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

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HOUSING REPORT
"Casa Torre" construction: multistory tower masonry with stone pillars and wood or arched beams

Report #	113
Report Date	01-10-2005
Country	ITALY
Housing Type	Stone Masonry House
Housing Sub-Type	Stone Masonry House : Rubble stone without/with mud/lime/cement mortar
Author(s)	Mauro Sassu, Chiara Cei
Reviewer(s)	Svetlana N. Brzev

Summary

This construction originated during the Middle Ages in response to the threat of military

invasions. The building plan is a square lattice, 5-7 meters, formed by three or four floors, with one room on each floor, and a total height of 15-20 m. It is a common technique found in Pisa but also found frequently in many municipalities of Tuscany and adjacent districts. The structure of the building is supported by four stone columns connected by arches (circle or oval) or by beams at each floor; the floor is supported by a series of wood beams (especially pine) with wood tables and/or clay blocks. The upper floors of the earlier historic buildings often contained a wood balcony supported by cantilevered wood beams. Some balconies were fully enclosed structures with clay-tile roofing. The entrance on the first floor could be accessed by means of a detachable wood staircase.

1. General Information

Buildings of this construction type can be found in Tuscany, but some of these buildings are also found in surrounding regions. This type of housing construction is commonly found in urban areas.

The Casa Torre technique has been used to increase the level of safety and protect inhabitants from invasion by foreign armies.

This construction type has been in practice for more than 200 years.

Currently, this type of construction is not being built. The Casa Torre type originated around 1100 AD and was modified during the 17th century by incorporating the single masonry towers into adjacent buildings.

Figure 1: "Il Campano."

Figure 2: Typical early version of tower: very slender structure with stone pillars.

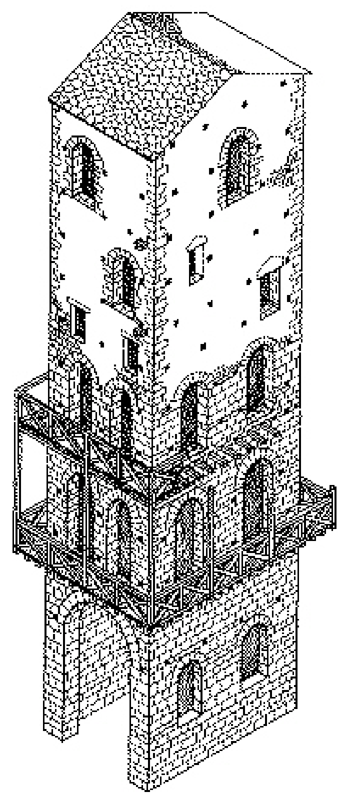

Figure 3: Axonometry of the original version of the tower in Figure 2.

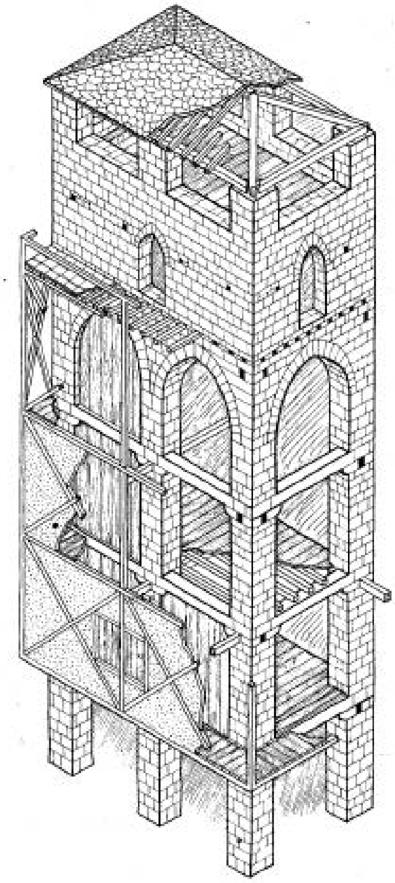

Figure 4: "Torre della Verga d'oro" (Gold bar): structural arrangement of the original version.

Figure 5: Tower of "S. Pietro in Vicoli" (11th-12th century); subsequently it was converted into a bell tower.

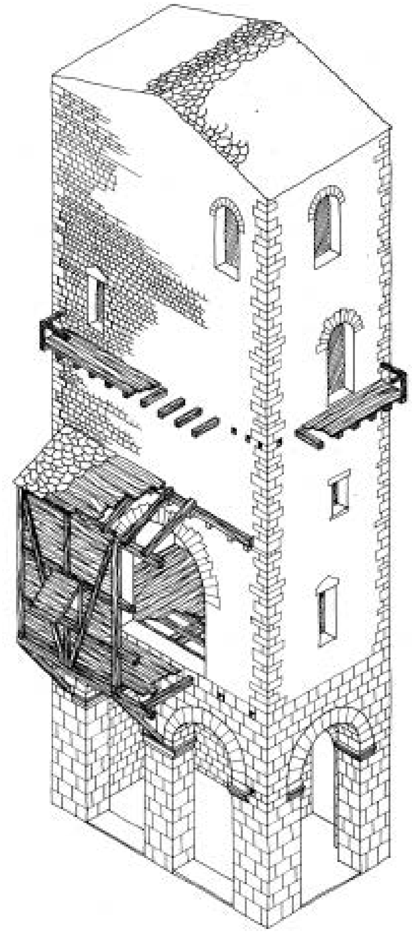

Figure 6: Axonometry of the tower of "S. Pietro in Vicoli."

Figure 7: Example of modified position of openings in the fa

Figure 8: East tower of S. Martino alla Pietra (beginning of 12th century). It has been incorporated into adjacent buildings. Structural deficiencies have been caused by the subsequent unaligned openings as well as by the wide doorways at the ground-flo

Figure 9: "Il Campano" (bell tower): detail of the holes (black circle) made to support the framework (while the tower was being built) and the balcony after it was finished. The balconies were also strengthened by wood beams supported by shaped stones (r

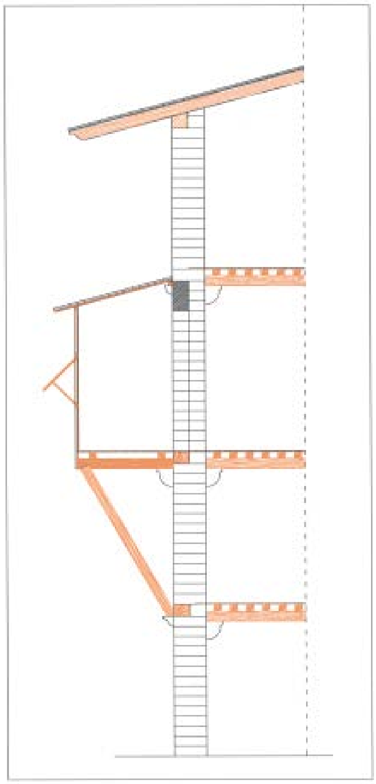

Figure 10: Typical section of the building.

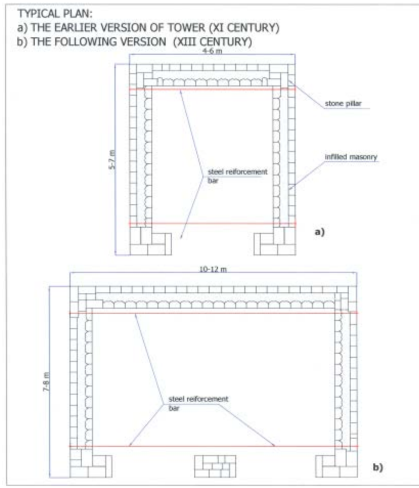

Figure 11: Design plan with the arrangement of steel reinforcement bars.

Figure 12: Opposite walls are connected by the use of tie-rods, with evident improvement in seismic behavior.

Figure 13: "Torre della Verga d'oro." Structural reinforcements: two large arched openings supporting horizontal forces at the base of the tower have been infilled by clay units.

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They do not share common walls with adjacent buildings. The typical plan dimensions of the Casa Torre were 6 meters; sometimes adjacent buildings were created with two common pillars When separated from adjacent buildings, the typical distance from a neighboring building is 6 meters.

2.2 Building Configuration

Three or four floors; one room over each other, in an approximately square plan. In the first version (ca 1100), the openings were situated on one, or perhaps two, opposite walls. In the second period (ca 1200), openings might be seen on all four walls. In most cases, the openings were centered, vertically aligned, and narrow (0.80-1.20 m) in relation to the total dimension of the wall (6 m). Originally, the ground floor contained no openings (the entrance was accessed on the first floor with the help of a ladder); afterwards, wider openings (1.5-2.5 m) were created, mostly at the ground-floor level.

2.3 Functional Planning

The main function of this building typology is single-family house. The height of the house was indicative of the family's prestige, so rich families competed to attain the greatest height. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. None.

2.4 Modification to Building

Incorporating single masonry towers with adjacent buildings was often undertaken to create a unique "Palazzo" with wider buildings or multifamily dwellings.

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	☐
		17	Flat slab structure	☐
			Designed for gravity loads	

Structural concrete	Moment resisting frame	18	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 historic Casa Torre performs its structural functions by means of high-quality stones, moment-resisting connections of the beams, and regular plan shape.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is others (described below). Limestone masonry pillars infilled with clay or sandstone walls with openings supported by wood or brick lintels. The floor is supported by small wood beams (span 1.7 m: distance 25-30 cm) which rest on two or three primary wood beams (span 5 m: distance 1.7 m).

3.3 Lateral Load-Resisting System

The lateral load-resisting system is others (described below). The system consists of plane frames formed by stone pillars and wood beams or wood-masonry arches. The "moment-resisting" connections between pillars and beams or arches are generally well executed. The stones at the edges have high mechanical strength. There are no moment-resisting connections between the floors and the walls or arches.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 7 and 12 meters, and widths between 4 and 8 meters. The building has 4 to 7 storey(s). The typical span of the roofing/flooring system is 5 meters. The typical storey height in such buildings is 3 meters. The typical structural wall density is up to 10 %. 5 to 10 %.

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	☑	☑

The existing wood floor/roof structures are not considered to be a rigid diaphragm unless they are tied with diagonal ties and connected to the walls.

3.6 Foundation

Type	Description	Most appropriate type
	Wall or column embedded in soil, without footing	☐
	Rubble stone, fieldstone isolated footing	☑
	Rubble stone, fieldstone strip footing	☐

Shallow foundation	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 1 housing unit(s). 1 units in each building. The number of inhabitants in a building during the day or business hours is less than 5. The number of inhabitants during the evening and night is less than 5. The ground floor was often modified further for handicrafts or commercial activities.

4.2 Patterns of Occupancy

Houses of this type were occupied only by the owner-family.

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)	☑

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), 1 toilet(s) only and no bathroom(s) including toilet(s).

Originally, the latrine was located on the wood balcony; later, the bathroom and latrines were placed inside the building. .

4.4 Ownership

The type of ownership or occupancy is outright ownership.

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

5. Seismic Vulnerability

5.1 Structural and Architectural Features

Structural/ Architectural Feature	Statement	Most appropriate type		
		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	☐	☑	☐
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	There is sometimes evidence of vertical foundation movement due to the soil properties or to further interventions.			

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	Originally, the walls were not tied by means of steel or wood ties. The connection of the multileaf walls is partially ensured by the wood floor beams.	Massive stone masonry cavity walls, filled with sand, clay units, and lime inserted between the stone pillars, capable of dissipating seismic energy	Cracking (not necessarily due to an earthquake) at the interface of the pillars and walls.
Frame (columns, beams)	The corner pillars are made of large and squared stones with thin joints filled with lime mortar, well connected to the beams: the moment-resisting connection between pillars and beams is not ductile.		
Roof and floors	Made of simply supported wood beams and planks, so they do not provide an effective connection between two opposite walls.	Very lightweight and elastic structures.	None

Other	Steel tie-rods to ensure anchorage between opposite masonry walls in case of structural restoration.		

In spite of its slender shape, this building achieves an enviable seismic performance for two main reasons. First, materials are made of good quality and secondly, the pillars or walls are well constructed. Moreover, in the event of masonry damage caused by shaking, the structure can dissipate energy without substantially reducing its overall vertical loading strength.

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
1846		6	
1984		5	
1987		4.5	

No visible effects on load-bearing structures from earthquakes.

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	"Verrucano" or limestone masonry for blocks; lime mortar joints	20 - 50 MPa (verrucano or limestone) compression strength; 1-4 MPa (mortar) compression strength.		Big, regular-shaped blocks. The mortar layers are very thin and the gaps are not visible.
Foundation	"Verrucano" stone masonry support or clay units	10-20 MPa (clay unit) compression strength 1-4 MPa (mortar) compression strength.		
Frames (beams & columns)	Clay units masonry arches or wood beams.	8-15 MPa (wood) collapse stress due to bending moment		
Roof and floor(s)	Wood beams (chestwood and oak)	8-15 MPa (wood) collapse stress due to bending moment.		

6.2 Builder

The builder didn't live in this construction type. These buildings were made for rich and important families; the ordinary house is smaller and made of wood and clay units.

6.3 Construction Process, Problems and Phasing

In the first two floors, the walls consist of two parallel stone wythes filled with clay units and lime mortar joints. Both wythes are made of large, sharp, squared stones with thin layer of mortar without gaps. The upper floors are made of smaller stones approximately shaped with bigger mortar gaps; large squared stones are still used in the corners and overlap masonry units in order to have adequate connection to the perimeter walls. Roof and floor beams are supported by particular shaped stones coming out of the walls.The framework is supported by wood beams embedded in specific holes in the front, which are still visible (see picture). The construction of this type of housing takes place incrementally over time. Typically, the building is originally not designed for its final constructed size. As they became richer and more powerful, many owners increased the height of their "casa torre" in a competition with the neighboring families for greater status.

6.4 Design and Construction Expertise

Technical historical knowledge and devices were remarkable; several original buildings constructed in the 12th century are well preserved with almost no specific maintenance problems. These buildings didn't require knowledge of engineering or analytical design: the builder followed unwritten rules and knowledge based on experience and tradition.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. D.M. (Ministerial Decree) 20 November 1987 (Italian Code on Masonry Structures) D.M. 16 January 1996 (Italian Seismic Code). The year the first code/standard addressing this type of construction issued was 1974. Replaced O.M. (Ministerial Order) 20 March 2003 n. 3274 with further modifications. The most recent code/standard addressing this construction type issued was A national seimic code was issued in several Tuscany zones in July 1981. Title of the code or standard: D.M. (Ministerial Decree) 20 November 1987 (Italian Code on Masonry Structures) D.M. 16 January 1996 (Italian Seismic Code) Year the first code/standard addressing this type of construction issued: 1974 National building code, material codes and seismic codes/standards: Replaced O.M. (Ministerial Order) 20 March 2003 n. 3274 with further modifications When was the most recent code/standard addressing this construction type issued? A national seimic code was issued in several Tuscany zones in July 1981.

Building Code enforcement was not available. From 1088-1092, church regulations limited the height of the towers in order to prevent any one family from gaining too much power and control. Constructing wood galleries on the outside walls has been prohibited for safety reasons since 1300.

6.6 Building Permits and Development Control Rules

This type of construction is a non-engineered, and not authorized as per development control rules. Building permits are not required to build this housing type.

6.7 Building Maintenance

Typically, the building of this housing type is maintained by Builder. These buildings are commonly listed by the local heritage conservation office. (Soprintendenza ai Beni Architettonici, Artistici e Storici).

6.8 Construction Economics

In modern times, construction of building improvements and retrofitting is particularly concerned about preserving the original features. The average refurbishment cost is about 1.000 euros/m2. Refurbishment of this building type is under the strict control of the Historic Superintendent; only skilled laborers --- a builder, one assistant, a minimum of two skilled laborers and two manual laborers --- are allowed to perform work on these buildings.

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. Earthquake insurance is not available in Italy.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Transverse connection between opposite walls	Steel tendons: grid wood floor frame
Vertical settlement	Reinforcement of the foundations with RC tub-fix micropiles

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?
Steel bars are used as connections between opposite walls or to absorb horizontal forces in the arched beams of several buildings.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
Sometimes the work has been done to repair structural damage or to stop potential cracking of the masonry (not necessarily after an earthquake); sometimes it's undertaken just to stabilize the building.

8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?
Inspections were not routinely performed.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?
The building was constructed by a contractor without the involvement of an engineer or architect.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?
Generally remarkable, but highly dependent on the quality of the strengthening work; subsequent earthquakes have had no effect on load-bearing structures.

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Author(s)

1. Mauro Sassu
   Associate Professor, Dept. of Structural Engineering, University of Pisa
   Via Diotisalvi 2, Pisa 56126, ITALY
   Email:m.sassu@ing.unipi.it FAX: 39 050 554597

2. Chiara Cei
   Engineer, D.I.S.
   Viale Italia 255, Livorno , ITALY
   Email:angiochi@sysnet.it

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