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 (lower and middle income)

Report #	121
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
Author(s)	Riccardo Vetturini, Fabrizio Mollailoli, Paolo Bazzurro
Reviewer(s)	Svetlana N. Brzev

Summary

Typical house occupied by low-income and middle-class families in rural areas of central Italy. The building studied in this report is located in the municipality of Nocera Umbra, province of Perugia, Umbria region, Italy. This type of building, with minor differences in construction

practice and material, is frequently found throughout central Italy. The four-story building was constructed more than 200 years ago and is located on a steep hillside, with the elevation facing the valley completely above grade; the uphill elevation is two stories above grade, with the two stories below ground-level surrounded on two sides by earth-retaining stone masonry walls. This building was severely damaged by the 1997 Umbria-Marche earthquake and was further weakened by the elements before repair and reconstruction efforts began in 2003. Figures 1 through 5 show the damaged building before reconstruction. Figure 6 helps to locate this building in the cluster of buildings around the old citadel. The exterior elevation facing the downhill slope is displayed in Figure 7. The overall floor plan of this building is L-shaped; it accommodates two residential units and has a basement with four separate spaces and entrances for housing farm animals and storing tools. Building plans showing the extent of wall and floor reconstruction can be seen in Figures 8 to 10. Figures 12 to 14 display details of the seismic retrofit. Most buildings of this type, however, are smaller in size, rectangular in shape, and often have one unit. It is very common for these buildings to share perimeter walls with adjacent buildings. In these rural regions it is typical for many generations of a single family to live in the same residence and the building has undergone numerous additions and modifications over its life span to accommodate changing living requirements. The construction modifications are typical of Italian rural regions. The architecture is fairly plain with few architectural details of significant historic value; these were repaired and restored during the seismic reconstruction project. Gravity loads in the building are carried by thick unreinforced stone walls constructed using a technique referred to as "a sacco". The walls consist of two outer stone wythes that are poorly connected by a limited number (if they are present at all) of bond-stones. The space between the two outer wythes is filled with an inner core of smaller rubble masonry, poorly consolidated and poorly graded by a mixture of lime or mud mortar. This construction technique results in walls with limited vertical and lateral capacity because of the presence of voids between the stone masonry and the lack of effective continuity between the inner and outer wythes. The pre-earthquake construction technique and the quality of the mortar in the stone masonry walls were poor. The lack of continuity between the original stone masonry walls and the walls constructed during the various structural additions worsened their condition (see Figure 4). The majority of the floor slabs are constructed of timber beams with intermediate timber joists. Other areas of more recent vintage consist of vaulted floor construction assembled from steel beams and clay-infill bricks arching between them with a lightweight concrete topping layer. Poor seismic performance is expected, mostly because of the ineffective connection between interior and exterior wythes of the walls and existing structural deficiencies (e.g., flues, niches, etc.); lack of effective wall-to-wall, wall-to-slab, and wall-to-roof connections; and lack of continuous foundation-to-roof walls due to the vertically unaligned openings on the façade. Very thick walls present throughout the building, especially at the foundation level, and occasional iron tie-rods add to the structural strength.

1. General Information

Buildings of this construction type can be found in Central Italy. This housing type covers approximately 60% of the entire building stock in rural areas of the Umbria region. This type of housing construction is commonly found in rural areas. This construction type has been in practice for less than 100 years.

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

Figure 1: UMI 11 Le Cese overall view of the downhill elevation. UMI 11 is the structure immediately facing the hillside to the left of the photo. UMI 9, to the right of UMI 11, almost completely collapsed in the 1997 Umbria-Marche earthquake.

Figure 2: UMI 11 Le Cese overall view of the downhill elevation. The roof structure on the far side of the building (over the older portion) has completely collapsed.

Figure 3: UMI 11 Le Cese view from the uphill side, where there are only two stories above grade. The residence sustained major damage to the stone masonry walls on this elevation in the 1997 Umbria-Marche earthquake. The roof completely collapsed as well.

Figure 4: UMI 11 Le Cese view of the downhill exterior fa

Figure 5: UMI 11 Le Cese view of downhill fa

Figure 6: Site map to help locate the UMI 11 Le Cese building in the photographs shown in Figures 1 to 5.

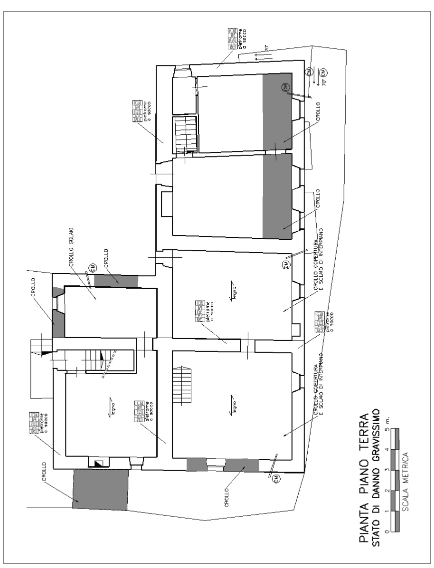

Figure 8: First-floor (ground-level) plan illustrating extent of earthquake damage.

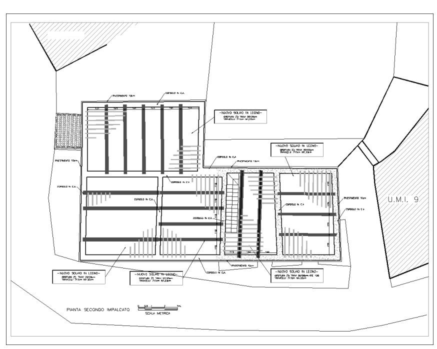

Figure 9: Second-floor plan illustrating floor reconstruction.

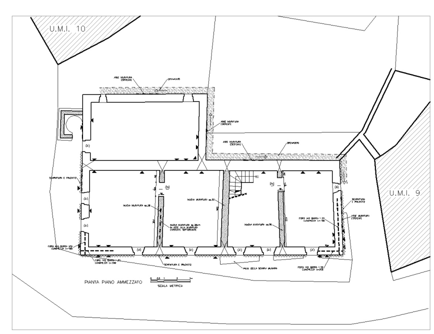

Figure 10: Typical floor plan illustrating the extent of stone masonry wall reconstruction.

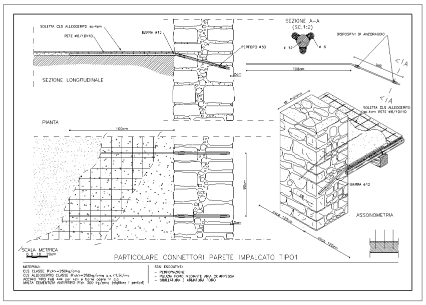

Figure 11: Typical floor-wall tie detail from floor diaphragm to new stone masonry wall construction.

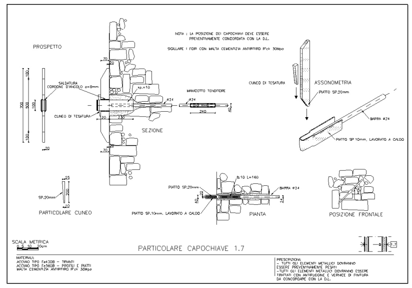

Figure 12: Detail of a steel tie-rod anchoring the two outer wythes of stone masonry to the inner mortar bed

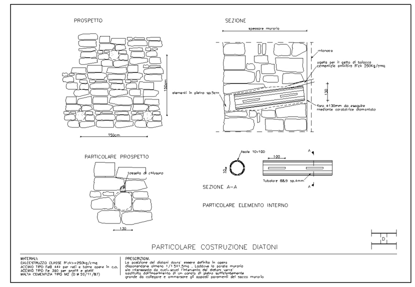

Figure 13: Detail illustrating the

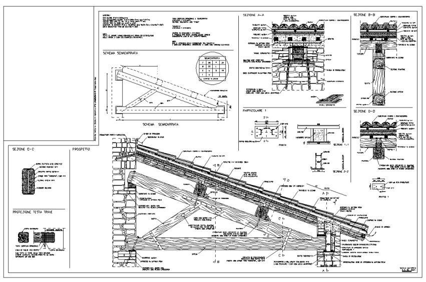

Figure 14: Roof-truss retrofit construction details and typical wood framing to stone masonry wall tie details.

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat, sloped and hilly terrain. They share common walls with adjacent buildings. This type of building can be found both on hilly and flat areas throughout central Italy. There is no typical distance between adjacent buildings of this kind. The separation distance could range between zero (i.e., common wall) to hundreds of meters in the case of isolated buildings in the countryside When separated from adjacent buildings, the typical distance from a neighboring building is 0 meters.

2.2 Building Configuration

The shape is irregular, often rectangular. In this case it has a L-shaped configuration. About 15 openings for a 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%. Openings in the facades are usually aligned and located not too close to corner of the perimeter walls.

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.

2.4 Modification to Building

Over the centuries, these residential buildings have undergone several transformations, mainly due to the different living needs of the owners (e.g., more children and new marriages). These needs generated either enlargement of the living area and the addition of stories or, more simply, internal changes to the layout, to the internal and external openings, and to the fireplace locations. All these changes often weakened the existing structure because the new openings were frequently not coupled with adequate strengthening measures for the affected walls. It is common to find old doors and windows closed up by a simple layer of clay bricks and large niches or unused fireplaces, which significantly compromise the structural uniformity 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 belongs to Type 1, except that lime mortar has been used instead of mud mortar. The exterior wythe, and sometimes the interior one as well, are made of stone blocks that are regularly cut in similar dimensions. Only the space between the wythes is filled with rubble stones.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is others (described below). Stone masonry walls (see above) and slabs with wooden planks and beams or, more recently, with steel beams and small clay-brick vaults in between.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is others (described below). Masonry walls are made of fairly regularly cut stones of regular size for the exterior wythe. The interior wythe is often made by stone of smaller size and rounder in shape. The perimeter walls are connected by corner stones made by squared blocks. The space in between the wythes is filled with debris of even smaller size (walls "a sacco"). Bond-stones are often absent and the lime mortar is of poor quality. The local presence of clay bricks is not unusual. Steel ties are rarely present.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 20 and 20 meters, and widths between 12 and 12 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 refer to the case study presented here. Single-unit buildings are significantly smaller. Typical Number of Stories: In this case study, four stories. Given the steep terrain, the bottom two are above ground only on that side that faces the valley. Buildings of two or three stories are probably more common. The typical storey height in such buildings is 3.2

meters. The typical structural wall density is up to 10 %. 5 - 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	☐	☐
Structural concrete	Solid slabs (cast-in-place)	☐	☐
	Waffle slabs (cast-in-place)	☐	☐
	Flat slabs (cast-in-place)	☐	☐
	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	☑	☑

Floor diaphragms are flexible. 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 flat 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).

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	☐
	Reinforced-concrete bearing	☐

	piles	
Deep foundation	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 1 housing unit(s). Typically, one or two units in each building; two units in the example shown here. In addition, there are four spaces in the basement with separate entrances. Each space was used for housing farm animals and storing tools. 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.

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)	☐

The housing price can vary considerably, depending on location, the state of preservation, and the level of modern comforts present. These houses are usually inhabited by lower-class families with modest incomes and sometimes by middle-class families. Some houses are used today as holiday homes (mainly by relatives living in other parts of the country). Economic Level: The ratio of price of each housing unit to the annual income can be 10:1 for poor families and 5:1 for middle 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 1 bathroom(s) without toilet(s), 1 toilet(s) only and 1 bathroom(s) including toilet(s).

Typically, one bathroom and one latrine per housing unit. .

4.4 Ownership

The type of ownership or occupancy is renting, outright ownership and ownership with debt (mortgage or other).

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.	☐	☑	☐
	There is no evidence of excessive foundation movement			

Foundation performance	(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	The quality of workmanship and level of maintenance vary considerably from building to building. A typical value of the ultimate shear strength of this type of stone wall is about 3.0 t/m2 (30 kPa).			

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	Lack of efficient wall-to-wall connections; poor-quality wall construction due to the lack of bond stones between the wythes (walls a sacco are known to perform very poorly during earthquakes); lack of vertical alignment of openings in the facade that interrupts the continuity of walls from the foundation to the roof.	Presence of tapered walls ("a scarpa" - literally, shaped like a shoe) at the ground floor; thick walls throughout the building	Detachment between slabs and walls; collapse of the roof structure; detachment of the corner walls; diffuse diagonal cracks; compression of the base of the foundation "tapered" walls
Frame (columns, beams)	Lack of efficient slab-to-wall and roof-to-wall connections.	A limited number of tie-rods.	Collapse of most of the roof structure.
Roof and floors	Lack of efficient slab-to-wall and roof-to-wall connections.	A limited number of tie-rods.	Collapse of most of the roof structure.
Other			

Figures 1 to 5 show the damage pattern 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
1279	Serravalle Chienti, Nocera Umbra, Camerino	6.4	IX
1747	Gualdo Tadino, Nocera Umbra	6	IX
1751	Gualdo Tadino, Busche	6.3	X
1832	Valle Umbra, Cannara, Foligno	6.1	IX-X

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 in this area with epicentral intensity between VII and X degrees of the Mercalli-Cancani-Sieberg scale. Within the examined seismic region, 15 destructive earthquakes with M greater than or equal to 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 blocks	30 kPa (shear)	The lime/sand (perhaps 1/3) mortar is of poor quality. The dimension of the blocks is variable: ranging from 50 x 30 x 20 cm for the largest blocks down to 10 x 5 x 3 cm for the smallest ones.	Walls "a sacco"
Foundation	Stone blocks	30 kPa (shear)	The lime/sand (perhaps 1/3) mortar is of poor quality. The dimension of the blocks is variable: ranging from 50 x 30 x 20 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

These buildings were usually inhabited by lower-income families. Local craftsmen or the owner themselves built these residential houses without any supervision by local architects. This construction type is common in predominately rural and agricultural areas.

6.3 Construction Process, Problems and Phasing

The construction process was generally influenced by the number of family members, animals, and agriculture tools that needed to be accommodated. The building layout, both in plan and in elevation, changed over time to serve evolving living requirements. 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 interior layout changes took place over time.

6.4 Design and Construction Expertise

The construction was based on the state of practice and it 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 exceed 5.5 m. The thickness of the walls can range from 50 to 80 cm above ground and exceed 1.0 m close to the foundation (walls "a scarpa"). In most cases the construction was essentially based on the mason's experience without supervision from formally trained professionals (engineers or architects). Input from engineers and architects was absent in most cases. The construction process was carried out entirely by local masons and craftsmen.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. This building type predated modern design codes. However, the seismic retrofit of the building was based on the local regulations DGR 5180/98 and L.61/98 of the Umbria 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. Title of the code or standard? This building type predated modern design codes. However, the seismic retrofit of the building was based on the local regulations DGR 5180/98 and L.61/98 of the Umbria 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, all these constructions are registered and subject to national urban codes. This, however, was not the case at the time of their original construction. Hence, the answers above are valid for retrofitting and seismic upgrade 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 an amount in the neighborhood of 700 $/m2 (about $550/m2) from the government to rebuild in accordance with the current regulations for new buildings. This amount is a lower-range 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, 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 building in Italy at the time of this 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 the wythes and existing deficient structural components, (e.g., flues, niches, etc.).	Injection of good-quality grout and the addition of artificial diatones (bond-stones). In the most serious cases, the walls were replaced. The niches were closed and 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 the roof structure and supporting walls.

The extent of the reconstruction of this building and several construction details of the strengthening measures that were adopted are shown in Figures 8 to 14.

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 description of the retrofit measures provided in the table is routinely 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; local masons and carpenters paid by the owner, or the owners themselves, undertook the construction. 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 a 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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Author(s)

1. Riccardo Vetturini
   Senior Engineer, Riccardo Vetturini Engineering Design & Consulting
   Corso Cavour 84, Foligno (PG) , ITALY
   Email:ing.vetturini@libero.it FAX: +39 0742 350701

2. Fabrizio Mollailoli
   Engineer/Assistant Professor, Dipartimento di Ingegneria Strutturale e Geotecnic, University of Rome ?La Sapienza?
   Via Gramsci 53, ROMA 197, ITALY
   Email:fabrizio.mollaioli@uniroma1.it FAX: (39-632) 21410

3. Paolo Bazzurro
   Engineer, AIR-Worldwide
   388 Market Street Suite 750, San Francisco CA 94111, USA
   Email:pbazzurro@air-worldwide.com FAX: 415 912-3112

Reviewer(s)

1. Svetlana N. Brzev
   Instructor
   Civil and Structural Engineering Technology, British Columbia Institute of Technology
   Burnaby BC V5G 3H2, CANADA
   Email:sbrzev@bcit.ca FAX: (604) 432-8973