World Housing Encyclopedia Report

Country: Italy

Housing Type: Single-family stone masonry house

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1 General Information

1.1 Country

Italy

FIGURE 1: Typical Building

1.3 Housing Type

Single-family stone masonry house

1.4 Summary

These buildings form the historic centers of most hilltop villages and towns in central Italy. They are arranged in long terraced arrays, with common party walls and variable number of stories on the hillside (up to 2 or 3) and valley side (usually 4 or 5, with a maximum of 6). The typical house is usually formed by one or two masonry cells, depending on the depth of the block, with a staircase running, usually but not necessarily, along the party walls. 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 openings. At ground level there are sometimes vaulted structures, while 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 recent past, many of the original floors have been replaced either with iron "I" beams and jack arches (refurbishments occurred before the World War II) or more recently with weakly reinforced concrete slabs (last fifty years). Other alterations include vertical extensions, closing and opening of windows, introduction of hygienic services. A high proportion of these houses show traditional iron ties introduced in the 18th Century to tie together orthogonal walls and floors, to ensure better seismic performance. After the introduction of modern seismic codes in 1980s many buildings have undergone further strengthening, represented by RC ring beams and concrete jacketing of walls.

1.5 Typical Period of Practice for Buildings of This Construction Type

How long has this construction been practiced	
< 25 years	
< 50 years	
< 75 years	
< 100 years	
< 200 years	X
> 200 years	

Is this construction still being practiced?	Yes	No
	X	

Additional Comments: Traditional construction practice followed in the last 200 years with updates and modification during the last 100 years

1.6 Region(s) Where Used

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.

1.7 Urban vs. Rural Construction

Where is this construction commonly found?	
In urban areas	X
In rural areas	
In suburban areas	
Both in rural and urban areas	

Additional Comments: 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.

2 Architectural Features

2.1 Openings

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

2.2 Siting

	Yes	No
Is this type of construction typically found on flat terrain?		X
Is this type of construction typically found on sloped terrain? (hilly areas)	X	
Is it typical for buildings of this type to have common walls with adjacent buildings?	X	

The typical separation distance between buildings is meters

2.3 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

2.4 Building Function

What is the main function for buildings of this type?	
Single family house	X
Multiple housing units	
Mixed use (commercial ground floor, residential above)	
Other (explain below)	

Additional Comments: Originally single housing units, sometime with commercial ground floor. Often cadastral units have been coupled in recent years to form larger units

2.5 Means of Escape

Single entry and single staircase, usually (2 to 4 storey, typically).

2.6 Modification of Buildings

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.

3 Socio-Economic Issues

3.1 Patterns of Occupancy
From 1 to 2 families depending on size of the building

3.2 Number of Housing Units in a Building
2 units in each building.

Additional Comments: From 1 to 4 units in each building.

3.3 Average Number of Inhabitants in a Building

How many inhabitants reside in a typical building of this construction type?	During the day / business hours	During the evening / night
< 5	X	
5 to 10		X
10-20		
> 20		
Other		

Additional Comments: Some of these units have now been converted in holiday homes, only occupied at weekends and in the summer months.

3.4 Number of Bathrooms or Latrines per Housing Unit
Number of Bathrooms: 1
Number of Latrines: 1

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

3.5 Economic Level of Inhabitants

Economic Status		House Price/Annual Income (Ratio)
Very poor		/
Poor	X	5/1
Middle Class	X	4/1
Rich		/

3.6 Typical Sources of Financing

What is the typical source of financing for buildings of this type?	
Owner Financed	X
Personal Savings	
Informal Network: friends and relatives	X
Small lending institutions/microfinance institutions	X
Commercial banks / mortages	
Investment pools	
Combination (explain)	
Government-owned housing	
Other	

3.7 Ownership

Type of Ownership/Occupancy	
Rent	X
Own outright	X
Own with Debt (mortgage or other)	
Units owned individually (condominium)	X
Owned by group or pool	
Long-term lease	
Other	

4 Structural Features

4.1 Lateral Load-Resisting System

Masonry walls with or without metal ties

4.2 Gravity Load-Bearing Structure

Single or double leaf masonry walls with rubble infill

4.3 Type of Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	
Masonry	Stone masonry walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	X
		2	Massive stone masonry (in lime or cement mortar)	X
	Earthen walls	3	Mud walls	
		4	Mud walls with horizontal wood elements	
		5	Adobe block or brick walls	
		6	Rammed earth/Pise construction	
	Unreinforced brick masonry walls	7	Unreinforced brick masonry in mud or lime mortar	
		8	Unreinforced brick masonry in mud or lime mortar with vertical posts	
		9	Unreinforced brick masonry in cement or lime mortar (various floor/roof systems)	
	Confined masonry	10	Confined brick/block masonry with concrete posts/tie columns and beams	
	Concrete block masonry walls	11	Unreinforced in lime or cement mortar (various floor/roof systems)	
		12	Reinforced in cement mortar (various floor/roof systems)	
		13	Large concrete block walls with concrete floors and roofs	
Concrete	Moment resisting frame	14	Designed for gravity loads only (predating seismic codes i.e. no seismic features)	
		15	Designed with seismic features (various ages)	
		16	Frame with unreinforced masonry infill walls	
		17	Flat slab structure	
		18	Precast frame structure	
		19	Frame with concrete shear walls-dual system	
		20	Precast prestressed frame with shear walls	
	Shear wall structure	21	Walls cast in-situ	
		22	Precast wall panel structure	
Steel	Moment resisting frame	23	With brick masonry partitions	
		24	With cast in-situ concrete walls	
		25	With lightweight partitions	
	Braced frame	26	Concentric	
		27	Eccentric	
Timber	Load-bearing timber frame	28	Thatch	
		29	Post and beam frame	
		30	Walls with bamboo/reed mesh and post (wattle and daub)	
		31	Wooden frame (with or without infill)	
		32	Stud wall frame with plywood/gypsum board sheathing	
		33	Wooden panel or log construction	
Various	Seismic protection systems	34	Building protected with base isolation devices or seismic dampers	
	Other	35		

Additional Comments: 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.

4.4 Type of Foundation

Type	Description	
Shallow Foundation	Wall or column embedded in soil, without footing	
	Rubble stone (fieldstone) isolated footing	
	Rubble stone (fieldstone) strip footing	X
	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	
	Wood piles	
	Steel skin friction piles	
	Cast in place concrete piers	
	Caissons	
Other		

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

4.5 Type of Floor/Roof System

Material	Description of floor/roof system	Floor	Roof
Masonry	Vaulted	X	
	Composite masonry and concrete joist		
Structural Concrete	Solid slabs (cast in place or precast)		
	Cast in place waffle slabs		
	Cast in place flat slabs		
	Precast joist system	X	
	Precast hollow core slabs		
	Precast beams with concrete topping		
	Post-tensioned slabs		
Steel	Composite steel deck with concrete slab		
Timber	Rammed earth with ballast and concrete or plaster finishing		
	Wood planks or beams with ballast and concrete or plaster finishing	X	
	Thatched roof supported on wood purlins		
	Wood single roof		
	Wood planks or beams that support clay tiles		X
	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			

Additional Comments: 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.

4.6 Typical Plan Dimensions

Length: 4 - 4 meters
Width: 4 - 4 meters
Additional Comments: The masonry cell dimensions are usually 4 X 6 m, but houses might result from aggregation of cells.

4.7 Typical Number of Stories

2 - 5

4.8 Typical Story Height
3 meters

Additional Comments: Story height varies from 2.5 to 3.2 meters.

4.9 Typical Span
5 meters

Additional Comments: Usually typical span is from 4 to 6 meters

4.10 Typical Wall Density
Total wall area/plan area (for each floor) is from 0.17 to 0.25

4.11 General Applicability of Answers to Questions in Section 4
The building is typical of the region. Variable parameters are geometric size.

5 Evaluation of Seismic Performance and Seismic Vulnerability

5.1 Structural and Architectural Features: Seismic Resistance

Structural/ Architectural Feature	Statement	True	False	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 form the building to the foundation.		X	
Building configuration	The building is regular with regards to both the plan and the elevation.	X		
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.		X	
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.		X	
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.	X		
Wall and frame structures- redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	X		
Wall proportions	Height-to-thickness ratio of the shear walls at each floor level is: 1) Less than 25 (concrete walls); 2)Less than 30 (reinforced masonry walls); 3) Less than 13 (unreinforced masonry walls).	X		
Foundation- wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	X		
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps.	X		
Wall openings	The total width of door and window openings in a wall is: 1) for brick masonry construction in cement mortar: less than 1/2 of the distance between the adjacent cross walls; 2) for adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; 3) for precast concrete wall structures: less than 3/4 of the length of a perimeter wall.		X	
Quality of building materials	Quality of building materials is considered to be adequate per requirements of national codes and standards (an estimate).	X		
Quality of workmanship	Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).	X		
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).		X	
Other				

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, see Figure 5B. -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 floors	Original structures are flexible diaphragms. Some roofs can also produce active thrust on the walls.	In some cases the main timber structure is laid out orthogonally at different floor level to tie in both sets of walls.	Partial or total collapse of floor or roof structure associated with partial or total collapse of load-bearing walls
Roof and floors			

Additional Comments: 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 Seismic Vulnerability Rating

	Vulnerability					
	High (Very Poor Seismic Performance) A	B	Medium C	D	E	Low (Excellent Seismic Performace) F
Seismic Vulnerability Class	<	0	>			

0 - probable value
< - lower bound
> - upper bound

6 Earthquake Damage Patterns

6.1 Past Earthquakes Reported To Affect This Construction

Year	Earthquake Epicenter	Richter magnitude(M)	Maximum Intensity (Indicate Scale e.g. MMI, MSK)
1997	Serravalle	5.6	VIII MMI

Additional Comments: 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.

7 Building Materials and Construction Process

7.1 Description of 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	
Foundations	Dressed stone masonry	Comp.= 2 MPa Shear = 0.07 MPa	Lime mortar 1:3 or 1:2:9	
Roof and floors	Timber	6 to 10 MPa		Depends on type and age of timber

7.2 Does the builder typically live in this construction type, or is it more typically built by developers or for speculation?

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

7.3 Construction Process

See above. However modern tools tend to be used for repairs, strengthening or upgrading interventions.

7.4 Design/Construction Expertise

Most of buildings were constructed many years ago and didn't have any kind of expertise

7.5 Building Codes and Standards

	Yes	No
Is this construction type addressed by codes/standards?	X	

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

7.6 Role of Engineers and Architects

The design of repair and strengthening has to be signed by an engineer. The architect would typically get involved if refurbishment is planned.

7.7 Building Permits and Development Control Rules

	Yes	No
Building permits are required	X	
Informal construction	X	
Construction authorized per development control rules		

Additional Comments: 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.

7.8 Phasing of Construction

	Yes	No
Construction takes place over time (incrementally)	X	
Building originally designed for its final constructed size		X

Additional Comments: 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

7.9 Building Maintenance

Who typically maintains buildings of this type?	
Builder	X
Owner(s)	X
Renter(s)	
No one	
Other	

7.10 Process for Building Code Enforcement

N/A

7.11 Typical Problems Associated with this Type of Construction

There is a need for mass strengthening of buildings.

8 Construction Economics

8.1 Unit Construction Cost (estimate)

800 Euro/m²

8.2 Labor Requirements (estimate)

4-6 working weeks depending on size.

9 Insurance

9.1 Insurance Issues

	Yes	No
Earthquake insurance for this construction type is typically available		X
Insurance premium discounts or higher coverages are available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features		X

9.2 If earthquake insurance is available, what does this insurance typically cover/cost?

10 Seismic Strengthening Technologies

10.1 Description of Seismic Strengthening Provisions

Type of intervention	Structural Deficiency	Description of seismic strengthening provision used
Retrofit (Strengthening)	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.

Additional Comments: 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.

10.2 Has seismic strengthening described in the above table been performed in design 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.

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

The work could be performed in both cases.

10.4 Was the construction inspected in the same manner as new construction?

N/A

10.5 Who performed the construction: 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.

10.6 What has been the performance of retrofitted buildings of this type in subsequent earthquakes?

Generally good, but highly dependent on the quality of implementation of the strengthening.

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12 Contributors

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13 Figures

FIGURE 1: Typical Building

FIGURE 2A: Key Load-Bearing Elements

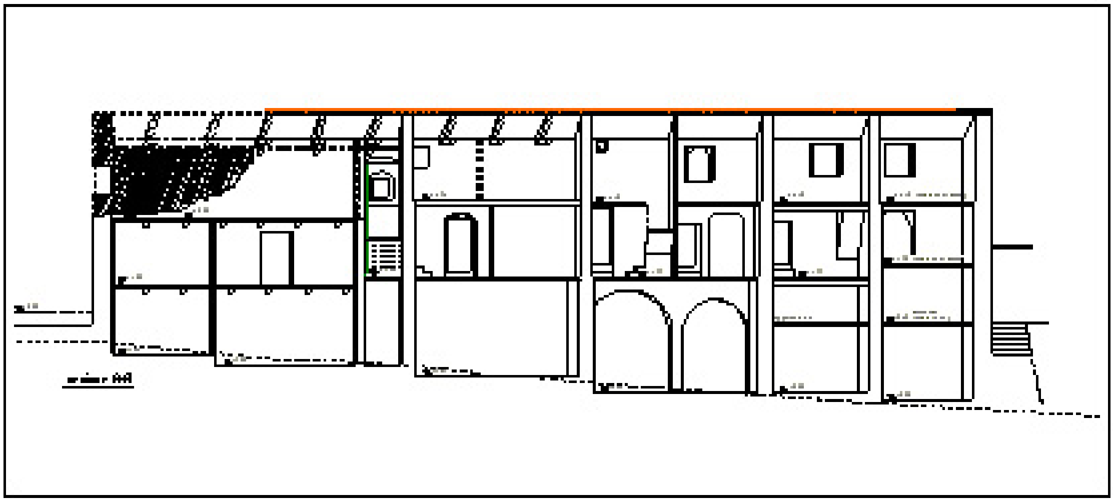


FIGURE 2B: An Elevation of a Typical Building

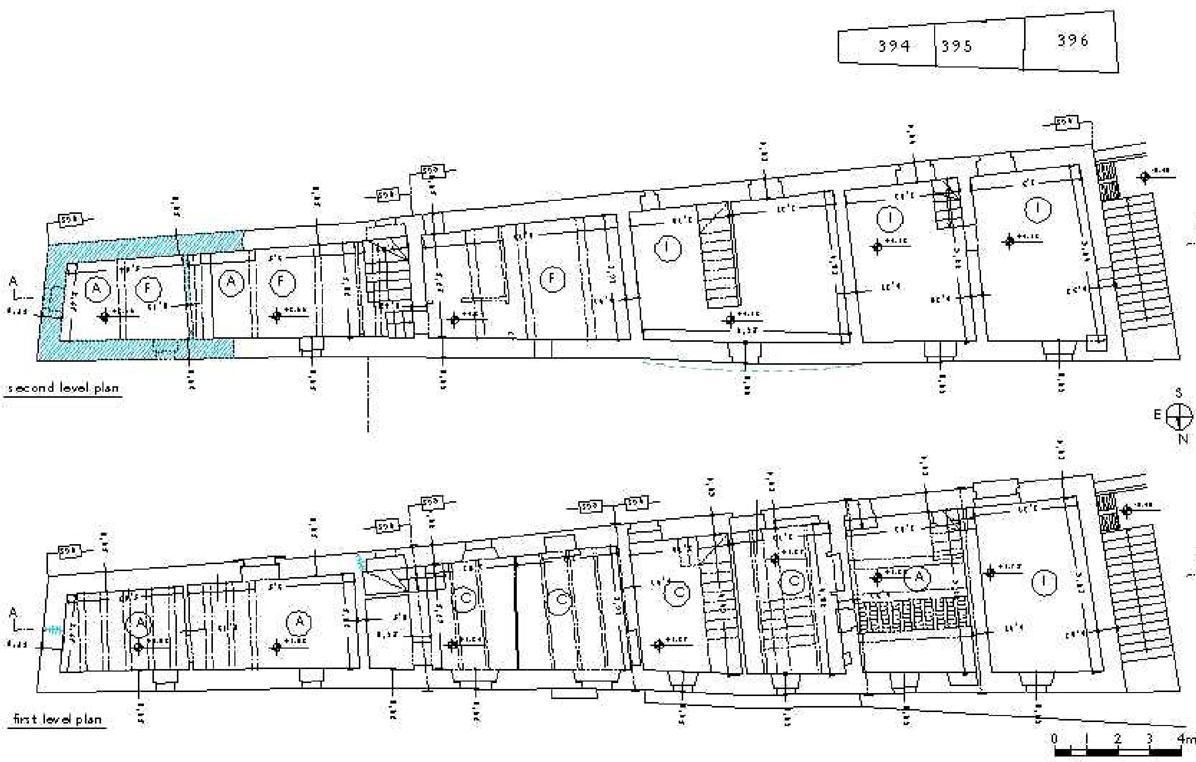


FIGURE 3: Plan of a Typical Building

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 Between the Blocks, Probably as a Result of Damage in Previous Earthquakes and Visible Loose Stones Around the Arch

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

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

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

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

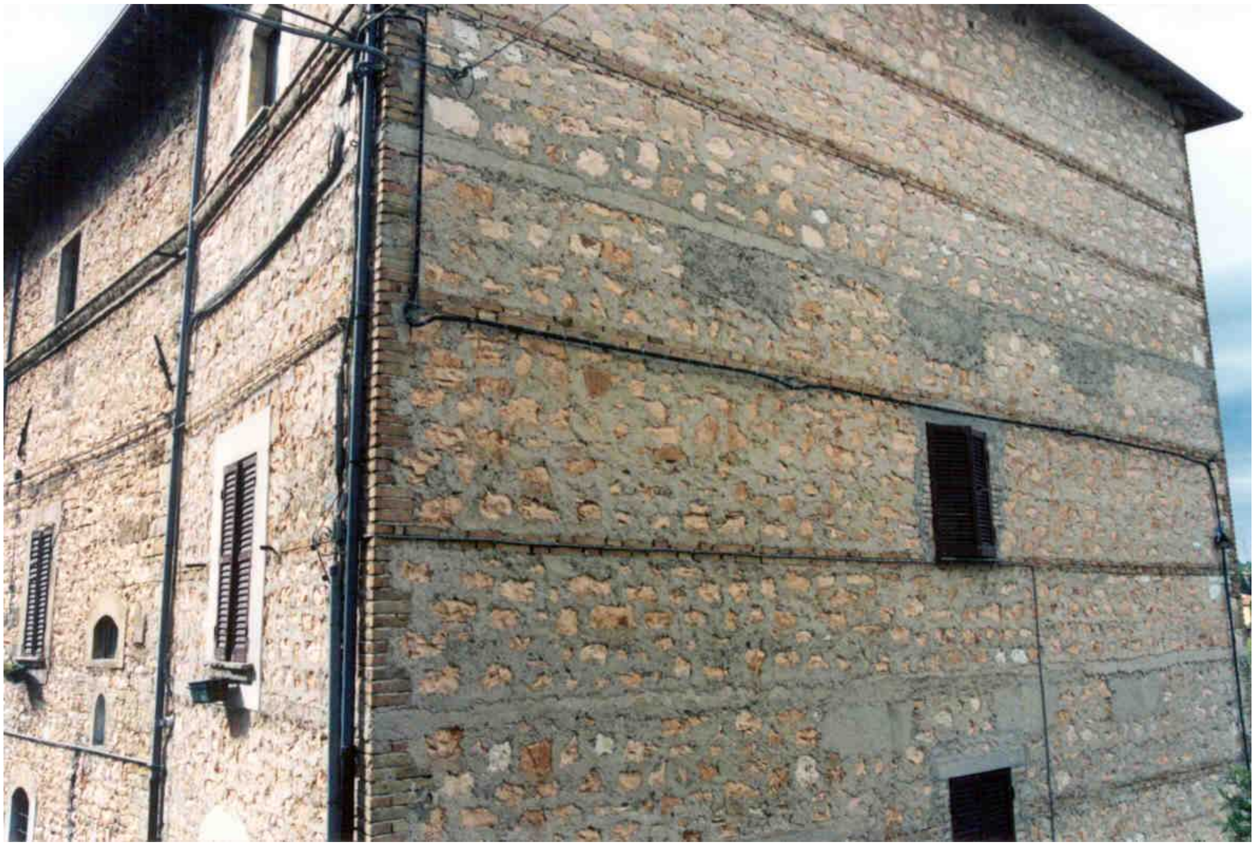
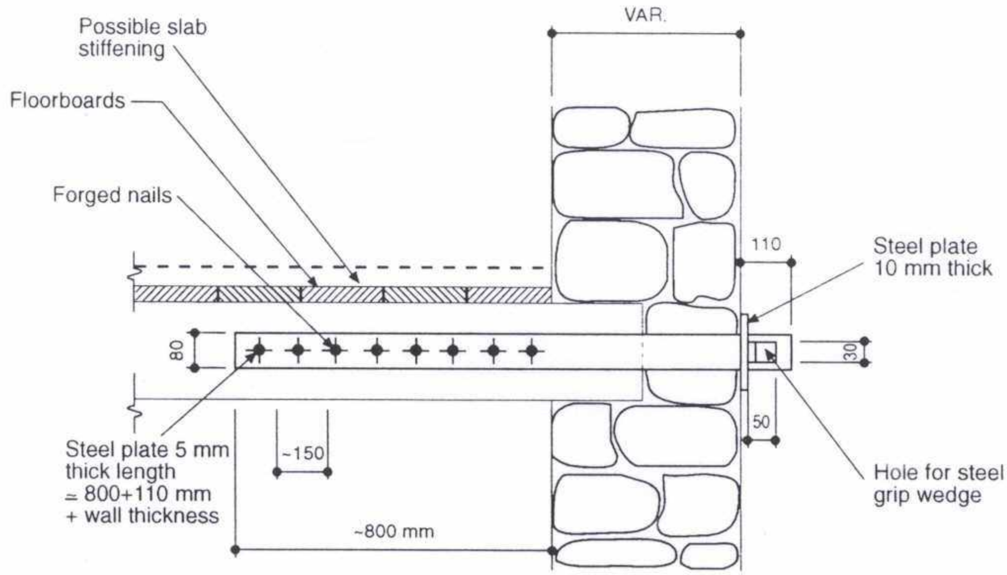


FIGURE 7A: Illustration of Seismic Strengthening Techniques

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

SECTION A-A



NB. CAVITIES MUST BE SEALED WITH GROUT

HORIZONTAL SECTION

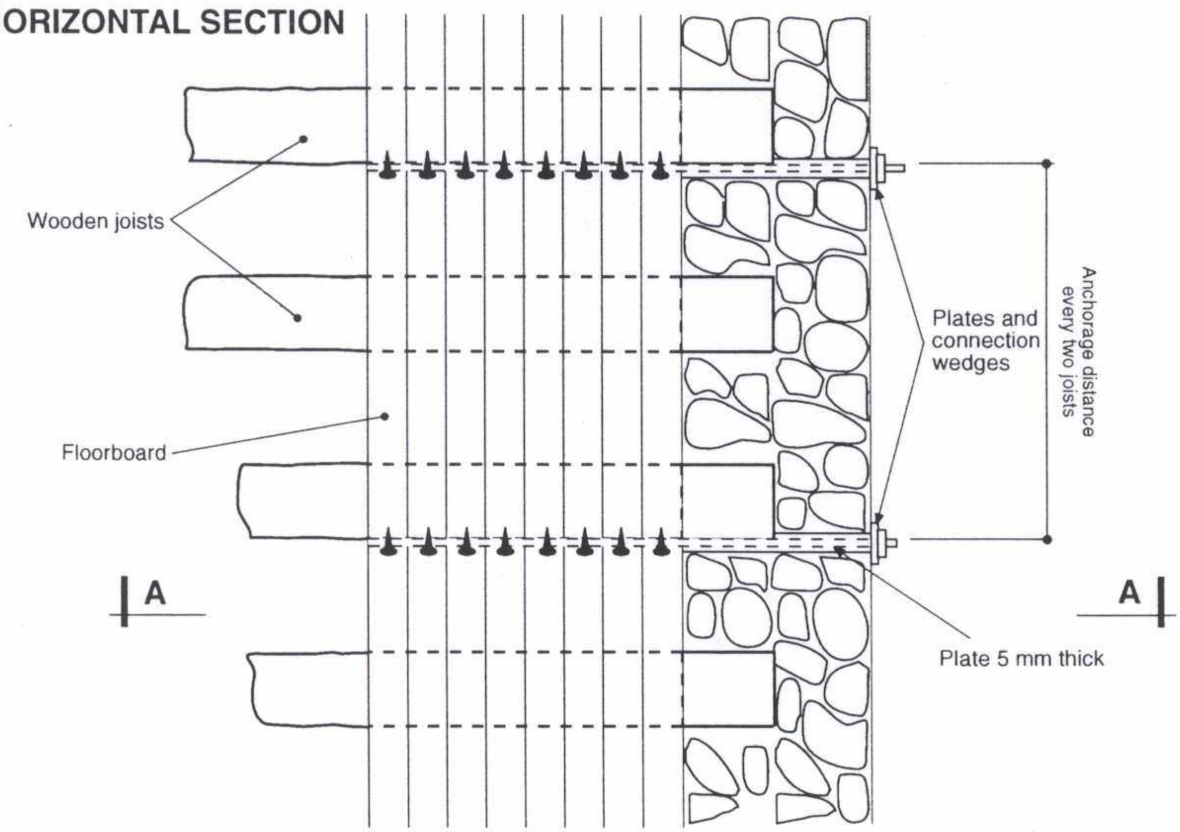


FIGURE 7C: Seismic Strengthening - Steel Strap Used to Connect an Existing Masonry Wall to Timber Floor Joists

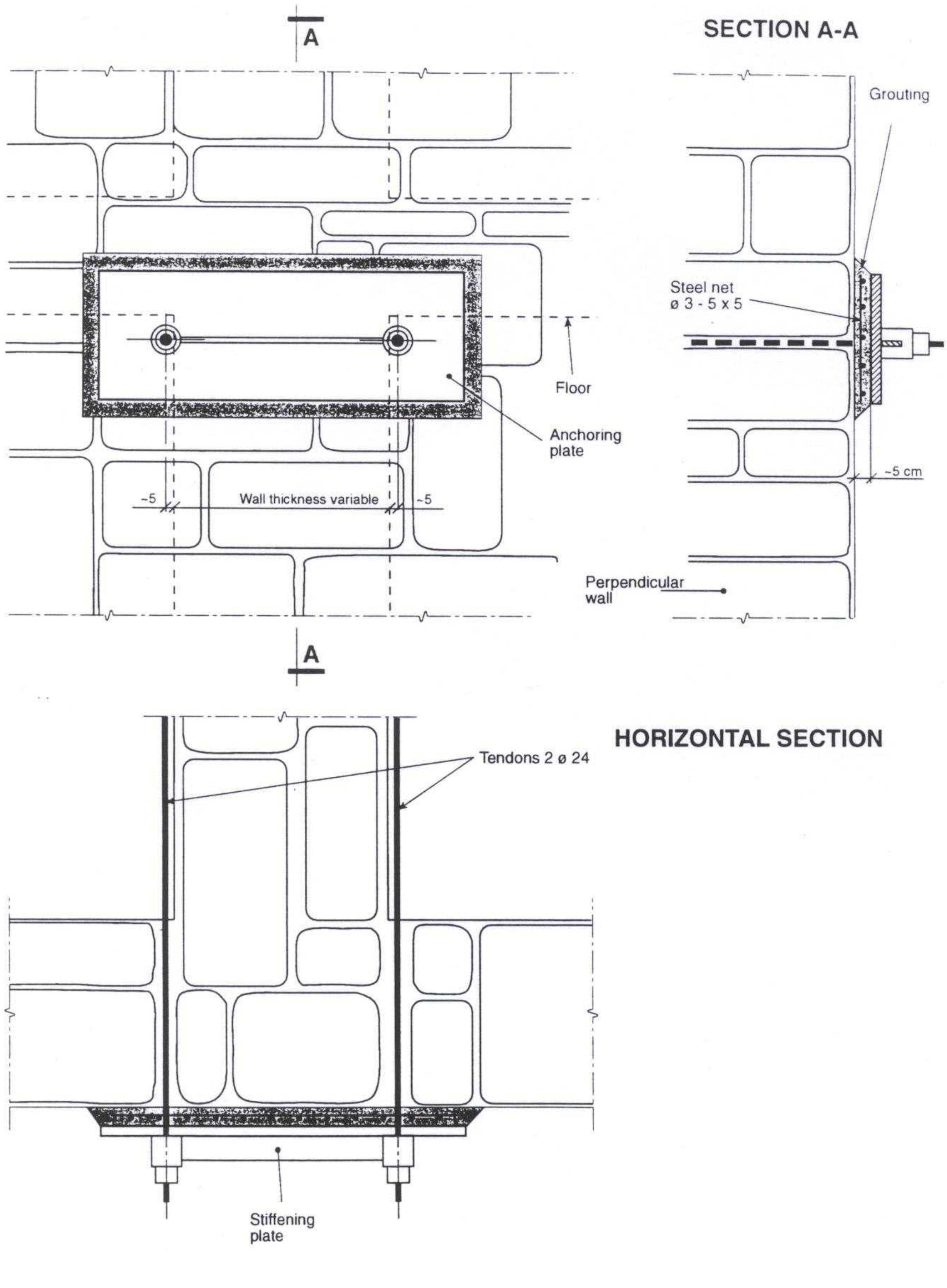


FIGURE 7D: Seismic Strengthening - Installation of Ties with an Anchor Plate at the Exterior Wall Face

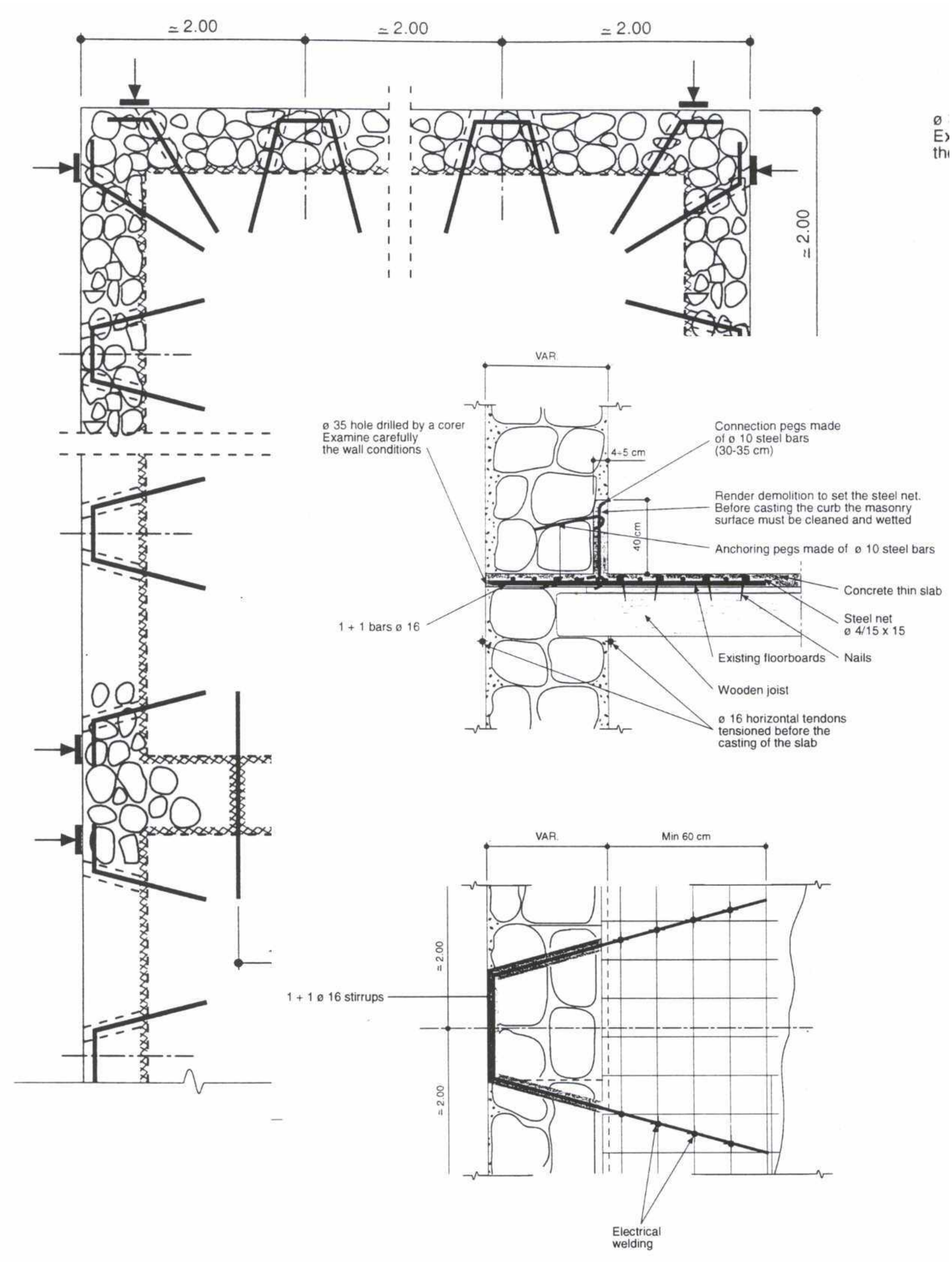
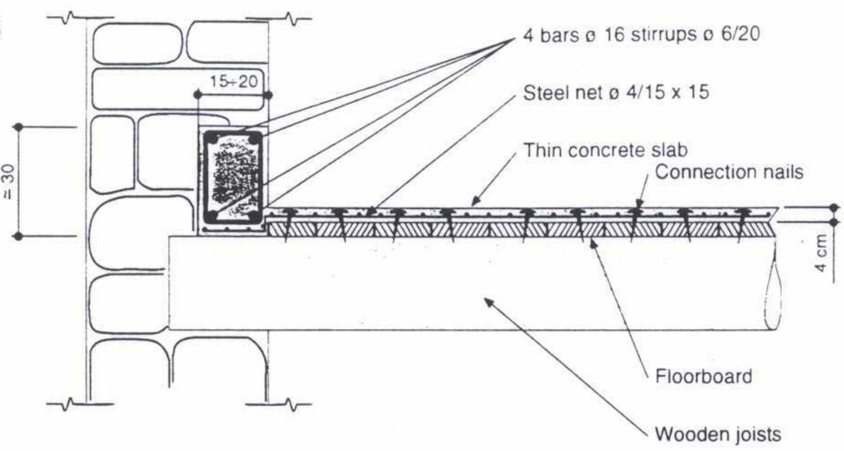
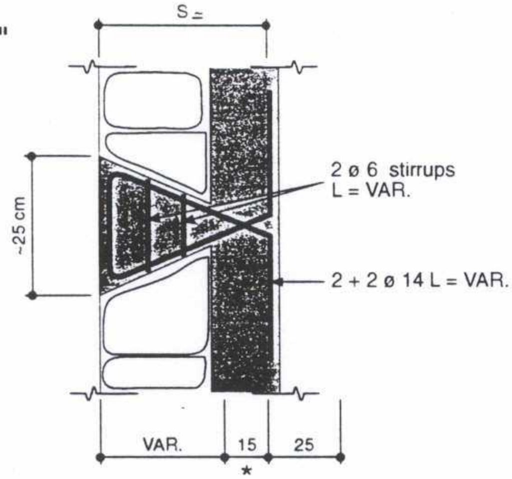


FIGURE 7E: Seismic Strengthening - Installation of New Steel Anchors Grouted Into Existing Walls and

SECTION B-B



SECTION "A"



NB.
THE THIN CONCRETE SLAB MUST BE CASTED AFTER JOISTS UNDERPINNING, TO BE MAINTAINED UNTIL COMPLETE HARDENING OF THE CONCRETE SLAB

HORIZONTAL VIEW

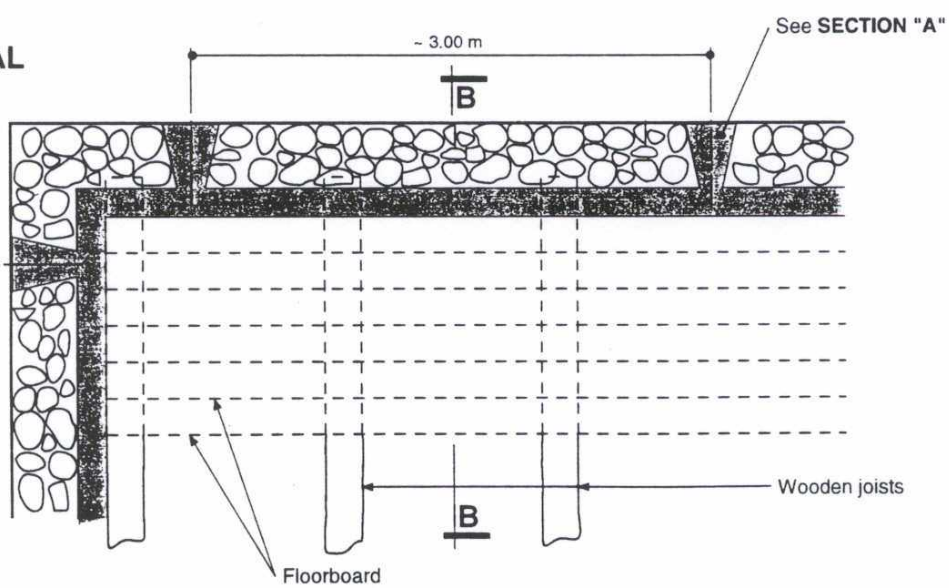


FIGURE 7F: Seismic Strengthening - Installation of New RC Ring Beam