World Housing Encyclopedia

A Resource on Construction in Earthquake Regions

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HOUSING REPORT
Unreinforced stone wall rural housing

Report#	120
Last Updated	
Country	Italy
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General Information

Building Type:	Unreinforced stone wall rural housing
Country:	Italy
Author(s):	Riccardo Vetturini Anacleto Cleri Fabrizio Mollailoli

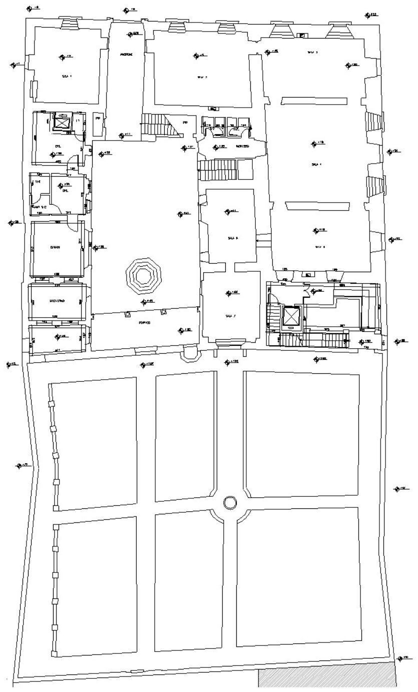
	Paolo Bazzurro
Last Updated:	
Regions Where Found:	Central Italy. This housing type were constructed in urban areas and were inhabited by wealthy families.
Summary:	This is a typical house occupied by affluent families in urban areas of central Italy. The building discussed in this report is called Palazzo 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 faade. 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
Length of time practiced:	More than 200 years
Still Practiced:	Yes
In practice as of:	
Building Occupancy:	Single dwelling
Typical number of stories:	4
Terrain-Flat:	Typically
Terrain-Sloped:	Never
Comments:	The construction technique shown in this example is no longer practiced as commonly replaced or alterated in many important stru

Features

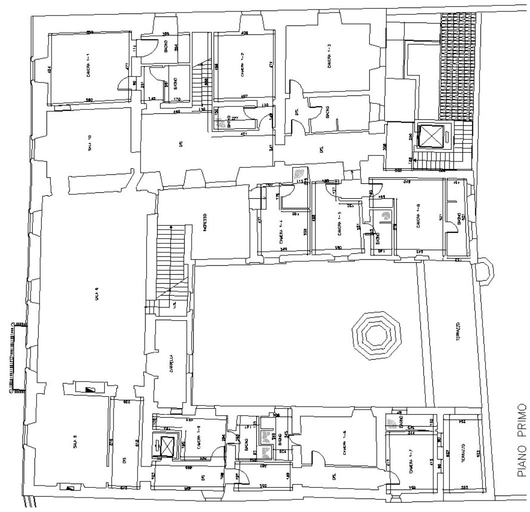
Plan Shape	Rectangular, with an opening in plan

Additional comments on plan shape	The shape is often irregular. In this case it is formed by an external rectangular outline with a central patio.
Typical plan length (meters)	33
Typical plan width (meters)	32
Typical story height (meters)	5.2
Type of Structural System	Wooden Structure: Load-bearing Timber Frame: Wood frame (with special connections)
Additional comments on structural system	1.The pre-earthquake structure lacked a complete seismic force resisting system. The horizontal seismic force-resisting elements (floors and roof) were of generally poor quality construction, although construction quality varied throughout the different generations of construction. There was no adequate roof diaphragm to transfer loads to the stone walls. Lateral forces at the floor levels were carried by a variety of construction types, generally consisting of an unreinforced concrete topping slab supported by a mixture of timber and steel floor framing with clay in-fill tiles. The vertical elements of the seismic force-resisting system consisted of poorly bonded a sacco stone masonry walls. The walls were unreinforced and provided little strength and virtually no ductility.The stone walls were constructed using the same a sacco technique. The construction 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 by a lime or mud mortar.
Gravity load-bearing & lateral load-resisting systems	The building is Type 1, except that lime mortar has been used instead of mud mortar, and the wythes are made ofdressed stone. Rubble constitutes the infill. The plan dimensions can vary from building to building. The dimensions provided above are larger than average for this type of building.
Typical wall densities in direction 1	5-10%
Typical wall densities in direction 2	5-10%
Additional comments on typical wall densities	About 7% (percentage of the ratio between the walls area and the overall area). The unitary weight of masonry is 20-23 kN/m3.
Wall Openings	Openings are generally aligned and not close to edge of the walls.
Is it typical for buildings of this type to have common walls with adjacent buildings?	Yes
	In the upper portions of the building additional deficiencies exist due to some modifications occurred during the time. The numerous stairwells created significant holes in the diaphragms. And their placement adjacent to the exterior facade contributed to the lack of continuity between the floor construction and the exterior faade. At the

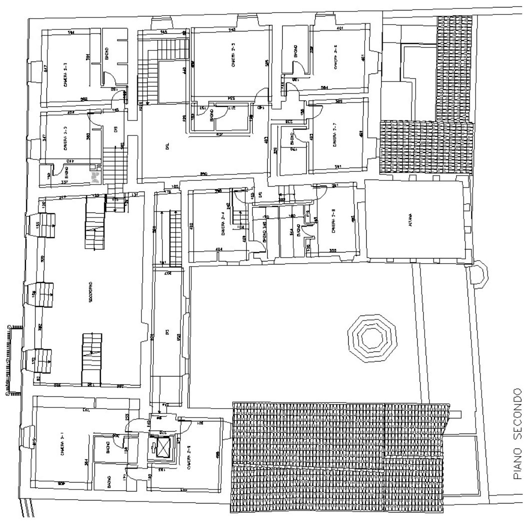
Modifications of buildings	roof level, outward-horizontal thrust forces from the roof trusses act perpendicular to the walls, further separating the roof framing from the exterior walls. A similar condition exists on the South wing of the building. It is not likely part of the original construction, but results from the removal of buildings that were once adjacent to the palazzo.There is a unique means of egress from the main building and from each of the basement units that way out directly on an important approach route (Via Mazzini) leading to the centre of the town of Foligno, from one side, and to a large square (San Domenico square), on the other side. Only one staircase connects the different stories. It is also present a wide garden in the back with an egress on a secondary road.
Type of Foundation	Shallow Foundation: Rubble stone, fieldstone strip footing
Additional comments on foundation	
Type of Floor System	Vaulted masonry floorOther floor system
Additional comments on floor system	Timber: Wood planks or beams with ballast and concrete or plaster finishing
Type of Roof System	Roof system, other
Additional comments on roof system	Wood planks or beams that support clay tiles. longitudinal dimension). The roof structure is fairly flexible.
Additional comments section 2	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 undergroundbasement.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.



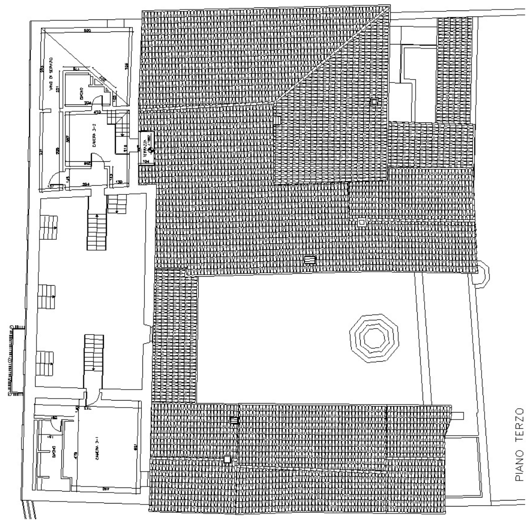
First (ground-level) floor plan of the Palazzo Spinola in Foligno, Umbria.



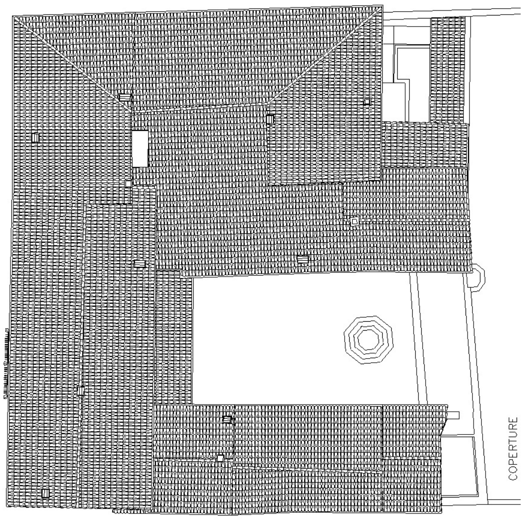
Second-floor plan of the Palazzo Spinola.



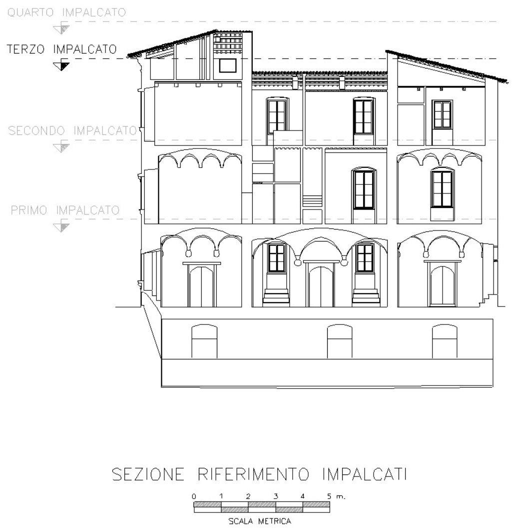
Third-floor plan of the Palazzo Spinola.



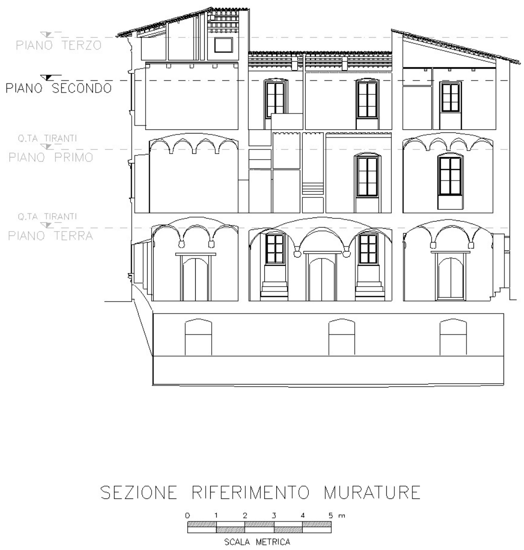
Plan of the fourth floor and lower roof of the Palazzo Spinola.



Upper-roof plan of the Palazzo Spinola.



First cross-section (Palazzo Spinola in Foligno, Umbria).



Second cross-section (Palazzo Spinola in Foligno, Umbria).

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	Stone block	Characteristic Strength-50-70 kPa (shear) 2MPa (compression)Mix Proportion/Dimensions- 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 blocksdown to 10 x 5 x 3 cm for the smallest ones.Walls "asacco ".
Foundations	Stone block	Characteristic Strength-50-70 kPa (shear) 2MPa (compression)Mix Proportion/Dimensions- The lime/sand (perhaps 1/3) mortar is of poor quality. The dimension of theblocks is variable; it ranges from 60 x 30 x 30 cm for the largest blocksdown to 10 x 5 x 3 cm for the smallest ones.Taperedwalls "ascarpa".
Floors		
Roof	Wood planks andbeams that support claytiles. Vaulted ceilings	Characteristic Strength: 50 MPa (tension-beams) 30 MPa (compression-beams)
Other		

Design Process

Who is involved with the design process?	Other
Roles of those involved in the design process	The role of engineers and architects was minimal. In most cases the construction process was carried out entirely by local craftsmen.
Expertise of those involved in the design process	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 exceeded rarely 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.

Construction Process

Who typically builds this construction type?	Other
Roles of those involved in	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. The

the building process	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.).
Expertise of those involved in building process	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 exceeded rarely 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.
Construction process 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 housingtakes 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.
Construction issues	

Building Codes and Standards

Is this construction type address by codes/standards?	Yes
Applicable codes or standards	Additional comments: 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
Process for building code enforcement	n/a

Building Permits and Development Control Rules

Are building permits required?	Yes

Is this typically informal construction?	No
Is this construction typically authorized as per development control rules?	Yes
Additional comments on building permits and 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 retrofitting and seismic upgrading projects but not for the original construction.

Building Maintenance and Condition

Typical problems associated with this type of construction	o Low strength of the bearing walls due to poor quality of the building material, inadequate connection between the interior and exterior wythes, and lack of suitable connections between orthogonal walls and floor slabs.o Floor slabs and roof structures without a suitable connection with the walls (e.g., the timber roofs do not have any ring beam and lack adequate connection between primary and secondary beams.o Outward thrust of vaults not balanced.
Who typically maintains buildings of this type?	Owner(s)
Additional comments on maintenance and building condition	

Construction Economics

Unit construction cost	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 newbuildings. 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 buildingsvary significantly from case to case.
Labor requirements	Several months to years depending on the size.
Additional comments section 3	

Socio-Economic Issues

Patterns of occupancy	Single family occupancy.
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

Additional comments on number of inhabitants	Four bathrooms per housing unit: one per story.
Economic level of inhabitants	High-income class (rich)
Additional comments on economic level of inhabitants	Rich families able to afford such large buildings were few in comparison with the total population. Of course, theratio 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.
Typical Source of Financing	Owner financedPersonal savings
Additional comments on financing	
Type of Ownership	RentOwn outright
Additional comments on ownership	
Is earthquake insurance for this construction type typically available?	No
What does earthquake insurance typically cover/cost	No earthquake insurance is available for residential buildings in Italy at the time of writing.
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
1477	Foligno
1703	Appennino Umbro Reatino
1832	Valle Umbra, Cannara, Foligno
1832	Foligno, Bevagna

Past Earthquakes

	The area where this building is located, which was

Damage patterns observed in past earthquakes for this construction type	hit by the 1997 Umbria-Marche seismic sequence, belongs to aregion of the Apennines with significant historical seismicity. The seismic catalogues and specific studies (e.g., Decaniniet al., 2000 and 2002 in Section 11) show numerous earthquakes with epicentral intensity between the VII and the Xdegree of the Mercalli-Cancani-Sieberg scale in this area. Within the examined seismic region, 15 destructive earthquakeswith M >= 6 may be found from the historical data.
Additional comments on earthquake damage patterns	(walls): 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. (roof/floors): Detachment of the vaults and floor slabs. Figures 10 and 11 show damage that was caused by the 1997 Umbria-Marche earthquake.

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)	FALSE
Building Configuration-Horizontal	The building is regular with regards to the plan. (Specify in 5.4.2)	FALSE
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 (unreinforced masonry walls);	FALSE
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		FALSE
Quality of Building Materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	TRUE
Quality of Workmanship	Quality of workmanship (based on visual inspection of a few typical buildings) is considered to be good (per local construction standards).	TRUE
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).	TRUE

Building Irregularities

Additional comments on structural and architectural features for seismic resistance	The ultimate shear strength of this type of stone wall is between 5.0 and 7.0 t/m2 (50-70 kPa).

Vertical irregularities typically found in this construction type	Other
Horizontal irregularities typically found in this construction type	Other
Seismic deficiency in walls	Lack of efficient bonding between orthogonal walls andbetween the faade and the walls and slabs; a sacco walls areknown to perform very poorly during earthquakes; openingsare present close to the connections between the facade andthe orthogonal walls.
Earthquake-resilient features in walls	Presence of tapered walls (a scarpa, literally, shaped like a shoe) at the ground floor; very thick walls throughout the building.
Seismic deficiency in frames	
Earthquake-resilient features in frame	
Seismic deficiency in roof and floors	Lack of efficient connection between walls and floor slabs;vaults without horizontal ties to prevent outward thrustingforce; existing iron tie-rods not efficient because of corrosion.
Earthquake resilient features in roof and floors	A limited number of tie-rods.
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	-|				

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

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

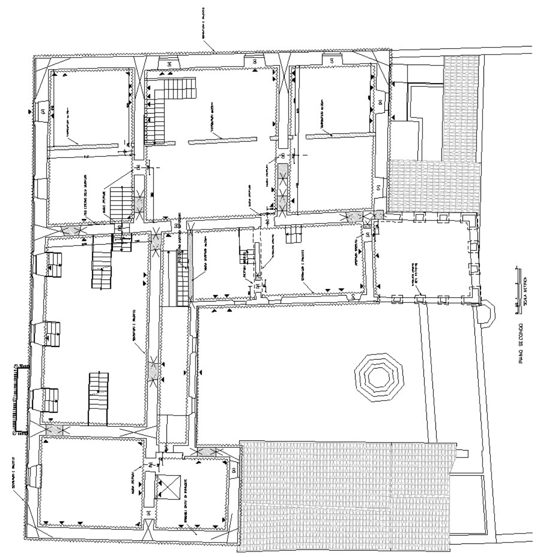
Retrofit Information

Description of Seismic Strengthening Provisions

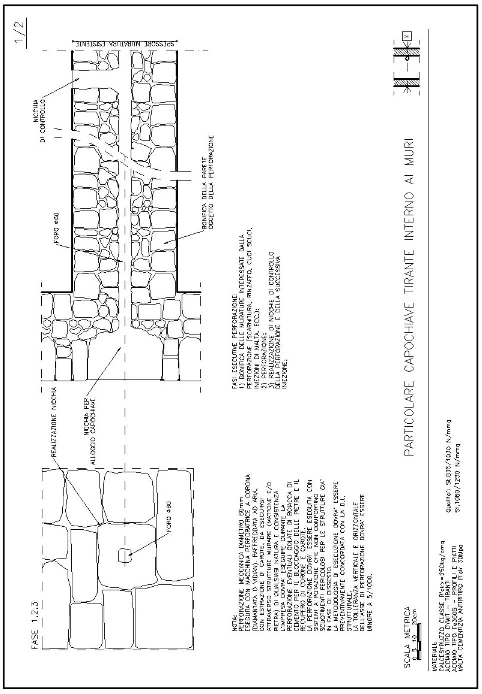
Structural Deficiency	Seismic Strengthening
Ineffective connection betweenwythes; existing structural deficiencies(e.g., flues, niches, etc.)	Injection of good-quality grout and addition of artificial diatones (bond stones). In the most serious cases, thewalls were replaced. The niches were closed and the more seriously damaged wall parts were fixed using thecuci-scuci technique.
Lack of effective wall-to-wallconnections	Insertion of tie-rods inside the wall connections.
Lack of effective wall-to-slabconnections	Insertion of tie-rods between the floor slabs and the adjacent walls.
Lack of effective connection betweenthe 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 abovethe vault and construction of lightweight brick walls above the vault to provide the support for the horizontalstructure of the slab above the vault.

Additional comments on seismic strengthening provisions	Several details of the strengthening measures applied to retrofit this building are shown in Figures 12 to 18.
Has seismic strengthening described in the above table been performed?	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 a repair following earthquake damages?	As a repair following 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 original design most likely did not involve engineers or architects, and local masons and carpenters paid by theowner performed the construction. An architect and an engineer designed the retrofit and a contractor performed the execution.
What has been 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 thisbuilding.
Additional comments section 6	

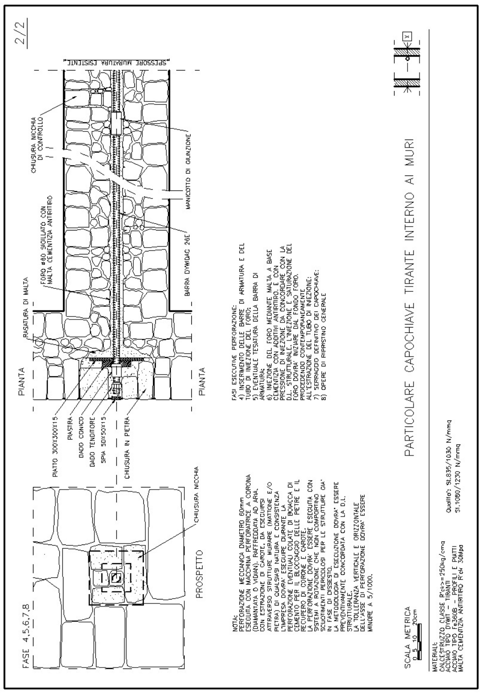
Typical floor plan illustrating the floor framing reconstruction.



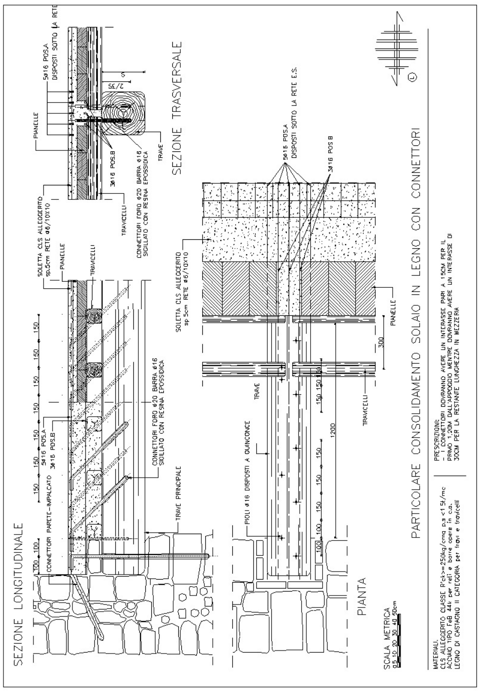
Typical plan illustrating the extent of the stone masonry wall replacement and repair.



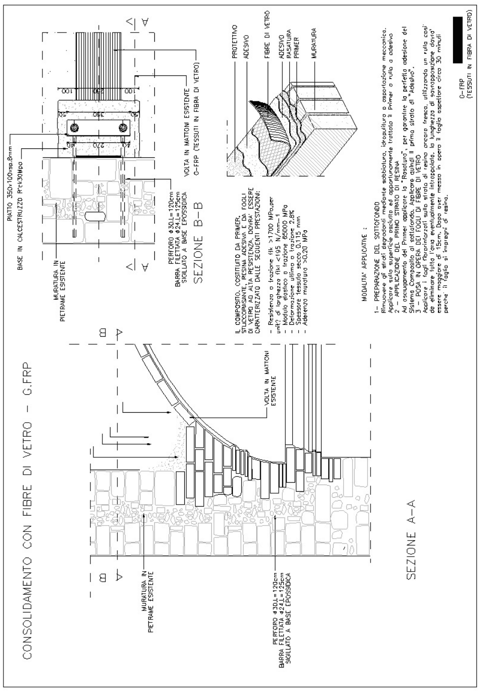
Detail illustrating first step in tying two stone masonry walls together: coring the penetration in the masonry walls and cleaning them out in preparation for the steel rod and epoxy.



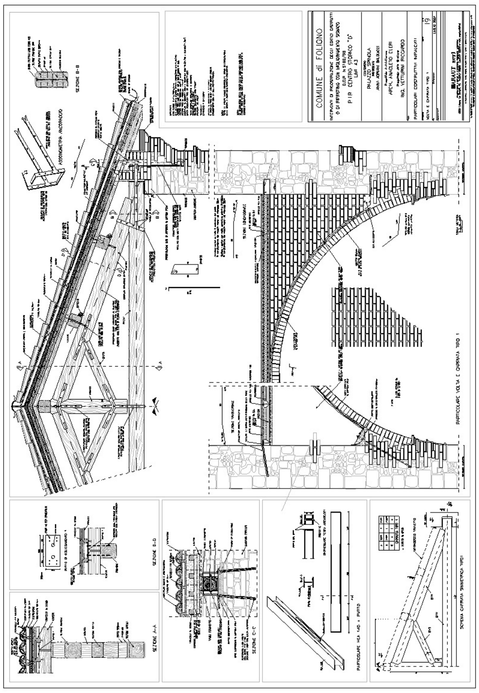
Detail of second step in tying two stone masonry walls together: the steel rod is inserted and the opening is filled with epoxy resin and grout.



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



Detail illustrating the carbon fiber strip reinforcement of a typical arched opening.



Roof framing, wall and floor-tie details.

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Structural and seismological implications of the 1997 seismic sequence in Umbria and Marche, ItalyDecanini,L., Mollaioli,F., and Oliveto,G.Innovative Approaches to Earthquake Engineering, G. Oliveto, Editor, WIT Press, Southampton, pp. 229-323 2002

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