

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

Reinforced clay/concrete block masonry building

Report#	5
Last Updated	
Country	Chile
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Reviewers	Sergio Alcocer,

Important

This encyclopedia contains information contributed by various earthquake engineering professionals around the world. All opinions, findings, conclusions & recommendations expressed herein are those of the various participants, and do not necessarily reflect the views of the Earthquake Engineering Research Institute, the International Association for Earthquake Engineering, the Engineering Information Foundation, John

General Information

Building Type:	Reinforced clay/concrete block masonry building
Country:	Chile
Author(s):	Ofelia Moroni Cristian Gomez Maximiliano Astroza
Last Updated:	
Regions Where Found:	<p>This housing type is used throughout Chile. Between 1992 and 2002 this type of building represented about 7% of the total social dwellings (Jaramillo, 2011).</p>
Summary:	<p>This is a rather recent construction practice followed since 1970s, and it has been widely used for dwellings and up to 4-story high apartment buildings. Buildings of this type can be found both in urban and rural areas of Chile. The main load-bearing elements are masonry walls reinforced with vertical steel reinforcement bars placed in the hollow cores of clay masonry units (hollow clay tiles) or concrete blocks. Horizontal reinforcement bars are placed in horizontal bed joints. Masonry shear walls are tied together at floor levels by means of reinforced concrete beams, in a regular structural layout. Stiffness distribution both in plan and elevation is uniform. Prior to 1986 there was no seismic design code for this structural type. During the March 3, 1985 Lolleo earthquake, performance of buildings of this type was rather poor, mainly due to construction problems, such as partial grouting in the hollow cores with reinforcement, poor quality of the mortar, and lack of horizontal reinforcement. Following the earthquake, the Chilean Design Code NCh1928 code was published based on the U.S. Uniform Building Code (UBC-1979) and the seismic performance of this construction type reported in previous earthquakes. Since 1993, when NCh1928.Of93 was published, and more restricted requirements were enforced, the use of this type of construction has been less frequent, in part due to economic reasons.</p>
Length of time practiced:	25-60 years
Still Practiced:	Yes

In practice as of:	
Building Occupancy:	Residential, 10-19 units
Typical number of stories:	2-4
Terrain-Flat:	Typically
Terrain-Sloped:	Occasionally
Comments:	Construction practice followed in the last 40 years. Due to economic reasons its use for social dwellings has declined in the la

Features

Plan Shape	Rectangular, solid
Additional comments on plan shape	
Typical plan length (meters)	12-30
Typical plan width (meters)	5-8
Typical story height (meters)	2.3
Type of Structural System	Masonry: Reinforced Masonry: Clay brick masonry in cement mortar Masonry: Reinforced Masonry: Concrete block masonry in cement mortar
Additional comments on structural system	Gravity load bearing and Lateral load-resisting system: The main load-bearing elements are masonry walls reinforced with vertical steel reinforcement bars placed in the hollow cores of clay masonry units (hollow clay tiles) or concrete blocks. Horizontal reinforcement bars are placed in horizontal bed joints. Although the cores and voids containing reinforcement should be filled with grout, this is not always done. Most of the time cores and voids are filled only with the same mortar used in the horizontal joints. In addition, the size of the hollow in the ceramic unit is quite small so it is difficult to fill it. Concrete blocks, mostly used in the northern part of Chile, have larger hollow cores, however they are experiencing water leakage problems and since 1997 the use of these blocks has been banned in Central Chile. Masonry shear walls are tied together at floor levels by means of reinforced concrete beams, in a regular structural

	<p>layout. In most cases, wall layout is symmetrical with regards to at least one axis. Stiffness distribution both in plan and elevation is uniform. The Chilean code for reinforced masonry building specifies the size and the minimum quantity of vertical and horizontal bars that must be used in a reinforced masonry walls. The sum of the areas of horizontal and vertical reinforcement shall be at least 0.0015 times the gross-sectional area of the wall and the minimum area of reinforcement in either direction shall not be less than 0.0006 times the gross cross-sectional area of the wall. The spacing of reinforcement shall not exceed 120 cm or 6 times the thickness of the wall. The diameter of the vertical reinforcement shall not be less than 8 mm and the horizontal bar shall not exceed 0.5 times the thickness of the horizontal mortar joint.</p>
Gravity load-bearing & lateral load-resisting systems	Walls are made of clay or concrete block masonry.
Typical wall densities in direction 1	2-3%
Typical wall densities in direction 2	2-3%
Additional comments on typical wall densities	<p>The total wall area/plan area per unit floor d/n % correlates quite well with observed damage. This index varies between 0.5 and 1.5%. If d/n in longitudinal and transverse direction are different, the smallest value controls the behavior of the building. The unit shear strength may also be considered, so a larger d/n is required for buildings built with concrete blocks. (Jaramillo, 2011).</p>
Wall Openings	In each facade there may be 3 to 4 openings of 0.8 to 1.5 m width probably equally spaced.
Is it typical for buildings of this type to have common walls with adjacent buildings?	No
Modifications of buildings	Typical patterns of modification observed are infill balconies or openings of door in exterior walls
Type of Foundation	Shallow Foundation: Reinforced concrete strip footing
Additional comments on foundation	Usually the foundation does not have reinforcement, unless the soil is clay or silt
Type of Floor System	Other floor system

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	Wall: 1) Clay brick 2) Concrete block	Wall: 1) Characteristic Strength clay brick : 6-12 MPa Dimensions: 14 x 292) Characteristic Strength concrete block: 3-10 Mpa Dimensions: 19x39x19 or 14x39x9
Foundations		
Floors		
Roof		
Other	Concrete H18 Steel A44-28H	Characteristic Strength concrete: 18 Mpa Steel strength: 280 Mpa

Design Process

Who is involved with the design process?	Owner
Roles of those involved in the design process	The owner of the construction site hires a professional team that includes engineer and architects
Expertise of those involved in the design process	The structural engineer has 6 years of studies and more than 3-5 years of experience. The construction engineer has 6 years of studies and less experience than the structural engineer. There is not compulsory inspection during the construction, but when inspection does exist larger masonry compression strength is allowed. Since year 2001 (ley no 19748), peer revision of the structural project is compulsory for buildings taller than 3 story. The designer may visit the construction site once or twice during the construction.

Construction Process

Who typically builds this construction type?	Contractor
Roles of those involved in the building process	In the past, construction companies hired by the state build it. Nowadays, private companies built and sell directly under the supervision of governmental staff.
Expertise of those involved in building process	The expertise is the same stated in 3.2.3

Construction process and phasing

One contractor builds large quantities of this type of building, so project management and control techniques are used in order to increase productivity and to diminish cost. When constructing the vertical reinforcing bars are usually first placed into position before laying the masonry units. Then, the horizontal bars can be placed in horizontal mortar joints. Finally, vertical reinforcement is grouted as the work progresses. With respect to equipment the following is commonly used: concrete mix, trucks, travelling crane, winch, pneumatic cramp. This building is not typically constructed incrementally and is designed for its final constructed size.

Construction issues

Partial grouting in vertical reinforcement. Bending of reinforcement bars Bad reinforcement detailing at the corners or intersection of walls. Insufficient concrete covers for horizontal reinforcement.

Building Codes and Standards

Is this construction type address by codes/standards?

Yes

Applicable codes or standards

NCh1928.Of93 Albanileria Armada-Requisitos para el diseno y calculoThe first code/standard addressing this type of construction was issued in 1986, although provisionally dispositions to design this type of buildings existed since 1981. The most recent code/standard addressing this construction was issued in 1993, however at present time it is in a revision process. Applicable national building code, material codes and seismic code/standards: NCh433.Of96 Seismic Design of BuildingsNCh1928.Of93 Albanileria Armada-Requisitos para el diseno y calculoThe first code/standard addressing this type of construction was issued in 1986, although provisionally dispositions to design this type of buildings existed since 1981. The most recent code/standard addressing this construction was issued in 1993, and modified in 2003. Applicable national building code, material codes and seismic code/standards: NCh433.Of96 Seismic Design of Buildings, last modification in 2011

Process for building code enforcement

The building design must follow the NCh433.of96 code (modified in 2011) and NCh1928.of93 (modified in 2003). SERVIU a governmental office in charge of social dwellings has a professional staff to review the projects and to inspect during construction. In case of damage an arbitrage

process may take place at the court of justice.

Building Permits and Development Control Rules

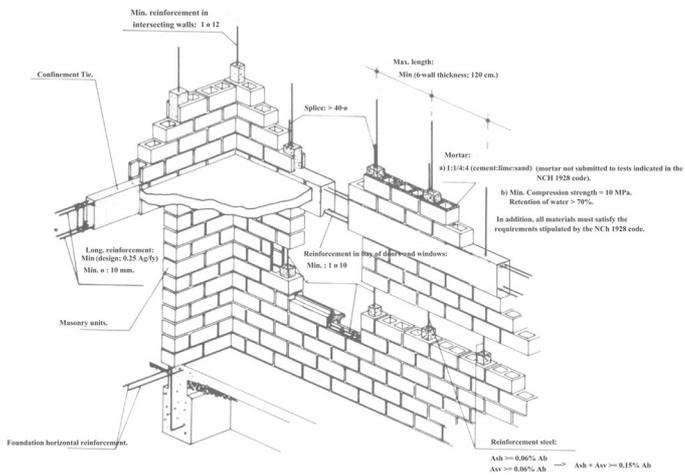
Are building permits required?	Yes
Is this typically informal construction?	No
Is this construction typically authorized as per development control rules?	No
Additional comments on building permits and development control rules	

Building Maintenance and Condition

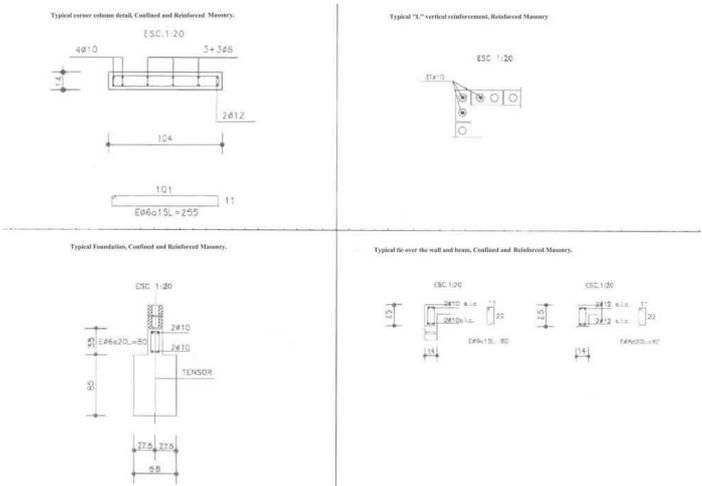
Typical problems associated with this type of construction	Concrete blocks buildings have had water ingress.
Who typically maintains buildings of this type?	Owner(s)Renter(s)
Additional comments on maintenance and building condition	Maintenance is quite low, because inhabitants are low income people

Construction Economics

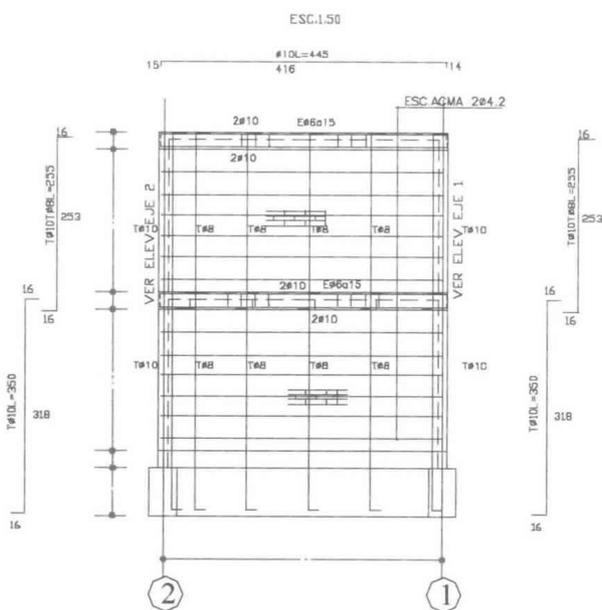
Unit construction cost	According to Bravo and Martinez (1993) the total cost of this type of building can be blotted out in site 15%, construction cost 40%, urbanization 17%, operating cost 13% and profit 15%.In 2001, the cost of one unit was 200 to 400 UF (area 45 m ²), \$78.000 to \$140.000 /m ² (US\$135- US\$245/m ²).Better quality unit may cost up to \$174.000 /m ² (US\$300/m ²).
Labor requirements	At present, depending on technology used, the construction of several units built simultaneously may take 2-3 stories per month .
Additional comments section 3	



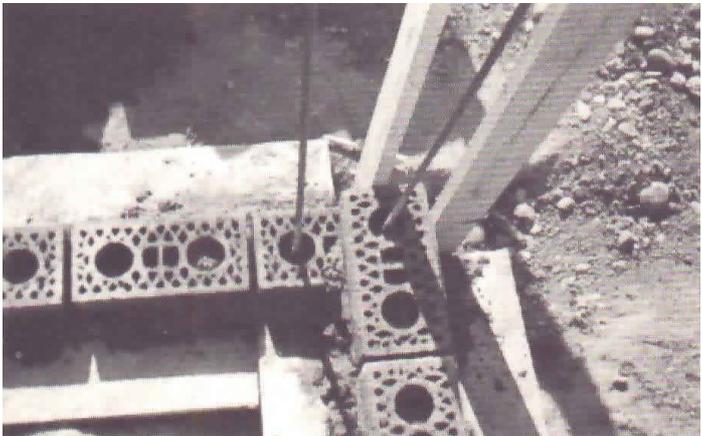
Key load-bearing elements



Critical structural details: reinforced masonry wall and footings

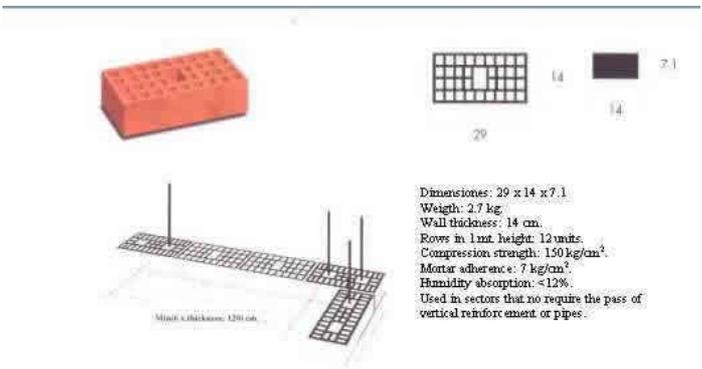
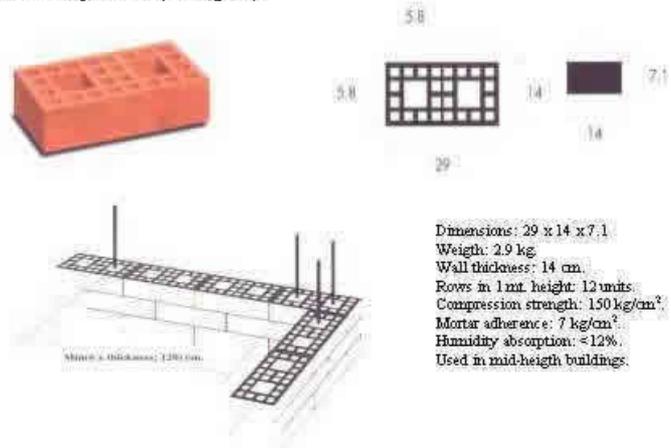


Vertical elevation through a masonry wall



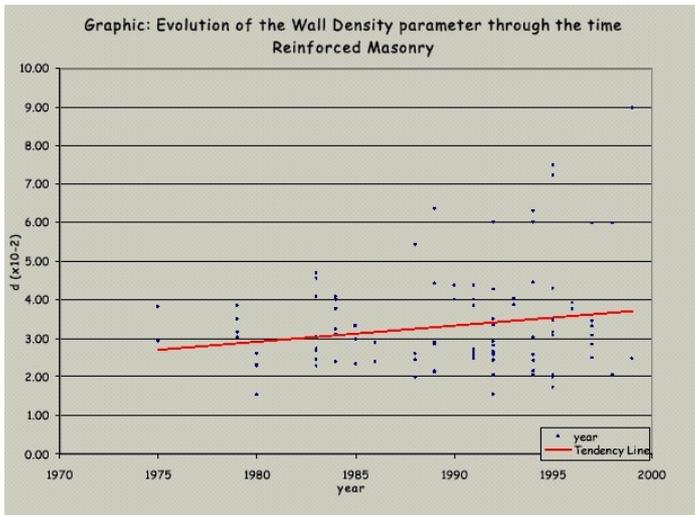
Typical masonry units

Masonry Units (examples).



Typical masonry units

Typical masonry units



Key seismic features: high wall density

Socio-Economic Issues

Patterns of occupancy	Typically one family occupies one housing unit. However, poor families may shelter 1 or 2 families more called "allegados".
Number of inhabitants in a typical building of this construction type during the day	10-20
Number of inhabitants in a typical building of this construction type during the evening/night	>20
Additional comments on number of inhabitants	At present, the average size of a family is 5.5 persons, so if one unit is occupied by up to 3 families, the number of inhabitants in a building may be quite high.
Economic level of inhabitants	Very low-income class (very poor)Low-income class (poor)Middle-income class
Additional comments on economic level of	House Price/Annual Income (Ratio) expressed in US\$: 10000/2000 Very Poor 10000/4000 Poor 20000/6150 Middle ClassThe prices correspond to year 2001 and are expressed in US\$.The poorest quintile has an average annual income of US\$ 2.010. They pay for a 45 m2 dwelling that is subsidized by the State between US\$ 5.445 to US\$10.885.The next quintile has an average annual income of US\$ 4.020, but they live in the same dwellings of the poorest group.The third quintile has

inhabitants	an average annual income of US\$ 6.150, and they may choose larger or better quality housing. Common prices are between US\$ 10.885 to US\$27.000. Subsidies may be between 15 to 25% of the total cost. In 2013, the average annual income per quintile was the following: first quintile U\$ 5600 second quintile U\$ 9600 third quintile U\$ 14400 and the cost of propriety probably have increased in 50%
Typical Source of Financing	Owner financed Personal savings Informal network: friends or relatives Small lending institutions/microfinance institutions Commercial banks/mortgages Other
Additional comments on financing	Other: Governmental subsidies.
Type of Ownership	Rent Own outright Own with debt (mortgage or other)
Additional comments on ownership	
Is earthquake insurance for this construction type typically available?	Yes
What does earthquake insurance typically cover/cost	Earthquake insurance is available as supplement of other insurance (fire, robbery) and people living in these buildings do not have money to pay for that. This insurance typically covers repairs to same condition as before the earthquake.
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	

Earthquakes

Past Earthquakes in the country which affected buildings of this type

Year	Earthquake Epicenter
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1985	Llolleo, V Region
1997	Punitaqui, IV Region
2005	Tarapaca, I Region
2010	Maule, VII Region
2014	Iquique, I Region

Past Earthquakes

Damage patterns observed in past earthquakes for this construction type

After the 1985 earthquake the Ministry of Housing appointed an especial committee to review the seismic effects on social dwellings. About 12.000 units were reinforced masonry type and 44% of them had some type of damage. A 100% of the 3 or more story buildings (2800 units) were severely damaged. The following characteristic damage patterns were observed:- shear cracks in walls, spandrels part of the walls and window piers- vertical cracks at the wall bottom due to compression failure- horizontal cracks at the joints between masonry walls and reinforced concrete floors or foundation- cracks in window piers and walls due to out-of-the-plane action. Some damage occurred in houses located in Illapel during 1997 earthquake due to differential settlement in a sloped terrain. Heavy damage occurred in reinforced masonry houses located in Pozo Almonte during 2005 earthquake, probably because the wall density in one direction was quite low and the construction quality was very poor (Astroza et al, 2005). During 2010 earthquake, a substandard quality of masonry construction was observed in some severely damaged buildings in Rancagua, although the seismic intensity in that location was moderate (Nunez, 2010).

Additional comments on earthquake damage patterns

Up to 1986 there was not any seismic design code for this structural type, so its behavior during March 3, 1985 earthquake was quite bad, mainly due to construction problems, partial grouting in the hollow with reinforcement, bad quality of the mortar and lack of horizontal reinforcement. The same had occurred in the later earthquakes, when requirements according to NCh1928.of1993 have not been accomplished to the full.

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
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.	TRUE
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.	TRUE
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.	TRUE
Foundation Performance	There is no evidence of excessive foundation movement (e.g. settlement) that would	FALSE

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.	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 masonry walls); Less than 13 (unreinforced masonry walls);	TRUE
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.	FALSE
Wall Openings		TRUE
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	FALSE

are no visible signs of deterioration of building elements (concrete, steel, timber).

Building Irregularities

<p>Additional comments on structural and architectural features for seismic resistance</p>	<p>Average story height is 2.3 m and the thickness brick most used is 14 cm, so the ratio height to thickness is less than 30.</p>
<p>Vertical irregularities typically found in this construction type</p>	<p>No irregularities</p>
<p>Horizontal irregularities typically found in this construction type</p>	<p>No irregularities</p>
<p>Seismic deficiency in walls</p>	<p>Low shear strength, so it is difficult to get flexural ductile failure. It is difficult to achieve good anchoring and bonding conditions especially if poor quality masonry units and poor mortar instead of grout are used. Hollow sizes in clay units are inappropriate. Vertical reinforcements without grouting are ineffective. Lack of reinforced concrete horizontal tie-beams may cause out-of-plane bending effects. Lack of appropriate reinforcement at opening edges. Earthquake Damage Patterns: - Shear cracks in walls, spandrel part of the walls and window piers - Vertical cracks at the wall bottom due to compression failure- Horizontal cracks at the joints between masonry walls and reinforced concrete floors or foundation - Cracks in window piers and walls due to out-of-the-plane action.</p>
<p>Earthquake-resilient features in walls</p>	<p>Relatively high wall density per unit floor. In general these buildings are quite stiff, they must resist a base shear of 10-22% depending on the seismic zone and the story drift must be equal or less than 0.002, (calculated with a reduced spectra, $R = 3$ or 4).</p>
<p>Seismic deficiency in frames</p>	
<p>Earthquake-resilient features in frame</p>	
<p>Seismic deficiency in roof and floors</p>	

Earthquake resilient features in roof and floors

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	-	



Shear fails in reinforced masonry walls.

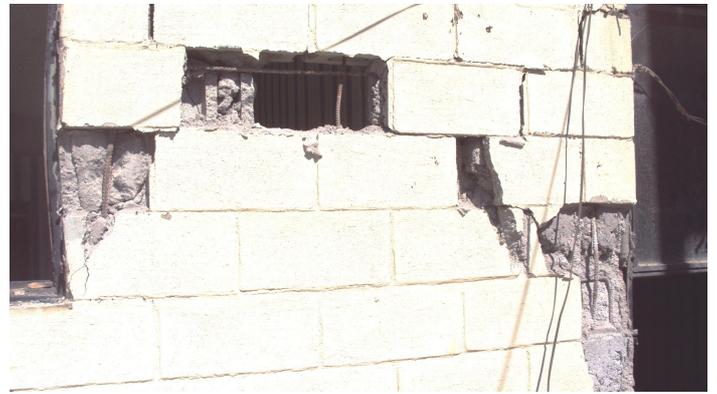


Compression fail in reinforced masonry wall.



Failure of masonry walls in March 3, 1985 Lolleo earthquake

March 3, 1985 earthquake in Central Chile. Damage to masonry buildings in Santiago.



***Villa Cordillera, Rancagua, VI region,
4 story-building***

***Villa Cordillera, Rancagua, VI region,
4 story-building***



***Reinforced masonry house at Pozo
Almonte***

Retrofit Information

Description of Seismic Strengthening Provisions

Structural Deficiency

Seismic Strengthening



Lack of appropriate reinforcement	Addition of new tie-columns

Additional comments on seismic strengthening provisions	The strengthening procedure consist in confining the masonry wall with reinforced concrete tie-column and tie-beam. This may cost up to 20% of the original cost. With this procedure ductility is also improved. When only some bricks have been damaged, they have been replaced; the same occurs when cracks appeared in the mortar joints.
Has seismic strengthening described in the above table been performed?	The seismic strengthening described in the above table was performed after 1985 earthquake in some "conjuntos". After 2010 earthquake, most of severe damage buildings were demolished.
Was the work done as a mitigation effort on an undamaged building or as a repair following earthquake damages?	As it was pointed out in Section 6, after the 1985 earthquake a committee chaired by Prof. Rodrigo Flores was appointed by the Ministry of Housing in order to review the damaged buildings, to prepare restoration projects and supervise its execution.
Was the construction inspected in the same manner as new construction?	Yes
Who performed the construction: a contractor or owner/user? Was an architect or engineer involved?	Contractors hired by the government. Engineers were involved.
What has been the performance of retrofitted buildings of this type in subsequent earthquakes?	Repaired buildings after 1985 earthquake, had an adequate behavior during 2010 earthquake.
Additional comments section 6	

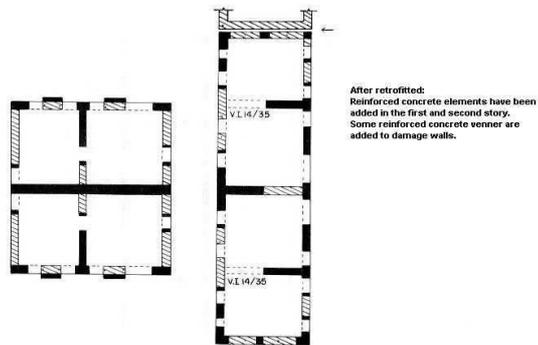
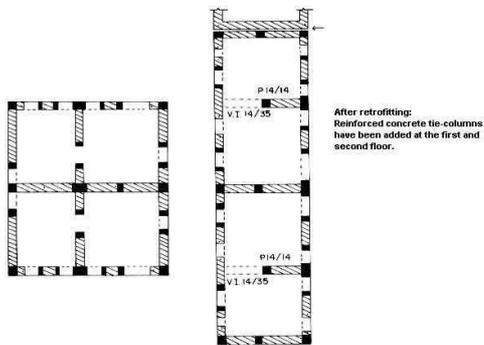
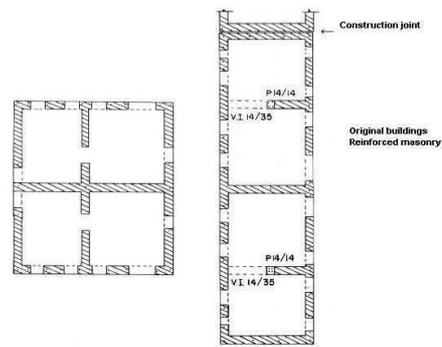
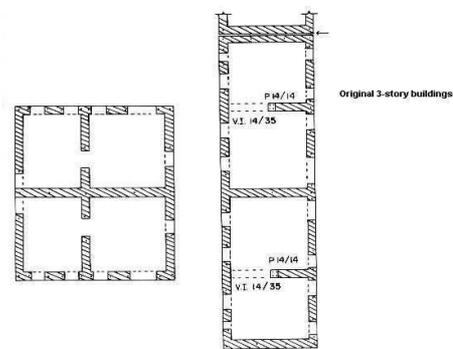


Illustration of seismic strengthening techniques

Illustration of seismic strengthening techniques

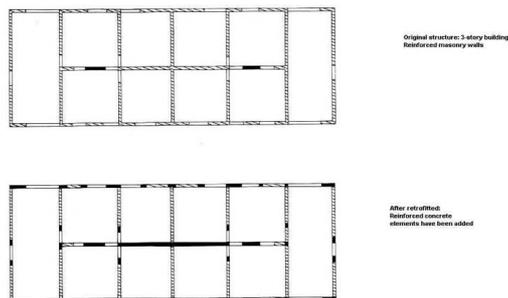


Illustration of seismic strengthening techniques

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