World Housing Encyclopedia

A Resource on Construction in Earthquake Regions

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

HOUSING REPORT
Loadbearing stone masonry building

Report#	16
Last Updated	
Country	Greece
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Important

participant’s organizations.

General Information

Building Type:	Loadbearing stone masonry building
Country:	Greece
Author(s):	T. P. Tassios Kostas Syrmakezis
Last Updated:	
Regions Where Found:	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.
Summary:	These buildings are mainly found in the historical centers of Greek cities and provinces. The main loadbearing 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.
Length of time practiced:	More than 200 years
Still Practiced:	Yes
In practice as of:	
Building Occupancy:	Single dwelling
Typical number of stories:	2-3
Terrain-Flat:	Typically
Terrain-Sloped:	Typically
Comments:	Currently, this type of construction is being built. Only in historic districts, however. The main function of this building ty

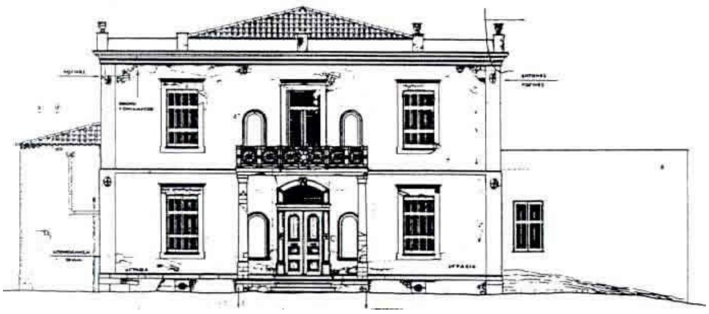
Features

Plan Shape	Rectangular, solid
Additional comments on plan shape	

Typical plan length (meters)	10
Typical plan width (meters)	15
Typical story height (meters)	41702
Type of Structural System	Masonry: Stone Masonry Walls: Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)
Additional comments on structural system	The vertical load-resisting system is timber frame load-bearing wall system. - Load bearing walls - Timber or metal strengthening elements. The lateral load-resisting system is unreinforced 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.
Gravity load-bearing & lateral load-resisting systems	
Typical wall densities in direction 1	>20%
Typical wall densities in direction 2	>20%
Additional comments on typical wall densities	The typical structural wall density is more than 20 %. Total wall area/plan area (for each floor) 30-40%.
Wall Openings	The building has eleven openings per floor, of an average size of 3.5 sq m each. The estimated opening area to the total wall surface is 18%. This is relevant to the resistance of this type of building.
Is it typical for buildings of this type to have common walls with adjacent buildings?	No
Modifications of buildings	Usually demolition of interior load bearing walls, or partial demolition for the insertion of an opening.
Type of Foundation	Shallow Foundation: Rubble stone, fieldstone strip footing
Additional comments on foundation	Masonry footings (footing width by 300 mm greater as compared to the walls).
Type of Floor System	Other floor system
Additional comments on floor system	Wood planks or beams with ballast and concrete or plaster finishing; The floors and roofs are considered to be rather flexible.

Type of Roof System	Roof system, other
Additional comments on roof system	The floors and roofs are considered to be rather flexible.
Additional comments section 2	When separated from adjacent buildings, the typical distance from a neighboring building is 5 meters.

Key Load-bearing Elements



A View of a Typical Building

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	Rubble stone Mortar	Stone: Compressive strength= 80 MPa Mortar: Tensile strength= 0.1 to 0.2 MPa lime/sand mortar
Foundations	Rubble stone Mortar	Stone: Compressive strength= 80 MPa Mortar: Tensile strength= 0.1 to 0.2 MPa lime/sand mortar
Floors	timber	
Roof	timber	
Other		

Design Process

Who is involved with the design process?	Other
Roles of those involved in the design process	

Expertise of those involved in the design process	Engineers and architects play an important role during the repair and strengthening of this type of structures.

Construction Process

Who typically builds this construction type?	MasonBuilder
Roles of those involved in the building process	The builders (usually traditional artisans) live in this construction type.
Expertise of those involved in building process	Experience of traditional builders.
Construction process 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.
Construction issues	

Building Codes and Standards

Is this construction type address by codes/standards?	No
Applicable codes or standards	Experience. European Codes.
Process for building code enforcement	

Building Permits and Development Control Rules

Are building permits required?	No
Is this typically informal construction?	Yes
Is this construction typically authorized as per development control rules?	No
Additional comments on building permits and development control rules	This type of structure was constructed without any explicit design requirements. Building permits are not required to build this housing type.

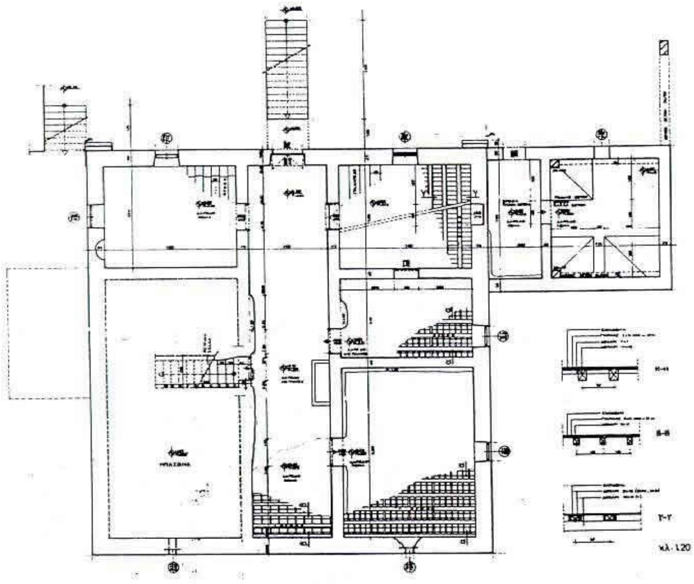
Building Maintenance and Condition

Typical problems associated with this type of construction	
Who typically maintains buildings of this type?	Owner(s)

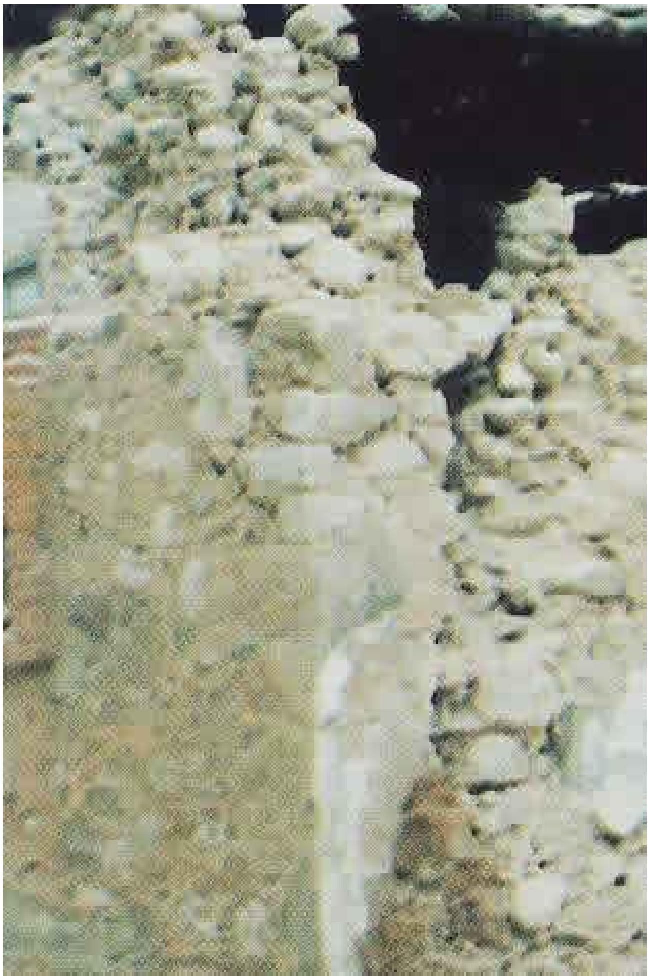
Additional comments on maintenance and building condition	

Construction Economics

Unit construction cost	Since this is a construction method that is no longer practiced, values for unit construction costs are not available.
Labor requirements	Information not available.
Additional comments section 3	



Plan of a Typical Building



Critical Structural Details

Socio-Economic Issues

Patterns of occupancy	One or two families per housing unit. Usually there are 1-2 units in each building.

Number of inhabitants in a typical building of this construction type during the day	<5
Number of inhabitants in a typical building of this construction type during the evening/night	5-10
Additional comments on number of inhabitants	
Economic level of inhabitants	Middle-income classHigh-income class (rich)
Additional comments on economic level of inhabitants	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: 1:1 or better
Typical Source of Financing	Owner financed
Additional comments on financing	
Type of Ownership	Own outright
Additional comments on ownership	
Is earthquake insurance for this construction type typically available?	No
What does earthquake insurance typically cover/cost	
Are premium discounts or higher coverages available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features?	No
Additional comments on premium discounts	
Additional comments section 4	

Earthquakes

Past Earthquakes in the country which affected buildings of this type

Year	Earthquake Epicenter

1996	Aegion
1999	Athens

Past Earthquakes

Damage patterns observed in past earthquakes for this construction type	On September 7, 1999, at 14:56 local time, a strong earthquake occurred 18 kilometres northwest of the center of Athens. The earthquake was magnitude .s =5.9 and the coordinates of the epicentre 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 accelerations were between 0.04 to 0.36g. The most heavily damaged areas lie within a 15 km radius from the epicentre. 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 meizoseismal 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.
Additional comments on earthquake damage patterns	Wall: 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) Roof/floors: Extensive masonry cracking, due to low tensile and shear strength and unsatisfactory diaphragm action of the horizontal members.

Structural and Architectural Features for Seismic Resistance

The main reference publication used in developing the statements used in this table is FEMA 310 “Handbook for the Seismic Evaluation of Buildings-A Pre-standard”, Federal Emergency Management Agency, Washington, D.C., 1998.

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.

Structural/Architectural Feature	Statement	Seismic Resistance
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.	FALSE
Building Configuration-Vertical	The building is regular with regards to the elevation. (Specify in 5.4.1)	TRUE
Building Configuration-Horizontal	The building is regular with regards to the plan. (Specify in 5.4.2)	TRUE
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.	FALSE
Floor Construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.	FALSE
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.	TRUE
Wall and Frame Structures-Redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	TRUE
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	TRUE

	(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.	TRUE
Wall-Roof Connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps.	FALSE
Wall Openings		TRUE
Quality of Building Materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	FALSE
Quality of Workmanship	Quality of workmanship (based on visual inspection of a few typical buildings) is considered to be good (per local construction standards).	FALSE
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).	FALSE

Building Irregularities

Additional comments on structural and architectural features for seismic resistance	
Vertical irregularities typically found in this construction type	Other
Horizontal irregularities typically found in this construction type	Other
	Rubble stone and lime mortar. The system has low tensile

Seismic deficiency in walls	and shear strength, especially for out-of-plane seismic effects. Presence of large openings reduces the strength of the bearing walls.
Earthquake-resilient features in walls	
Seismic deficiency in frames	
Earthquake-resilient features in frame	
Seismic deficiency in roof and floors	Usually they consist of wooden elements, thus diaphragm behaviour and good connections with masonry walls cannot be ensured.
Earthquake resilient features in roof and floors	Even for steel and timber floors/roof the presence of stiffness leads to a rigid diaphragm which is highly desired.
Seismic deficiency in foundation	
Earthquake-resilient features in foundation	

Seismic Vulnerability Rating

For information about how seismic vulnerability ratings were selected see the Seismic Vulnerability Guidelines

	High vulnerability		**Medium vulnerability**		**Low vulnerability**	
	A	B	C	D	E	F
Seismic vulnerability class	o	-|				

Typical Earthquake Damage - Shear Cracking of Masonry Walls (1999 Athens earthquake)

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

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

Retrofit Information

Description of Seismic Strengthening Provisions

Structural Deficiency	Seismic Strengthening
Roofs/floors	- Strengthening of wall-floor connections; - Strengthening of diaphragms;
Stone masonry walls	- Crack repair (see Figure 9); - Installation of RC belts or ties; - Deep repointing and installation of RC jackets (see Figure 11); - Strengthening of wall intersections (see Figure 10)

Additional comments on seismic strengthening provisions	The frist 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 10). The overall structural resistance is greatly improved since the reinforcement (provided in concrete jacket) is activated at the critical cracking point.
Has seismic strengthening described in the above table been performed?	Yes, to a great extent.
Was the work done as a mitigation effort on an undamaged building or as a repair following earthquake damages?	Repair following the earthquake damage.
Was the construction inspected in the same manner as new construction?	Yes
Who performed the construction: 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 has been the performance of retrofitted buildings of this type in subsequent earthquakes?	The performance was satisfactory.
Additional comments section 6	

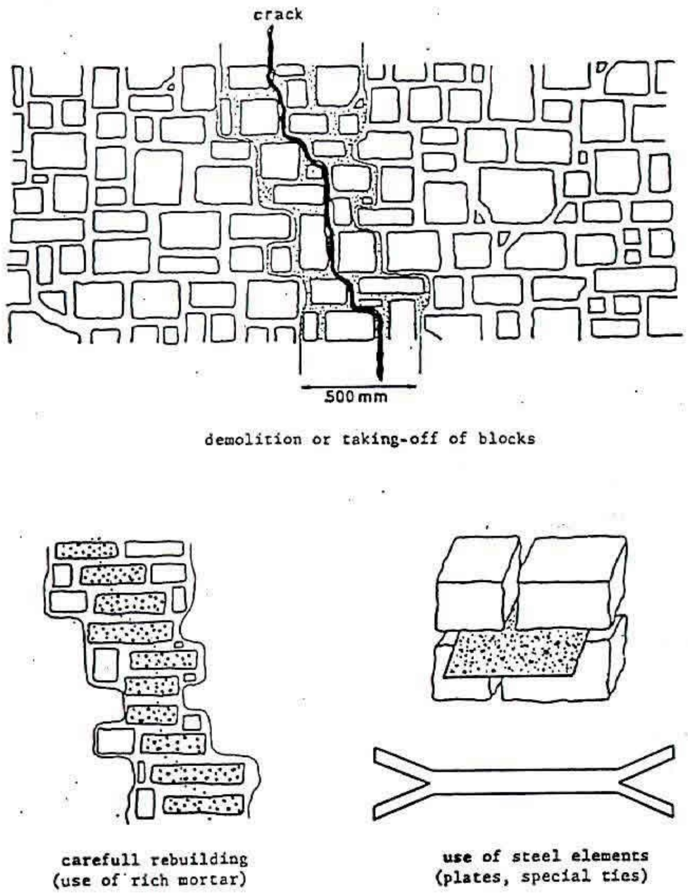
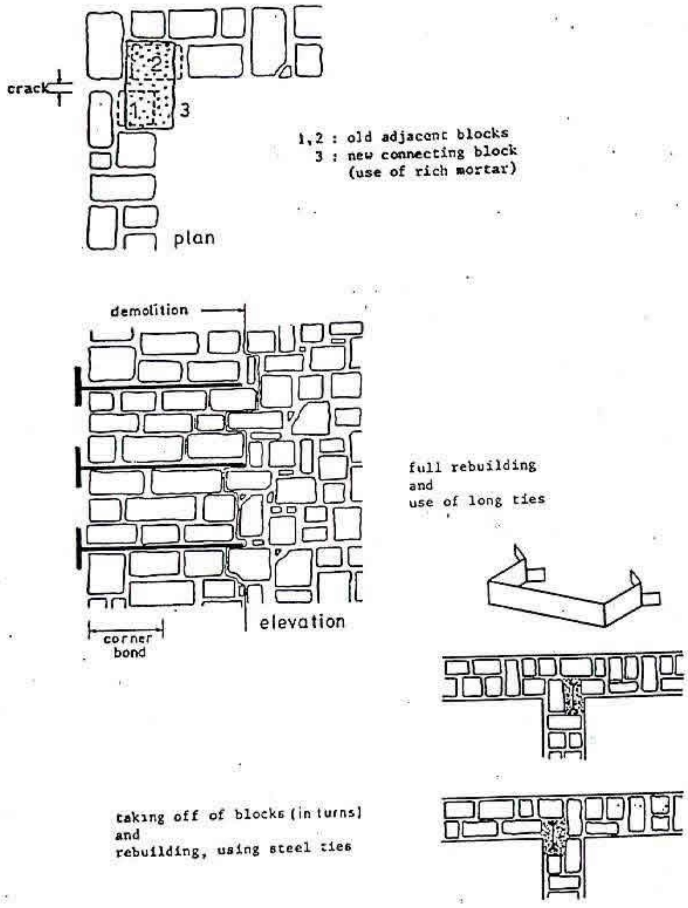
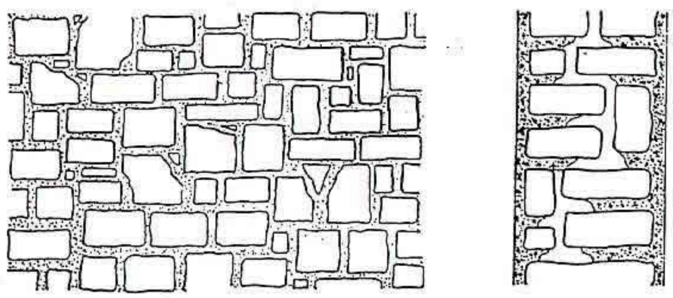
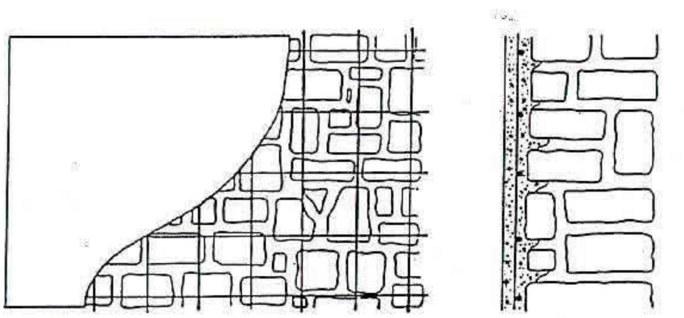


Illustration of Seismic-strengthening Techniques



Seismic Strengthening of Wall Intersections





Seismic-strengthening Techniques - A detail of repointing and the installation of RC jacket

References

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

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

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