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

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HOUSING REPORT
Single-family stone masonry house

Report #	28
Report Date	06-05-2002
Country	ITALY
Housing Type	Stone Masonry House
Housing Sub-Type	Stone Masonry House : Rubble stone without/with mud/lime/cement mortar
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Summary

These buildings form the historic centers of most hilltop villages and towns in central Italy. They are arranged in long terraced clusters. Hillside dwellings have common walls and a variable number of stories (up to 2 or 3). Buildings situated in the valley usually have 4 or 5, with a maximum of 6, stories. The typical house is usually formed by one or two masonry cells, depending on the depth of the block, and with a staircase (usually but not necessarily)

running along the common wall. The masonry is made of roughly squared stone blocks set in lime mortar, and the walls are made of two leaves with a rubble core at the base, tapering at the upper floors. Limestone is used for the blocks, while a particular type of tuffa stone is used for the lintels above the openings. At the ground level there are sometimes vaulted structures. The upper stories were originally spanned by timber beams, with joist and timber boards covered by tiles. The roof structure is usually original and made of timber trusses. In the recent past, many of the original floors have been replaced either with iron 'T' beams and jack arches (renovations occurring before World War II), or during the last fifty years, with weakly reinforced concrete slabs. Other alterations include vertical extensions, the closing and opening of windows, and introduction of hygienic services. A high proportion of these houses exhibit the traditional iron ties introduced in the 18th century to tie together the orthogonal walls and floors for better seismic performance. After the introduction of modern seismic codes in the 1980s, many buildings have undergone further strengthening through the use of RC ring beams and concrete jacketing of walls.

1. General Information

Buildings of this construction type can be found in Centro Italia, Umbria, Toscana, Alto Lazio, Marche, but also with some changes in other parts of Italy.The seismic performance is highly correlated to the masonry fabric and quality of bonding agents. This type of housing construction is commonly found in urban areas.

Most frequently found in medieval hilltop small and medium size town centers. The quality of the stonework in the towns tends to be better than in the rural examples.

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

Currently, this type of construction is being built. Traditional construction practice was followed in the last 200 years with updates and modified practice during the last 100 years.

Figure 1: Typical Building

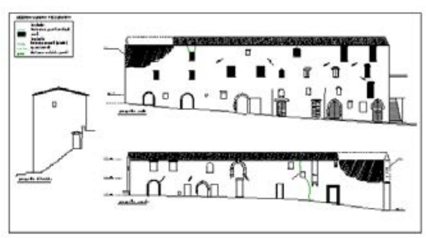

Figure 2: Key Load-Bearing Elements

2. Architectural Aspects

2.1 Siting

These buildings are typically found in sloped and hilly terrain. They share common walls with adjacent buildings.

2.2 Building Configuration

Roughly rectangular as usually part of arrays or terraces, but alterations and joining of cadastral units may result in different shapes. Also front and back walls are not necessarily parallel as are not the party walls. Opening layout is frequently altered over time, so that it is very often irregular from one floor to the next one. Typical percentage are 30% to 50% of wall surface on façade, much less on side walls, but with exceptions. In regular cases for each floor of each cell , there are two windows laid out in vertical arrays.

2.3 Functional Planning

The main function of this building typology is single-family house. Originally single housing units, sometime with commercial ground floor. Often cadastral units have been coupled in recent years to form larger units. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. Single entry and single staircase, usually (2 to 4 storey, typically).

2.4 Modification to Building

Addition of stories, insertion of balconies and some rearrangement of interior walls. Also as buildings have existed for a long time, some modernization and modifications have been introduced, such as bathrooms and kitchens with running water.

Figure 3A: An Elevation of a Typcial Building

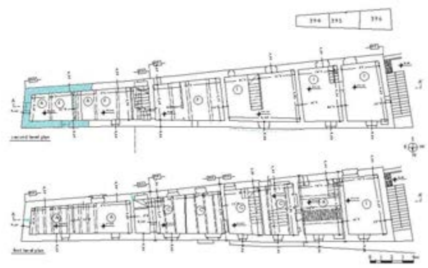

Figure 3B: Plan of a Typical Building

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	☐
			Stone masonry in cement	

	Reinforced masonry	14	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)	☐

Although stone walls are commonly used, insertion of brickwork is not uncommon. The quality of the masonry can be very variable. Mortar is usually lime based.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is stone masonry walls. Single or double leaf masonry walls with rubble infill.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is stone masonry walls. Masonry walls with or without metal ties.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 4 and 4 meters, and widths between 6 and 6 meters. The building has 2 to 5 storey(s). The typical span of the roofing/flooring system is 5 meters. Typical Plan Dimension: The masonry cell dimensions are usually 4 X 6 m, but houses might result from aggregation of cells. Typical Span: Usually typical span is from 4 to 6 meters Typical Story Height: Story height varies from 2.5 to 3.2 meters. The typical storey height in such buildings is 3 meters. The typical structural wall density is more than 20 %. Total wall area/plan area (for each floor) is from 0.17 to 0.25.

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	☑	☑

As mentioned in the general description, originally vaulted system at ground floor and timber beams at the upper floors would be the typical arrangement, but in the last 50 years these have been replaced by precast joist system. In most cases the floor structure cannot be considered as a rigid 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	☐
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	☐

In some cases, following problems with uneven settlements, in recent years some of these houses might have been underpinned using micro-piles.

Figure 4A: Critical Structural Details Stone Masonry Wall With Irregular Roughly Dressed Stone Blocks of Varying Dimensions Embedded into Thick Lime Mortar Joints (not properly repointed)

Figure 4B: Critical Structural Details-Movement the Blocks, Probably as a Result of Damage in Previous Earthquake and Visible Loose Stones Around the Arch

Figure 5A: Key Seismic Features and Deficiecies Showing the Regular Arrays of Floor Ties in One Unit, Irregular Distribution of Wall Ties in hte Next One, and Corner Return Return Stones in the Third Unit

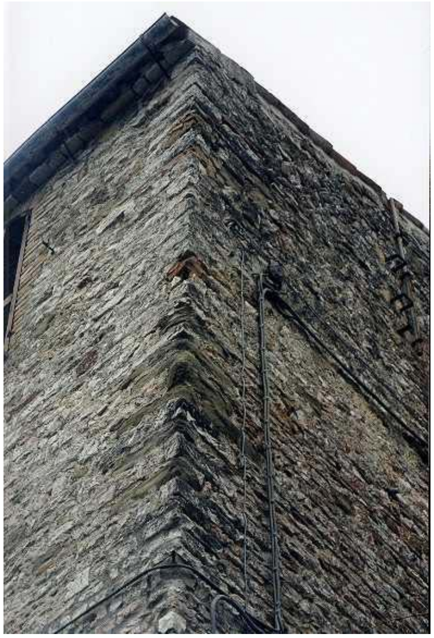

Figure 5B: Earthquake-Resilient Feature - Corner Returns between the Perpendicular Walls Made of Larger Stone Blocks

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 2 housing unit(s). 2 units in each building. From 1 to 4 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 5-10. Some of these units have now been converted in holiday homes, only occupied at weekends and in the summer months.

4.2 Patterns of Occupancy

From 1 to 2 families depending on size of the building.

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)	☐

Economic Level: For Poor Class the ratio of Housing Unit Price to their Annual Income is 5:1. For Middle Class the ratio of Housing Unit Price to their Annual Income is 4:1.

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)	☐

In each housing unit, there are 1 bathroom(s) without toilet(s), 1 toilet(s) only and 1 bathroom(s) including toilet(s).

The number of bathrooms depends on the level of refurbishment and varies from 1 to 2. .

4.4 Ownership

The type of ownership or occupancy is renting, 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.	☑	☐	☐
	The roof diaphragm is considered to be rigid and it is			

Roof construction	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	-Level of bond in the geometric thickness of the multi-leaf walls. -Extent of connection between façade and party walls, depending on alteration and position of windows. -Level of bond between mortar and units depending on decay of original material and regular repointing.	-Corner returns between the perpendicular walls made of larger stone blocks are an original feature in many buildings. -In some buildings built in the last 100 years iron anchors connecting the floor timber structure to the wall are an as-built feature, see Figure 5A.	- In cases of poor bond between leaves, disintegration of the masonry fabric is the most common damage. - In cases of poor connection between facades and party walls, out-of-plane mechanism will take place resulting in partial or total collapse of one or more walls. - In cases of good connections between orthogonal walls, in-plane mechanism will take place resulting in diagonal cracking ("X" cracks), see Figure 6A.
Roof and	Original structures are flexible	In some cases the main timber	Partial or total collapse of floor or roof structure associated

floors	diaphragms. Some roofs can also produce active thrust on the walls.	structure is laid out orthogonally at different floor level to tie in both sets of walls.	with partial or total collapse of load-bearing walls
Roof and floors			

Seismic features for a typical building of this type are illustrated in Figure 5A. Note the regular arrays of floor ties in one of the units, irregular distribution of wall ties in the next one, and corner return stones in the third unit. Due to the absence of adequate connections between internal and external leaves of masonry, a partial collapse of the area above the window opening took place.

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 C: MEDIUM VULNERABILITY (i.e., moderate 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
1997	Serravalle	5.6	VIII MMI

A small proportion of these buildings collapsed in the town centers and usually these had very poor maintenance record, i.e. the buildings had not been occupied for a number of years. A greater proportion of similar buildings (still within 25% of the total number) collapsed in the smaller mountain villages closer to the epicenter. Two main factors can be considered as possible causes of this disparity, assuming a similar level of seismic excitation: worse construction quality, and the fact that the houses in the villages are isolated, whereas in the towns they are built in the rows. Figure 6A shows a house in the historic centre of Nocera Umbra, subjected to the 1997 Umbria-Marche earthquake. Typical "X" cracks developed in masonry walls, in this case caused by the increased stiffness of roof structure that had been replaced by reinforced concrete slab with ring-beam. Figure 6B illustrates the earthquake damage associated with the inadequate ring beam-wall connection. The roof had slipped on the masonry and caused the wall damage.

Figure 6A: Typical Earthquake Damage - "X" cracking of walls (1997 Umbria-Marche earthquake)

Figure 6B: Earthquake Damage to a Retrofitted Building to the Inadequate RC Ring Beam-Wall Connection

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Rubble stone masonry.	Comp.= 1 MPa Shear = 0.02 MPa.	Lime mortar 1:3 or 1:2:9	
Foundation	Dressed stone masonry.	Comp.= 2 MPa Shear = 0.07 MPa.	Lime mortar 1:3 or 1:2:9	
Frames (beams & columns)				
Roof and floor(s)	Timber	6 to 10 MPa		Depends on type and age of timber.

6.2 Builder

Very rarely these houses are built nowadays, but contractors who will do maintenance or upgrading will live locally, in similar type of construction.

6.3 Construction Process, Problems and Phasing

See above. However modern tools tend to be used for repairs, strengthening or upgrading interventions. The construction of this type of housing takes place incrementally over time. Typically, the building is originally not designed for its final constructed size. Buildings would have typically undergone several alteration and refurbishments during their life, including addition of stories, replacement of staircases and demolition /erection of bearing walls.

6.4 Design and Construction Expertise

Most of buildings were constructed many years ago and didn't have any kind of expertise. The design of repair and strengthening has to be signed by an engineer. The architect would typically get involved if refurbishment is planned.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. Decreto Ministeriale 2-7-1981: Normativa per le riparazioni ed il rafforzamento degli edifici dannegiati dal sisma. The year the first code/standard addressing this type of construction issued was 1981. This type of historic construction is only addressed in terms of repair and strengthening. The first code was issued post The Campania earthquake of 1981. Decreto Ministeriale 2-7-1981: Normativa per le riparazioni ed il rafforzamento degli edifici dannegiati dal sisma. Revised in 1986 and in 1996. New brick masonry structures are addressed in a different standard. The most recent code/standard addressing this construction type issued was 1996. Title of the code or standard: Decreto Ministeriale 2-7-1981: Normativa per le riparazioni ed il rafforzamento degli edifici dannegiati dal sisma Year the first code/standard addressing this type of construction issued: 1981 National building code, material codes and seismic codes/standards: This type of historic construction is only addressed in terms of repair and strengthening. The first code was issued post The Campania earthquake of 1981. Decreto Ministeriale 2-7-1981: Normativa per le riparazioni ed il rafforzamento degli edifici dannegiati dal sisma. Revised in 1986 and in 1996. New brick masonry structures are addressed in a different standard. When was the most recent code/standard addressing this construction type issued? 1996.

N/A.

6.6 Building Permits and Development Control Rules

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

Most of these buildings fall within conservation areas, for which special permits have to be required. Alteration to the building are allowed only if accompanied by an improvement of the structural seismic behavior. Building permits are required to build this housing type.

6.7 Building Maintenance

Typically, the building of this housing type is maintained by Builder and Owner(s).

6.8 Construction Economics

800 Euro/m². 4-6 working weeks depending on size.

7. Insurance

Earthquake insurance for this construction type is typically unavailable. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is unavailable.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Lack of Structural Integrity	Installation of new RC ring beams with or without concrete slab. A procedure for the installation of a new RC ring beam in an existing stone masonry building is presented in Figure 7F. Note the dowels anchored into the existing walls and the new concrete slab atop the existing wood floor. Figure 7E shows an alternative solution, which includes the installation of steel anchors grouted into the existing walls and the installation of new concrete floor slab atop the existing wood floor. Figure 7A shows a building strengthened with new RC ring beams. It is very important to achieve the connection between the new RC ring beam and the existing masonry, otherwise the earthquake damage may be caused, as illustrated in Figure 6B.
Inadequate Wall-Floor Connection	Installation of new steel ties. Figure 7C shows a steel strap detail connecting an existing stone masonry wall to a timber floor joists. Figure 7D shows a detail of ties with an anchor plate at the exterior face of the wall. A building with the installed ties is shown on Figure 5A. It is very important to accomplish a regular distribution of ties - irregular tie distribution may be a cause of earthquake damage, as illustrated in Figure 6A.
Low Lateral-Load Resistance of the Walls	Grouting, see Figure 7A.

Figure 7A illustrates the following seismic strengthening provisions: RC ring beams and anchorage of floor beams to the wall, repointing and grouting using cement-based grout, corner return in brickwork, and the installation of concrete window frame. Figure 7B illustrates modern anchors with anchorage plates and concrete lintels over openings.

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?
Seismic strengthening is recommended by a local authority and required when other forms of alteration or improvement are performed. It is quite common in design practice.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
The work could be performed in both cases.

8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?
N/A.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?
An architect or engineer is required to sign the strengthening design submitted to the local building authority.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?
Generally good, but highly dependent on the quality of implementation of the strengthening.

Figure 7A: Illustration of Seismic Strengthening Techniques

Figure 7B: Seismic Strenghthening Techniques- Installation of modern anchors with anchorage plates and concrete lintels over openings

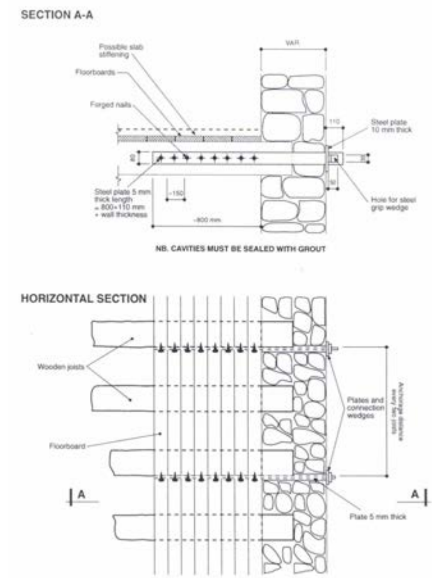

Figure 7C: Seismic Strengthening - Steel Strap Used to Connect an Existing Masonry Wall to Timber Floor Joists

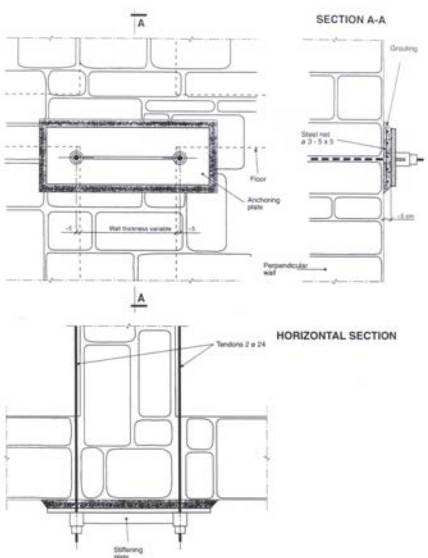

Figure 7D: Seismic Strengthening - Installation of Ties with an Anchor Plate at the Exterior Wall Face

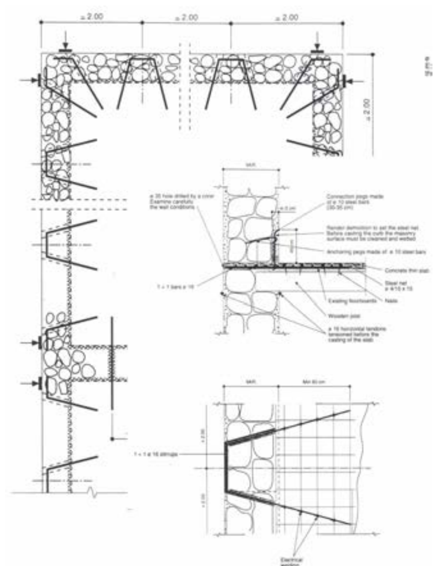

Figure 7E: Seismic Strengthening - Installation of New Steel Anchors Grouted Into Existing Walls and the New RC Floor Slabs

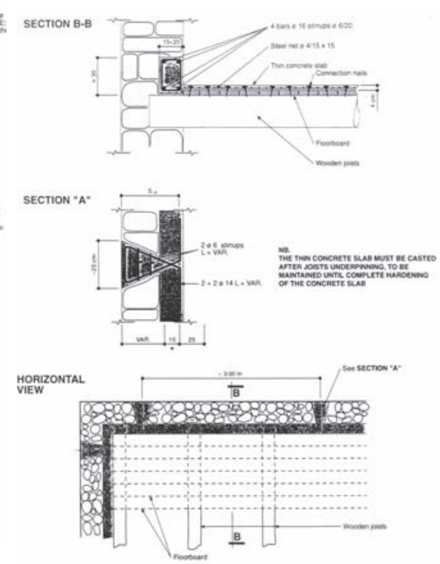

Figure 7F: Seismic Strengthening - Installation of New RC Ring Beam

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