Seismic Resistance of Masonry Structural Systems in Albania

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Abstract— **Masonry is a building material possessing excellent properties in terms of appearance, durability and cost in comparison with alternatives. The quality of the masonry in a building depends on the materials used. All masonry materials must conform to certain minimum standards. The basic components of masonry are stone, fired or unfired brick (adobe), block and mortar. The latter is a composite of cement, lime and sand and sometimes of other constituents. Masonry has been used for construction of buildings since ancient times. Nowadays, materials like reinforced concrete and steel are used extensively. Despite of those modern construction materials, masonry buildings still represent a majority of both residential and public buildings in Albania. A wide variety of different kinds of masonry exists. In these paper are presented typical masonry structural systems in Albania and some proposals for improving the seismic resistance of these systems.**

Keywords- masonry; structural system; seismic resistance

I. INTRODUCTION

Distinction of masonry types can be made according to:
- materials used for construction (stone, adobe, brick, ceramic blocks),
- place of construction (urban or rural areas),
- period of construction (prior to World War One, between the two World Wars, post-War period, after the adoption of aseismic regulations),
- use of buildings (residential, public)
- structural system.

TABLE I. BEARING WALL CATEGORY

Type of bearing wall	Bearing Wall Category		
	Mortar Class (daN/cm^2)		
	50	25	15
1. Fired brick walls	I	II	III
2. Silicate brick	II	III	_
3. Concrete hollow blocks, Class ≥ 100	II	III	_
4. Stone bricks, Class ≥ 200			
a) regular shape	II	III	_
b) irregular shape	III	_	_

Brick masonry is used as construction material in urban areas from the last half of the XIX century onwards. The structural layout, is frequently irregular, with many offsets and setbacks. Poor quality lime-sand mortar is often used. Floors are usually of timber, sometimes brick vaults supported by steel beams, or reinforced concrete slabs.

After the World War One, reinforced concrete tie beams were introduced, increasing number of stories to 4-5 with story heights about 3-4m. Mixed structural systems are found, using reinforced concrete columns as inner load bearing elements. In that case, the number of stories is relatively small (2-4), but the storey height reach 5-6m.

During the post-war period is used the construction of apartment buildings, up to 6 stories. Load bearing walls mostly are set in transversal direction because of longitudinal walls weakened by openings. In case of reinforced concrete confined masonry the number of stories could reach up to 6.

II. STRUCTURE TYPES IN MASONRY BUILDINGS

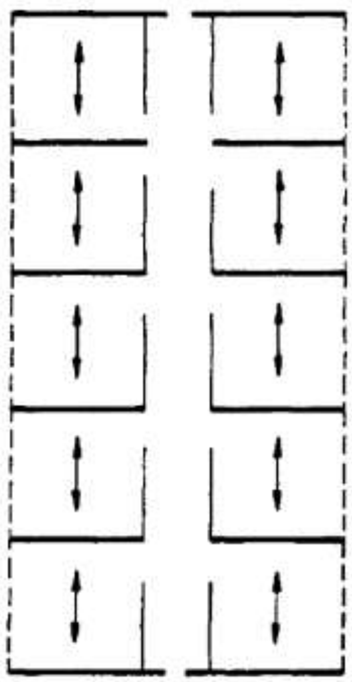
The great variety of possible wall arrangements in a masonry building makes it rather difficult to define distinct types of structure. The classification might be made as follows:

- Cellular wall systems
- Simple or double cross-wall systems
- Complex arrangements.

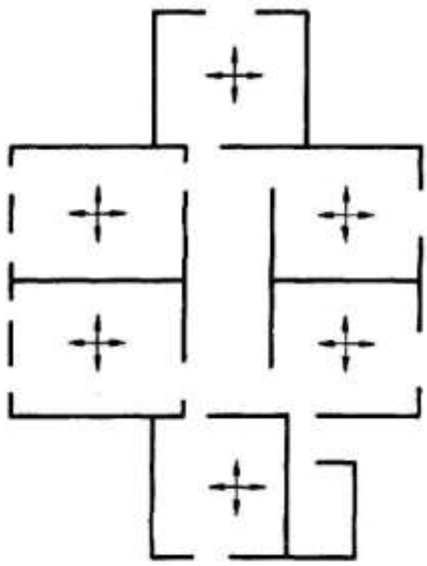
A cellular system, is one in which both internal and external walls are loadbearing. These walls form a cellular pattern in plan. Fig. 1.a shows an example of such a wall layout.

The second category includes simple cross-wall structures. The main bearing walls are at right angles to the longitudinal axis of the building. The floor slabs span between the main cross-walls. Longitudinal stability is achieved by means of corridor walls, as shown in Fig. 1b. This type of structure is suitable for a hotel building having a large number of identical rooms. The outer walls may be non-loadbearing masonry or other materials. There is a limit to the depth of building which can be constructed on the cross-wall principle, to have effective day-lighting in the rooms.

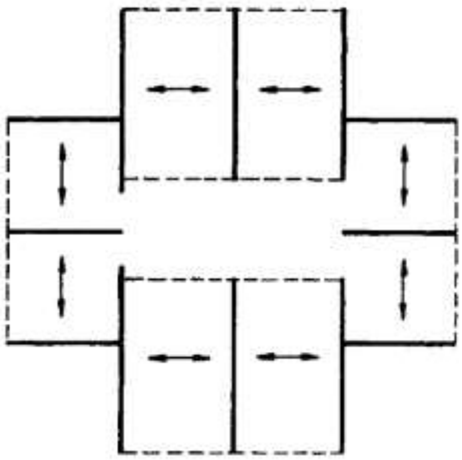
If a deeper block with a service core is required, a somewhat more complex system of cross-walls set parallel to both major axes of the building may be used, as in Fig. 1.c. All kinds of hybrids between cellular and cross-wall arrangements are possible. These are included under the heading 'complex', a typical example being shown in Fig. 1.d.



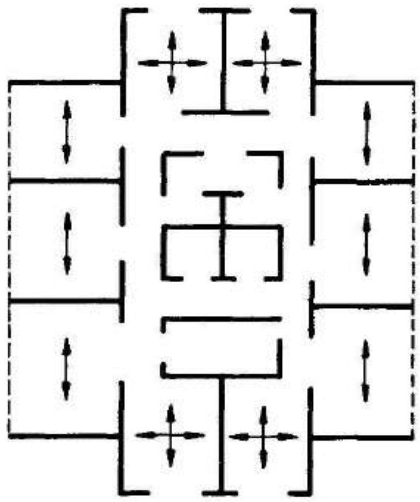
1.a. Cellular wall arrangement



1.b. Simple cross-wall structure



1.c. Double cross-wall structure



1.d Complex wall arrangements

	One-way spanning slabs	__ __	Non-loadbearing wall
	Two-way spanning slabs		Loadbearing wall

Figure 1. Typical wall arrangements in masonry buildings

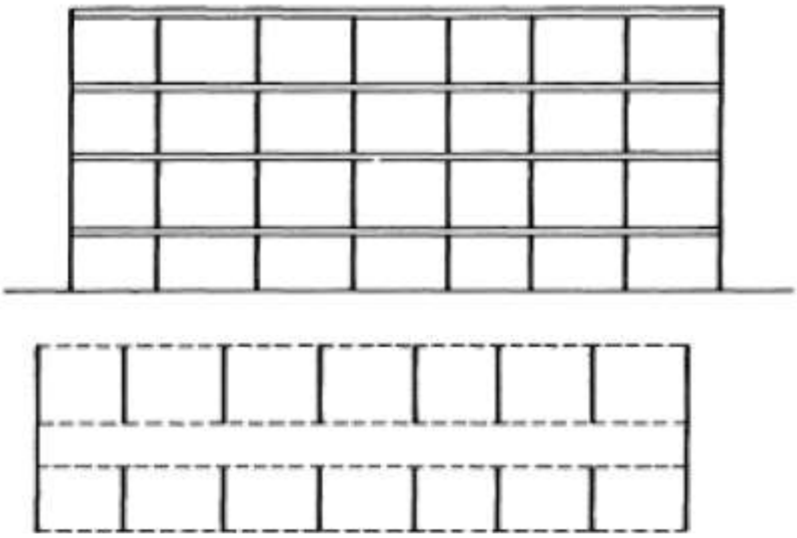
Considerable attention has been devoted in recent years to the necessity for ensuring the 'robustness' of buildings. This has arisen from a number of building failures in which, although the individual members have been adequate in terms of resisting their normal service loads. However, the building as a whole has still suffered severe damage from abnormal loading, resulting for example from a gas explosion or from vehicle impact.

It is impossible to quantify loads of this kind. The request is to construct buildings in such a way that an incident of this category does not result in catastrophic collapse, out of proportion to the initial forces. Meeting this requirement begins with the selection of wall layout since some arrangements are inherently more resistant to abnormal forces than others. This point is illustrated in Fig. 2. Building consisting only of floor slabs and cross-walls Fig. 2.a is obviously unstable and liable to collapse under the influence of small lateral forces acting parallel to its longer axis. This particular weakness could be removed by incorporating a lift shaft or stair well to provide resistance in the weak direction, as in Fig 2.b. However, the flank or gable walls are still vulnerable, for example to vehicle impact. The limited damages to this wall on the lowermost storey would result in the collapse of a large section of the building.

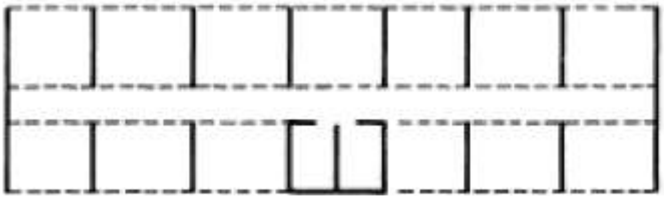
A building having a wall layout as in Fig. 2.c on the other hand is clearly much more resistant to all kinds of disturbing forces, having a high degree of lateral stability. This building does not suffer extensive damage from failure of any particular wall. Robustness is not, however, purely a matter of wall layout.

Thus a floor system consisting of unconnected precast planks will be much less resistant to damage than one which has cast-in-situ concrete floors with two-way reinforcement. Similarly, the detailing of elements and their connections is of great importance.

For example, adequate bearing of beams and slabs on walls is essential in a gravity structure. It can prevent possible failure not only from local over-stressing but also from relative movement between walls and other elements. Such movement could result from foundation settlement, thermal or moisture movements. An extreme case occurs in seismic areas where positive tying together of walls and floors is essential. The above discussion relates to multi-storey, loadbearing masonry buildings. Similar considerations apply to low-rise buildings where there is the same requirement for essentially robust construction.



2.a cross-walls without longitudinal walls: unstable



2.b cross-walls with service shaft: normally stable but vulnerable to accidental damage

2.c cross-walls with longitudinal walls and service shaft: robust construction

— — Non-structural wall
——— Structural walls

Figure 2. Liability of a simple cross-wall structure to accidental damage

II. MASONRY BUILDINGS, DESIGNED AND CONSTRUCTED ACCORDING TO ALBANIAN SEISMIC CODES

In Albania the main two types of loadbearing masonry buildings are widely spread:

1. unreinforced (non-compex or nonconfined) masonry
2. reinforced (complex or confined) masonry

Considering the response to earthquakes, adobe and stone masonry buildings are classified as low-strength structural system, suffering severe damage during earthquake.
The insufficient interlocking between intersecting walls and lack of anchorage between wall and floors must be avoid. This can cause, cracks between intersecting walls, separation of walls and even collapse out of plane.
The quality of wall materials often is insufficient to prevent the walls from diagonal cracking, disintegration and ultimate collapse. In case of old brick masonry buildings, the unfavorable effect is caused from insufficient

anchorage between walls and floors. Irregular structural layout in plan, large openings, lack of bearing walls in both orthogonal direction often cause severe damage or collapse of buildings.

The unsatisfactory behavior of brick masonry buildings often result from the poor quality of materials used for construction, especially mortar.

Also poor behavior results in mixed structural type buildings, because the lateral load resisting system concentrated in outer walls, often perforated by many openings. Poor behavior presents also masonry structural system with load bearing walls in one direction only.

Masonry buildings, designed and constructed according to seismic codes, behaves more or less satisfactory. Cases of collapse and heavy damage occur unfrequently.

Earthquake protection regulations, during the 1960-'80 period up to nowadays, introduced several measures to improve the earthquake resistance of masonry buildings. These regulations required the use of RC horizontal tie-beams and the uniform distribution of walls in both orthogonal directions.

In aseismic design the constructional measures are very important. The seismic damage investigation provides very important experience. Great attention must be concentrated on the research work in aspect of improving the seismic resistance reducing the earthquake responses.

In that view some general requirements to improve seismic resistance are:

A. Aseismic Joint

Discontinuity in plan and elevation results in quite different stiffness of building parts. Those are cases in which one part of building is higher than another, slabs are not in the same elevation etc.

The local failure during strong earthquake can be avoid through seismic joints arranged on different parts of masonry building.

In case of reinforced masonry the above case is not so serious during earthquake. However the seismic joints arrangements are suggested in reinforced masonry, as well.

So, if aseismic joints are needed does not depend upon the site condition and structure characteristic. The purpose of arranging the aseismic joints is to reduce the earthquake response.

B. Arrangement of Aseismic Walls

Masonry building with transversal bearing wall is better than that with longitudinal bearing wall in regard to seismic capacity.

The spacing of aseismic wall in a masonry building shall be limited. According to Albanian seismic Code (KTP-N.2-1989) the spacing is stipulated as in Table II.

In case of reinforced masonry buildings the maximum spacing given in Table II should be multiply by coefficient 1.5.

TABLE II. MAXIMUM SPACING OF TRANSVERSAL BEARING WALLS

Seismic Intensity	Maximum spacing of transversal bearing walls (m)		
	Category of longitudinal bearing walls		
	I	II	III
7	11	10	4.5
8	9	8	4.5
9	7	5	4.5

C. Total Height of Unreinforced Masonry Building

It is known that the stiffness of unreinforced masonry building depends on the height of the building. The response of higher masonry building is stronger than that of lower. The maximum height (number of stories) of masonry building shall be limited as it is given in Table III.

TABLE III. MAXIMUM HEIGHT. MAXIMUM STORIES NUMBER

Type of Masonry Building	Maximum height (maximum stories number) (m)		
	Seismic Intensity		
	7	8	9
Confined (reinforced) masonry			
a) Bearing wall category I	20(6)	17(5)	13(4)
b) Bearing wall category II	17(5)	13(4)	10(3)
Un-Confined (unreinforced) masonry			
a) Bearing wall category I	17(5)	13(4)	10(3)
b) Bearing wall category II	13(4)	10(3)	6(2)
c) Bearing wall category III	6(2)	6(2))	3(1)

III. Specific requirements to improve seismic resistance

A. Closed beam

Arranging of closed reinforced beam at every storey, improve the seismic capacity of unreinforced masonry building during earthquake. The reason is that the closed beams improve the integrity of masonry, increase the stiffness and confine the cracks during earthquake.

B. Constructional Column

When the masonry building is strengthened with "constructional columns", its aseismic capacity is improved. The minimum section of "constructional columns" is 25x25cm with 4 longitudinal bars, diameter of which is 12mm. The column should be anchoraged in the footing beam. In order to connect with the walls, 2 embedded steel bars in diameter 6mm with spacing of 50cm along the constructional column shall be anchoraged in masonry wall in length of 1m.

C. Cast in Site Reinforced Concrete Slab

The cast in site reinforced concrete slab has a good behavior for diaphragm in masonry building due to its rigidity and monolithic.

D. Precast Reinforced Concrete Slab

In case of precast, reinforced concrete slab should be connected with wall by embedded steel.

E. Wooden Slab

Because of relatively weaker rigidity of wooden slab it is effective to connect it with loadbearing wall through steel connectors.

F. Connection between Internal and External Walls

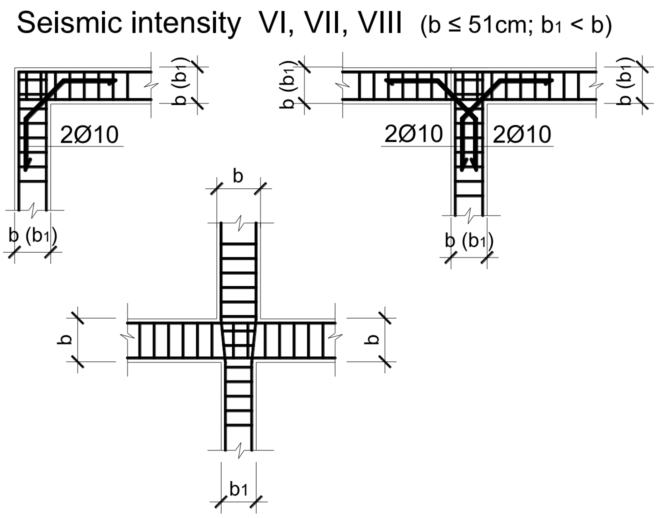
The use of steel, shown in Fig.3 improve the connection between internal and external walls.

G. Corner of External Walls

The use of steel, shown in Fig. 3 improve the connection between external transversal and longitudinal walls of masonry building.

E. Local Minimum Dimensions of Masonry Buildings

In order to improve seismic resistance of masonry building it should be limited the maximum dimension of the openings. In any case the pier of masonry should not be less than 1 m or 2/3 of the opening.



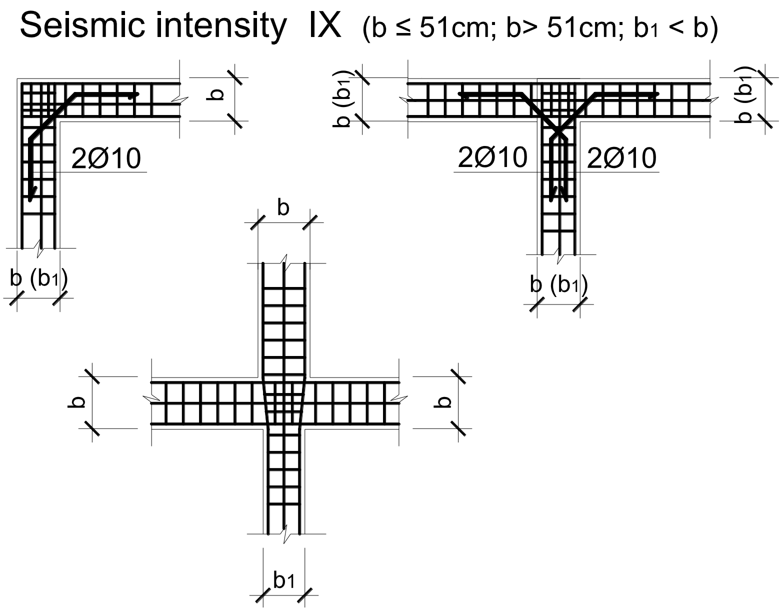


Figure 3. Connection between Internal and External Walls

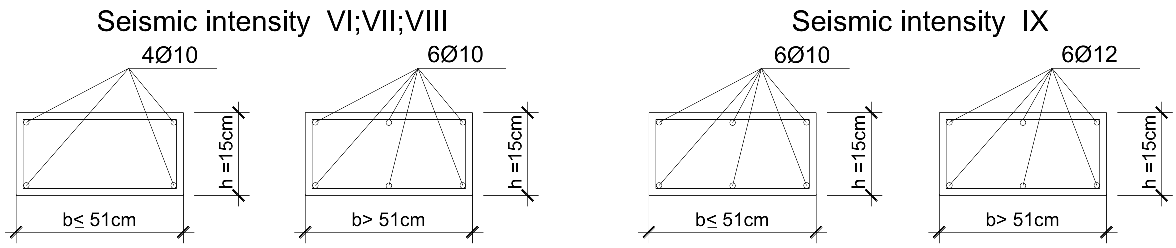


Figure 4. Antiseismic belt

IV. ADVANTAGES AND FUTURE TRENDS

The possible to use the same brick element in different solutions is the basic advantage of masonry building. Masonry may provide subdivision of space, thermal, acoustic insulation, fire and weather protection. As a material, it is relatively cheap and durable.

In the past loadbearing walls were designed by empirical rules, with thick walls that waste lot of material, space and time to build.

The future trend in Albania is wider use of masonry building mostly in suburban areas where clay as brick material can be found easily.

Also, introduction of structural codes which make possible to calculate the wall thickness and strength more rationally. So, those code refinements based on serious research can provide a basis for design of multistory reinforced masonry buildings above actual height limits.

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