World Housing Encyclopedia

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

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HOUSING REPORT
Unreinforced stone wall rural housing (upper income)

Report #	120
Report Date	26-05-2007
Country	ITALY
Housing Type	Stone Masonry House
Housing Sub-Type	Stone Masonry House : Rubble stone without/with mud/lime/cement mortar
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Summary

This is a typical house occupied by affluent families in rural areas of central Italy. The building discussed in this report is called "Palazzo Spinola" and is located in the town of Foligno in the Umbria region (see Figures 1 and 2). The building has four stories above ground and a

completely below-grade basement. Floor plans and cross sections are shown in Figures 3 to 9. Significant geometrical complexity has resulted from additional construction since it was originally built in the seventeenth century. The original construction includes only a portion of the interior building as well as the entire exterior façade. The building has an interior courtyard within the perimeter of the building. It contains a well and a cloister (a covered path with ornate columns) that separates it from the grounds. These are also part of the original construction and have significant artistic value. The upper portion of the cloister is accessible and serves as a connection between the two exterior wings of the residence. The thick walls are constructed using a typical technique called "a sacco." This construction technique consists of two outer wythes that are poorly connected by transversal bond-stones ("diatoni") and filled with essentially unconsolidated inner cores of rubble masonry, poorly cemented with lime mortar. The floor slabs may be of mixed construction, depending on the era. The ground floor has "a padiglione" vaulted ceilings, which are constructed of solid bricks assembled in fairly regular fashion. The second-floor ceilings are vaulted and partly frescoed. Some of the ceilings in the residence have great artistic value, with painted wooden panels ("cassettoni"). The floor slabs on the upper stories are considerably simpler in construction and are made of timber trusses with hollow-clay tiles in between. The structure supporting the roof is made of timber trusses with both vertical and diagonal struts and bottom chords. Some trusses are more complex, similar to Palladian trusses. Buildings of this type are expected to demonstrate fairly poor seismic performance, mostly due to the ineffective connection between interior and exterior wall wythes and existing structural deficiencies (e.g., flues, niches, etc.); lack of effective wall-to-wall, wall-to-slab, and wall-to-roof connections; and the unbalanced outward thrust of the vaults. The structural strengths are represented by very thick walls present throughout the building, especially at the foundation level, and by the occasional iron tie-rods.

1. General Information

Buildings of this construction type can be found in Central Italy. This housing type constitutes approximately 60% of the entire building stock in the rural areas of Umbria. Most of the buildings of this type, however, are inhabited by lower- and middle-class families and are therefore more modest, smaller, and have fewer (or no) details of artistic value than the one studied here. This type of housing construction is commonly found in rural areas. This construction type has been in practice for less than 200 years.

Currently, this type of construction is being built. This construction type is still being practiced today, although some of the details and materials used in new buildings may not be the same as those shown here.

Figure 1: Front elevation view from street of upper class residential building, Palazzo Spinola, in Foligno, Umbria (Photo).

Figure 2: Exterior elevation view from street of the Palazzo Spinola in Foligno, Umbria (Photo).

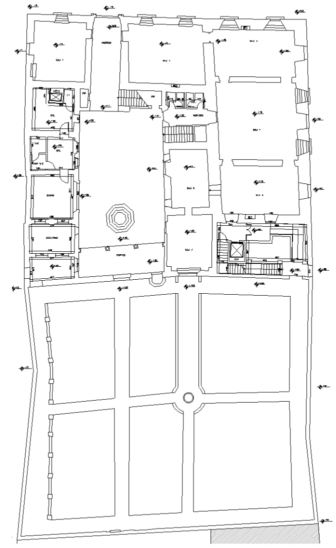

Figure 3: First (ground-level) floor plan of the Palazzo Spinola in Foligno, Umbria.

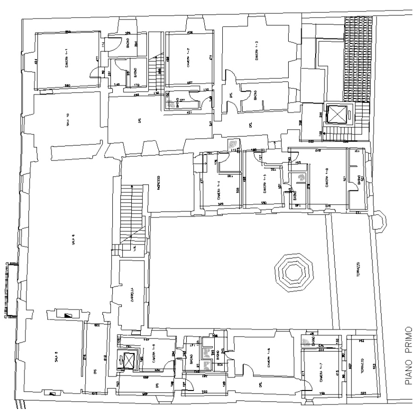

Figure 4: Second-floor plan of the Palazzo Spinola.

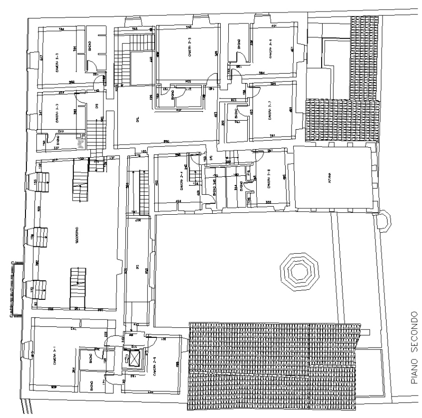

Figure 5: Third-floor plan of the Palazzo Spinola.

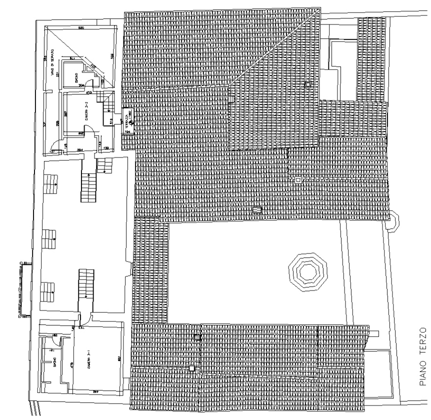

Figure 6: Plan of the fourth floor and lower roof of the Palazzo Spinola.

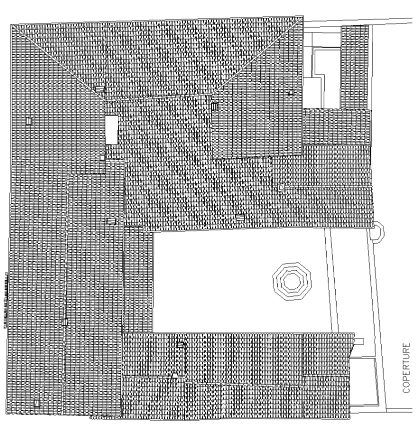

Figure 7: Upper-roof plan of the Palazzo Spinola.

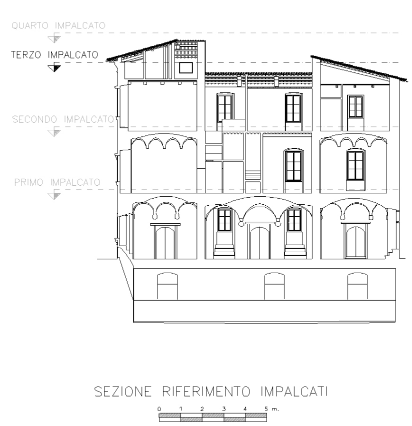

Figure 8: First cross-section (Palazzo Spinola in

Figure 9: Second cross-section (Palazzo Spinola in

Foligno, Umbria).

Foligno, Umbria).

Figure 10: Damage to vaulted entryway and fresco ceiling detailing after the 1997 Umbria-Marche earthquake.

Figure 11: Cracked stone masonry wall at the top level of the residence after the 1997 Umbria-Marche earthquake.

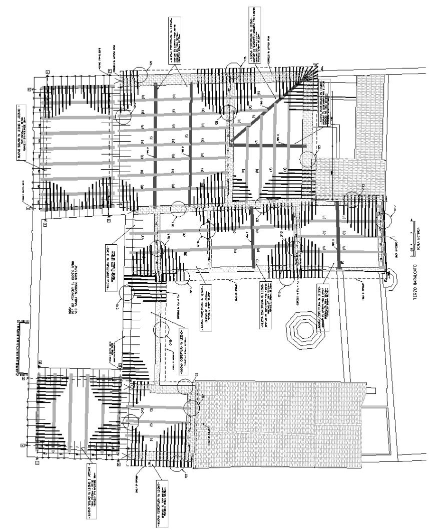

Figure 12: Typical floor plan illustrating the floor framing reconstruction.

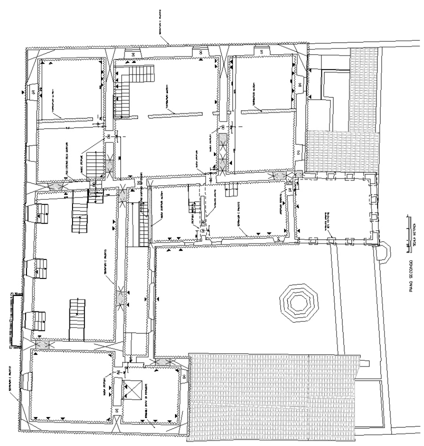

Figure 13: Typical plan illustrating the extent of the stone masonry wall replacement and repair.

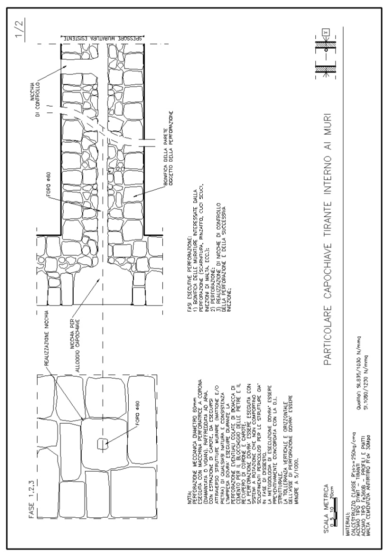

Figure 14: Detail illustrating first step in tying two stone masonry walls together: coring the penetration in the masonry walls and cleaning them out in preparation for the steel rod and epoxy.

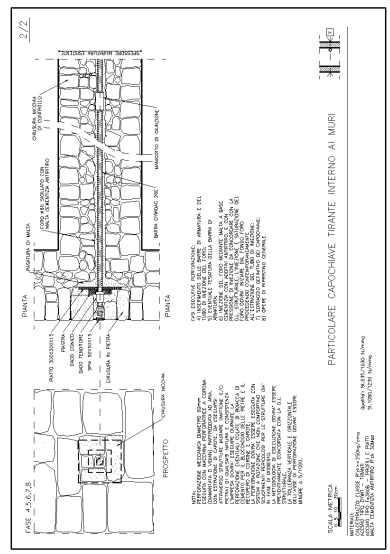

Figure 15: Detail of second step in tying two stone masonry walls together: the steel rod is inserted and the opening is filled with epoxy resin and grout.

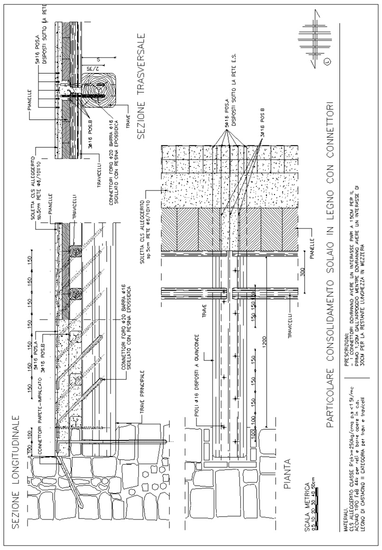

Figure 16: Detail illustrating the typical floor diaphragm to stone masonry wall tie and ties between the wood floor framing and the new floor diaphragm.

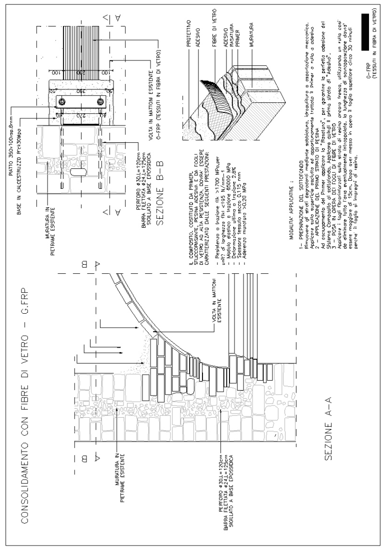

Figure 17: Detail illustrating the carbon fiber strip reinforcement of a typical arched opening. The carbon fiber strips are added to resist the outward

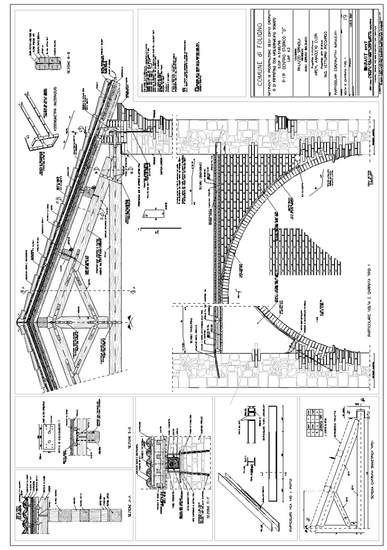

Figure 18: Roof framing, wall and floor-tie details.

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They share common walls with adjacent buildings. There is not a typical separation distance between adjacent buildings. The distance could range from zero (i.e., those with common walls) to several meters

2.2 Building Configuration

The shape is often irregular. In this case it is formed by an external rectangular outline with a central patio. About 15 openings for any typical floor. The dimensions of the windows are typically 1.0 m x 1.4 m and the dimensions of the doors are 0.90 m x 2.0 m with a void-to-wall ratio of about 15%.

2.3 Functional Planning

The main function of this building typology is single-family house. In a typical building of this type, there are no elevators and no fire-protected exit staircases. There is a unique means of egress from the main building and from each of the basement units. Only one staircase connects the different stories.

2.4 Modification to Building

Over the centuries these residential buildings have gone through several transformations, mainly as a result of the differing housing requirements of the owners (e.g., more children and new marriages). These needs prompted either enlarging the living area and adding stories, or more simply, making internal changes to the layout, to the internal and external openings, and to the fireplaces. These changes often weakened the existing structure because the new openings were frequently often not coupled with adequate strengthening measures for the affected walls. It is common to find old doors and windows closed up with a simple layer of clay bricks, and large niches or unused fireplaces that significantly compromise the structural integrity of the walls.

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	☐
Steel	Moment-resisting frame	29	With brick masonry partitions	☐
		30	With cast in-situ concrete walls	☐
		31	With lightweight partitions	☐
	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)	☐

The building is Type 1, except that lime mortar has been used instead of mud mortar, and the wythes are made of dressed stone. Rubble constitutes the infill.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is earthen walls. Stone masonry walls (see above) are connected by solid clay-brick vaults, and slabs with wooden planks and beams, or in the more recent cases, with steel beams and small clay-brick vaults in between.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is earthen walls. Stone masonry walls are made of dressed rectangular stones of regular size for the wythes and debris of smaller size for between the walls "a sacco". Bond stones are often absent and the lime mortar is poor quality. Not unusual is the local presence of clay bricks. Steel ties may or may not be present.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 32 and 32 meters, and widths between 32 and 32 meters. The building is 4 storey high. The typical span of the roofing/flooring system is 4.5-5.5 meters. Typical Plan Dimensions: The dimensions can vary from building to building. The dimensions provided above are larger than average for this type of building. Typical Number of Stories: Four above ground and an additional underground basement. Typical Story Height: The height of the stories of buildings owned by wealthy families is greater than the typical height found in more common buildings (approximately 3 m) with similar construction characteristics and materials.. Typical Span: The typical span is between 4.5 and 5.5 meters. However, some of the spans are more than 10 meters. The typical storey height in such buildings is 5.20 meters. The typical structural wall density is up to 10 %. About 7%.

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 roof structure is made of timber trusses, connected by beams of local chestnut wood, and purlins. The interior part of the roof cover is made of small vaults of clay bricks covered by mortar, which provides the bed for two layers of the typical clay-brick tiles, called coppi. Coppo is the name of a tile that is shaped like a half cylinder (cut through the longitudinal dimension). The roof structure is fairly 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	☐

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 5-10 housing unit(s). One unit 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 less than 5.

4.2 Patterns of Occupancy

Single family occupancy.

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)	☑

Rich families able to afford such large buildings were few in comparison with the total population. Of course, the ratio of the housing price to annual income varied considerably according to the level of the family's prosperity.
Economic Level: The ratio of price of each housing unit to the annual income can be 20:1 for rich class families.

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 no bathroom(s) without toilet(s), no toilet(s) only and 4 bathroom(s) including toilet(s).

Four bathrooms per housing unit: one per story. .

4.4 Ownership

The type of ownership or occupancy is renting and 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		
		Yes	No	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.	☐	☑	☐
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.	☐	☑	☐
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	☐	☑	☐
	The total width of door and window openings in a wall is:			

Wall openings	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	The ultimate shear strength of this type of stone wall is between 5.0 and 7.0 t/m2 (50-70 kPa).			

5.2 Seismic Features

Structural Element	**Seismic Deficiency**	**Earthquake Resilient Features**	**Earthquake Damage Patterns**
Wall	Lack of efficient bonding between orthogonal walls and between the façade and the walls and slabs; a sacco walls are known to perform very poorly during earthquakes; openings are present close to the connections between the facade and the orthogonal walls.	Presence of ? "tapered" walls ("a scarpa", literally, shaped like a shoe) at the ground floor; very thick walls throughout the building.	Detachment between slabs and walls; collapse of the roof structure; detachment of the corner walls; diffuse diagonal cracks; crushing of the base of the foundation "tapered" walls.
Frame (columns, beams)	N/A	N/A	N/A
Roof and floors	Lack of efficient connection between walls and floor slabs; vaults without horizontal ties to prevent outward thrusting force; existing iron tie-rods not efficient because of corrosion.	A limited number of tie-rods.	Detachment of the vaults and floor slabs.
Other			

Figures 10 and 11 show damage that was caused by the 1997 Umbria-Marche earthquake.

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 *A: HIGH VULNERABILITY (i.e., very 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
1477	Foligno	5.1	IX
1703	Appennino Umbro Reatino	6.8	X-XI
1832	Valle Umbra, Cannara, Foligno	6.1	IX-X
1832	Foligno, Bevagna	5.2	VII-VIII

The area where this building is located, which was hit by the 1997 Umbria-Marche seismic sequence, belongs to a region of the Apennines with significant historical seismicity. The seismic catalogues and specific studies (e.g., Decanini et al., 2000 and 2002 in Section 11) show numerous earthquakes with epicentral intensity between the VII and the X degree of the Mercalli-Cancani-Sieberg scale in this area. Within the examined seismic region, 15 destructive earthquakes with M >= 6 may be found from the historical data.

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Stone block	50-70 kPa (shear) 2 MPa (compression)	The lime/sand (perhaps 1/3) mortar is of poor quality. The dimension of the blocks is variable; it ranges from 60 x 30 x 30 cm for the largest blocks down to 10 x 5 x 3 cm for the smallest ones.	Walls "a sacco ".
Foundation	Stone block	50-70 kPa (shear) 2 MPa (compression)	The lime/sand (perhaps 1/3) mortar is of poor quality. The dimension of the blocks is variable; it ranges from 60 x 30 x 30 cm for the largest blocks down to 10 x 5 x 3 cm for the smallest ones.	Tapered walls "a scarpa".
Frames (beams & columns)				
Roof and floor(s)	Wood planks and beams that support clay tiles. Vaulted ceilings	50 MPa (tension-beams) 30 MPa (compression-beams)		

6.2 Builder

Buildings of this type were usually inhabited by the upper class. These rich families owned the land and lived in the residences after completion. Local craftsmen, probably without any supervision from the local architects, built these residential houses. This construction type is common in rural areas where the main activity is agriculture.

6.3 Construction Process, Problems and Phasing

The construction process was generally influenced by the number of family members, servants, animals, and agriculture tools that needed to be accommodated. The building layout, both in plan and elevation, changed over time to serve evolving needs. The construction tools were simple (trowel, etc.). The construction of this type of housing takes place in a single phase. Typically, the building is originally not designed for its final constructed size. Again, multiple additions and changes in the interior layout took place over time.

6.4 Design and Construction Expertise

The construction was based on the state of practice and was dictated by purely geometrical rules. For example, the maximum distance between walls was determined by the length of the timber beams that the local trees (e.g., chestnut and oak) could provide. From these considerations, it is apparent why the room dimensions rarely exceeded 5.50 m. Note that in the case of a vaulted ceiling, the maximum dimension of a room could be considerably larger (e.g., 10 m for the main living room at the second floor of this building). The thickness of the walls ranged from 50 to 80 cm above ground and exceeded 1.0 m close to the foundation (walls "a scarpa"). The construction was essentially dependent on the mason's experience without supervision from formally trained professionals (engineers or architects) in most cases. The role of engineers and architects was minimal. In most cases the construction process was carried out entirely by local craftsmen.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. This type of building predated modern design codes. However, seismic retrofit of these building was based on the local regulations, DGR 5180/98 and L.61/98, of the Umbrian region. The year the first code/standard addressing this type of construction issued was 1981. The first code was issued after the 1980 Irpinia earthquake. Decretory Ministerial 2-7-1981: "Normative per la riparazione ed il rafforzamento degli edifici danneggiati dal sisma". (Revised in 1986, 1996, and 2004). New brick masonry structures are addressed in a different standard. The most recent code/standard addressing this construction type issued was 2004. This type of building predated modern design codes. However, seismic retrofit of these building was based on the local regulations, DGR 5180/98 and L.61/98, of the Umbrian region. Year that the first code or standard addressing this construction type was issued: 1981 Building Code, Material Codes, Seismic codes/standards: The first code was issued after the 1980 Irpinia earthquake. Decretory Ministerial 2-7-1981: ? Normative per la riparazione ed il rafforzamento degli edifici danneggiati dal sisma?. (Revised in 1986, 1996, and 2004). New brick masonry structures are addressed in a different standard. Most recent codes/standard addressing this construction type: 2004.

N/A.

6.6 Building Permits and Development Control Rules

This type of construction is an engineered, and authorized as per development control rules.

At present, these constructions are registered and subjected to national/urban codes. This, however, was not the case at the time of their original construction. Hence, the answers above are valid for retrofitted and seismic upgrading projects but not for the original construction. Building permits are 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

In this region, the owners of collapsed buildings after the 1997 Umbria-Marche earthquake received approximately $700 /m2 (about $550/m2) from the government to rebuild in accordance with the current regulations for new buildings. This amount is a lower-bound estimate of unit construction costs for new buildings. Please note that this construction technique is seldom used today for new buildings. The unit construction costs for retrofitted buildings vary significantly from case to case. Several months to years depending on the size.

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. No earthquake insurance is available for residential buildings in Italy at the time of writing.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Ineffective connection between wythes; existing structural deficiencies (e.g., flues, niches, etc.)	Injection of good-quality grout and addition of artificial diatones (bond stones). In the most serious cases, the walls were replaced. The niches were closed and the more seriously damaged wall parts were fixed using the cuci-scuci technique.
Lack of effective wall-to-wall connections	Insertion of tie-rods inside the wall connections.
Lack of effective wall-to-slab connections	Insertion of tie-rods between the floor slabs and the adjacent walls.
Lack of effective connection between the roof structure and the walls	Addition of a tie-beam at the connection between roof structure and supporting walls.
Outward thrust of vaults not balanced	Systematic addition of tie-rods, reduction of mass by means of removal of nonstructural filling material above the vault and construction of lightweight brick walls above the vault to provide the support for the horizontal structure of the slab above the vault.

Several details of the strengthening measures applied to retrofit this building are shown in Figures 12 to 18.

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, the retrofit measures described in the table above are performed in design practice.

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

As a repair following 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 original design most likely did not involve engineers or architects, and local masons and carpenters paid by the owner performed the construction. An architect and an engineer designed the retrofit and a contractor performed the work.

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

The retrofitted building has not experienced any significant earthquake since the completion of the strengthening. However, the strengthening measures adopted are believed to have significantly improved the seismic behavior of this building.

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