World Housing Encyclopedia

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

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

HOUSING REPORT
Brick masonry farmhouse with a "dead door"

Report #	31
Report Date	05-06-2002
Country	ITALY
Housing Type	Unreinforced Masonry Building
Housing Sub-Type	Unreinforced Masonry Building : Brick masonry in mud/lime mortar
Author(s)	Agostino Goretti, Daniela Malvolti, Simona Papa
Reviewer(s)	Dina D'Ayala

Summary

This is a single-family farmhouse construction, found throughout the Padania plain (Reggio Emilia Province). This housing type accounts for approximately 20% of the entire housing stock in the Reggio Emilia municipality. This building practice is no longer followed. Most of the existing buildings were built in the 19th and 20th centuries. The residential and agricultural sections of the house are separated by a central area closed at one end and hence

called a "dead door." The residential section usually has two floors (typical story height 2.5 - 3.0 m) and a sloping roof. The agricultural portion, usually larger than the residential section, also has two floor levels. The first-floor height is on the order of 2.5 - 3.0 m whereas the second-story floor height ranges from 5.0 - 9.0 m. As a result, the roof in the agricultural section of the building is at a higher level than that of the residential. The first floor is used as a cow shed and the second as a hayloft. The load-bearing structure consists of brick masonry walls in lime mortar. The walls are characterized by variable thickness, decreasing from 280 mm at the first-floor level to 150 mm at the second-floor level. There are brick masonry columns in the interior of the agricultural section at the second-floor level. The buttresses can be found in the exterior brick masonry walls. Both the residential and agricultural sections have wooden floors; there are vaulted floors in the central area. In some cases, composite floors made of steel beams and perforated bricks can be found. Although the building plan is very regular, the seismic performance of this building type is rather poor due to the vertical irregularity (offset of the floors in the residential and agricultural sections), the absence of connections between walls and between the walls and floors, the thrusting of the roof, and the deterioration of materials.

1. General Information

Buildings of this construction type can be found in the Emila-Romagna region and in the south of the Padania Plain. It is widespread in the Reggio Emila Province. The total number of this building type in the Reggio Emilia municipality is less than 9,000. The percentage The percentage of this housing type as a fraction of the entire housing stock in the Reggio Emilia Municipality is approximately 20%. 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 not being built. .

Figure 1: Typical Building

Figure 2: Key Load-Bearing Elements

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They do not share common walls with adjacent buildings. When separated from adjacent buildings, the typical distance from a neighboring building is 10 meters.

2.2 Building Configuration

Building plan is usually regular, of a rectangular shape. In the residential portion a typical window size is 90 x120 cm. Windows are vertically aligned. At the first floor level in the agricultural portion, small windows are often densely distributed. Windows at the second floor level are used more for ventilation than for light in the hayloft. In the central part of the building there is a large door opening. Estimate of the overall window and door areas as a fraction of the overall wall surface area are: residential portion 25%, agricultural portion 15%, central portion 25%, overall 20%.

2.3 Functional Planning

Single family house, mixed residential and agricultural (cowshed and hayloft) use. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. No additional exit stair besides the main stairs.

2.4 Modification to Building

No significant structural modification can be observed in this housing type. Bathrooms have been recently added.

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)	☐

Type 7 with lime mortar instead of mud mortar. Brick dimension typically 28 x14 x 6 cm. Lime mortar 1-2 cm thick. Some mortar deterioration, at times due to water infiltration, can be found.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is un-reinforced masonry walls. The load bearing structure consists of brick masonry walls in lime mortar. The walls are characterized with a variable thickness, decreasing from 280 mm at the first floor to 150 mm at the second floor level. Brick masonry columns (560 mm depth) are present in the interior at the second floor level in the agricultural portion, and the buttresses can be found in the exterior walls. Both the residential and agricultural sections have wooden floors, while the vaults are present in the central area. In some cases, composite floors made of steel beams and perforated bricks can be found. On the second floor of the agricultural portion, diagonal bracing is present.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is un-reinforced masonry walls. Same as Vertical load bearing system.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 14 and 14 meters, and widths between 10 and 10 meters. The building is 2 storey high. The typical span of the roofing/flooring system is 4-6 meters. Typical Story

Height: 2.5 - 3.0 m in the residential portion and in the first floor of the agricultural portion. 5.0 - 9.0 m in the second level of the agricultural portion. The typical storey height in such buildings is 3 meters. The typical structural wall density is up to 5 %. 5% - 7% at first level, 3% - 4.5% at second level.

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	☑	☑

Wooden or steel beams with perforated bricks. Floors and roof are considered to be a flexible diaphragm.

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	☐

In buildings close to rivers, fieldstone strip footing can be found.


Figure 3: Critical Structural Detail - Roof Beam Support


Figure 4: Seismic deficiency- inadequate wall connection

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). 1 unit in each building. The number of inhabitants in a building during the day or business hours is 5-10. The number of inhabitants during the evening and night is 5-10.

4.2 Patterns of Occupancy

One family typically occupies one house.

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)	☐

Percentage of economic status: 50% Poor, 50% Middle Class. House Price over Annual Income has been set as a constant for different economic levels. In case of Middle Class Status, the annual income is greater but also the price of the house is greater, due to a higher level of maintenance. Economic Level: For Poor and Middle Class the ratio of Housing Unit Price to their Annual Income is 10:1.

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)	☐

This housing type is no longer built. In each housing unit, there are 1 bathroom(s) without toilet(s), 1 toilet(s) only and 1 bathroom(s) including toilet(s).

Originally there was only one latrine outside the building. Bathrooms and latrines inside the building have been added a few years ago. .

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	☐	☑	☐
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	Quality of building materials judged on present codes and standards.			

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	Absence of connections and/or iron ties able to prevent the out-of-plane wall overturning. At the second level, masonry wall is very slender with mortar often deteriorated.	Regular layout and solid bricks.	Separation of orthogonal walls, out of plane overturning, shear cracks, corner diagonal cracks due to the roof thrust.
Columns	At the second level of the agricultural portion (hayloft) columns can be up to 9.0 m high.		
Roof and floors	Flexible floors and roof are not effectively connected to walls. The vault in the central portion is usually very thin. The roof is often thrusting.	Floors and roof are light.	Separation of the floors and/or roof from the walls, beam hammering on walls.

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is B: MEDIUM-HIGH VULNERABILITY (i.e., 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 B: MEDIUM-HIGH VULNERABILITY (i.e., 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
1547	Reggio Emilia	4.7	VI-VII MCS
1832	Reggiano	5.2	VII-VIII MCS
1971	Parmense	5.5	VI MCS
1996	Bagnolo in Piano, Reggio Emilia.	4.5	VII MCS

Figure 5A: Wall damage (1996 Bagnolo earthquake)

Figure 5B: Wall damage at the roof beam support (1996 Bagnolo earthquake)

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Solid bricks with lime mortar.	characteristic normal stress =6.0 MPa characteristic shear stress=0.3 MPa.	1:3 lime/sand mortar.	Mortar is often deteriorated.
Foundation	Solid bricks with lime mortar.		1:3 lime/sand mortar.	
Frames (beams & columns)				
Roof and floor(s)	Wooden (or steel beam with perforated bricks).	+25 MPa, -12 MPa (200 MPa).		

6.2 Builder

This housing type is used by farmers. Buildings were built by local artisans.

6.3 Construction Process, Problems and Phasing

The construction process was driven by the fact that the owners typically had limited financial resources. Buildings were built with poor tools and materials and with low quality standards. The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size. Buildings were constructed without any design.

6.4 Design and Construction Expertise

Buildings were built relying on the experience of the local artisans, without any structural or architectural design. The need for cost control is demonstrated by structural elements that are not properly dimensioned and by the wall thickness reduction on the second floor. Engineers and architects were not involved in building construction in the past, now one can find them in charge of the structural design for building repairs or upgrades.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. Technical rules for the design, execution, testing and strengthening of masonry buildings, Ministry of Public Works, 1987. The year the first code/standard addressing this type of construction issued was 1909. The most recent code/standard addressing this construction type issued was 1987 for vertical loads, 1996 for seismic loads. Title of the code or standard: Technical rules for the design, execution, testing and strengthening of masonry buildings, Ministry of Public Works, 1987 Year the first code/standard addressing this type of construction issued: 1909 When was the most recent code/standard addressing this construction type issued? 1987 for vertical loads, 1996 for seismic loads.

In the case of repairs resulting from earthquake damage, as well as upgrades and retrofit, code enforcement and controls during the design and construction are performed by local authority (Region) officials. Public financial contributions are used for repair of earthquake damage, but upgrades and retrofit are privately financed .

6.6 Building Permits and Development Control Rules

This type of construction is a non-engineered, and not authorized as per development control rules.

In the past, building permits and authorizations were not required for building construction. Permits and authorizations are required for the building repair or upgrade performed at the present time. Building permits are not 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

500 Euro/m² (430 US$/m²). 90 days for 3-4 person team.

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.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Wall	-replacement of bricks with similar ones (sometimes with the insertion of horizontal steel rebars); -insertion of transverse connections made by bricks or steel bars into the wall; -tying of the orthogonal walls; -installation of iron ties; -Concrete jacketing is seldom

	performed.
Floors	Construction of new RC slab atop existing beams, tying the floor to the walls, replacement of the existing floor with RC floor
Roof	-replacement of existing wooden beams, -reinforcement (doubling) of the wooden boarding, -construction of RC ring beam
Columns	-Confinement with steel elements
Vaults	-RC slab on existing vaults

Upgrade or retrofit work have been seldom performed on this housing type.

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.

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

Mainly performed as a repair or upgrade 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?

A contractor performs the repair/upgrade construction. Architects or engineers are seldom involved in the construction phase, however they are involved in the design phase.

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

Good, provided that the retrofitting has been correctly performed.

Figure 6A: Illustration of Seismic Strengthening Techniques

Figure 6B: Seismic strengthening technique - installation of the iron ties

Reference(s)

1. Case rurali nel forese di Reggio Emilia
   Cremaschi,M.

Suppl. to Ricerche Storiche, n. 50-51 (In Italian) 1983

2. Le case della grande pianura
   Zaffagnin,M.
   Alinea, Florence (In Italian) 1997

3. Abitazioni rurali della Pianura
   Pietri C. and Pantaleoni L.
   Maggioli,P., (Ed.) (In Italian) 2000

Author(s)

1. Agostino Goretti
   Structural Engineer, National Seismic Survey
   Via Curtatone 3, Rome 185, ITALY
   Email:agostino.goretti@protezionecivile.it FAX: (+39)064466579

2. Daniela Malvolti
   Structural Engineer, Emilia-Romagna Region, Provincial Service for Land Management Emilia-Roma
   Via Emilia a S. Stefano 25, Reggio Emilia 42100, ITALY
   Email:spdsre@regione.emilia-romagna.it FAX: (+39) 0522 407750

3. Simona Papa
   Architect, Emilia-Romagna Region, Provincial Service for Land Management Emilia-Roma
   Via Emilia a S. Stefano 25, Reggio Emilia 42100, ITALY
   Email:spdsre@regione.emilia-romagna.it FAX: (+39) 0522 407750

Reviewer(s)

1. Dina D'Ayala
   Director of Postgraduate Studies
   Department of Architecture & Civil Engineering, University of Bath
   Bath BA2 7AY, UNITED KINGDOM
   Email:D.F.D'Ayala@bath.ac.uk FAX: 00 44 1225 386691