World Housing Encyclopedia

an Encyclopedia of Housing Construction in
Seismically Active Areas of the World

an initiative of
Earthquake Engineering Research Institute (EERI) and
International Association for Earthquake Engineering (IAEE)

HOUSING REPORT
Load-bearing stone masonry building

Report #	16
Report Date	06-05-2002
Country	GREECE
Housing Type	Stone Masonry House
Housing Sub-Type	Stone Masonry House : Rubble stone without/with mud/lime/cement mortar
Author(s)	T. P. Tassios, Kostas Syrmakezis
Reviewer(s)	Craig D. Comartin

Summary

These buildings are mainly found in the historical centers of Greek cities and provinces. The main load-bearing structure consists of stone masonry walls. The walls are built using local field stones and lime mortar. The floors and roof are of timber construction. The seismic performance is generally poor. Diagonal cracking at the horizontal and vertical joints are the common type of damage.

1. General Information

Buildings of this construction type can be found in historical cities of Greece. Perhaps 10% of housing stock in the region. This type of housing construction is commonly found in both rural and urban areas. This construction type has been in practice for more than 200 years.

Currently, this type of construction is being built. Only in historic districts, however.

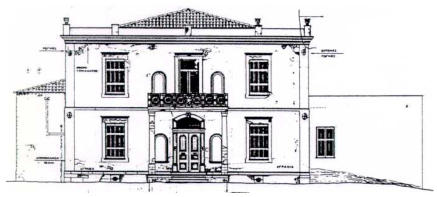

Figure 1: Typical Building

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat, sloped and hilly terrain. They do not share common walls with adjacent buildings. The typical separation distance between buildings is 5 meters and more as a rule When separated from adjacent buildings, the typical distance from a neighboring building is 5 meters.

2.2 Building Configuration

Typical shape of a building plan is mainly rectangular. The building has eleven openings per floor, of an average size of 3.5 m² each. The estimated opening area to the total wall surface is 18%. This is relevant to the resistance of this type of building.

2.3 Functional Planning

The main function of this building typology is single-family house. It is very common to find these historic buildings used for commercial purposes. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. Buildings do not have special means of escape besides main exit.

2.4 Modification to Building

Usually demolition of interior load bearing walls, or partial demolition for the insertion of an opening.

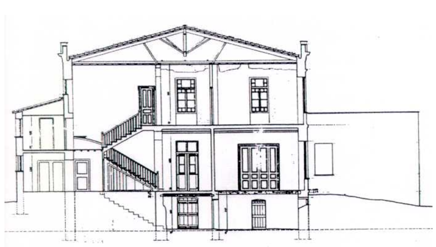

Figure 2A: Key Load-bearing Elements

Figure 2B: A View of a Typical Building

3. Structural Details

3.1 Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
Masonry	Stone Masonry Walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	☑
		2	Dressed stone masonry (in lime/cement mortar)	☐
	Adobe/ Earthen Walls	3	Mud walls	☐
		4	Mud walls with horizontal wood elements	☐
		5	Adobe block walls	☐
		6	Rammed earth/Pise construction	☐
	Unreinforced masonry walls	7	Brick masonry in mud/lime mortar	☐
		8	Brick masonry in mud/lime mortar with vertical posts	☐
		9	Brick masonry in lime/cement mortar	☐
		10	Concrete block masonry in cement mortar	☐
	Confined masonry	11	Clay brick/tile masonry, with wooden posts and beams	☐
		12	Clay brick masonry, with concrete posts/tie columns and beams	☐
		13	Concrete blocks, tie columns and beams	☐
	Reinforced masonry	14	Stone masonry in cement mortar	☐
		15	Clay brick masonry in cement mortar	☐
		16	Concrete block masonry in cement mortar	☐
Structural concrete	Moment resisting frame	17	Flat slab structure	☐
		18	Designed for gravity loads only, with URM infill walls	☐
		19	Designed for seismic effects, with URM infill walls	☐
		20	Designed for seismic effects, with structural infill walls	☐
		21	Dual system – Frame with shear wall	☐
	Structural wall	22	Moment frame with in-situ shear walls	☐
		23	Moment frame with precast shear walls	☐
	Precast concrete	24	Moment frame	☐
		25	Prestressed moment frame with shear walls	☐
		26	Large panel precast walls	☐
		27	Shear wall structure with walls cast-in-situ	☐
		28	Shear wall structure with precast wall panel structure	☐
	Moment-resisting frame	29	With brick masonry partitions	☐
		30	With cast in-situ concrete walls	☐
		31	With lightweight partitions	☐

Steel	Braced frame	32	Concentric connections in all panels	☐
		33	Eccentric connections in a few panels	☐
	Structural wall	34	Bolted plate	☐
		35	Welded plate	☐
Timber	Load-bearing timber frame	36	Thatch	☐
		37	Walls with bamboo/reed mesh and post (Wattle and Daub)	☐
		38	Masonry with horizontal beams/planks at intermediate levels	☐
		39	Post and beam frame (no special connections)	☐
		40	Wood frame (with special connections)	☐
		41	Stud-wall frame with plywood/gypsum board sheathing	☐
		42	Wooden panel walls	☐
Other	Seismic protection systems	43	Building protected with base-isolation systems	☐
		44	Building protected with seismic dampers	☐
	Hybrid systems	45	other (described below)	☐

3.2 Gravity Load-Resisting System

The vertical load-resisting system is timber frame load-bearing wall system. - Load bearing walls - Timber or metal strengthening elements.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is un-reinforced masonry walls. The main lateral load-resisting system consists of unreinforced stone masonry bearing walls. Floors and roof are wood structures. The wall layout in plan is critical for the lateral performance of this construction type. Also, the wall connections and roof/floor-to-wall connections are the critical elements of the lateral load resistance. The materials and type of construction are the most important factors affecting the seismic performance of these buildings.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 10 and 10 meters, and widths between 15 and 15 meters. The building has 2 to 3 storey(s). The typical span of the roofing/flooring system is 5 meters. The typical storey height in such buildings is 3-4 meters. The typical structural wall density is more than 20 %. Total wall area/plan area (for each floor) 30-40%.

3.5 Floor and Roof System

Material	**Description of floor/roof system**	**Most appropriate floor**	**Most appropriate roof**
Masonry	Vaulted	☐	☐
	Composite system of concrete joists and masonry panels	☐	☐
	Solid slabs (cast-in-place)	☐	☐
	Waffle slabs (cast-in-place)	☐	☐
	Flat slabs (cast-in-place)		

Structural concrete		☐	☐
	Precast joist system	☐	☐
	Hollow core slab (precast)	☐	☐
	Solid slabs (precast)	☐	☐
	Beams and planks (precast) with concrete topping (cast-in-situ)	☐	☐
	Slabs (post-tensioned)	☐	☐
Steel	Composite steel deck with concrete slab (cast-in-situ)	☐	☐
Timber	Rammed earth with ballast and concrete or plaster finishing	☐	☐
	Wood planks or beams with ballast and concrete or plaster finishing	☑	☐
	Thatched roof supported on wood purlins	☐	☐
	Wood shingle roof	☐	☐
	Wood planks or beams that support clay tiles	☐	
	Wood planks or beams supporting natural stones slates	☐	☐
	Wood planks or beams that support slate, metal, asbestos-cement or plastic corrugated sheets or tiles	☐	☐
	Wood plank, plywood or manufactured wood panels on joists supported by beams or walls	☐	☐
Other	Described below	☑	☑

The floors and roofs are considered to be rather flexible.

3.6 Foundation

Type	Description	Most appropriate type
Shallow foundation	Wall or column embedded in soil, without footing	☐
	Rubble stone, fieldstone isolated footing	☐
	Rubble stone, fieldstone strip footing	☑
	Reinforced-concrete isolated footing	☐
	Reinforced-concrete strip footing	☐
	Mat foundation	☐
	No foundation	☐
Deep foundation	Reinforced-concrete bearing piles	☐
	Reinforced-concrete skin friction piles	☐
	Steel bearing piles	☐
	Steel skin friction piles	☐
	Wood piles	☐
	Cast-in-place concrete piers	☐
	Caissons	☐
Other	Described below	☐

Masonry footings (footing width by 300 mm greater as compared to the walls).

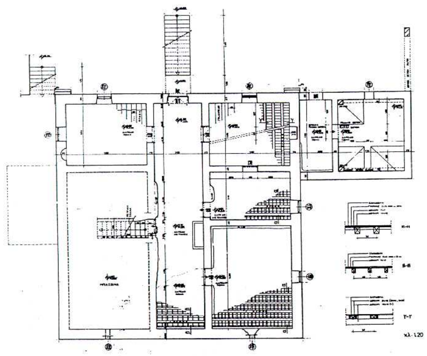

Figure 3: Plan of a Typical Building

Figure 4: Critical Structural Details

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). 1 units in each building. Usually there are 1-2 units in each building The number of inhabitants in a building during the day or business hours is less than 5. The number of inhabitants during the evening and night is 5-10.

4.2 Patterns of Occupancy

One or two families per housing unit.

4.3 Economic Level of Inhabitants

Income class	Most appropriate type
a) very low-income class (very poor)	☐
b) low-income class (poor)	☐
c) middle-income class	☑
d) high-income class (rich)	☑

It is primarily the wealthy who can afford to live in these buildings, when they are used for housing.

Ratio of housing unit price to annual income	Most appropriate type
5:1 or worse	☐
4:1	☐
3:1	☐
1:1 or better	☑

What is a typical source of	

financing for buildings of this type?	Most appropriate type
Owner financed	☑
Personal savings	☐
Informal network: friends and relatives	☐
Small lending institutions / micro-finance institutions	☐
Commercial banks/mortgages	☐
Employers	☐
Investment pools	☐
Government-owned housing	☐
Combination (explain below)	☐
other (explain below)	☐

In each housing unit, there are 1 bathroom(s) without toilet(s), no toilet(s) only and 1 bathroom(s) including toilet(s).

Housing unit has 1 or 2 bathrooms. .

4.4 Ownership

The type of ownership or occupancy is outright ownership.

Type of ownership or occupancy?	Most appropriate type
Renting	☐
outright ownership	☑
Ownership with debt (mortgage or other)	☐
Individual ownership	☐
Ownership by a group or pool of persons	☐
Long-term lease	☐
other (explain below)	☐

5. Seismic Vulnerability

5.1 Structural and Architectural Features

Structural/ Architectural Feature	Statement	Most appropriate type		
		True	False	N/A
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial forces from the building to the foundation.	☐	☑	☐
Building Configuration	The building is regular with regards to both the plan and the elevation.	☑	☐	☐
Roof construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e. shape and form, during an earthquake of intensity expected in this area.	☐	☑	☐
	The floor diaphragm(s) are considered to be rigid and it			

Floor construction	is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.	☐	☑	☐
Foundation performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.	☑	☐	☐
Wall and frame structures- redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	☑	☐	☐
Wall proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);	☑	☐	☐
Foundation-wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	☑	☐	☐
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps	☐	☑	☐
Wall openings	The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; For precast concrete wall structures: less than 3/4 of the length of a perimeter wall.	☑	☐	☐
Quality of building materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	☐	☑	☐
Quality of workmanship	Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).	☐	☑	☐
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber)	☐	☑	☐
Additional Comments				

5.2 Seismic Features

Structural Element	**Seismic Deficiency**	**Earthquake Resilient Features**	**Earthquake Damage Patterns**
Wall	Rubble stone and lime mortar. The system has low tensile and shear strength, especially for out-of-plane seismic effects. Presence of large openings reduces the strength of the bearing walls.		Stone masonry walls were damaged in the 1999 Athens earthquake. The damage included partial collapse of external walls, collapse of corners, separation of the two walls converging at a corner, and extensive cracking (Source: EERI)
Integral structural behavior.		The presence of reinforced concrete ring beams at the roof and floors levels as well as vertical confining elements (RC beams) near the opening, significantly improve the structural behavior.	
Roof and floors	Usually they consist of wooden elements, thus diaphragm behavior and good connections with masonry walls cannot	Even for steel and timber floors/roof the presence of stiffness leads to a rigid diaphragm which is highly desired.	Extensive masonry cracking, due to low tensile and shear strength and unsatisfactory diaphragm action

	be ensured.		of the horizontal members.

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is *A: HIGH VULNERABILITY (i.e., very poor seismic performance)*, the lower bound (i.e., the worst possible) is A: HIGH VULNERABILITY (i.e., very poor seismic performance), and the upper bound (i.e., the best possible) is *B: MEDIUM-HIGH VULNERABILITY (i.e., poor seismic performance)*.

Vulnerability	high	medium-high	medium	medium-low	low	very low
	very poor	poor	moderate	good	very good	excellent
Vulnerability Class	A	B	C	D	E	F
	☑	☑	☐	☐	☐	☐

5.4 History of Past Earthquakes

Date	Epicenter, region	Magnitude	Max. Intensity
1996	Aegion	6.1	MSK
1999	Athens	5.9	IX, MSK

On September 7, 1999, at 14:56 local time, a strong earthquake occurred 18 kilometers northwest of the center of Athens. The earthquake was magnitude Ms =5.9 and the coordinates of the epicenter were located at 38.12-23.64, in the area of Parnitha mountain. This earthquake came as a surprise, since no seismic activity was recorded in this region for the last 200 years. According to strong-motion recordings, the range of significant frequencies is approximately 1.5-10 Hz, while the range of the horizontal peak ground acceleration were between 0.04 to 0.36g. The most heavily damaged areas lie within a 15 km radius from the epicenter. The consequences of the earthquake were significant: 143 people died and more than 700 were injured. The structural damage was also significant, since 2,700 buildings were destroyed or were damaged beyond the repair and another 35,000 buildings experienced repairable damage. According to the EERI Reconnaissance report (see References), in the mezoseismal area, most stone masonry structures with undressed stones, constructed in the first half of the century, suffered significant damage. This included partial collapse of external walls, collapse of corners, separation of the two walls converging at a corner, and extensive cracking.

Figure 5A: Typical Earthquake Damage - Shear Cracking of Masonry Walls (1999 Athens earthquake)


Figure 5B: Typical Earthquake Damage - Falling of Plaster and Shear Cracking of the Walls (1999 Athens Earthquake)


Figure 5C: Partial Collapse of a Stone Masonry House in Nea Philadelphia (1999 Athens earthquake); Source: EERI

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Rubble stone Mortar.	Stone: Compressive strength = 80 MPa Mortar: Tensile strength = 0.1 to 0.2 MPa.	lime/sand mortar.	
Foundation	Rubble stone Mortar.	Stone: Compressive strength=80 MPa Mortar: Tensile strength= 0.1 to 0.2 MPa.	lime/sand mortar.	
Frames (beams & columns)				
Roof and floor(s)	Timber.			

6.2 Builder

The builders (usually traditional artisans) live in this construction type.

6.3 Construction Process, Problems and Phasing

Traditional builders. Stones from the area and mortar made in situ. The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size.

6.4 Design and Construction Expertise

Experience of traditional builders. Engineers and architects play an important role during the repair and strengthening of this type of structures.

6.5 Building Codes and Standards

This construction type is not addressed by the codes/standards of the country.

Experience. European Codes.

6.6 Building Permits and Development Control Rules

This type of construction is a non-engineered, and not authorized as per development control rules.

This type of structure was constructed without any explicit design requirements. Building permits are not required to build this housing type.

6.7 Building Maintenance

Typically, the building of this housing type is maintained by Owner(s).

6.8 Construction Economics

Since this is a construction method that is no longer practiced, values for unit construction costs are not available. Information not available.

7. Insurance

Earthquake insurance for this construction type is typically unavailable. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is unavailable.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Roofs/floors	- Strengthening of wall-floor connections; - Strengthening of diaphragms;
Stone masonry walls	- Crack repair (see Figure 6A); - Installation of RC belts or ties; - Deep repointing and installation of RC jackets (see Figure 6C); - Strengthening of wall intersections (see Figure 6B)

The first step in the seismic strengthening is the deep repointing of the wall. This technique improves the tensile strength of the wall (up to 10 times). Subsequently, cement-mortar injections are applied (if required) for the further improvement - homogenization of the wall. Finally, RC jacket is applied on the wall surface (Figure 6C). The overall structural resistance is greatly improved since the reinforcement (provided in concrete jacket) is activated at the critical cracking point.

8.2 Seismic Strengthening Adopted

Has seismic strengthening described in the above table been performed in design and construction practice, and if so, to what extent?

Yes, to a great extent.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?

Repair following the earthquake damage.

8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?

Yes.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?

The construction is usually performed by a contractor, not always with the involvement - supervision of an architect and/or a civil engineer.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?

The performance was satisfactory.

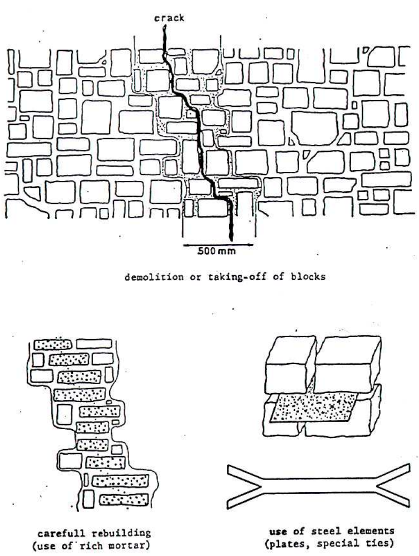

Figure 6A: Illustration of Seismic-strengthening Techniques

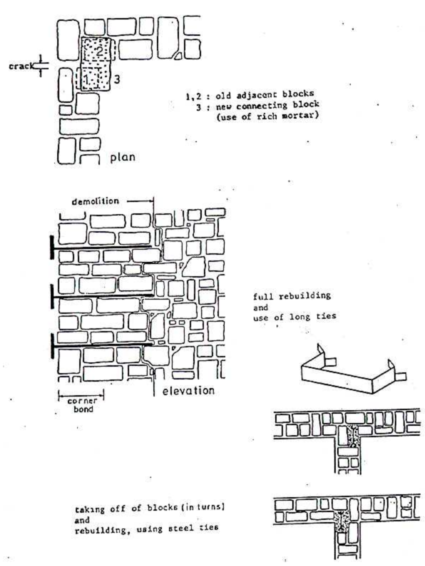

Figure 6B: Seismic Strengthening of Wall Intersections

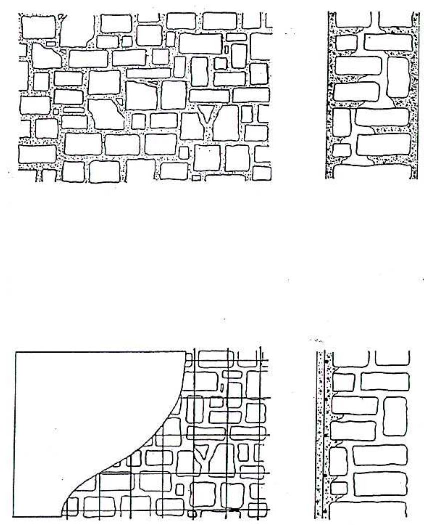
Figure 6C: Seismic-strengthening Techniques - A detail of repointing and the installation of RC jacket

Reference(s)

1. Report on the 1999 Athens Earthquake
   ITSAK
   Institute of Engineering Seismology and Earthquake Engineering, Thessaloniki, Greece (www.itsak.gr) 1999

2. The Athens, Greece Earthquake of September 7, 1999
   EERI Special Earthquake Report (www.eeri.org/earthquakes/Reconn/Greece1099/Greece1099.html) 1999

Author(s)

1. T. P. Tassios
   Professor, National Technical University of Athens
   9 Iroon Polytechniou, Zographou Athens 15780, GREECE
   Email:tassiost@central.ntua.gr FAX: +301 8045139

2. Kostas Syrmakezis
   Professor, National Technical University of Athens
   9 Iroon Polytechniou, Zographou Athens 15780, GREECE
   Email:isaarsyr@central.ntua.gr FAX: +301 7721582

Reviewer(s)

1. Craig D. Comartin
   President
   , C.D. Comartin Associates
   Stockton CA 95207-1705, USA
   Email:ccomartin@comartin.net FAX: (209) 472-7294