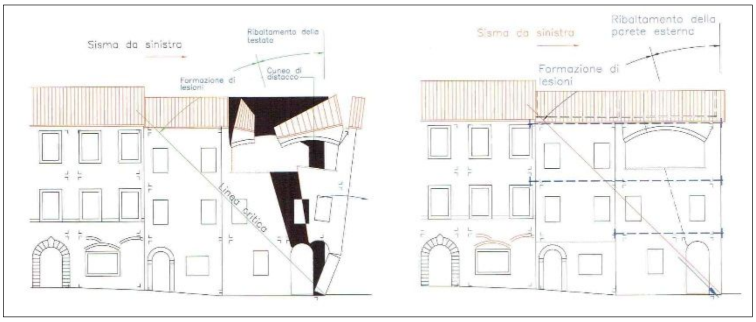


Fig 4.63: left; masonry cell collapse mechanism of the top, right; traction of devices to the head of the masonry cell *(Borri, 2011).*

These modelling performed on ordinary structural configurations indicate that earthquake VII-VIII degree of the scale. Under this scale of seismic activity crisis of sector A is occurred. If the seismic activity is higher than VIII, crisis of sector B is occurred *(Borri, 2011).*

- Non-aligned masonry cells

If the masonry cells are aligned, all the neighboring cells are more stable. And they are being to take the advantage on the enforcement efforts on both sides. However it is only happens if the masonry cell is aligned. Otherwise, the masonry walls one or two sides are not retained they will be collapsed. The major problems in masonry buildings are the free end wall which is not aligned of the neighboring cells (Fig 4.64) *(Borri, 2011).*

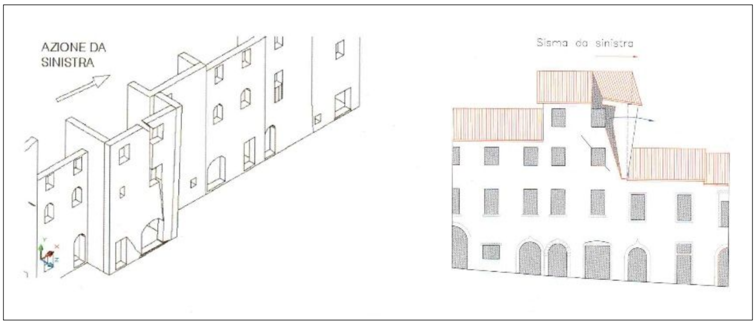


Fig 4.64: Case statement is not in line with neighboring cells and cracks parts, second figure case statement with free end cell break up from the top of the building *(Borri, 2011).*

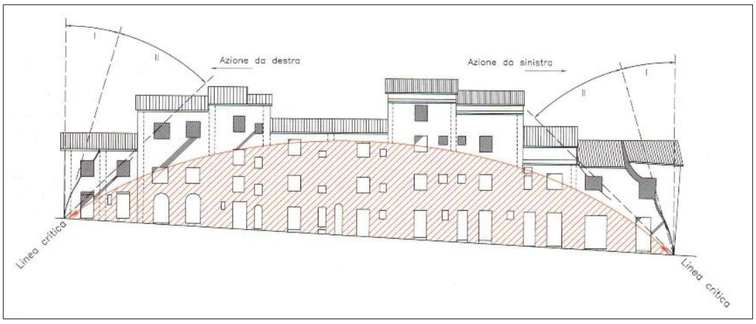


Fig 4.65: Stable area which is shown under the arcade of the critical line *(Borri, 2011).*

Under the arcade of the critical line, building appears relatively stable. In qualitative analysis two half lines angle about 45° is under more exposed of the risk of instability. If these areas are not bound efficiently to the rest of the structure may rotate (sector A) or slide (sector B) as it is shown on the previous figures (fig 4.65). Below the critical line, there is a static compression and it diverted the seismic actions and they can be transferred to the foundation *(Borri, 2011).*

Regular succession of supporting elements, such as that shown in (Fig 4.66), is able to reversed push action through reciprocal enforcement elements. This configuration constitutes a strongly stabilizing factor, provided that there is a substantial continuity and that the pressures exerted against the walls of the top be countered effectively. And also the removal of the structures that are thrusting within a single masonry cell may alter the fine balance of the forces which are applied to the building could be extremely harmful to the structure *(Borri, 2011).*

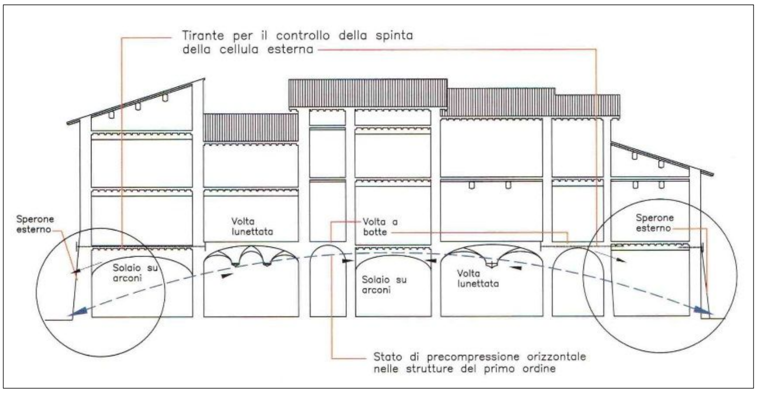


Fig 4.66: Support produced by the stabilizing elements in the row of blocks *(Borri, 2011).*

4.2.7. Damage and material analysis with graphics and descriptions

Damage and material analysis with its graphics and their descriptions are examined and shown in this part of the chapter. These graphical tables which are prepared according to the methodology are used for analyzing the case studies in this research *(Borri, 2011).*

The first table is related with quality analysis for the masonry structures. In the previous parts of this research the classification and the structural behavior of the masonry structures are examined. By the guidance of this table; criticization of the data's are simplified as symbols that are able to type and identify the quality of the masonry *(Borri, 2011).*

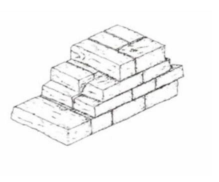
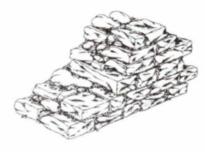
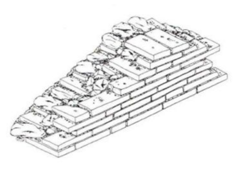
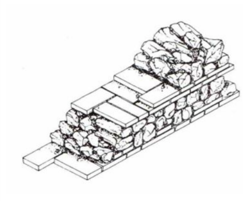
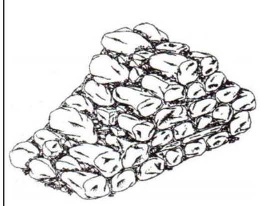
As it mention before the paragraphs are included; the quality of the masonry and the direction of the stresses (vertical load, horizontal load in plane action, horizontal load in out of plane action), there are three different types of behavior for the masonry wall that are distinguish in the following categories:

- Class A: Masonry is in an excellent quality, built according to the directions suggested by the "rule of art", characterized by a monolithic behavior during the possible mechanism of injury.
- Class B: Masonry is in an average quality of masonry, built according to some indications suggested by the "rule of art". The mechanism of damage is divided into several elements and characterized by a behavior that similar to a rigid masonry.
- Class C: Masonry is in a poor quality, it is not in compliance with the "rule of art". It is likely decohesion and crushing of the masonry, without the formation of a mechanism of collapse. The vulnerability factors that affect the morphology of the constructive elements of stone and brick walls in a structural unit are attributed as:

    - ✓ Prevalence of small construction materials in structural units such as square, round or slit shape stones. As well they have a little meshing between the leaves of the masonry and there is a small overlap between the horizontal elements of the structural units.
    - ✓ Presence of load-bearing walls of limited thickness in relation to height and load.
    - ✓ The leave of the masonry is entirely separate from the core and the opposite leave of the masonry wall.
    - ✓ Presence of stone sack vertical layer inside the masonry wall that is separated two leaves of the stone masonry.
    - ✓ The cohesion rate of the construction elements of the masonry wall are determined the vulnerability of the masonry structure *(Borri, 2011).*

In Table 4.9: represents the symbolism for the representation of masonry is intended to facilitate the reading information on the type of masonry wall material and its quality.

Table 4.9: Proposal of symbolism for the representation of the masonry *(Borri, 2011).*

MASONRY STRUCTURES		
Symbolic Description	**Category**	**Description Symbol**
	**A1**	**TYPE A1 - Masonry stone blocks perfectly square, bound with mortar of lime and sand. The construction material is cut stone which made from limestone or sand stone. The elements are put in place in regular rows of height. The heights of the stones are not very different to each other. The stones patterned in a horizontal position that is parallel to the plane of layers of stone. Diatones are used for connecting the layers of the masonry wall.**
	**A2**	**TYPE A2 - Masonry mixed with pebbles and stones bound with mortar of lime and sand, the front leaf of the masonry is perfectly cut stone. The cut stones are generally limestone or sand stone. These stone patterned in regular rows. Their height is not different to each other. The horizontal and vertical joints of the stone masonry are constructed with fine sand and dust of the same limestone. The thickness of the joints are very thin, they are between (4-10mm).**
	**A3**	**TYPE A3 - Masonry mixed with pebbles and stones bound with mortar of lime and sand, outer leaves of the masonry roughly squared. Outer face is roughly hewn limestone. Each of the unit stone has different heights. The inner bag of the masonry is very thin and sometimes is absent.**
	**B1**	**TYPE B1 - Masonry mixed with pebbles, stones and bricks bound with mortar of lime and sand. The outer and inner leaves are similar. The brick elements are placed within a disorderly manner and therefore they could not contribute to the formation of the floor beds of the stones. The structural features do not vary with increasing thickness. These types of buildings are found construction or reconstruction of damaged buildings by earthquakes.**
	**B2**	**TYPE B2 - Masonry mixed with pebbles, stones and bricks bound with mortar of lime and sand. Bricks are faced outside the masonry. This type of masonry walls are divided into two leaves masonry. The brick side of the masonry leaf is constituted for connection of whole mass of the wall. Typical thickness is 50-60 cm. This type of masonry walls can be recognized from the outside because of the prevalence of bricks.**
	**B3**	**TYPE B3 - Masonry mixed with pebbles, stones. Brick used as horizontal beds for stone masonry. Lime mortar and sand are used as bonding material. Outer and inner leaves of the masonry are the similar. The presence of bricks regulates the laying of the floors in horizontal direction. The presence of diatones provides the monolithic behavior of the masonry. The characteristics of the masonry do not change with increasing the thickness. Appropriate thickness of the masonry is 60cm. to 70cm.**
	**C1**	**TYPE C1 - Masonry mixed with pebbles and stones bound with mortar and sand. Outer facing of the masonry leaf is stone which is roughly squared. Inner filling of the masonry is pebbles, stone chips and mortar. The outer and the inner leaves of the masonry constructed with materials and techniques similar to the type A. The masonry wall thickness formed by significant mass of pebbles, stone chips and pieces of clay with lime mortar powdery. Diatones are not used frequently therefore on the leaves on the masonry the stones thickness are equal.**
	**C2**	**TYPE C2 – Masonry pebbles bound with lime mortar and sand with stones and stone chips. The outer leaves of the masonry are formed by large pebbles which are divided into two. Long side of the pebbles oriented into the depth of the masonry. The pebbles are arranged in horizontal rows of different heights, with the beds regularized by fragments of stone, mortar and large flakes of stone. Inner of the masonry wall is formed by irregular small pebbles and minute materials.**

- Damage mechanism of the masonry walls (General collapse facts about the masonry structures)

Frequent buckling of the masonry wall is recognizable by cracks near doors and window openings form buckling two opposite leaves of the masonry wall. The phenomenon of the two buckling leaves of the masonry wall with their damage and partial cut and deformation in the structure are observable. Also masonry piers have got a phenomenon of expulsion of corners of masonry walls *(Borri, 2011).*

A good quality of masonry wall is recognizable form effective horizontal meshing of the materials with good joints between the masonry walls. As well along the entire height of the wall the cohesion between the stone elements and mortar is sufficient. This type of masonry wall structural quality and damage behavior is listed on the below:

- A crack pattern concentrated in a few damages from each other and these cracks are not diffused.
- There is no buckling of the leaves of the masonry walls. They in plumb.

- Stability of the vault structures

The stability of the vault structures provided by presence of pushing elements placed on the adjacent structures which is tend to produce mutual enforcement between structures opposite. The removal of only one of the supporting elements can cause severe structural damages. In addition the removal of the elements has been to carefully evaluate for structural effective mechanisms to balance the forces. In the analysis of vaulted structures and their configurations (barrel vault, cross vault, dome, half dome, etc.), following important points have to be analyzed *(Borri, 2011).*

- A thorough-dimensional geometric survey of the current system, especially an archway, through significant sections that include supporting walls.
- Identification of the used materials and the function of individual structural elements belonging to the vault system.
- Identification of the structural system and construction techniques (resistant sections, arches, the presence of tension rods, etc.)
- An investigation of the physical and mechanical properties of the vault and the individual elements that are part of it.
- In particular, during the survey of vaulted structures should pay attention to any deformation of the intrados, the crack patterns, possible deformation of the floor above the vault and alignment of higher loads.
- Localized loads which are applied to the structure, and not compensated have to be defined. It is necessary to assess the adequacy of the sections of the structural elements is important to examine the vaults *(Borri, 2011).*

These are the only way for identify correctly the static operation of the structural system. The construction system of the overlapping elements connected by ties, that are easily transfer the vertical loads however they are less effective against horizontal seismic forces. Horizontal forces are tended to rip the tie beams from their support. They are decisive for the overall balance of the structure *(Borri, 2011).*

For doing a proper structural analysis of the entire building, it is necessary to realization support of the outer walls, their connection mode and the tie beams inside of the walls. And also it is necessary to;

- Determination of the system of loads, assessment of the functioning of the connections between walls and tie beams.
- Identification of the external behavior and constraints of the wooden elements and their possible failures.
- Identification of damage mechanisms like cracks, sliding and collapse caused by passive pressures, dynamic stress and related with supports *(Borri, 2011).*

▪ Connection between structural elements

Connection between structural elements means that; connection between masonry walls and connections between horizontal elements and horizontal walls. The predominant aspect is the determination of the effectiveness of the quality of the connections. The effective connections in masonry building are shown on the table 4.10 *(Borri, 2011).*

The first type of feature is the discontinuities between the structural elements. It has fundamental importance for the discontinuity of the constructive elements a result of construction and transformation such as angled connection between the masonry walls. Discontinuities are sometimes readable in dimensional geometric survey. Although it is necessary to be careful for identifying the cell walls and the clogging walls between the masonry cells. The extensions of the masonry buildings as well as transformation with simple connections with masonry walls are necessary to be identified *(Borri, 2011).*

Table 4.10: Proposal symbolism for the representation of the structural characteristics and stratigraphic (Structural Discontinuities) *(Borri, 2011), (Doglioni, 1999).*

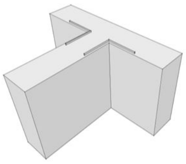
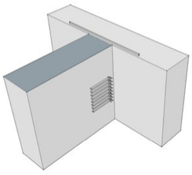
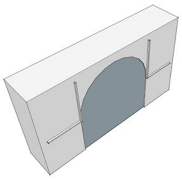
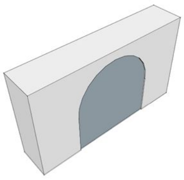
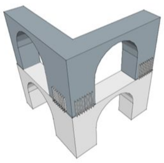
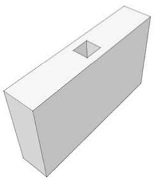
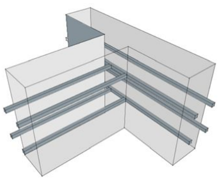
Proposal symbolism for the representation of the structural characteristics and stratigraphic	
CONSTRUCTION FEATURES	
Structural Discontinuities	
Symbolic Description	**Description of Symbol**
	**Continuity and consistency of the masonry wall construction in its angular connections.**
	**Discontinuity in node wall, a wall attached to the existing one (wall approached without scarfing)**
	**Discontinuity on the wall. The wall built as open and filled again.**
	**Discontinuity on the wall. Broken part of the wall and it filled again.**
	**Build a second store on the existing one.**
	**Presence of flue.**
A B C	**Quality construction of masonry structures.**
	**Timber rods.**

Table 4.11: Proposal symbolism for the representation of the structural characteristics and stratigraphic (Degradation of structural elements) *(Borri, 2011), (Doglioni, 1999).*

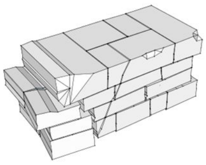
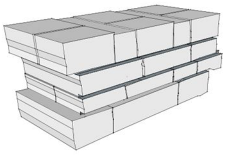
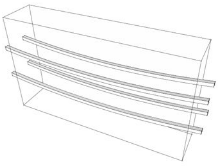
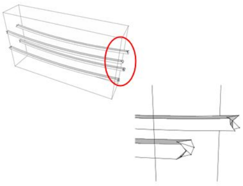
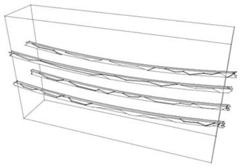
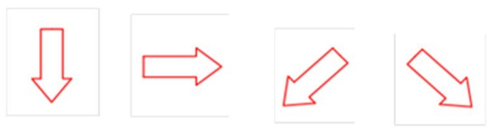
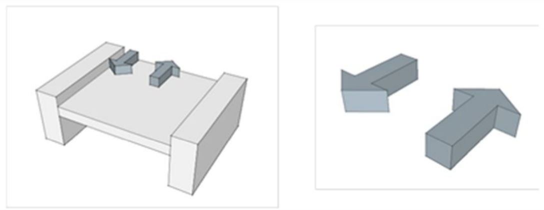
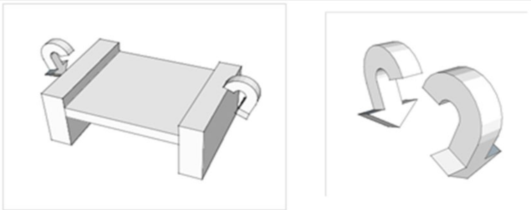
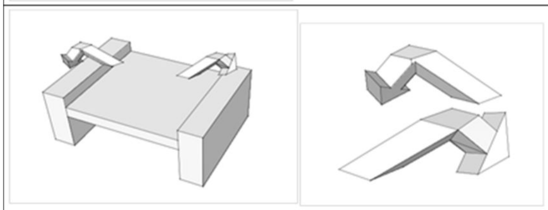
Proposal symbolism for the representation of the structural characteristics and stratigraphic	
CONSTRUCTION FEATURES	
Degradation of structural elements	
	**Deterioration of brick or stone elements (specify type: breakup, detachment, erosion, exfoliation, fracturing, dusting, spalling).**
	**Loss of binder between the joints.**
	**Inflection of timber elements.**
	**To decompose heads of timber elements.**
	**General deterioration of wooden element (biological attacks, decay).**

Table 4.12: Proposal symbolism for the representation of the structural characteristics and stratigraphic (Conditions) *(Borri, 2011).*

Proposal symbolism for the representation of the structural characteristics and stratigraphic	
CONSTRUCTION FEATURES	
Conditions	
	**Presence of vegetation.**
	**Areas where surveys have been carried out to identify, test points, withdrawals, checks.**

Table 4.13: Proposal of symbolism for the representation of the mechanisms of collapse. Each mechanism can be described as a set of actions, and displacements induced damage to the masonry walls *(Borri, 2011).*

DAMAGE MECHANISM	
SYMBOL	DESCRIPTION OF SYMBOL
	Vertical, Horizontal, Oblique
	Rotation axis in the plane of the wall
	Rotation axis out of plane of the wall
	Wobble with axis is not perpendicular to the plane of wall
	Point or hinge line

o Cracks, damages of the masonry structures and their identification

The purpose of the survey of the masonry is to define degradation and failures of materials and structure (Table 4.11). By these definitions the damage mechanism of the masonry structure is identified. In an analysis of typical vulnerabilities of the structure, defining degradation and disruption of the structure is to be determined. The cause of phenomena and establishing degree of risk and potential loss of structural efficiency has to be defined *(Borri, 2011).*

If the masonry structures materials are deteriorated, crack pattern are complex and observed structural defects and their assessment have to be explored in much detail survey.

The damage survey of the crack patterns must include the determination of the characteristics of the cracks. Size of the cracks, conditions and the status of the damages, their depth and direction are crucial to deepen the analysis. However these analyses are done with instrumental methods of survey. Careful survey drawings of the masonry structure with supported documentation related with their conservation history and general photographic detail of the structure is not only essential for understanding the structure of the building, they are useful for reading and defining the state of damages. In survey drawings of the structures, special attention must be given to modifications and alterations of the original building which can be done by human effects or degradations structures caused by alterations or physical and chemical erosion actions or destructive actions of the natural events *(Borri, 2011).*

Table 4.14: Proposal symbolism for the representation of the crack and collapse (Description of the effects of the collapse of the construction on the matter (physical damage) *(Borri, 2011), (Doglioni, 1999).*

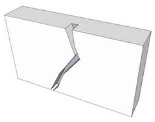
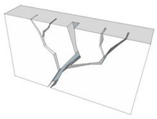
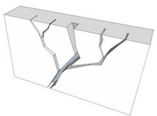
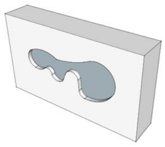
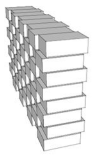
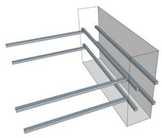
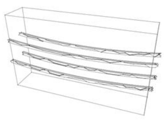
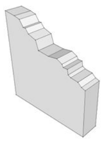
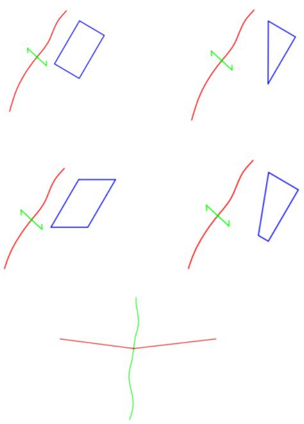
Proposal symbolism for the representation of the crack and collapse	
CRACKING AND INSTABILITY	
Description of the effects of the collapse of the construction on the matter (physical damage)	
Symbolic Description	**Description of Symbol**
	**Main cracks.**
	**Main cracks diffused, branched cracks.**
R 	**Diffuse cracks repaired compensated.**
	**Fractures concentrated, lost of adhesion between mortar and bricks, localized with or without expulsion of parts, plaster corrugations (usually due to phenomena of crushing, pounding, punching beams to 'support, etc.).**
	**Delamination spread of masonry (loss of adhesion between mortar and supports), crazing and widespread lesions close together can not be described graphically, disconnection of scaffolding terracotta.**
	**Extraction (from the place of wooden element in the wall), slipping or sliding closed joint (between elements of stone or masonry blocks) in mm displacement.**
	**Rupture of metal ties or wood, wooden beams, severe deformation of head of the beam.**
	**Collapse of parts and / or drop items from parameters (mark the edge of collapse and graphic reconstruction of the partially collapsed, according to surveys, photographic documentation, etc.).**
	**Overall configuration of the branch of the cracks:** **Shape in parallel with vector orthogonal to them (symbol: rectangle).** **Shape in parallel with non-orthogonal vector (symbol: diamond).** **Shape that diverge starting from apex of the lesion (symbol: delta).** **Shape that diverge starting already separated (symbol: trapeze).** **Variation in the plane of the masonry at the lesions (indicating likely hinge).**

Table 4.15: Proposal symbolism for the representation of the crack and collapse (Description of the effects of the collapse of the construction on the matter (geometrical modifications) *(Borri, 2011), (Doglioni, 1999).*

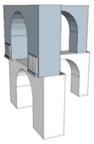
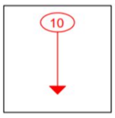
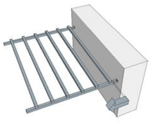
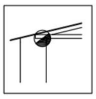
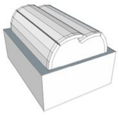
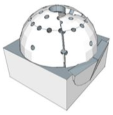
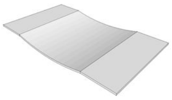
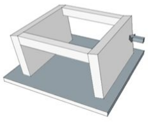
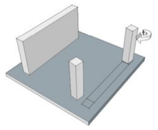
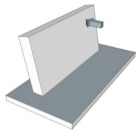
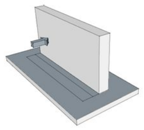
Proposal symbolism for the representation of the crack and collapse	
CRACKING AND INSTABILITY	
Description and measurent of displacements due to structural damage (geometrical modifications)	
	**Relief of the deviation from verticality (outside / inside lead) or the horizontality (bulging), with dimensions in mm. the deviation of the points noted by the vertical or horizontal line of reference.**
	**Out of plumb.**
	**Disconnection of the floor from the wall.**
	**Main beams not resting on the supports or inefficient.**
	**Depression vault.**
	**Depression dome.**
	**Deflection of the slab.**
	**Lost of sqare, out of shape of the opening or deformation of arcs and vault.**

Table 4.16: Proposal symbolism for the representation of the crack and collapse (Description of the effects of the collapse of the construction on the matter (Loss of verticality– entities of the ‘tilt’) *(Borri, 2011), (Doglioni, 1999).*

Proposal symbolism for the representation of the crack and collapse	
CRACKING AND INSTABILITY	
Loss of verticality - entities of the 'tilt'	
	**Recognizable components of the displacement vector of building masses.** **Rotation in the plane (P) or out of plane (FP) or mixed (angular-M) (C indicate with large circled or hinge points).**
	
	**Horizontal translation (TH) (related to slipping in elevation or foundation)** **Vertical translation (TV) or sub-vertical (T.SV) (related to foundation settlement), both of them are detected observed moment.**

The following steps that classifying the causes of the damages and their indicators. These steps are used for examining the possible instability and collapse mechanisms with a view of macro analysis of the structures. Therefore in each step; descriptive and photographic documentary of the damages are needed to analyze. Even with one or more hypothesis about the origin of the damage mechanism is examined for define type of damage *(Borri, 2011).*

Different vulnerabilities produced by seismic activity over time. The damages occurred from the recent earthquakes are the verifications of the previous effectiveness of the interventions. For these reasons Region Marche, suggest a protocol for the diagnosis of the vulnerability of the expected damages, which provides:

- Consultation of specific vulnerabilities in similar case structures.
- The identification of specific vulnerabilities in structure.
- The interpretation of the role of specific vulnerabilities in the structure.
- A description of the probable and possible damage related to specific vulnerabilities.
- Consultation with the similar buildings that are under damaged and their damage mechanisms in macro scale.
- The divisions of the building in macro scale and macro elements. And their identification of typical vulnerabilities related to them.
- The interpretation of the mechanisms already activated (visible damages).
- The prediction of the behavior of the damage to local and whole structure and expected future damages under the seismic activity. This step divided into two sections:
    - ✓ The formation of a new damage related to vulnerability of the existing structural specifications.
    - ✓ Further advanced damage linked to specific vulnerability of the structure and the mechanisms that are already activated or activation of new mechanisms.
- The repair techniques of masonry structures and improvements of these techniques are the feedback of the behavior of the structures under the seismic effects *(Borri, 2011).*

- Interpretative analysis and critique of masonry construction

The survey drawings of the structure have got a dimensional geometry of the whole parts. These drawings include also contained extensive information of the parts and materials of the structure and as a conservation status of their applications for use in the structure. Material degradations, collapse of structures, structural connections, defects in load bearing structures, mortar joints and etc… are shown in the survey projects *(Borri, 2011).*

The survey projects can serve as a tool for connective investigations of diagnosis character and be repeatedly updated over time as a dynamic relief to understand the evolution of the degradation in time.

For defining the actual status of each structural component, the analysis of the macro modelling is determined by historical information on the construction phases. The conditions of all elements are highlighted from the survey of the masonry structure *(Borri, 2011).*

As mentioned before, survey drawings of the structure highlighted the historical information of the structure. As well in these drawings there is information about the construction techniques of the structure. Correct structural reading through the survey projects, data's that are gained with the combination of historical studies, accurate measurements and construction techniques which are emerged from quantitative and qualitative approaches to are determined for the safety of the structures. The qualitative aspects are essentially based on the direct observation of structural instability and degradation of materials as well as the historical and archaeological research. While quantitative aspects are essentially based on surveys of materials and structures as well as on structural analysis by methods more or less sophisticated calculations *(Borri, 2011).*

- Method of the kinematic mechanism of collapse

The objective method of the kinematic mechanism of collapse is to identify the possible mechanisms of collapse of the masonry buildings. Furthermore assess the multiplier of the loads, if they are applied in a static manner to the structure that are causes the loss of balance of the kinematic chain *(Borri, 2011).*

This method therefore is divided in two phases:

1- Structural analysis in order to identify the structural deficiencies of the structure and its consequent collapse mechanisms as possible.

2- Calculation of the numerical value of coefficient of collapse mechanism and possible safety check by comparing the coefficient of collapse found with a coefficient of reference defined by the seismic codes *(Borri, 2011).*

- Analysis of the structure

  - Macro portions in which are divided into masonry wall sections due to seismic actions. These portions have a certain internal monolithic behavior which is produced by static and seismic loads as well as the disconnections inherent of the building due to the type and construction methods *(Borri, 2011).*

  - Kinematic mechanism of collapse is effective by the kinematic chain that made it possible by the mutual movement of one or more macro elements. The starting movement for the kinematic chain of the masonry structure occurred by seismic action *(Borri, 2011).*

- Collapse coefficient “C” is the value that causes loss of balance of the kinematic chain for the given mechanism *(Borri, 2011).*

The macro elements of the masonry structure will tend to behave monolithically if the wall is constructed in good quality of materials and construction techniques. Without internally disconnection of materials, the masonry behaves like a rigid body *(Borri, 2011).*

If the masonry wall does not present exceptional quality and good implementation, the behavior of the masonry wall is not monolithic. Therefore the wall behavior is like a “double separate leaves”. Such behavior is the tendency of the masonry wall to be divided into two monolithic leaves which has to be taken into the consideration in collapse mechanism of the structure *(Borri, 2011).*

The masonry wall in category “C” is the weakest type of wall under the seismic actions. When this wall faced with the seismic action, there is a disconnection between the materials internal of the wall and there is no forming of separation of monolithic leaves. The wall crumbles to the pieces of stones without formation of macro elements *(Borri, 2011).*

Usually the masonry types "C" are excluded from the analysis because their resistance limit. When they are subjected to seismic activity, they are break up immediately. The limit analysis, therefore, is not applicable to these types of walls with poor quality *(Borri, 2011).*

Depending on the direction of the seismic action with respect to the plane of the wall, identify damage mechanisms of first and second order.

- If the mechanism of the damage happened in the first order which tend to displaced the masonry wall in a direction perpendicular to its plane of resistance. These mechanisms must be absolutely avoided; these mechanisms are often produce disastrous actions, even if they are not carried to the extreme force. And also the causes of instability are difficult to heal. To avoid such of these mechanisms, monolithic masonry wall structure and its well meshed thickness are provided. However masonry walls infilling with double leaves are particularly susceptible behavior towards the mechanism of the first order. For this reason enormous importance are given to the effectiveness of the connections between the floors, domes etc. and masonry walls which are perpendicular to them *(Borri, 2011).*

- The mechanism of damage happened in the second order; masonry walls are affected from the seismic action parallel to the longitudinal direction which is the greatest strength of the wall. If the fabric is in good quality the damages may occur also in certain extent without the wall loses to its load-bearing capacity. The fundamental aspect of this behavior is under the fact that, the masonry walls which are able to withstand with higher loads in that direction than the first order.

The damage mechanism of first or second way, in most real cases these mechanisms are combined manner. It is often possible to observe that the cracks are formed on the elevations of the buildings on the basis of second order. This is clear that when the actions that are the appeared form earthquake, it cannot separated into components which are orthogonal or coplanar. But they involves the building entirely, that they may be resulted damages on first or second order *(Borri, 2011).*

The identification of the failure mechanisms in an existing masonry building is the most difficult part of the analysis method in macro. It can only be achieved by a thorough structural survey of the building.

Any error of the identification of the collapse mechanism of the structure is able to greatly alter the value of the coefficient of collapse and final result of the analysis *(Borri, 2011).*

Need of identification is facilitated for carry out studies on buildings that are already damaged by an earthquake in macro portions of the structure because they bounded the damages produced by seismic actions. Through the crack types that are happen in masonry structures, their motion graphics with various macro elements in the buildings under the seismic activity are identified *(Borri, 2011).*

The prior damage analysis that are happened form the earthquake, present major difficulties especially on buildings that are not damaged and particularly not degraded. It is essential to make a reliable structural survey of the building that are in questioned. The survey project specifies at least the following data.

- Actual geometry and dimensions of the structure are essential. Their positions size and the load-bearing masonry walls, openings on the walls, roof, domes, stairs, vaults and arches have to be identified in these drawings.
- Type of the horizontal elements in relation to the loads that are induced on the masonry walls (floors and roofs that are made up of stone, steel, wood etc.)
- Constraints on the masonry walls divided into two parts. Ties between the masonry walls and the ties between the masonry walls those are parallel to each other.
- Type of masonry walls, particularly with regard to ability of the walls keep monolithic or conversely separate into two leaves.
- Analysis of the conservation status, the presence of the degradation or disruption of the structure *(Borri, 2011).*

The priority of the identification of the failure mechanisms as a result of survey drawings, the characteristics has to be described above and they executed based on assumptions. They are developed specifically for the case study which identified of mechanisms of collapse. The failure mechanisms are identified according to the hierarchy of dangerousness among the possible mechanisms *(Borri, 2011).*

The first is to identify masonry walls according to their collapse mechanisms. According to the pragmatic point of view, it is acceptable to extend the analysis of the damage mechanisms only external walls of the structure *(Borri, 2011).*

The masonry walls which are located on the perimeter of the building, their connection between horizontal elements like floors and external and internal walls and possible presence of anti-seismic principals are determines the fundamental conditions of collapse calculations *(Borri, 2011).*

A masonry wall stressed by an action perpendicular to its middle plane, tend to separate into protruding by the means of a kinematic chain. The sequence of the action happened according to the steps on the below:

- Consistency of compressive strength of masonry wall.
- Tensile strength of the masonry wall.
- The constraints of the horizontal movements. The macro element is move only the rotation of the horizontal hinge axis.
- The constraints of the vertical movements. Two masonry walls neither are separated nor rotate around the vertical axis passing through the clamping.
- The constraints of internal movements. Only the walls devoid of diatones can be separated into two leaves of masonry under the movement of out of plane action.

- Minimum energy. The minimum energy is smallest coefficient value of collapse for triggering the macro elements *(Borri, 2011).*

Table 4.17: Mechanism of collapse of the masonry walls with their function of the boundary conditions *(Borri, 2011).*

<table>
<tr><th colspan="4">Mechanisms of collapse of the masonry walls with their function of the boundary conditions</th></tr>
<tr><th rowspan="2">Horizontal constraint</th><th rowspan="2">Vertical constraint</th><th colspan="2">Internal constraint</th></tr>
<tr><th>Monolithic wall</th><th>Double leaves wall</th></tr>
<tr><td rowspan="3">Upper bonded wall</td><td>Clamp one side</td><td colspan="2">One side of the masonry is overturning with two sided crack</td></tr>
<tr><td>Clamp two sides</td><td colspan="2">Two sides of the masonry is overturning with two sided crack</td></tr>
<tr><td>No clamp</td><td>Vertical bending (monolithic)</td><td>Vertical bending (double leaves)</td></tr>
<tr><td rowspan="6">Free upper wall</td><td rowspan="2">Clamp one side</td><td>Rollover part of the masonry wall in one side (monolithic)</td><td>Rollover part of the masonry wall in one side (double leaves)</td></tr>
<tr><td>Overturning single part of the masonry</td><td>Overturning single part of the masonry</td></tr>
<tr><td rowspan="2">Clamp two sides</td><td>Horizontal bending (monolithic)</td><td>Horizontal bending (double leaves)</td></tr>
<tr><td>Overturning part of the masonry with two sided crack</td><td>Overturning part of the masonry with two sided crack</td></tr>
<tr><td rowspan="2">No clamp</td><td>Overturning (monolithic)</td><td>Overturning (double leaves)</td></tr>
<tr><td>Horizontal bending (monolithic)</td><td>Horizontal bending (double leaves)</td></tr>
</table>

Table 4.18: Different failure mechanisms that are subjected to seismic action found in buildings, under vertical loads *(Borri, 2011), (Doglioni, 1999).*

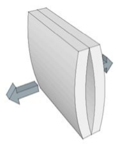
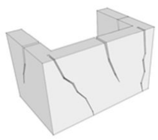
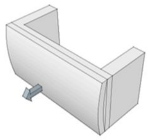
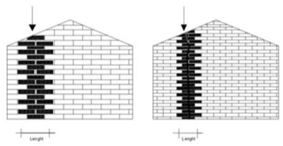
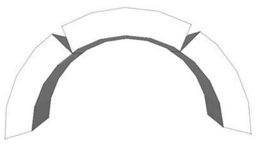
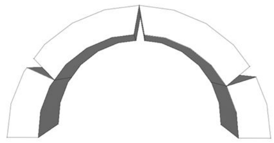
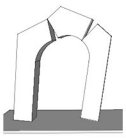
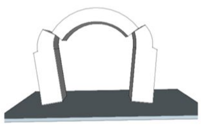
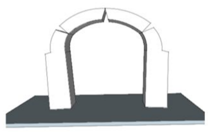
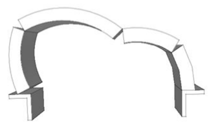
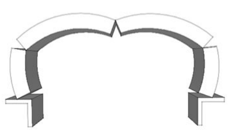
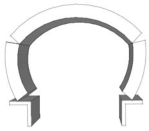
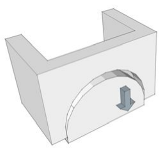
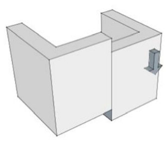
Failure mechanisms that are subjected to different seismic actions found in buildings			
VERTICAL LOADS; Masonry cracks and possible of sector of rotations			
Masonry single wall failure mechanisms			
	**The compressive force pushed away two masonry leaf from each other. The masonry wall gets into the formation of symmetric bulging.**		**Vertical cracks on the masonry wall that tends to collapse of the structure.**
	**Outer vertical deflection. Inside leaf of the masonry wall under pressure. Therefore outside of the leaf pushed away from the wall.**		**Typical mode of failure of the masonry wall, due to the applied forces which are triggers the thickness of the masonry with seismic orthogonal action. Thinner bricks have got lower diffusion therefore there is higher stress, and also cracks could be on this area (left figure).**
Masonry arch failure mechanisms			
	**Curve of the pressures in the configuration of minimum thrust.**		**Curve of the pressures in the configuration of maximum thrust.**
	**Four hinge mechanisms of collapse for the triumphal arch, involvement with two piers.**		**Four hinge mechanisms of collapse for the triumphal arch, involvement with one pier.**
	**Arch collapse mechanism according to "Mascheroni". Two hinges are occured and the arch walls tend to open outward.**		**Arch collapse mechanism according to "Mascheroni". Three hinges are occured and the arch tends to move from top hinge to downward.**
Masonry vault failure mechanisms; All possible failure mechanisms of barrel vaults loaded with vertical actions, with round-arched or circular axis lowered, fall into four main cases.			
	**Collapse mechanism produced by a non-symmetric load**		**Collapse mechanism produced by a symmetric load;**
	**Collapse mechanism produced by minimum thrust**		**Collapse mechanism produced by piers or tie rods**
Masonry cell failure mechanisms			
	**Bottom part of the masonry wall tend to seperate from the cell.**		**Half part of the cell tend to move downward.**

Table 4.19: Different failure mechanisms that are subjected to seismic action found in buildings, under horizontal loads in plane action and horizontal loads out of plane action *(Borri, 2011), (Doglioni, 1999).*

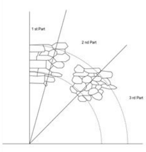
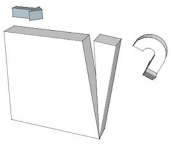
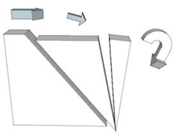
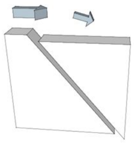
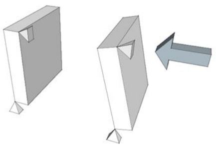
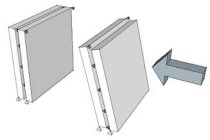
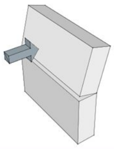
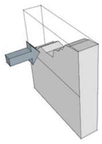
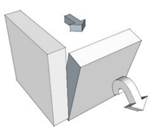
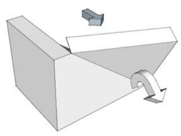
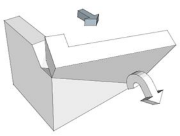
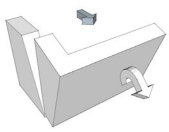
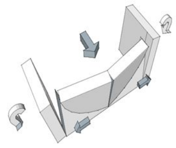
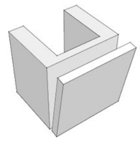
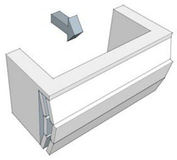
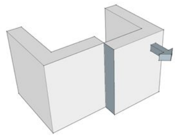
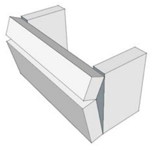
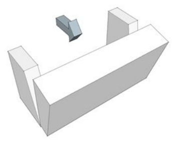
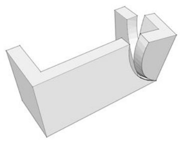
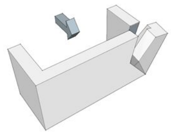
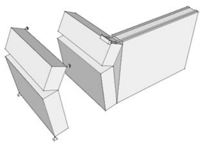
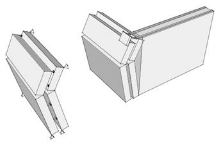
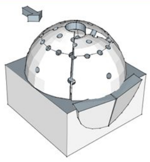
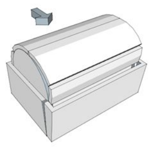
Failure mechanisms that are subjected to different seismic actions found in buildings			
HORIZONTAL LOADS IN PLANE ACTION; Masonry cracks and possible of sector of rotations			
Masonry single wall failure mechanisms			
	**Masonry cracks and possible of sector of rotations caused by actions coplanar with the wall**		**Sector of rotations; part A. Emphasizing the main effect of the kinamatic mechanism which essentially consist of rigid rotation of the broken part.**
	**Sector of rotations; part B. The kinematic horizontal mechanism in sector B is occured in higher values of the seismic effects on the structure.**		**Sector of rotations; part C. It is a critical line, seismic actions diverted static compression and they can be transfered to the foundation.**
HORIZINTAL LOADS OUT OF PLANE ACTION; Masonry cracks and possible of sector of rotations			
Masonry single wall failure mechanisms			
	**Overturning a monolithic wall under the seismic actions.**		**Over turning a two leaves wall under seismic actions.**
	**Horizontal forces applied to the well arranged masonry wall with straight horizontal joints.**		**Horizontal forces applied to the chaotic masonry wall without straight horizontal joints.**
Masonry angled wall failure mechanisms			
	**Overturning a monolithic wall.**		**Mechanism of diagonal damage.**
	**Mechanism with formation of an intermediate diagonal hinge.**		**Mechanism of damage and crack start from diagonal of the wall.**

Table 4.20: Different failure mechanisms that are subjected to seismic action found in buildings, under horizontal loads out of plane action *(Borri, 2011), (Doglioni, 1999).*

Failure mechanisms that are subjected to different seismic actions found in buildings			
HORIZINTAL LOADS OUT OF PLANE ACTION; Masonry cracks and possible of sector of rotations			
Masonry cell failure mechanisms			
	The mechanism of damage on a masonry cell wall structure under the horizontal forces.		Reversal of the external leaves
	Bending deflection outward of the masonry. The crack lines are the parts that are the void spaces for timber tie beams.		Half part of the cell tend to move outward.
	Monolithic vertical deflection.		Tilt mechanism composed of double corner cracks.
	Tipping masonry piece with an single corner and with simple diagonal crack		Tipping masonry piece with double corner and double diagonal crack
	Monolithic masonry wall is attached from the top with metal chins. Bending stress applied to the wall.		Double leaf masonry wall attached from the top with metal chins. Bending stress applied to the wall.
Masonry cell closure failure mechanisms			
	Folding mechanism of rupture in bending out of plane, amplified by the central thrust of the segment.		Folding mechanism amplified by the thrust distribution of the barrel vault.

- Failure mechanisms of different structural elements in buildings

▪ Arch

Arch is formed by series of segments which have a rigid behavior. These segments are assembled with connecting joints. In some of these joints mortar is used and some of them mortar is not used. The hypothesis is certainly in a favor of safety as neglect even the smallest tensile strength of the joints. The arch is bound at its ends and constructed with the aid of tie or supported from the sides. Supposing that, if these supports are removed, arch discharged and begun to exert horizontal thrust. The structural conditions of the arch refer first all the equilibrium conditions which have to be met: In this equation; internal actions must balance the external loads including its own weight *(Borri, 2011).*

According to the "safe theorem" stated by Heyman, "Structural engineer does not focus its attention more actual state of the structure, but what interest him is to know only a state of balance favorable to the stability". In a time manner small movements in arch or supports of the arch are greatly changed the equilibrium state of the structure. In other words, destruction the form of the curve, change the stresses inside of the arch. However if these destruction are reasonable, this change will not affect the overall strength and stability of the structure. The pressure line adapted to the new conditions but never come out from the masonry wall. In this point the theorem becomes conceptually static theorem *(Borri, 2011).*

The stability of structures as arched or vaulted masonry can also be analyzed by reference to the possible collapse mechanisms. These mechanisms are given collapse possibilities for the structure in accordance with the external constraints and the condition of congruence. In all cases of arch structures, the spatial system can be traced to a simple system plan; to arch mechanism *(Borri, 2011).*

Fig 4.76: Curve of the pressures in the configuration of minimum thrust (a) and maximum (b) in an arch.

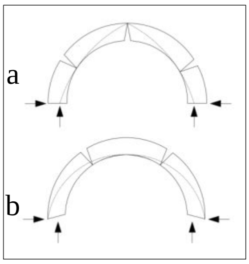


Fig 4.67: Curve of the pressures in the configuration of minimum thrust (b) and maximum (a) in an arch *(Heyman, 1995).*

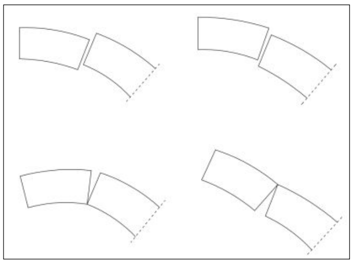


Fig 4.68: The four mechanisms of collapse connections due to "Coulomb" *(Borri, 2011).*

In the case of cross vaults, there is always a case for impossibility of the masonry withstands tensile stresses. In these structures the loads are transferred from the arch to diagonals. If two vault structures are intersected to each other, the loads transferred from one arch to another. Structural system of the roof with parallel arches is resistant to the loads. In this case, the spatial structure is revealed to be constituted by the flat-resistant structures. The generalization of all types of these structures; arches, vaults, domes etc. are not resistant to the traction. All these systems are the formation of the basic structure of arch *(Borri, 2011).*

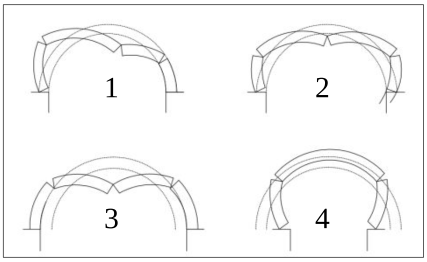


Fig 4.69: Type of collapse mechanisms of arch *(Borri, 2011).*

The first pair can be attributed a type of collapse resulting from insufficient thickness or non-symmetric load of the arch. The second pair can be attributed a type of collapse resulting insufficient support of piers. These two mechanisms do not require special explanations. However the third one occurred when the particular conditions are realized. The pressure on arch or vault must be between a minimum and maximum value. Under these conditions the structure is stable. Therefore collapse mechanism produced by minimum thrust. On the forth case, collapse mechanism produced by piers or tie rods *(Borri, 2011).*

For the triumphal arch collapse mechanism are shown on the below;

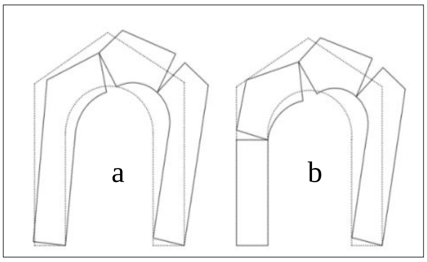


Fig 4.70: Four hinge mechanisms of collapse for the triumphal arch *(Borri, 2011).*

a) Involvement with two piers

b) Only involvement with outer pier

- Collapse analysis for complex structural systems

It is observed that, in the case study of barrel vault structures, there is a state of incipient failure of the systems. The assumption formation of the barrel vault structure is placing the arches parallel to each other. Tensile strength of the masonry structure prevents the spread of internal compression through the masonry walls. If the vertical load acts to the vault structure, it distributes the load to the masonry walls again. However the load distribution of the vault is not homogeneous on the perimeter which must be absorbed by the masonry walls *(Borri, 2011).*

The dome structures with double curvature; main axial stresses distributed in both directions (meridians and parallels) at each point of their surface. The tangential stresses arise only for asymmetric conditions of loading as under the effect of seismic activity. In these structures magnitude of the bending moment is limited, so it can be said that in these types of structures membrane behavior is due. The structural behavior of the dome structure is determined by the shape. General distribution of the stress in a dome can be observed that, along parallels of compressive stresses arise in the upper part of the dome and tensile stresses arise in the lower part of the dome. Stresses are also affected the drum at the base of the dome and it performs the function of absorbing the traction in parallel. Along the meridians, they are localized flows of compressions. When the exceeded tensile stresses occurred on the meridians and masonry damages are formed. A convenient way to build a balanced solution for a dome structure is to divide the structure into a number of segments. For each segment of the dome, the curves are identified according to the pressure. Each segment considered as an isolated however in collapse mechanisms entire segments are taken to the consideration. Moreover, the curves of pressures are occurred in dome structures and if they pass the limits the hinges are formed on the surface of the dome structures. In the collapse mechanism for the dome structures as a global acceptance; central area of the dome is not deformed however it lowered vertically. When the dome collapses, the adjacent segments are separated from one to another between the bases of the dome *(Borri, 2011).*

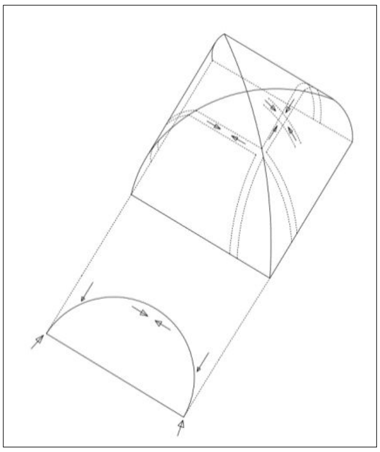


Fig 4.71: Schematic of the decomposition of the elementary pavilion vault arches *(Borri, 2011).*

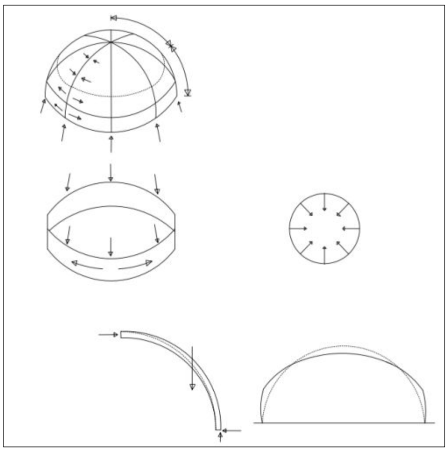


Fig 4.72: Schematic of the decomposition of the dome: distribution of the forces along the meridians of a dome, decomposition of the dome into segments, each of which is calculated as a semi-arch *(Borri, 2011).*

4.2.8. Analysis of case study bath structures

In this part; damage and collapse analysis of the four case studies of the bath structures are investigated. Each case study is analyzed according to the steps that are summarized on the previous paragraphs in the methodology part. Analyzes done in two steps as they are shown on the below paragraph.

1-Damage analysis of case study bath structures

Damage analysis of bath structures is done according to the “cell units” of the bath structure. And the damages of the cells are shown on the tables with descriptions.

2-Collapsed analysis of case study bath structures

In this part, critical damaged or collapsed parts of the structure are analyzed with the guidance of the qualitative analysis of collapse and they are examined on the following tables. In addition for the analysis, the rate of critical situation of collapsed is shown by icon in each structural unit. This icon is shown the quality of the masonry and the actions that the structural unit will be faced under the seismic actions. On the icon the ratio of the risks of the structural units is shown by the widening radius of the circle. In the below icon of the “rule of art” is shown. The objective for forming this icon is; to understand whole critical situation of the structure in general skim of the charts.

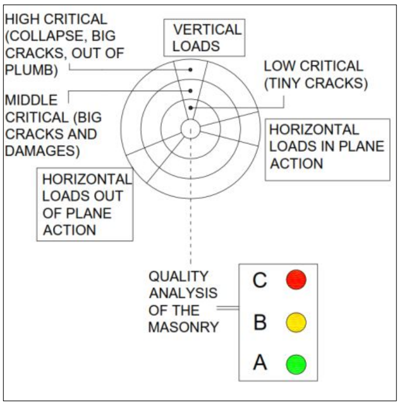


Fig 4.73: Icon for the ratio of the risks of the structural units