

World Housing Encyclopedia

A Resource on Construction in Earthquake Regions



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

HOUSING REPORT

Single-family stone masonry house

Report#	28
Last Updated	
Country	Italy
Author(s)	Dina D Ayala, Elena Speranza,
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Important

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General Information

Building Type:	Single-family stone masonry house
Country:	Italy
Author(s):	Dina D Ayala Elena Speranza
Last Updated:	
Regions Where Found:	<p>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.</p>
Summary:	<p>These buildings form the historic centres 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</p>

many buildings have undergone further strengthening, represented by RC ring beams and concrete jacketing of walls.

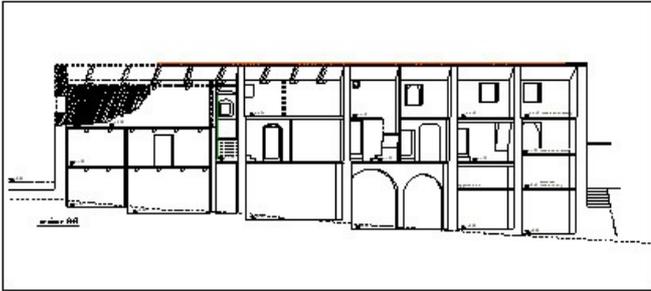
Length of time practiced:	101-200 years
Still Practiced:	Yes
In practice as of:	
Building Occupancy:	Single dwelling
Typical number of stories:	2-5
Terrain-Flat:	Typically
Terrain-Sloped:	Typically
Comments:	Traditional construction practice followed in the last 200 years with updates and modification during the last 100 years.

Features

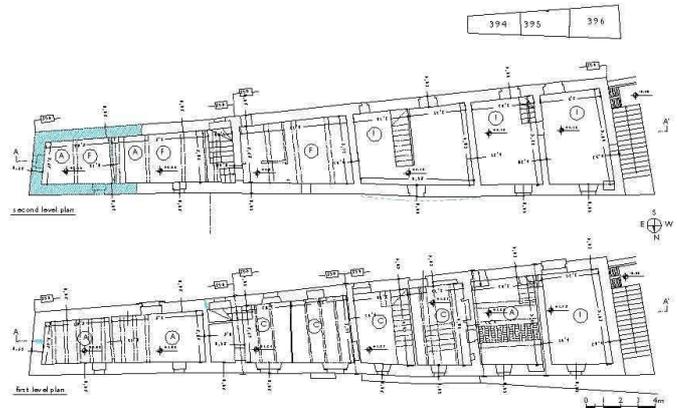
Plan Shape	Rectangular, solid
Additional comments on plan shape	Roughly rectangular as usually part of arrays or terraces, but alterations and joining of cadastral units may result in different shapes. Also front and back walls are not necessarily parallel as are not the party walls.
Typical plan length (meters)	4 meters
Typical plan width (meters)	6 meters
Typical story height (meters)	3 meters
Type of Structural System	Masonry: Stone Masonry Walls: Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)
Additional comments on structural system	Lateral load-resisting system consists of masonry walls with or without metal ties. Gravity load-bearing system consists of single or double leaf masonry walls with rubble infill.
Gravity load-bearing & lateral load-resisting systems	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.
Typical wall densities in	~ 200%

direction 1	~20%
Typical wall densities in direction 2	5-10%
Additional comments on typical wall densities	Total wall area/plan area (for each floor) is from 0.17 to 0.25.
Wall 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 facade, 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.
Is it typical for buildings of this type to have common walls with adjacent buildings?	Yes
Modifications of buildings	Addition of storeys, 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.
Type of Foundation	Shallow Foundation: Rubble stone, fieldstone strip footing
Additional comments on foundation	In some cases, following problems with uneven settlements, in recent years some of these houses might have been underpinned using micro-piles
Type of Floor System	Vaulted masonry floor Other floor system
Additional comments on floor system	Other: wood planks or beams with ballast and concrete or plaster finishing 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.
Type of Roof System	Wooden beams or trusses with heavy roof covering
Additional comments on roof system	
Additional comments section 2	The main function of this building typology is single-family house. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. Building of this type can have as the one main entry so the two doors. These buildings are typically found in flat, sloped and hilly terrain. They do not share common walls with adjacent buildings.

This value of 5 meters is average distance. Buildings of this type in some places are located close together and in other places are scattered. When separated from adjacent buildings, the typical distance from a neighboring building is 5 meters.



An Elevation of a Typical Building



Plan of a Typical Building

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	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
Floors	Timber	6 to 10 MPa Depends on type and age of timber
Roof	Timber	6 to 10 MPa Depends on type and age of timber
Other		

Design Process

Who is involved with the design process?	EngineerArchitect
Roles of those involved in the design process	The design of repair and strengthening has to be signed by an engineer. The architect would typically get involved if refurbishment is planned.

Expertise of those involved in the design process	Most of buildings were constructed many years ago and didn't have any kind of expertise.
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Construction Process

Who typically builds this construction type?	Builder
Roles of those involved in the building process	Very rarely these houses are built nowadays, but contractors who will do maintenance or upgrading will live locally, in similar type of construction.
Expertise of those involved in building process	Most of buildings were constructed many years ago and didn't have any kind of expertise.
Construction process 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.
Construction issues	

Building Codes and Standards

Is this construction type address by codes/standards?	Yes
Applicable codes or standards	Decreto Ministeriale 2-7-1981: Normativa per le riparazioni ed il rafforzamento degli edifici danneggiati dal sisma 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. Revised in 1986 and in 1996. New brick masonry structures are addressed in a different standard.
Process for building code enforcement	N/A

Building Permits and Development Control Rules

Are building permits required?	Yes
Is this typically informal	No

construction?

Yes

Is this construction typically authorized as per development control rules?

No

Additional comments on building permits and 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 behaviour.

Building Maintenance and Condition

Typical problems associated with this type of construction

Who typically maintains buildings of this type?

BuilderOwner(s)

Additional comments on maintenance and building condition

Construction Economics

Unit construction cost

800 Euro/sq m.

Labor requirements

4-6 working weeks depending on size.

Additional comments section 3



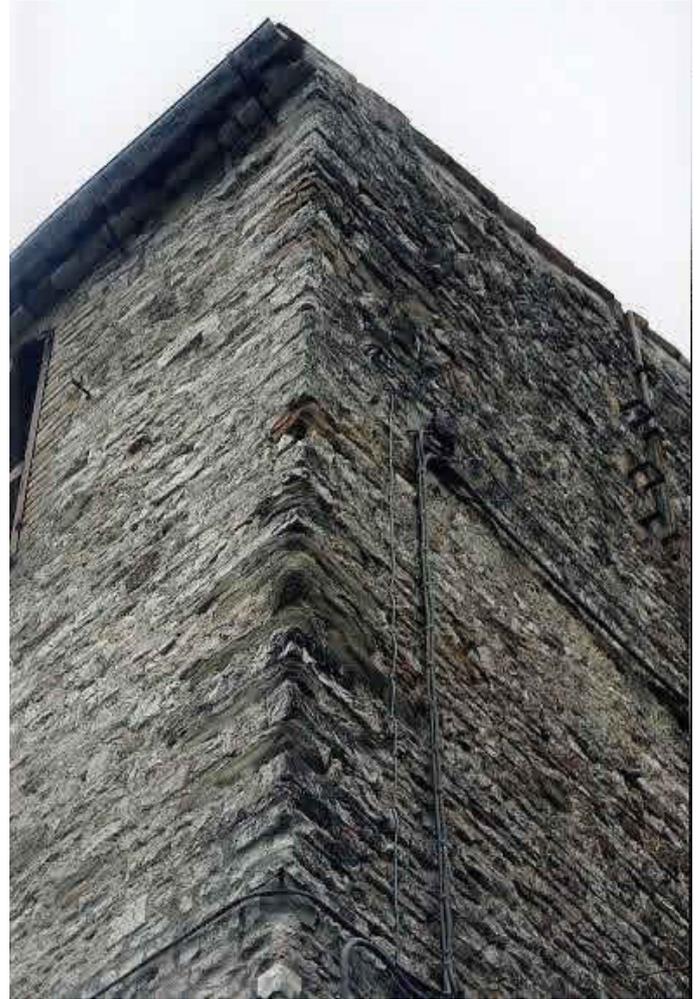
Critical Structural Details Stone Masonry Wall With Irregular Roughly Dressed Stone Blocks of



Critical Structural Details-Movement the Blocks, Probably as a Result of Damage in Previous Earthquake and

Varying Dimensions Embedded into Thick Lime Mortar Joints (not properly repointed)

Visible Loose Stones Around the Arch



Key Seismic Features and Deficiencies Showing the Regular Arrays of Floor Ties in One the Next One, and Corner Return Return Stones in the Third Unit

Earthquake-Resilient Feature - Corner Returns between the Perpendicular Walls Made of Larger Stone Blocks

Socio-Economic Issues

Patterns of occupancy	From 1 to 2 families depending on size of the building Each building typically has 1 to 4 units in each building.
Number of inhabitants in a typical building of this construction type during the day	<5
Number of inhabitants in a typical building of this construction type during the evening/night	5-10

Additional comments on number of inhabitants	Some of these units have now been converted in holiday homes, only occupied at weekends and in the summer months.
Economic level of inhabitants	Low-income class (poor)Middle-income class
Additional comments on economic level of inhabitants	Ratio of housing unit price to annual income: 5:1 or worse 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.
Typical Source of Financing	Owner financedInformal network: friends or relativesSmall lending institutions/microfinance institutions
Additional comments on financing	
Type of Ownership	RentOwn outrightUnits owned individually (condominium)
Additional comments on ownership	
Is earthquake insurance for this construction type typically available?	No
What does earthquake insurance typically cover/cost	N/A
Are premium discounts or higher coverages available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features?	No
Additional comments on premium discounts	
Additional comments section 4	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.

Earthquakes

Past Earthquakes in the country which affected buildings of this type

Year

Earthquake Epicenter

1997	Serravelle

Past Earthquakes

<p>Damage patterns observed in past earthquakes for this construction type</p>	<p>A small proportion of these buildings collapsed in the town centres 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 epicentre. 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 9 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 10 illustrates the earthquake damage associated with the inadequate ring beam-wall connection. The roof had slipped on the masonry and caused the wall damage.</p>
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Additional comments on earthquake damage patterns

Structural and Architectural Features for Seismic Resistance

The main reference publication used in developing the statements used in this table is FEMA 310 "Handbook for the Seismic Evaluation of Buildings-A Pre-standard", Federal Emergency Management Agency, Washington, D.C., 1998.

The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than $\frac{1}{2}$ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than $\frac{1}{3}$ of the distance between the adjacent cross walls; For precast concrete wall structures: less than $\frac{3}{4}$ of the length of a perimeter wall.

Structural/Architectural Feature	Statement	Seismic Resistance
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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.	FALSE
Building Configuration-Vertical	The building is regular with regards to the elevation. (Specify in 5.4.1)	TRUE
Building Configuration-Horizontal	The building is regular with regards to the plan. (Specify in 5.4.2)	TRUE
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.	FALSE
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.	FALSE
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.	TRUE
Wall and Frame Structures-Redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	TRUE
Wall Proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced	TRUE

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 doveled into the foundation.	TRUE
Wall-Roof Connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps.	TRUE
Wall Openings		FALSE
Quality of Building Materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	TRUE
Quality of Workmanship	Quality of workmanship (based on visual inspection of a few typical buildings) is considered to be good (per local construction standards).	FALSE
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).	FALSE

Building Irregularities

Additional comments on structural and architectural features for seismic resistance	
Vertical irregularities typically found in this construction type	Other
Horizontal irregularities	

typically found in this construction type	Other
Seismic deficiency in walls	-Level of bond in the geometric thickness of the multi-leaf walls. -Extent of connection between facade and party walls, depending on alteration and position of windows. -Level of bond between mortar and units depending on decay of original material and r
Earthquake-resilient features in walls	-Corner returns between the perpendicular walls made of larger stone blocks are an original feature in many buildings, see Figure 8. -In some buildings built in the last 100 years iron anchors connecting the floor timber structure to the wall are an as bu
Seismic deficiency in frames	
Earthquake-resilient features in frame	
Seismic deficiency in roof and floors	Original structures are flexible diaphragms. Some roofs can also produce active thrust on the walls. Earthquake Damage Patterns: Partial or total collapse of floor or roof structure associated with partial or total collapse of load-bearing walls.
Earthquake resilient features in roof and floors	In some cases the main timber structure is laid out orthogonally at different floor level to tie in both sets of walls
Seismic deficiency in foundation	
Earthquake-resilient features in foundation	

Seismic Vulnerability Rating

For information about how seismic vulnerability ratings were selected see the [Seismic Vulnerability Guidelines](#)

	High vulnerability		Medium vulnerability		Low vulnerability	
	A	B	C	D	E	F
Seismic vulnerability class	-	o	-			



Earthquake Damage to a Retrofitted Building to the Inadequate RC Ring Beam-Wall Connection

Typical Earthquake Damage - "X" cracking of walls (1997 Umbria-Marche earthquake)

Retrofit Information

Description of Seismic Strengthening Provisions

Structural Deficiency	Seismic 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 15. Note the dowels anchored into the existing walls and the new concrete slab atop the existing wood floor. Figure 14 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 11 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 10.

Inadequate Wall-Floor Connection	Installation of new steel ties. Figure 13 shows a steel strap detail connecting an existing stone masonry wall to a timber floor joists. Figure 14 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 7. 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 9.
Low Lateral-Load Resistance of the Walls	Grouting

Additional comments on seismic strengthening provisions	Figure 11 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 12 illustrates modern anchors with anchorage plates and concrete lintels over openings.
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Has seismic strengthening described in the above table been performed?	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.
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Was the work done as a mitigation effort on an undamaged building or as a repair following earthquake damages?	The work could be performed in both cases.
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Was the construction inspected in the same manner as new construction?	N/A
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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.
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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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Additional comments section 6	
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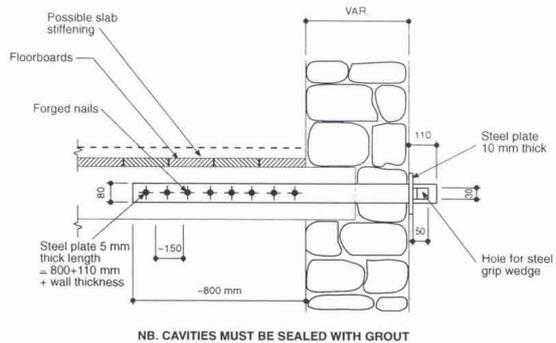


Illustration of Seismic Strengthening Techniques

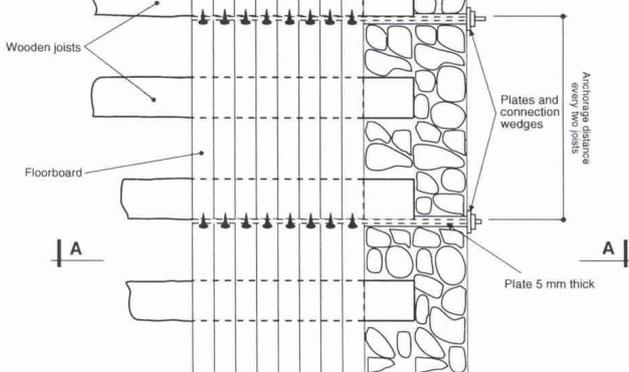


Seismic Strengthening Techniques- Installation of modern anchors with anchorage plates and concrete lintels over openings

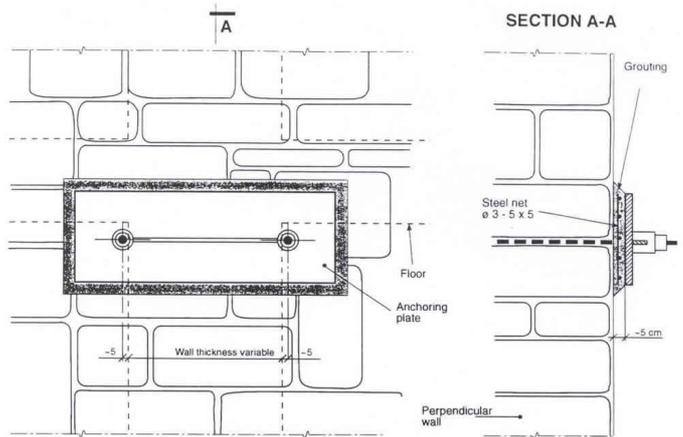
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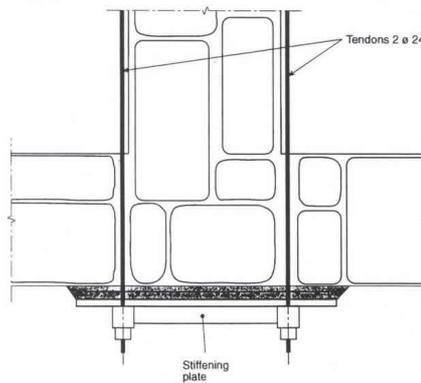
HORIZONTAL SECTION



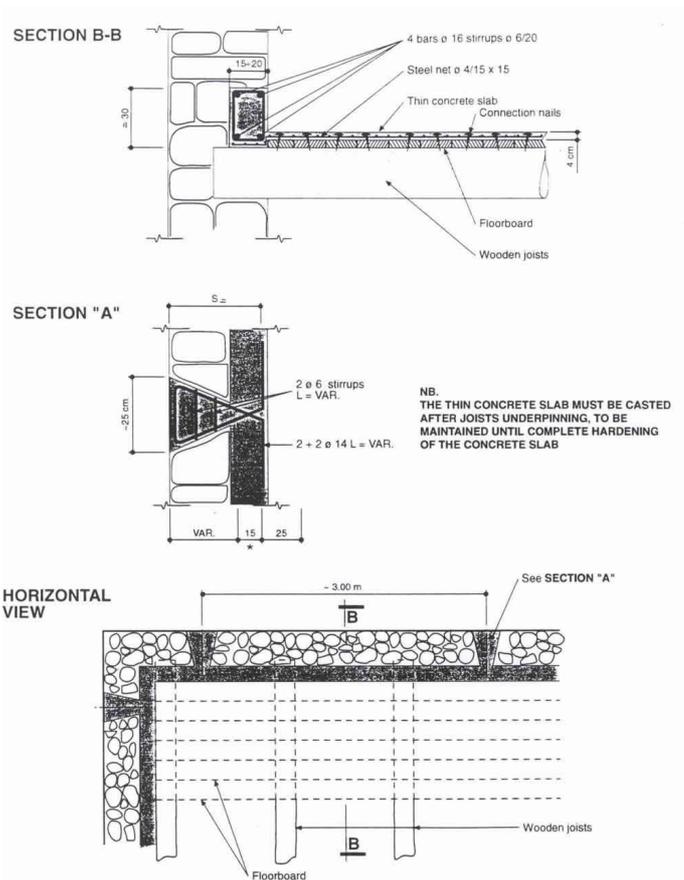
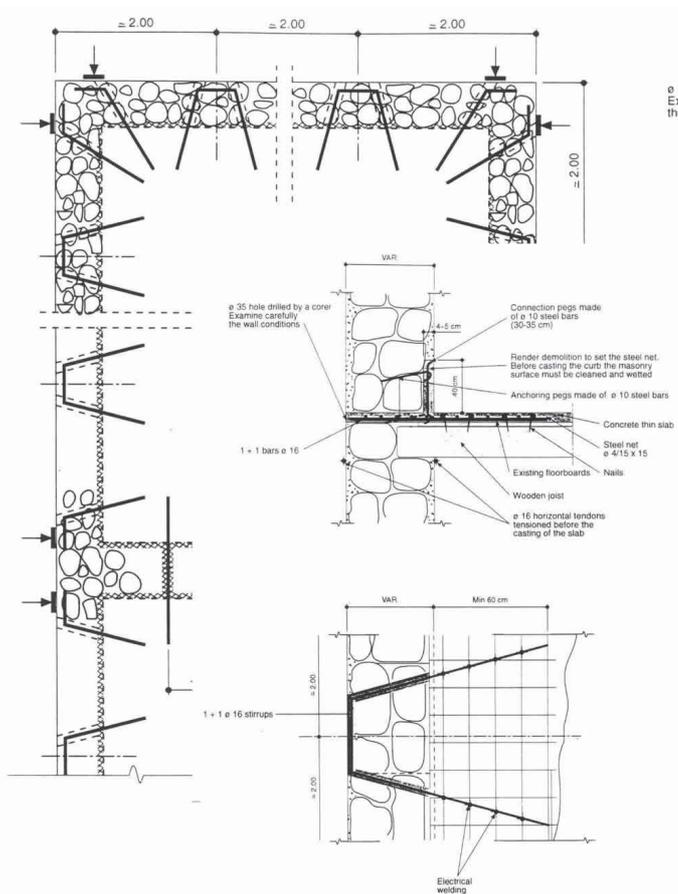
Seismic Strengthening- Steel Strap Used to Connect an Existing Masonry Wall to Timber Floor Joists



HORIZONTAL SECTION



Seismic Strengthening- Installation of Ties with an Anchor Plate at the Exterior Wall Face



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

Seismic Strengthening- Installation of New RC Ring Beam

References

1. D Ayala, D., Spence, R. (1995). Vulnerability of Buildings in historic town centres. Proceedings of the VII National Conference Ingegneria Sismica in Italia, pp.363-372, Siena, Italy.
2. D'Ayala, D., Spence, R., Oliveira, C., & Pomonis, A. (1997). Earthquake Loss Estimation for Europe's Historic Town Centres. Earthquake Spectra Special Issue on Earthquake Loss Estimation, (November).
3. 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).
4. 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.
5. D Ayala, D., Speranza, E. (1999) Identificazione dei Meccanismi di Collasso per la stima della Vulnerabilita Sismica di Edifici nei Centri Storici. Proceedings of the IX National Congress, Ingegneria Sismica in Italia, Torino, Italy (in Italian).

6. 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, Auckland, New Zealand.

7. D Ayala, D, Speranza, E. 2000, Confronto di misure di vulnerabilita 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, Italy (in Italian).

8. 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.

9. D Ayala, D, Speranza, E. (2001) A procedure for evaluating the seismic vulnerability of historic buildings at urban scale based on mechanical parameters. Proceedings of the 2nd International Congress #Studies in Ancient Structures, Yildiz, Istanbul, Turkey.

10. 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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