World Housing Encyclopedia Report

Country: Italy

Housing Type: Single-family historic brick masonry house (Casa unifamiliare in centro storico, Centro Italia)

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1 General Information

1.1 Country

Italy

1.3 Housing Type

Single-family historic brick masonry house (Casa unifamiliare in centro storico, Centro Italia)

FIGURE 1: Typical Building

1.4 Summary

This single-family housing type, found throughout the Central Italy (Centro Italia) mainly in hill towns and small cities, is typically built on sloped terrain. A typical house is 3-stories high, built between two adjacent buildings with which it shares common walls. The main facade of the house faces a narrow road. The ground floor level (perforated with openings on one side only) is used for storage, while the other two stories are used for residential purposes. Typical buildings of this type are approximately 3 m wide and 9 m long. The building height on the front side is on the order of 4.5 m, whereas the height on the rear side is larger (close to 5 m). All the walls are made of unreinforced brick masonry in lime mortar, while the floor structures are vaults at the ground floor level, and timber floor structures at the higher levels. The roof is made of timber and it is double pitched, sloping down towards the front and rear walls. Buildings of this type are expected to demonstrate rather good seismic performance, mostly due to their modest height. Problems related to seismic performance might be caused by the adjacent buildings (typically one storey higher). Seismic strengthening techniques for the buildings of this type are well established and strengthening of some buildings has been done after the recent earthquake.

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 modifications during the last 100 years.

1.6 Region(s) Where Used

Centro Italia, Marche, Emilia Romagna, and (with some modifications) in other parts of Italy as well. The specific example discussed in this contribution and the photographic and seismic documentation refer to the small town of Offida, in the Marche region.

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: This construction type is found most frequently in medieval hill towns.

2 Architectural Features

2.1 Openings

Opening layout is frequently being modified over time, due to the changes in the living requirements. A very common change is made to the ground floor entrance door which is widened in order to allow for car passage. The openings account for approximately 25% - 30% of the wall surface area. There are no openings in the side walls.

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

Rectangular plan, usually part of arrays or terraces, however alterations and joining of cadastral units may occur. In such case, rectangular shape still remains the most common shape. The most common "alteration" to the typical housing plan is joining of the two adjacent cadastral units.

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: The ground floor is originally used as storage room. At present it is used also mixed use as garage or for commercial use.

2.5 Means of Escape

Usually there is not additional door besides the main entry in this building type.

2.6 Modification of Buildings

Alteration of door and window openings is most typical pattern of modification observed.

3 Socio-Economic Issues

3.1 Patterns of Occupancy

One family per house.

3.2 Number of Housing Units in a Building

1 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	X
5 to 10		
10-20		
> 20		
Other		

Additional Comments: In case when a house consists of only one cadastral unit, it can provide shelter for very few people. In the case of two adjacent cadastral units joined together, a larger number of inhabitants (5-7, a typical family) can be accommodated.

3.4 Number of Bathrooms or Latrines per Housing Unit

Number of Bathrooms: 1
Number of Latrines: 1

Additional Comments: Originally, there has been 1 latrine per housing unit, however there is often a newly fitted bathroom in recently renovated buildings.

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		/

Additional Comments: The house price can vary considerably, depending on the state of conservation and the level of modern comfort introduced. The houses of this type are usually inhabited by retirees with modest income. Some houses of this type are used as holyday homes (mainly by relatives living in other parts of the country).

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)	
Owned by group or pool	
Long-term lease	
Other	

4 Structural Features

4.1 Lateral Load-Resisting System

Brick masonry walls with or without metal ties. Typical brick dimensions are : 160 X 60 X 320 mm. In the case of very old masonry the depth of brick units can reach 80 mm. The lime mortar joints are 3-5 mm thick.

4.2 Gravity Load-Bearing Structure

Depending on the thickness, the walls are built either entirely in brick masonry or, in the case of walls of larger thickness, as multi-wythe walls with rubble infill in the middle portion.

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)	
		2	Massive stone masonry (in lime or cement mortar)	
	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	X
		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		

<u>Additional Comments:</u> The building is of type 7, except that lime mortar has been used instead of mud mortar.

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	
Shallow Foundation	Brickwork foundation	X

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		
	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	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			

4.6 Typical Plan Dimensions

Length: 3 - 3 meters
Width: 3 - 3 meters
Additional Comments: Length varies from 3 - 4 m and the width varies from 8 - 9 m.

4.7 Typical Number of Stories

2 - 3

4.8 Typical Story Height

3.0 meters

Additional Comments: Story height varies from 2.5 to 3 m.

4.9 Typical Span

3 meters

<u>Additional Comments:</u> Span varies from 3 - 4 m.

4.10 Typical Wall Density

0.10 to 0.20

4.11 General Applicability of Answers to Questions in Section 4

This contribution is not based on a case study of one building.

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).			
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	The perimeter walls are not sufficiently connected at the corners, and they behave as separate elements. This seismic deficiency is common for the buildings that were built later than the adjacent buildings. In this case, the side walls of the existing adjacent buildings were used to support the roof and floor structures of the new buildings, whereas the front and rear walls were built separately, without any connection to the existing side walls.	Presence of ties between the front walls and party walls. In some cases, metal ties perpendicular to the front wall are inserted for improving the wall connections and the global seismic performance of the building.	- Damage to the vertical addition of the building due to the out-of-plane wall failure. - Vertical cracks associated with horizontal arch effects.
Interior Partitions	This building type is usually characterized with only one interior partition wall, running orthogonal to the front wall. This partition wall was used to support a narrow staircase joining the ground floor with the upper floors. This partition is also used to support the floor structure of the floor above it. Due to a rather moderate thickness of 150 mm, this partition wall is usually a slender wall and it represents a seismic deficiency for this building type.	In some cases, there is one interior spine wall parallel to the front wall spanning throughout the building height from the ground to the roof level. If present this wall has a role to reduce unsupported span lengths for the floor structures and provide a better support for the roof structure.	Collapse of internal timber staircase replaced by self-supported concrete staircase.
Roof and floors	Roof and floors are both spanning between the front and the rear wall. In some cases, no ties or other wall-floor connections are present. This results in a weak connection between the front/rear walls and the side walls.	Occasionally floor and roof joists are anchored to the wall by ties.	Partial or total collapse of timber floors later replaced by concrete structures.

<u>Additional Comments:</u> Seismic features characteristic for the buildings of this type are shown in Figures 5A and 5B. Seismic failure mechanisms are presented in Figure 5C.

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)
1943	Castorano (AP)		VIII - IX (MMI)

Additional Comments: The most common earthquake damage was the collapse of interior floors. The original timber floors were replaced by concrete floors in the recent past and these concrete floors caused the damage. At present there are very few original timber floors; concrete floors are much more common. It was observed that the strengthening with concrete structures tends to substantially alter the stiffness ratio of wall-to-floor structures and if not implemented properly can cause serious damage to load-bearing walls. Also, earthquake damage in buildings of this type often occurs in the vertical addition to the building (a portion of more recent construction). Earthquake damage patterns include the flexural wall failure and the horizontal arch effect (see Figure 6).

7 Building Materials and Construction Process

7.1 Description of Building Materials

Structural Element	Building Material	Characteristic Strength	Mix Proportions/ Dimensions	Comments
Walls	Brick masonry Mortar	0.22 MPa (tension) 4 MPa (compression)	1/3 lime/sand mortar	18 KN/m³ (unit weight density)
Roof and floors	Wooden beams	50 MPa (tension-beams) 30 MPa (compression-beams)		1.5 kN/m² (floor weight)

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

Buildings of this type were usually inhabited by the poor and middle class population, and they were built by local craftsmen for the residential purpose only.

7.3 Construction Process

The construction process was generally influenced by the owner's attempt to do the construction at the minimum cost. In the urban layout, an empty space between two existing buildings offered an opportunity to build a new house using the two existing side walls; only the front and rear walls would need to be built. The construction tools were simple (trowel, etc.).

7.4 Design/Construction Expertise

The construction was based on the mason's experience. For this reason , the structural elements were generally oversized in order to achieve high safety.

7.5 Building Codes and Standards

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

Title of the code or standard: Normativa per le riparazioni ed il rafforzamento degli edifici dannegiati dal sisma (in Italian). Note that this standard addresses only repair and strengthening of existing buildings, and not the new construction.
Year the first code/standard addressing this type of construction issued: 1981
National building code, material codes and seismic codes/standards: The first code was issued after the 1981 Campania earthquake. Decretory Ministerial 2-7-1981: Normative per le reparation ed il rafforzamento degli edifici dannegiati dal sisma. (Revised in 1986 and 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

Engineers and architect did not have any role in the design and construction, because the construction process was entirely carried out by masons and/or owners themselves.

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: At present all these constructions are registered and subjected to national/urban codes, which was not the case at the time of their original construction.

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: In some cases one storey has been added as a part of the refurbishment.

7.9 Building Maintenance

Who typically maintains buildings of this type?	
Builder	
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

A need for strengthening the buildings of this type.

8 Construction Economics

8.1 Unit Construction Cost (estimate)

Unit construction cost cannot be expressed for this type of historic building, because its construction technique and process are no longer practiced. When built up today, these building types are usually constructed with concrete slabs in place of wooden roofs and floors, and very often lintel and staircase are made of reinforced concrete too. In these case the cost unit construction cost can range between 1,000 EURO and 2,000 EURO/m², but it greatly depends upon the quality of materials used.

8.2 Labor Requirements (estimate)

Around 20 days per building.

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)	Roof/floors	Reinforced concrete overlay; the effectiveness of strengthening depends on the roof -to-wall connections.
	Roof/floors- Lack of Integrity	Installation of new RC ring beam at the roof level. A procedure for the installation of a RC ring beam is presented in Figure 7B. Figure 7C shows a building strengthened with new RC ring beam at the roof level. 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.
	Wall-Floor Connection	Installation of metallic ties. Figures 7D and 7E show two different details of ties with anchor plates at the exterior face of the wall. A building strengthened with the ties (similar to detail shown on Fig. 7E) is shown on Figure 7A. It is very important to accomplish a regular distribution of ties - irregular tie distribution may be a cause of earthquake damage.
	Inadequate seismic resistance of masonry walls	Shotcreting- strengthening walls with shotcrete jackets. Figure 7F shows a masonry wall with shotcreting applied at both faces. The strengthening consists of installing new steel wire mesh and attaching it to the existing wall with through-wall ties or strips spaced at 500 mm on centre both horizontally and vertically. In case shotcreting is not properly applied, the wall can experience earthquake damage as illustrated in Figure 7G.
	Inadequate seismic resistance of masonry walls	Stitching and grouting - consists of drilling holes through the walls and installing steel bars; subsequently, the holes are grouted with cement grout, as illustrated in Figure 7H. A building strengthened using this technique is shown on Figure 7I.

Additional Comments: Typical seismic repair costs are summarized in Figure 7J.

10.2 Has seismic strengthening described in the above table been performed in design practice, and if so, to what extent?

Yes, to various extent depending on location and buildings.

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

In Offida mainly as repair following earthquake damage, but it is expected that some mitigation work should be implemented in conjunction with other architectural or functional alterations to existing unstrengthened buildings.

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

Project plans need to be presented to local authority, but it is expected that there is no formal site inspection.

10.5 Who performed the construction: a contractor, or owner/user? Was an architect or engineer involved?

An engineer is usually involved, but work might be carried out either by a contractor or by the user.

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

The performance varies highly depending on the quality of construction. Buildings retrofitted with anchors, which are less sensitive to workmanship usually perform well in preventing the out-of plane failures.
Ring beams and other strengthening with concrete structures tends to substantially alter the stiffness ratio of wall-to-floor structures and if not implemented properly can cause serious damage to load-bearing walls.

11 References

D'Ayala, D., Spence, R. 1995, "Vulnerability of Buildings in historic town centres" in Proceedings of the VII National Conference "L'Ingegneria Sismica in Italia", Siena. pp.363-372.

D'Ayala, D., Spence, R., Oliveira, C., and Pomonis, A. (1997). Earthquake Loss Estimation for Europe's historic Town Centres. Earthquake Spectra Special Issue on Earthquake Loss Estimation, (November), pp. 773-793.

R. Spence, D. D'Ayala, (1999) The Umbria-Marche Earthquake of September 1997. Preliminary Structural Assessment. The Structural Engineering International, Journal of the IABSE. Vol . 9 n.3 pp. 229-233 (also available on line at http://www.iabse.ethz.ch/sei/sei_f.html)".

D'Ayala, D. (1999). 'Correlation of seismic damage between classes of buildings: churches and houses'. Seismic damage to masonry buildings, pp. 41-58. Balkema Press, Rotterdam.

D'Ayala, D., Speranza, E. 1999, "Identificazione dei Meccanismi di Collasso per la stima della Vulnerabilità Sismica di Edifici nei Centri Storici" in: Proceedings of the IX National Congress "L'Ingegneria Sismica in Italia", Torino 20-23 settembre.

D'Ayala D. (2000) Establishing Correlation Between Vulnerability And Damage Survey For Churches Proceedings of 12th World Conference On Earthquake Engineering, paper 2237/10/a

D'Ayala, D, Speranza, E. 2000, "Confronto di misure di vulnerabilità ottenute con metodi statistici per edifici in centri storici", research carried out in collaboration with the GNDT U.R. of Padova (Italy), internal report of Dept. of. "Costruzioni e Trasporti" of University of Padova, (It).

D'Ayala, D, Speranza, E. 2001, "Seismic vulnerability of historic centres: the case study of Nocera Umbra, Italy" Proceedings of the UNESCO Congress "More than two thousand years in the history of architecture".

D'Ayala, D, Speranza, E. 2001, "A procedure for evaluating the seismic vulnerability of historic buildings at urban scale based on mechanical parameters". In: Proceedings of the 2nd International Congress "Studies in Ancient Structures, Yildiz, Instanbul Turkey, July.

D'Ayala, D., Speranza, E. (2001). Unreinforced Brick-Block Masonry - Traditional Housing in Central Italy. Workshop on the EERI/IAEE Housing Encyclopedia Project, Pavia, Italy (also available online at www.world-housing.net)

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13 Figures

FIGURE 1: Typical Building

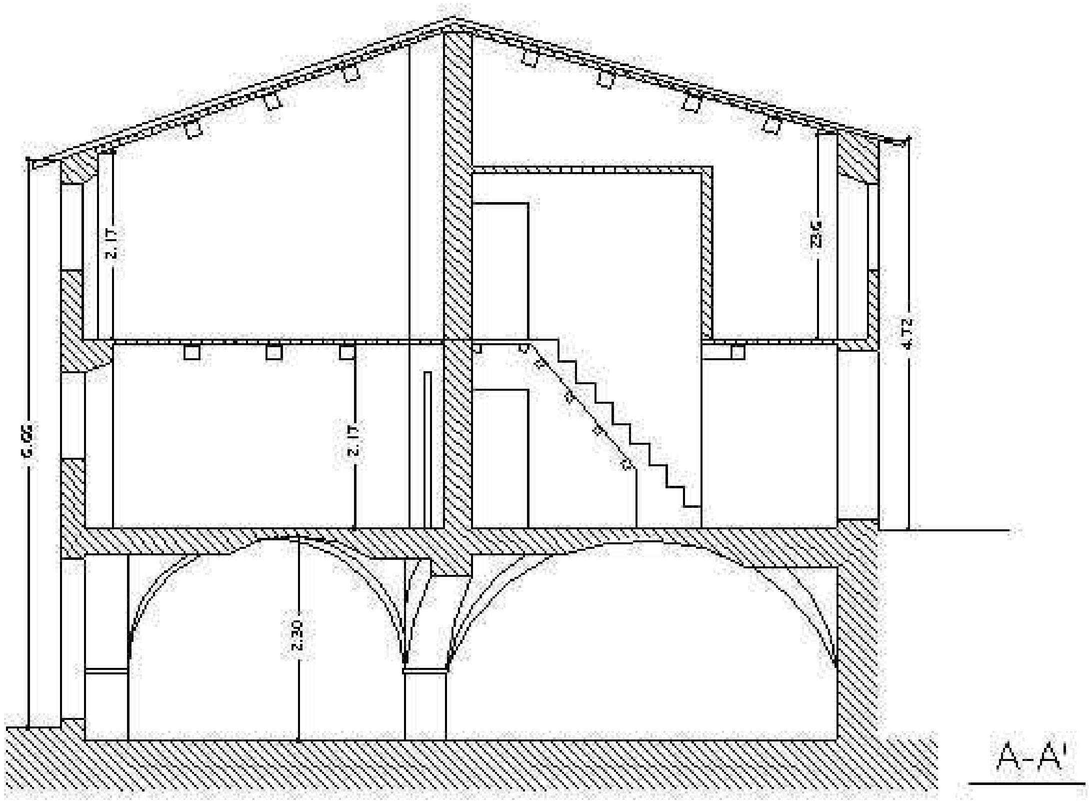


FIGURE 2: Key Load-Bearing Elements

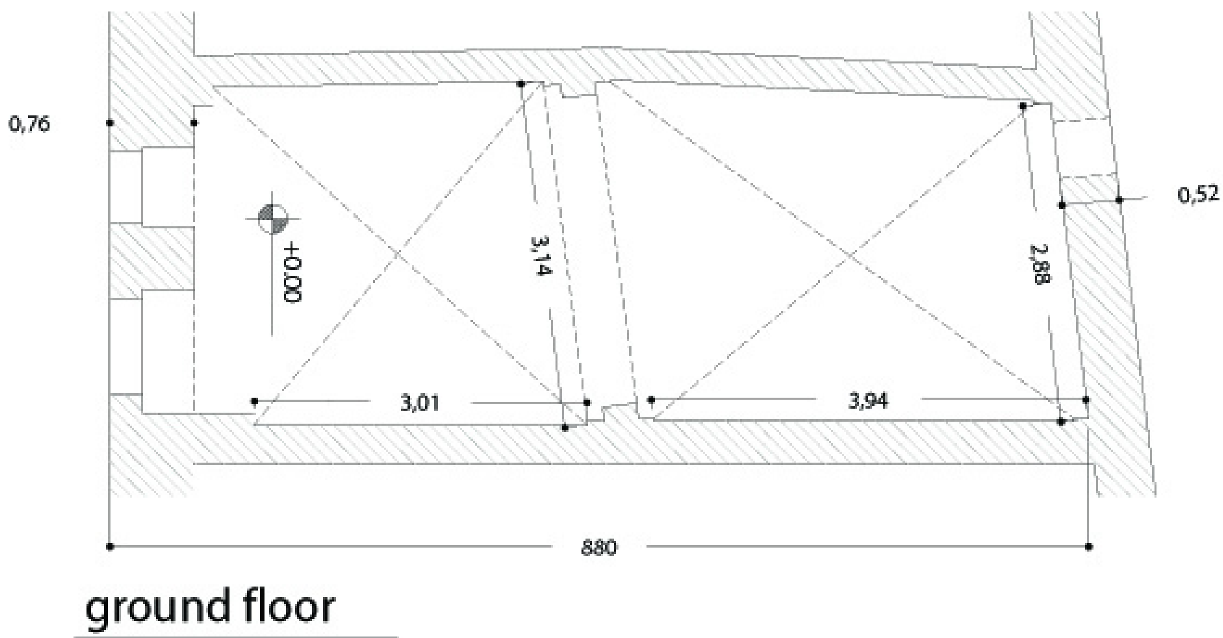


FIGURE 3: Plan of a Typical Building

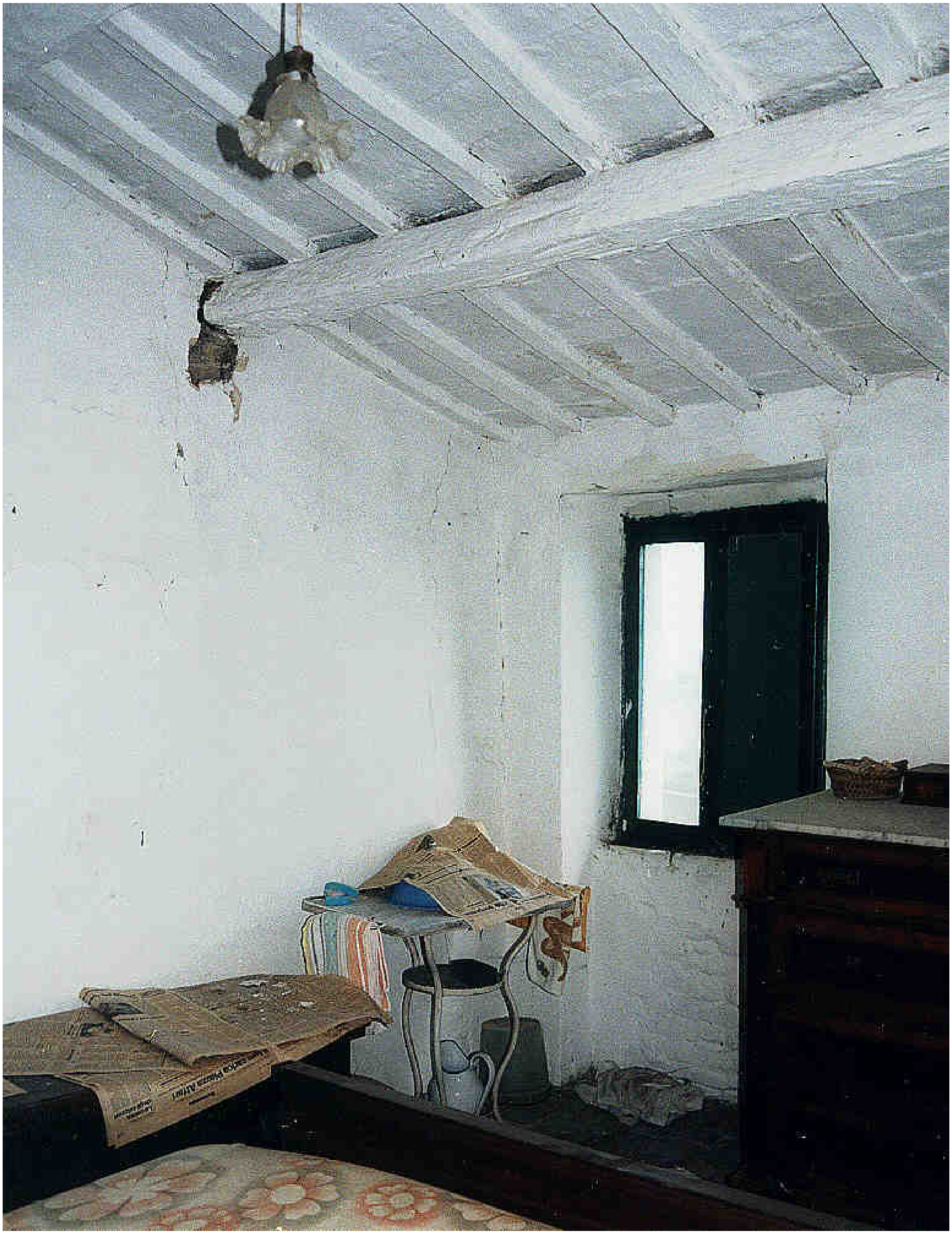


FIGURE 4A: Critical Structural Details - Brick Walls and Sloping Timber Roof

FIGURE 4B: Brick Walls Supporting the Cross-Vault System

FIGURE 4C: Cross-Section of a Typical Brick Masonry Wall

FIGURE 5A: Key Seismic Deficiencies-Proximity of Windows to the Corners and Vertical Extension of the Building (note also added balconies)

FIGURE 5B: Seismic-Resilient Features - Metal Ties in Two Orthogonal Direction and Brickwork Frame Around Windows

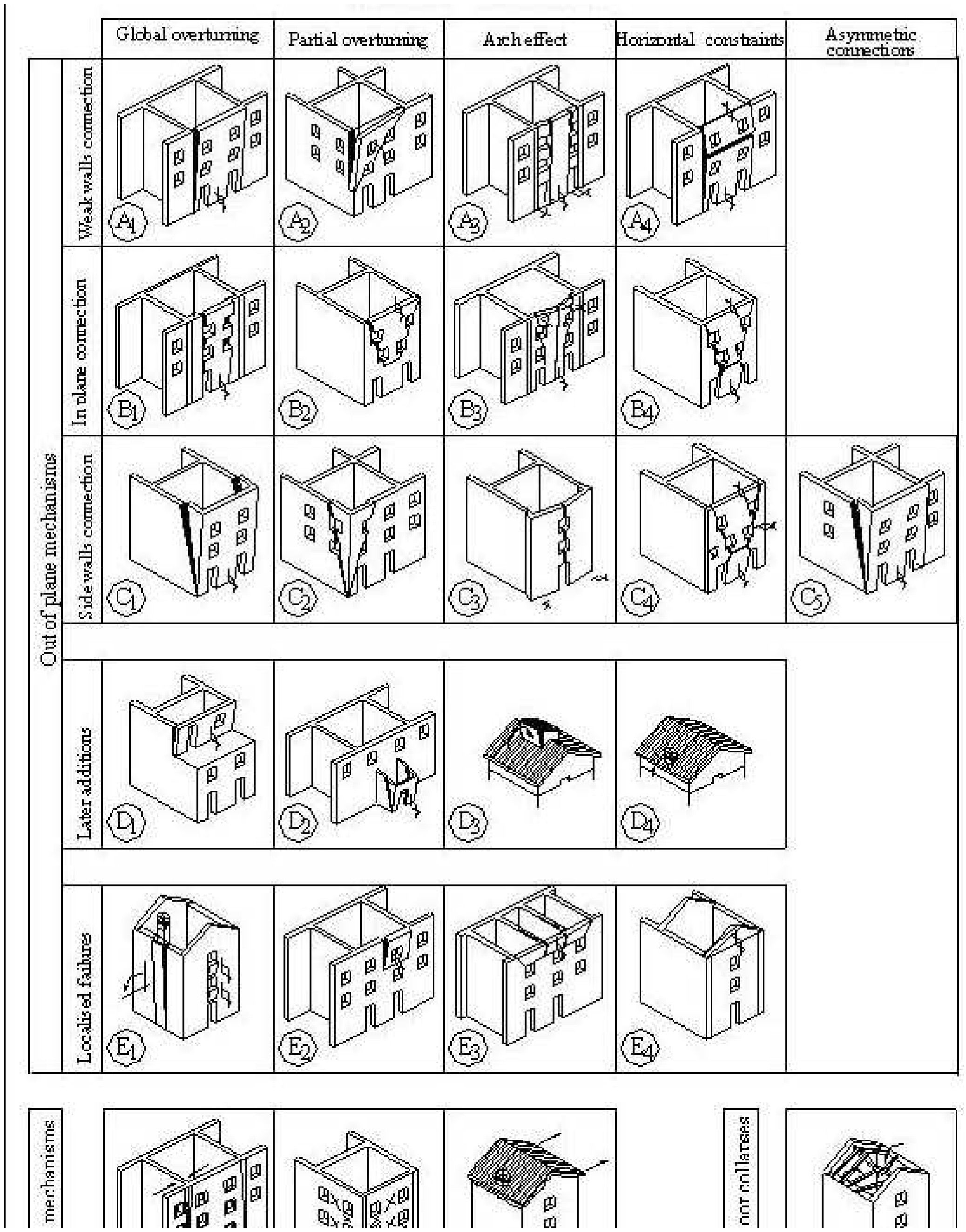


FIGURE 5C: Seismic Deficiencies - Failure Mechanisms

FIGURE 6: A Photograph Illustrating Typical Earthquake Damage (1997 Umbria-Marche earthquake)

FIGURE 7A: Illustration of Seismic Strengthening Techniques

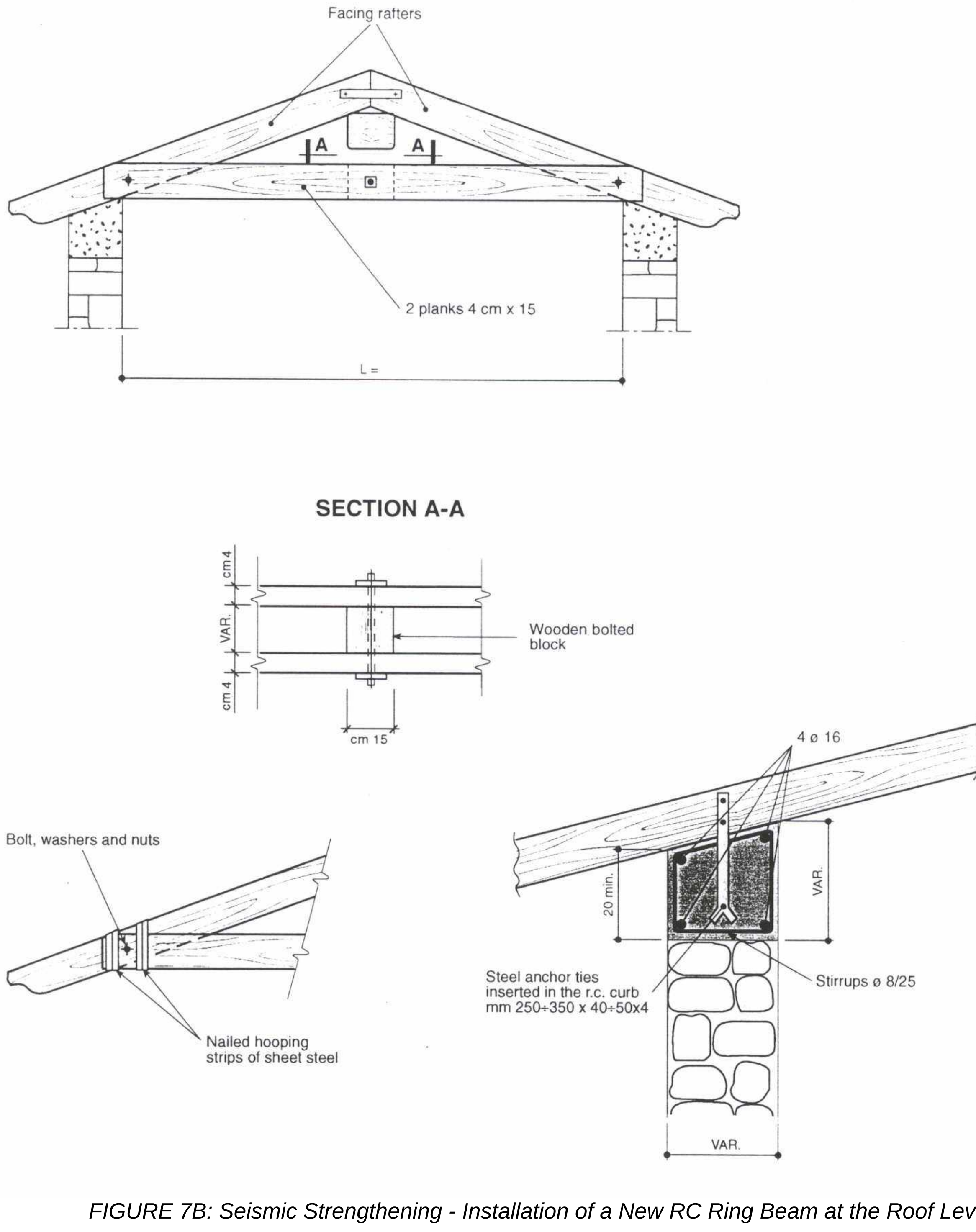


FIGURE 7B: Seismic Strengthening - Installation of a New RC Ring Beam at the Roof Level

FIGURE 7C: Seismic Strengthening - Installation of a New RC Ring Beam at the Roof Level (Design Application)

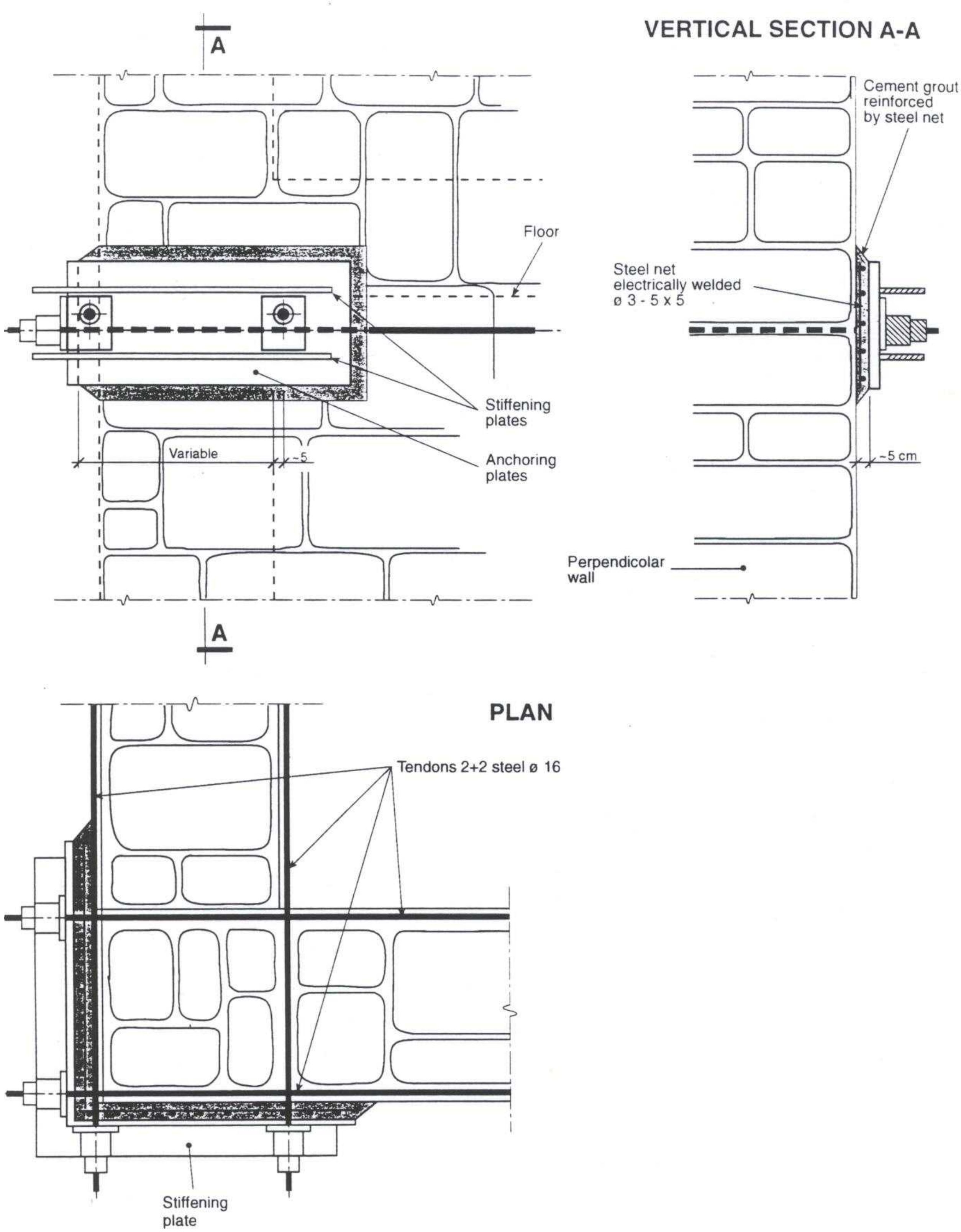


FIGURE 7D: Seismic Strengthening : Wall-to-Floor Anchorage

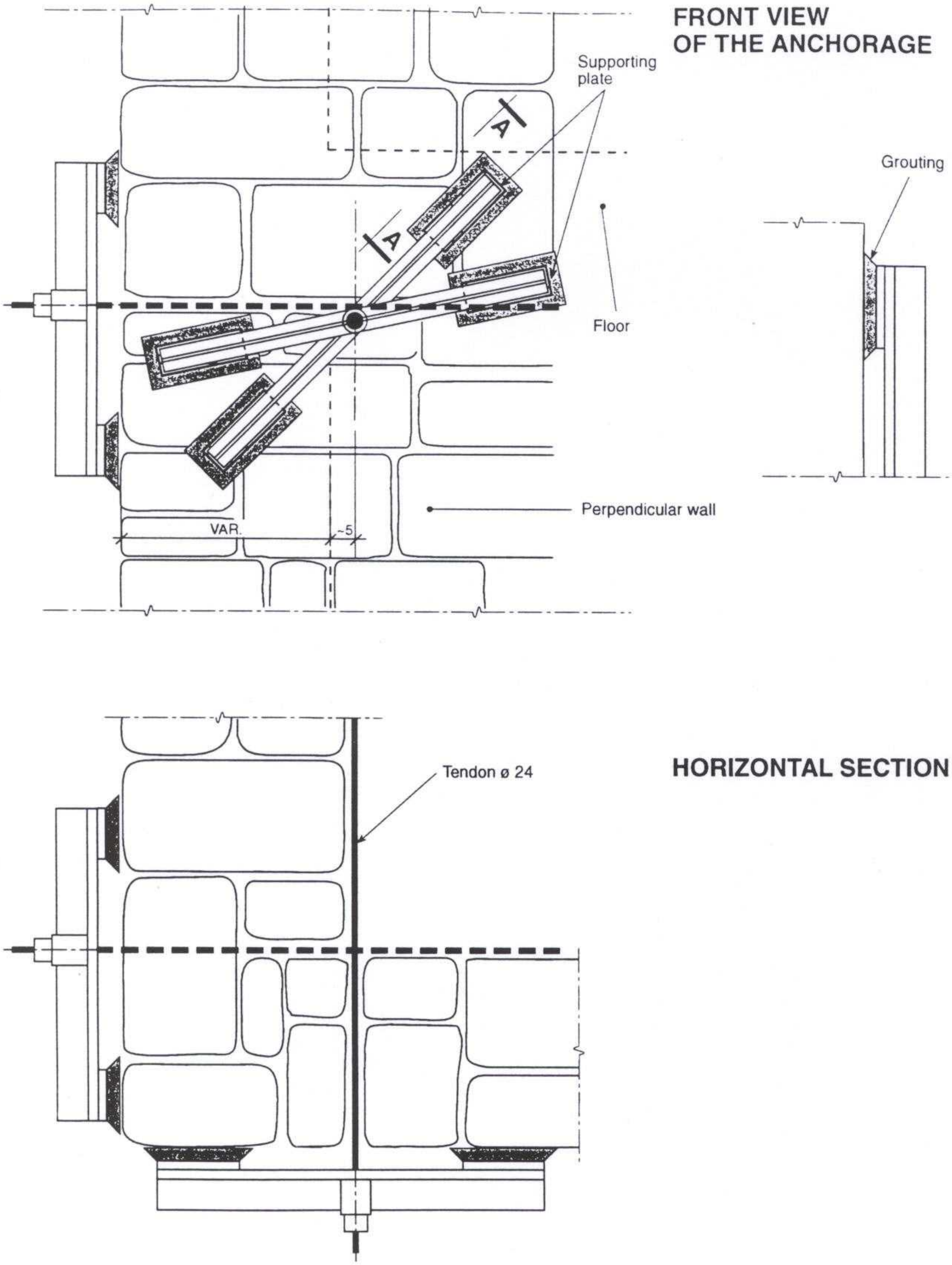
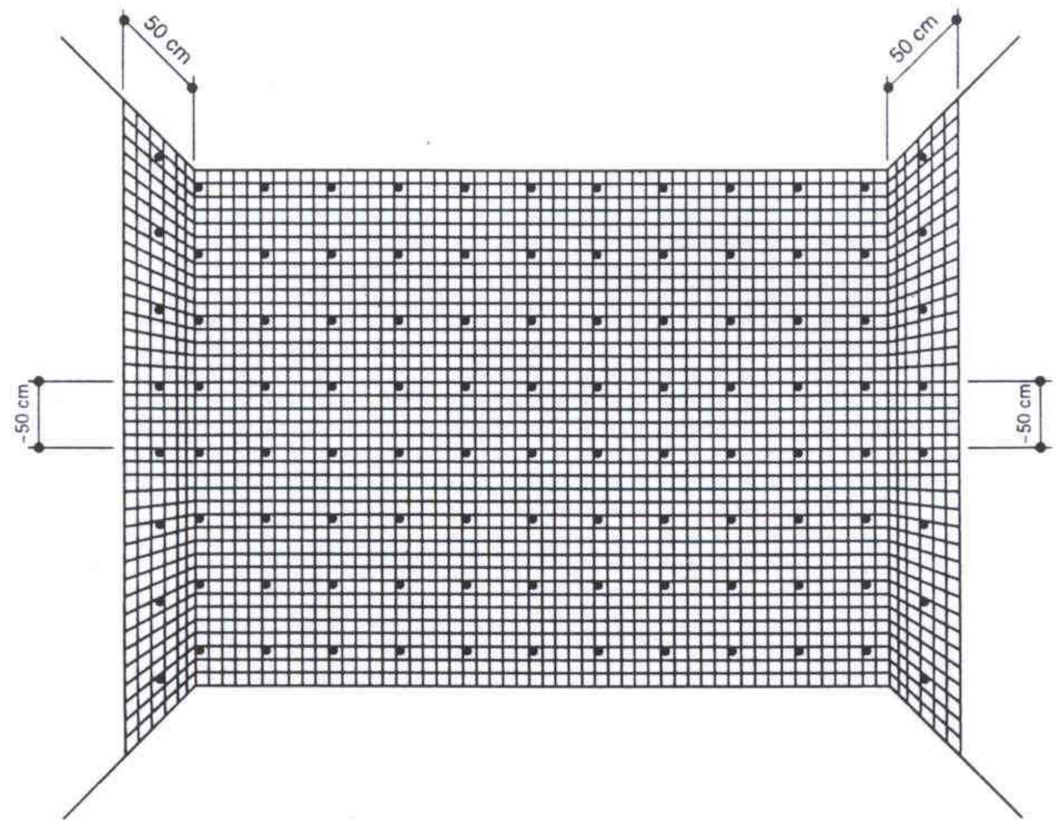


FIGURE 7E: Seismic Strengthening : Wall-to-Floor Anchorage

FRONT VIEW



HORIZONTAL SECTION

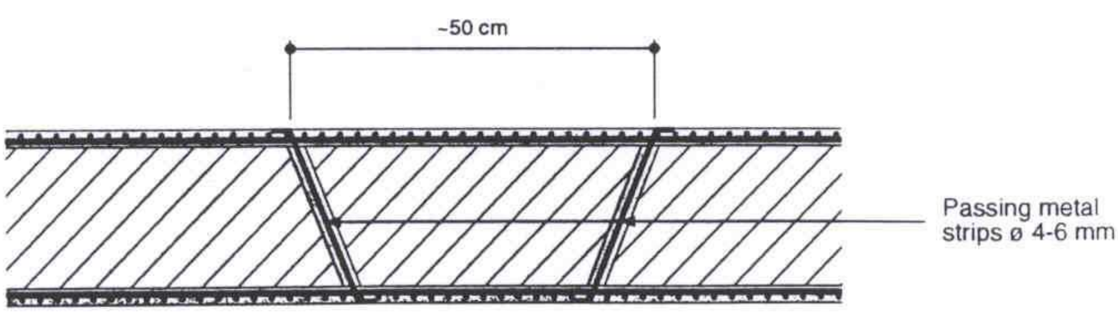


FIGURE 7F: Seismic Strengthening - Shotcreting

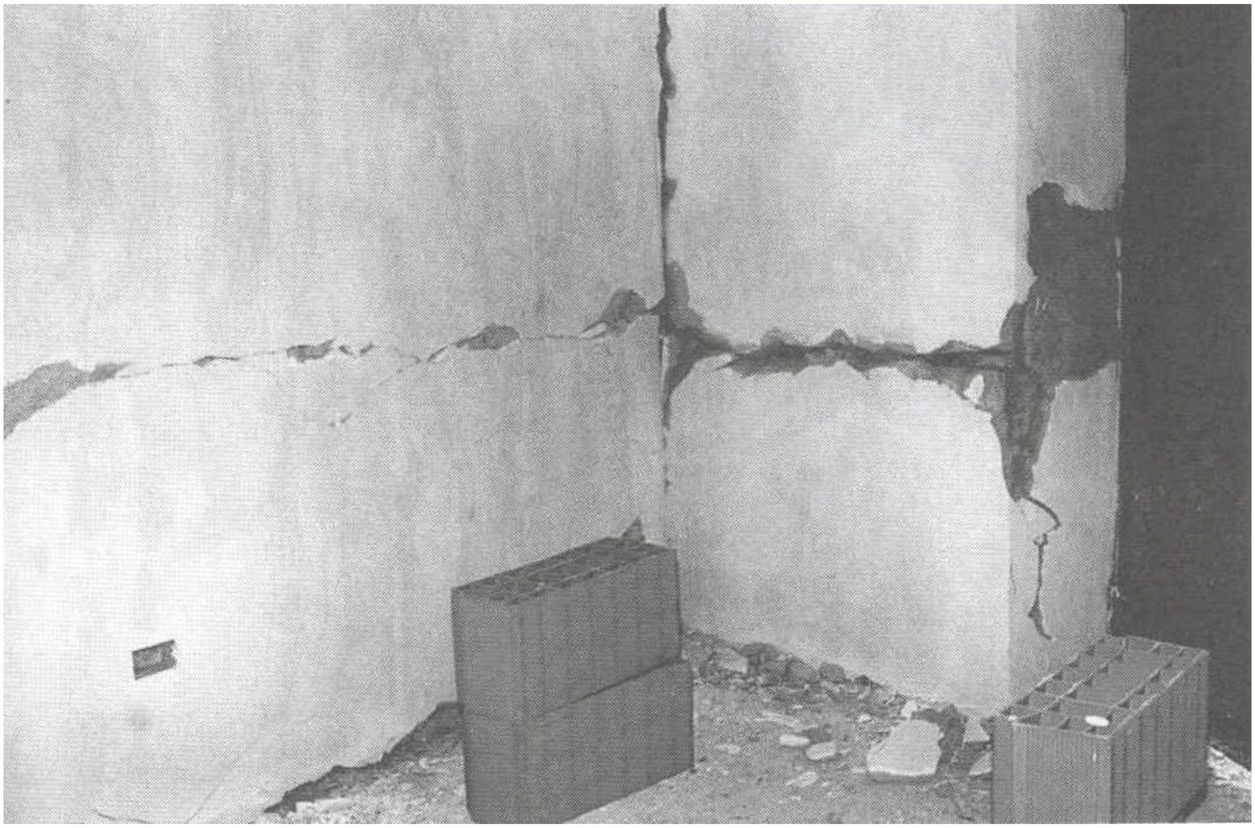
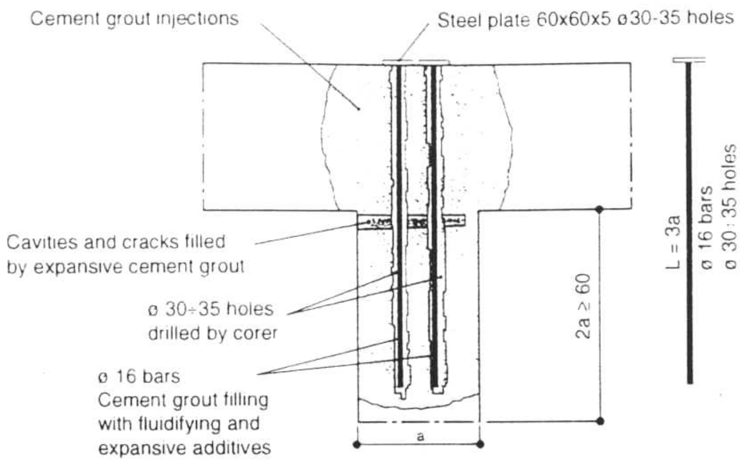
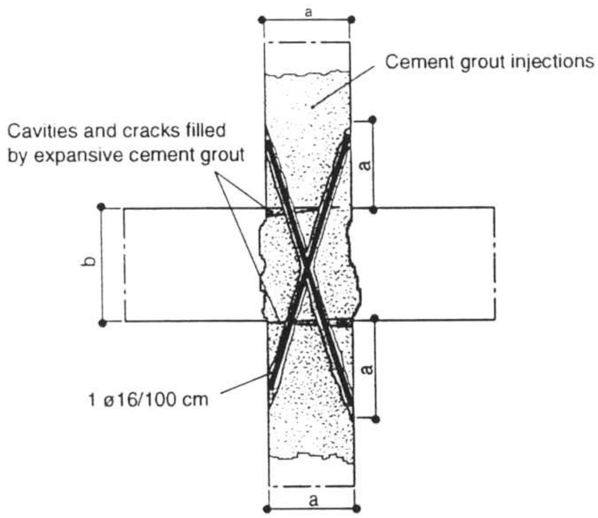


FIGURE 7G: Seismic Strengthening - Damage of Wall Strengthened by Shotcreting



Cracks consolidation by reinforced cemented drillings: case 1



Cracks consolidation by reinforced cemented drillings: case 2

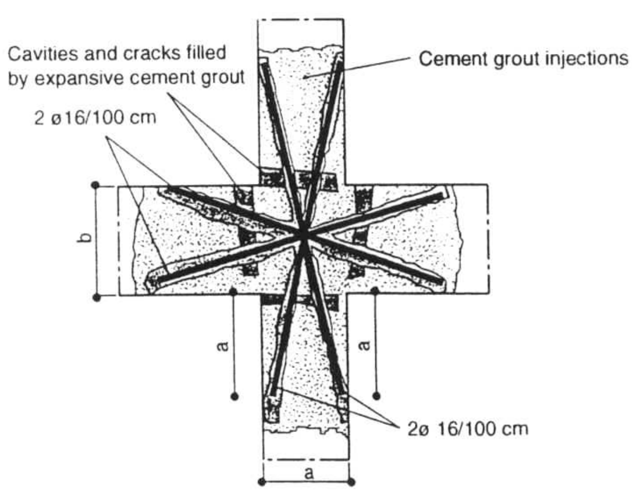


Fig. 2

FIGURE 7H: Seismic Strengthening - Stitching and Grouting

FIGURE 7I: Seismic Strengthening - Stitching and Grouting (Design Application)

Int.	Repair work	Unit labour cost	Cost per unit element (£/sq.m)	Cost coefficient ct £/mq)/(£/mc)
1	Masonry repair by rebuilding around crack	672.750 £/mc	127.000	0.363
2	Steel reinforced plaster	124.000 £/mq	124.000	0.354
3	Steel tie rods	43.700 £/m	29.100	0.089
4	Plaster repair on internal walls	46.600 £/mq	3.100	0.009
5	Plaster	20.650 £/mq	20.650	0.059
6	Tiling	53.650 £/mq	53.650	0.153
7	Color painting	4.650 £/mq	4.650	0.013
8	Partitions	26.850 £/mq	26.850	0.077
9	Partition repair	4.150 £/m	3.320	0.009
10	Wall beams of Reinf. Concr. floor	161.000 £/m	128.800	0.368
11	Reinforced concrete floor	75.000 £/mq	75.000	0.214
12	Floor repairing	105.000 £/mq	105.000	0.300

FIGURE 7J: Seismic Strengthening- Costs of Typical Repairs (After SSI, 1999)