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

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HOUSING REPORT
Reinforced concrete frame building

Report #	30
Report Date	06-05-2002
Country	ITALY
Housing Type	RC Moment Frame Building
Housing Sub-Type	RC Moment Frame Building : Designed for gravity loads only, with URM infills
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Summary

This building type is commonly used for multifamily housing in urban areas of Italy and is particularly common in the region of Potenza (Basilicata). Prior to 1981, this region was not included in the official seismic zonation map of Italy, in spite of the historical evidence. However, after the major earthquake of November 1980, the entire Potenza province was recognized as a seismically prone area. Consequently, seismic considerations were not taken

into account for in the building design projects predating the 1980 earthquake. The main load-bearing structure is reinforced concrete frame with masonry infill walls. Many buildings of this type were strengthened using the financial assistance provided by the government. The upgrade typically consists of installing new shear walls and L-shaped columns, and strengthening the foundation.

1. General Information

Buildings of this construction type can be found in many cities throughout Italy. This type of housing construction is commonly found in urban areas.

This type of construction is also present in suburban areas.

This construction type has been in practice for less than 50 years.

Currently, this type of construction is not being built. This building type was common in the cities when the area was not officially in the seismic zone (pre-1980).

Figure 1A: Typical Building

Figure 1B: Typical Building

Figure 1C: Typical Building

Figure 1D: Typical Building

Figure 2A: Key Load-Bearing Elements (Building Shown on Figure 1A)

Figure 2B: Key Load-bearing Elements (Building Shown on Figure 1D)

2. Architectural Aspects

2.1 Siting

These buildings are typically found in sloped and hilly terrain. They do not share common walls with adjacent buildings. When separated from adjacent buildings, the typical distance from a neighboring building is 8-10 meters.

2.2 Building Configuration

Typical shape of the building plan is rectangular. The size of door opening is 0.80 m width and 2.00 m height. In the new RC shear walls installed as a part of the upgrade, there is only 1 door opening per apartment. The ratio of door area/shear wall area is approximately 9%.

2.3 Functional Planning

The main function of this building typology is multi-family housing. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. There is no additional exit stair besides the main stairs.

2.4 Modification to Building

The structural upgrade did not modify the building function (the same housing features were preserved after the upgrade).

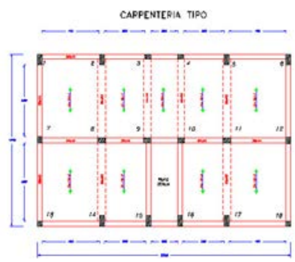


Figure 3A: Plan of a Typical Building

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	☐
			Concrete block masonry in	

		16	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)	☐

3.2 Gravity Load-Resisting System

The vertical load-resisting system is reinforced concrete moment resisting frame. Reinforced concrete frame.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is reinforced concrete structural walls (with frame). Originally the buildings were designed for gravity loads only. Unreinforced masonry infill walls exist as partitions (non-load-bearing elements). The strengthening was carried out after the November 1980 earthquake, in order to incorporate elements of lateral load-resisting system. The upgrade consists of installing new RC shear walls, L-shaped concrete columns and strengthening the foundation (using internal micropiles and external macropiles).

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 35 and 35 meters, and widths between 12 and 12 meters. The building has 4 to 10 storey(s). The typical span of the roofing/flooring system is 4.5 meters. Typical Plan Dimensions: The length varies from 20 to 50 m (35 m is stated as an average value). Typical Story Height: In the older buildings of this type (with stone masonry infill walls) the typical story height is 3.50 - 4.00 m. Typical Span: Span between the columns is on the order of 4.5 m. The typical storey height in such buildings is 3 meters. The typical structural wall density is up to 5 %. Approximately 0.05 (i.e. 5%).

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 floor/roof is considered to act as a rigid diaphragm.

3.6 Foundation

Type	Description	Most appropriate type
	Wall or column embedded in soil, without footing	☐

Shallow foundation	Rubble stone, fieldstone isolated footing	☐
	Rubble stone, fieldstone strip footing	☐
	Reinforced-concrete isolated footing	☐
	Reinforced-concrete strip footing	☐
	Mat foundation	☐
	No foundation	☐
Deep foundation	Reinforced-concrete bearing piles	☑
	Reinforced-concrete skin friction piles	☐
	Steel bearing piles	☐
	Steel skin friction piles	☐
	Wood piles	☐
	Cast-in-place concrete piers	☐
	Caissons	☐
Other	Described below	☐

It consists of reinforced concrete end-bearing piles. For all the buildings built before the 1980 earthquake, without any seismic features, the reinforcement of piles was limited to the first 2.50-3.00 m, for the anchorage to the plinths. Fortunately, foundation collapse was not reported due to very good soil conditions (over consolidated clay) with resetting of bending moment.

Figure 3B: Typical Floor Plan

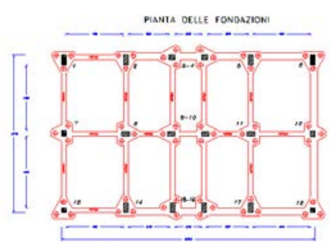


Figure 3C: Typical Foundation Plan

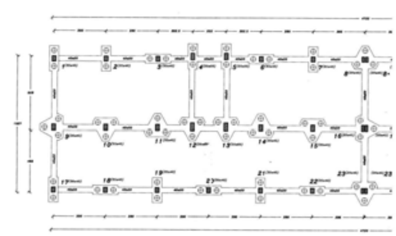


Figure 3D: Typical Foundation Plan

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 10-20 housing unit(s). 20 units in each building. Typically 10 to 30 units in each building.

The number of inhabitants in a building during the day or business hours is more than 20. The number of inhabitants during the evening and night is more than 20.

4.2 Patterns of Occupancy

One family per apartment (housing unit).

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)	☐

Very Poor: lowest 10%, Poor: lowest 30%, Middle Class: lowest 30% to top 20%, Rich: top 20%.

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)	☑

At present time, the Government does not support any new construction of this type. In each housing unit, there are 1 bathroom(s) without toilet(s), 1 toilet(s) only and 1 bathroom(s) including toilet(s).

Typically 1 bathroom and 1 latrine per housing unit or a bathroom and a latrine together. .

4.4 Ownership

The type of ownership or occupancy is outright ownership and individual 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				

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	Unreinforced hollow clay tile infill walls.		Diagonal ("X"-cracking) and failure see Figure 4A and 4B.
Frame (columns, beams)	Designed for gravity loads only.		
Roof and floors	Designed for gravity loads only.		

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is C: MEDIUM VULNERABILITY (i.e., moderate seismic performance), the lower bound (i.e., the worst possible) is B: MEDIUM-HIGH VULNERABILITY (i.e., poor seismic performance), and the upper bound (i.e., the best possible) is D: MEDIUM-LOW VULNERABILITY (i.e., good 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
1980	Irpinia-Basilicata	6.8	8.7 (MMI)
1990	Potenza	5.4	6.6 (MMI)
1991	Potenza	5	6.0 (MMI)
1998	Pollino-Lauria	5.5	6.75 (MMI)

The list includes the significant earthquakes in the Basilicata region after this construction practice has started.

Figure 4A: Typical Earthquake Damage - Cracking of Hollow Clay Tile Partitions

Figure 4B: Typical Earthquake Damage-Cracking of Masonry Partitions

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Reinforced Concrete, Steel	300 kg/cm², 4400 kg/cm²		
Foundation	Reinforced Concrete, Steel	300 kg/cm², 4400 kg/cm²		
Frames (beams & columns)	Reinforced Concrete, Steel	300 kg/cm², 4400 kg/cm²		
Roof and floor(s)	Reinforced Concrete, Steel	300 kg/cm², 4400 kg/cm²		

6.2 Builder

The builder typically lives in a building of this construction type.

6.3 Construction Process, Problems and Phasing

This construction type is built by contractors. The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size.

6.4 Design and Construction Expertise

Design for building of this type: by a graduate technician (a college graduate). Structural design: by a Civil Engineer. The structural design of this construction was completely done by a civil engineer. The architects usually design buildings with better aesthetic features (and functionality).

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. Italian Code. The year the first code/standard addressing this type of construction issued was 1971. National ByLaw #1086, November 5, 1971 National ByLaw #64, February 2, 1974 Ministerial Order January 16, 1996. The most recent code/standard addressing this construction type issued was 1996. Title of the code or standard: Italian Code Year the first code/standard addressing this type of construction issued: 1971 National building code, material codes and seismic codes/standards: National ByLaw #1086, November 5, 1971 National ByLaw #64, February 2, 1974 Ministerial Order January 16, 1996 When was the most recent code/standard addressing this construction type issued? 1996.

Building permit is issued if the design documents have been approved by the Building Committee of Town Municipality (Planning and Building Departments) and by the Regional Committee (named "Genio Civile") for Structural Project.

6.6 Building Permits and Development Control Rules

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

500 \$US/m². The construction of a typical load-bearing structure of this type (5-story high) would take from 126 to 180 days for a team of 8-10 persons.

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
Pile Foundations	Strengthening
RC Columns	Strengthening
Deficient Lateral Load-Resisting Capacity	Installation of new RC shear walls

The initial phase of the seismic upgrade design included the evaluation of the existing building in order to identify seismic deficiencies. Dynamic analysis was performed using the Super ETABS software, and the natural periods of the structure for six different modes. After the strengthening design was performed, the new periods have been calculated, showing that the strengthened building is characterized with a significantly higher stiffness as compared to the original building. A chart showing the variation of natural vibration periods for the same five-story building before and after the retrofit is illustrated in Figure 5H (corresponding to the building shown in Figures 1A, 2A and 3A). A similar chart is presented on Figure 5I, corresponding to a four-story building shown in Figures 1E, 2B and 3.

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 strengthening has been performed in practice. This type of strengthening assures the protection of the building from seismic effects and improved dynamic response.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
Repair and retrofit after the earthquake.

8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?
No.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?
Contractor performed the construction and an engineer was involved.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?
The performance of retrofitted building was excellent in the earthquakes of 1990/1991.

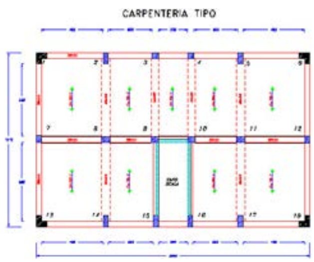


Figure 5A: Seismic Strengthening Techniques : Floor Plan of a Strengthened Building

Figure 5B: Seismic Strengthening - Floor Plan of a Strengthened Building

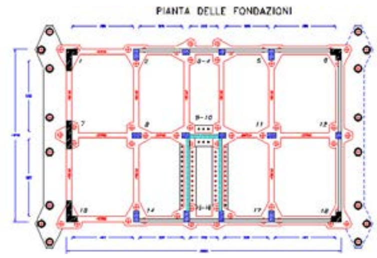


Figure 5C: Seismic Strengthening - Foundation Plan

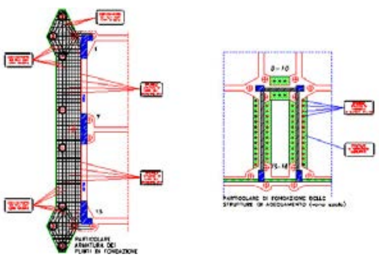
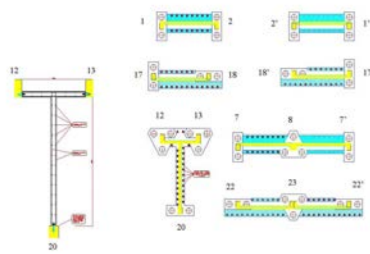


Figure 5D: Seismic Strengthening- Foundation Details


Seismic Strengthening-Foundation and Wall Details

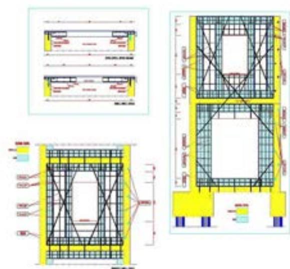


Figure 5F: Seismic Strengthening- Details of New RC Shear Wall

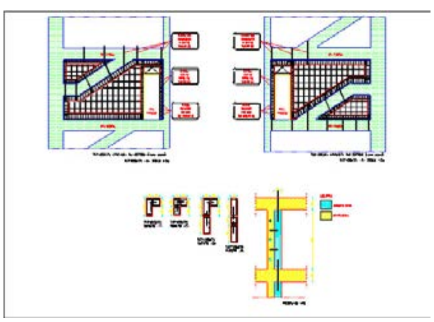


Figure 5G: Seismic Strengthening- Details of New Shear Wall

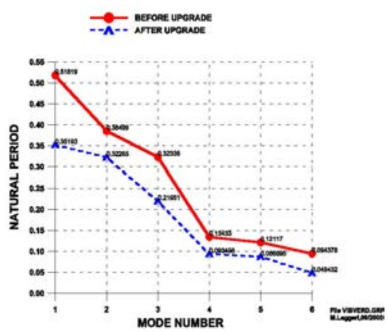


Figure 5H: Dynamic Characteristics (Natural Period) of a Five-Story Building Before and After the Retrofit (corresponding to the building shown on Figures 1A, 2A, and 3A)

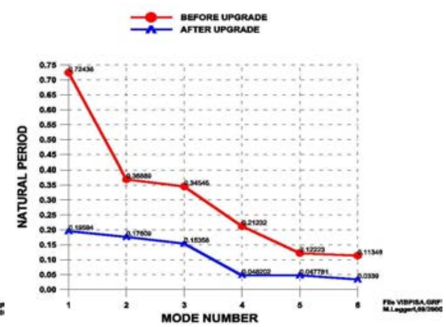


Figure 5I: Dynamic Characteristics (Natural Period) of a Four-Story Building Before and After the Retrofit (correspoding to the building shown on Figures 1E, 2B and 3B)

Reference(s)

1. Censimento ISTAT Popolazione ed Abitazioni
   Italian Seismic Code (in Italian) 1990

2. I Terremoti Della Basilicata
   Leggeri,M.
   Edizioni Ermes, Potenza, Italy (in Italian)

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