World Housing Encyclopedia

A Resource on Construction in Earthquake Regions

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

HOUSING REPORT

Buildings with hybrid masonry walls

Report#	8
Last Updated	
Country	Chile
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Important

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General Information

Building Type:	Buildings with hybrid masonry walls
Country:	Chile
Author(s):	Ofelia Moroni Cristian Gomez Maximiliano Astroza
Last Updated:	
Regions Where Found:	This housing type is used throughout Chile.
Summary:	This housing type represents a common multi-family urban construction in Chile. This construction practice started in the 1980s, and it is mainly used for dwellings and up to 4-story apartment buildings. The main load-bearing system consists of masonry walls in transverse direction and reinforced concrete walls or reinforced masonry walls in the longitudinal direction. Masonry walls in the transverse direction are usually confined with concrete posts at the ends (like in confined masonry construction).Buildings of this type are usually regular in plan and in elevation. Seismic design code does not address buildings of this type, however the Chilean Ministry of Housing has issued specifications for 1 and 2-story dwellings, which have been mainly followed in the design, even in case of taller buildings of this type. Performance of buildings of this type in the 1985 Llolleo and 2010 Maule earthquakes was rather poor, with most buildings experiencing structural damage.
Length of time practiced:	25-60 years
Still Practiced:	Yes
In practice as of:	
Building Occupancy:	Residential, 5-9 unitsResidential, 10-19 units
Typical number of stories:	3-4
Terrain-Flat:	Typically
Terrain-Sloped:	Occasionally
Comments:	Buildings of this type may be single family houses too. In the last 25 years, due to economical

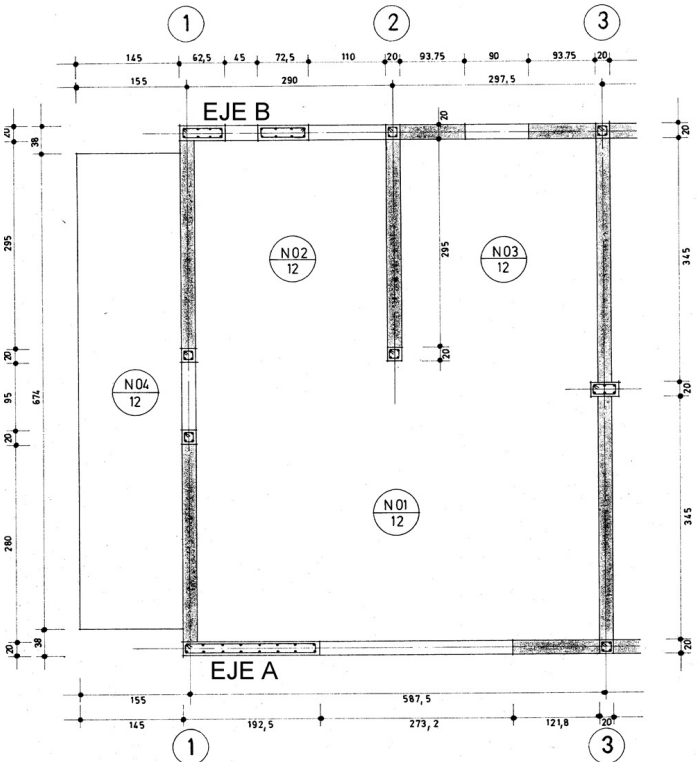
reasons, 80% of the total socia

Features

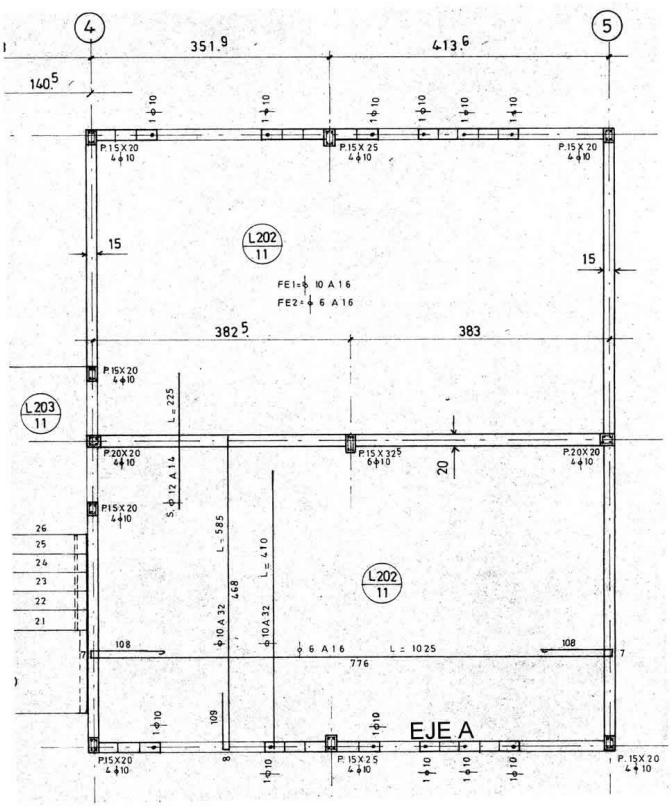
Plan Shape	Rectangular, solid
Additional comments on plan shape	The typical shape of a building plan is rectangular. These buildings are characterized with the regular structural layout, symmetrical with regards to at least one axis. As a result, there is a uniform distribution of stiffness both in plan and in elevation.
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 mortarMasonry: Reinforced Masonry: Concrete block masonry in cement mortar
Additional comments on structural system	Lateral load-resisting system: The main lateral load-resisting system in the buildings of this type consists of masonry shear walls tied together at floor levels by means of reinforced concrete beams.In the transverse direction, the masonry walls are partially reinforced or confined with reinforced concrete columns. In the longitudinal direction, there are reinforced masonry or reinforced concrete walls or partially confined walls (mainly used around the openings). The reinforced masonry walls have a 10 mm bar at each end plus 8 mm bars distributed along the wall. Although the maximum allowed spacing between bars is 84 cm they are located between 120 and 150 cm. The diameter of the extreme bars is less than required (12 mm) for dwellings higher than 2 stories. Horizontal reinforcement does not meet the minimum steel ratio requirement of 0.06.The brick thickness in the exterior (facade) walls is 140 mm and 150 mm in the interior walls. Although the cores and voids containing reinforcement should be filled with grout, this is not accomplished in all cases. Most of the time the blocks are filled with the same mortar used in the horizontal joints . In addition, the size of the hollow cores in the ceramic unit is quite small so it is difficult to fill it. Concrete blocks (mostly used in the north of Chile) have larger hollow cores but they have water leakage problems and since 1997 the

	use of these blocks has been banned in Central Chile.Gravity load-bearing system: Masonry shear walls in both directions.Reinforced concrete slab. Average thickness 11 cm.
Gravity load-bearing & lateral load-resisting systems	As is stated in the summary, the main load-bearing system consists of masonry walls in transverse direction and reinforced concrete walls or reinforced masonry walls in the longitudinal direction. Masonry walls in the transverse direction are usually confined with concrete posts at the ends. Clay brick or concrete hollow blocks are used.
Typical wall densities in direction 1	3-4%
Typical wall densities in direction 2	3-4%
Additional comments on typical wall densities	Wall densities vary between 1.5 to 7.0 % in each direction; the average is about 3.2%. On the other hand, the wall density per unit floor has been related to expected level of damage; for values lower than 1.15% some moderate damage may be expected. Generally, lower values correspond to 3 or 4 story buildings. The wall density and wall density per unit floor variation with time are shown in figures 5, 5a and 5b. Additionally, the relation between wall density per unit floor and damage after 2010 earthquake is also shown.
Wall Openings	Each longitudinal facade may be 3 to 4 openings of 0.8 to 1.5 m in width, probably equally spaced.The ratio for the overall window and door areas over the wall surface area is about 25-30%
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 extension of building through a window or door
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. Concrete strip footing is used only under the walls with reinforced tie beams in between.
Type of Floor System	Other floor system
	Floor system: cast in place solid slabs or precast

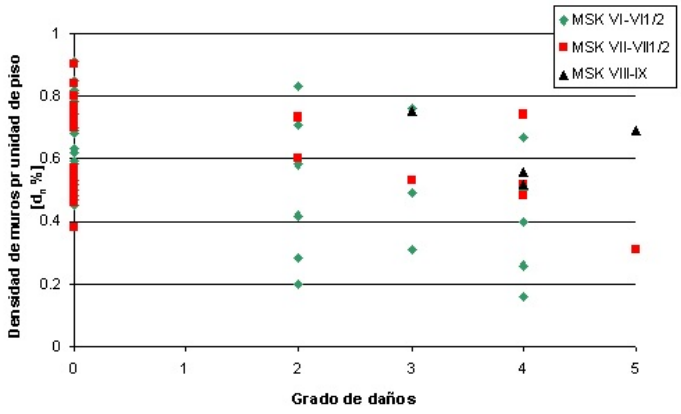
Additional comments on floor system	with large hollow masonry blocks (called bovedillas in Spanish) laid horizontally between precast reinforced concrete beams. In the analysis the floor is considered to be a rigid diaphragm.
Type of Roof System	Roof system, other
Additional comments on roof system	Timber: wood planks or beams that support slate, metal, asbestos-cement or plastic corrugated sheets or tiles. In the analysis, a rigid diaphragm is considered.
Additional comments section 2	Typical separation distance between buildings: 5-10 meters. Buildings of this type are located close together, conforming what is called "conjuntos", "poblaciones" or "villas". They represent several buildings of the same type with some free space left for garden or communities activities that most of the time nobody cares about them, ending filled with garbage or at most, as an earth soccer field.



Plan of a typical building



Plan of a typical building



Damage grade vs wall density area per unit floor. Data from 2010 earthquake, VI region.

Opening of door in the first floor. Constitucion.

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	Wall: 1) Clay brick2) Concrete block	Wall: 1) Characteristic Shear Strength clay brick: 6 - 12 MPaDimensions- 140mm x 290mm2) Characteristic Shear Strength concrete block: 8 - 10 MPaDimensions: 390x190x90 or 390x140x90
Foundations	Concrete block	Characteristic Strength: 3-10Mix Proportion/Dimensions: / 39x19x9 / 39x14x9 5-12
Floors		
Roof		
Other	Concrete Steel A44-28H	Characteristic Strength: 18 20 Steel strentgh: 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 engineers and

the design process	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. For private projects there is not compulsory inspection during the construction, but since year 2001 (ley no19748) there is compulsory peer revision of the structural project for buildings taller than 3 floors. However, when inspection does exist during the construction, larger masonry compression strength is allowed. The designer may visit the construction site once or twice during the construction. Projects hired by the state are revised and inspected during construction by SERVIU, that depends from Ministry of Housing.

Construction Process

Who typically builds this construction type?	Contractor
Roles of those involved in the building process	As is stated above, the owner of the construction site is related with a construction company and a professional team. The buildings may be sold directly or through the Ministry of Housing.
Expertise of those involved in building process	It applies 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 diminish cost. However, inspection and supervision is difficult because too many activities are done simultaneously. When constructing, 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. For confined walls, the bricks are laid in first then the columns and beams are built against the walls. ICH is developing guidelines to build this type of structures properly.With respect to equipment the following is commonly used: concrete mix, trucks, travelling crane, winch.This building is not typically constructed incrementally and is designed for its final constructed size.
	Partial grouting in vertical reinforcement. Bending of reinforcement bars. Bad reinforcement detailing

Construction issues	at the corners or intersection of walls.Insufficient concrete covers for horizontal reinforcement. Inadequate joint construction, stone cage in reinforced concrete element.Lack of quality of brick materials, lack of control of humidity and so the serviceability of the buildings is in discussion.

Building Codes and Standards

Is this construction type address by codes/standards?	No
Applicable codes or standards	The seismic loads are determined based on the NCh433.of96 "Seismic Design for Buildings" (modified in 2011). In general, these buildings are quite stiff and they must resist a base shear of 10-22% depending on the seismic zone; the story drift must be equal or less than 0.002 (calculated with a reduced spectra, R = 3). A specific code addressing this type of construction does not exist. Designers follow only some requirements of NCh1928.Of93 (Reinforced Masonry Design Code) or NCh 2123.Of97 (Confined Masonry Design Code) because they consider that the codes are too strict. In general, designers follow guidelines prepared by the Ministry of housing for 1 or 2 stories houses, independently of the number of floors of the project.
Process for building code enforcement	The building design must follow the NCh433.of96 code (modified in 2011). SERVIU, a governmental office in charge of social dwellings, has a professional staff to review the projects and to inspect during construction. Unfortunately, technical expertise is quite low in regions outside the Metropolitan where Santiago, the capital is located. 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	

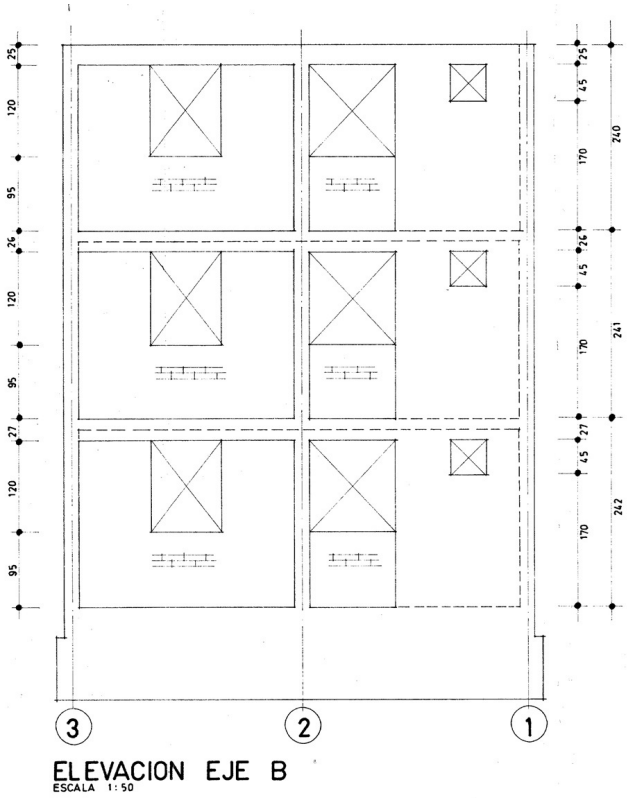
Building Maintenance and Condition

Typical problems associated with this type of construction	Buildings using Concrete blocks have shown water ingress.
Who typically maintains buildings of this type?	No one
Additional comments on maintenance and building condition	Low income people lives in this type of building, so they cant afford any maintenance of them. When problems appear in the media, municipalities try to solve them.

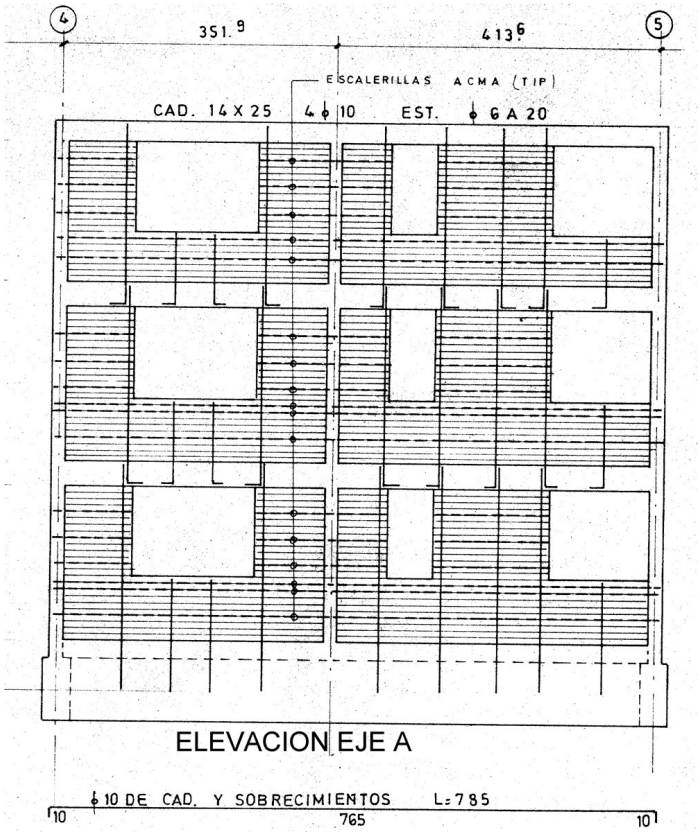
Construction Economics

Unit construction cost	The total cost of this type of building can be divided in main structure 62%, finishing work 25%, urbanization, operating cost and profit 13%.At 2001, the cost of one unit is 200 to 400 UF (area 45 m2), $78.000 to $140.000 /m2 (US$135-US$245/m2).Better quality unit may cost up to $174.000 /m2(US$300/m2).
Labor requirements	At present, depending on technology used, the construction of several units simultaneously built, may take 2-3 stories per month
Additional comments section 3	

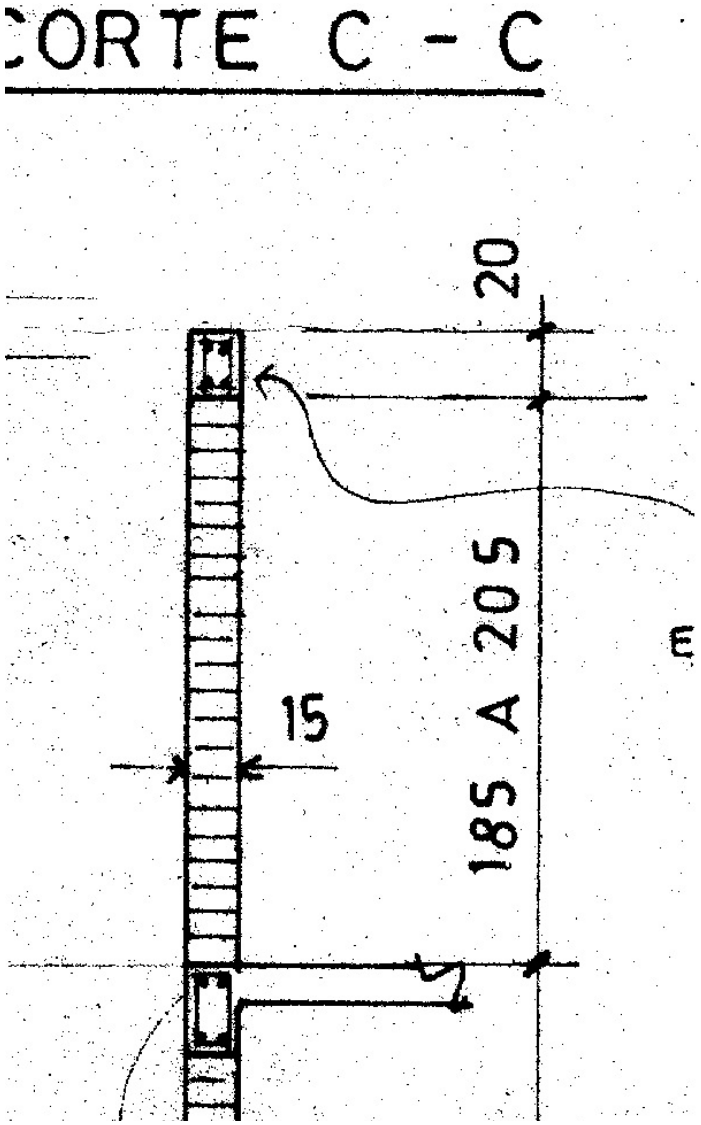
Key load-bearing elements

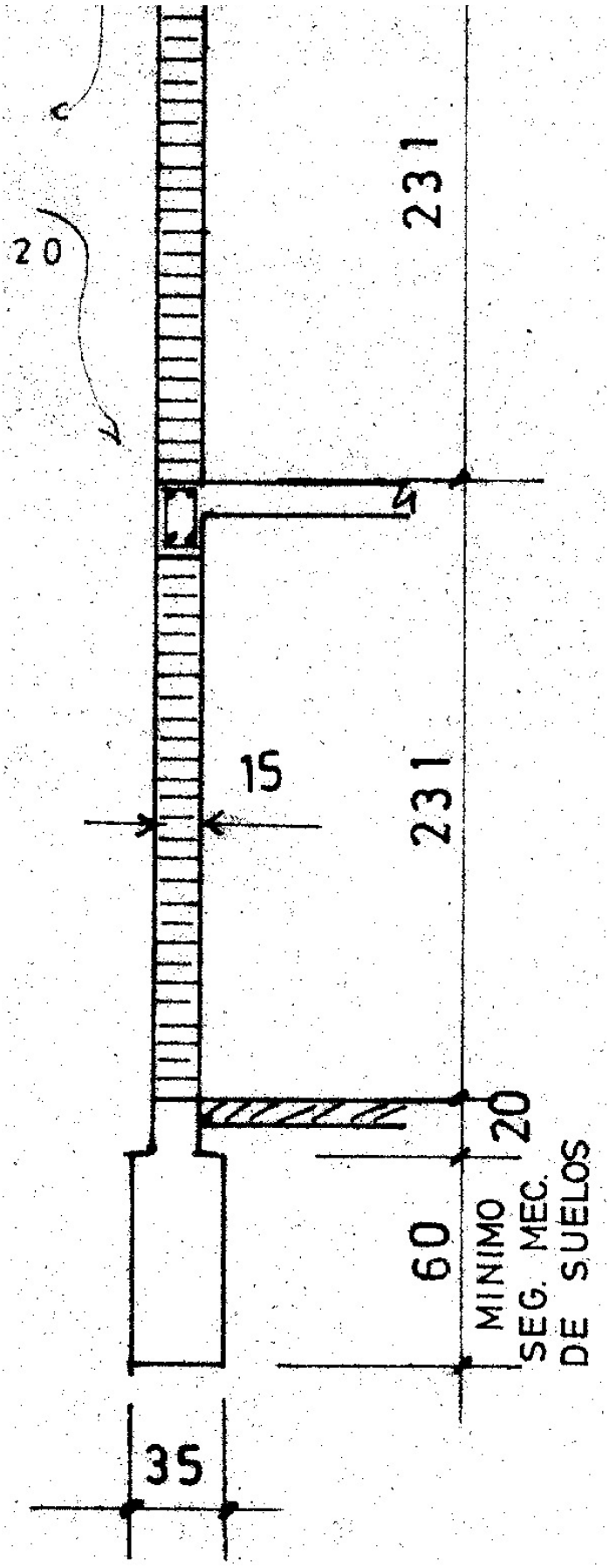


Critical structural details: elevation of aconfined masonry wall

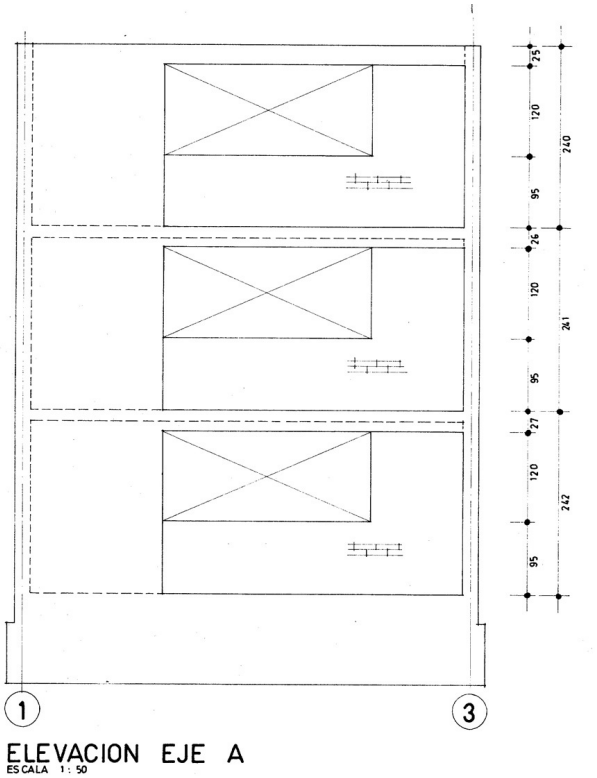


Critical structural details: elevation of aconfined masonry wall showing reinforcementdetails

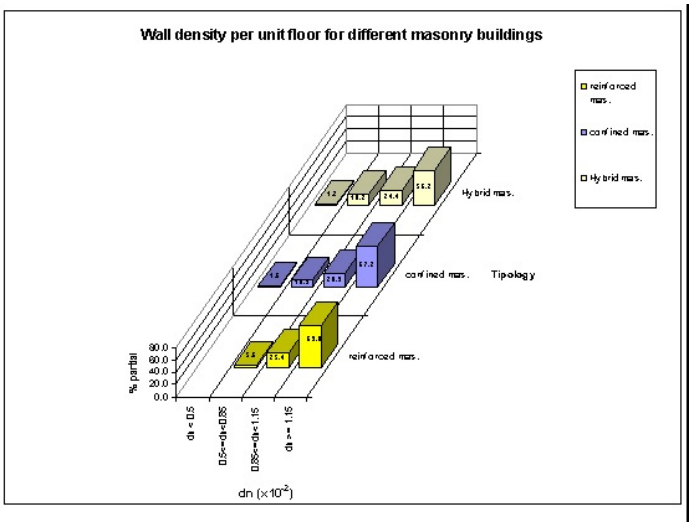




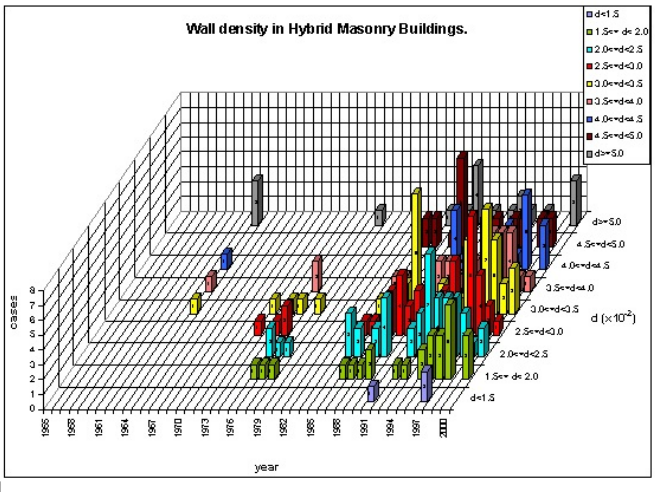
Critical structural details: vertical sectionthrough the wall showing reinforced concretebeams at floor levels



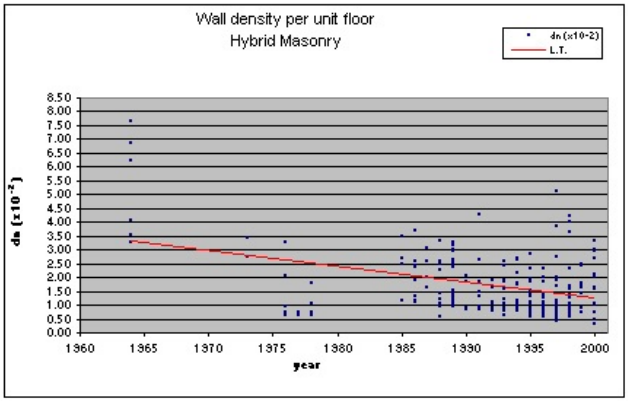
Critical structural details: elevation of aconfined masonry wall



Wall density per floor area for differentmasonry buildings



Wall density for hybrid masonrybuildings



Wall density per unit floor: hybridmasonry

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	>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 inhabitants	House Price/Annual Income (Ratio in year 2001): 8000/2000 Very Poor 25000/6000 Poor 50000/12000 Middle Class
Typical Source of Financing	Personal savings
Additional comments on financing	Dwelling for poor and very poor people is subsidized by the State.
Type of Ownership	RentOwn outrightOwn with debt (mortgage or other)
Additional comments on ownership	
Is earthquake insurance for this construction type typically available?	No
What does earthquake insurance typically cover/cost	Earthquake insurance is available as a supplement to other insurance (fire, robbery) and people living in these buildings do not have money to pay for that.This insurance covers the cost of restoring the building to its condition prior to 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	Buildings may be from 1 to 4 floors. One-floor houses may be isolated or grouping up to 4 units. Two floor houses may be isolated or grouping up to 8 units. Up to 6 units per floor may exist in higher buildings.

Earthquakes

Past Earthquakes in the country which affected buildings of this type

Year	Earthquake Epicenter
1971	La Ligua
1985	Llolleo
1997	Punitaqui
2005	Tarapaca
2010	Maule
2014	Iquique

Past Earthquakes

Damage patterns observed in past earthquakes for this construction type	Due to 1971 earthquake, about 1000 one-story houses at Choapa Valley partially collapsed. The masonry walls had tie-reinforced concrete beams and some tensile bars at the extremes of the walls or at the joint corners between walls.After the 1985 earthquake the Ministry of Housing appointed an especial committee to review the seismic effects on social dwellings. About 84.000 units were reviewed, concluding that 50% of the units had some structural damage, 2.6% of these being hybrid reinforced masonry, 3 or 4 story, buildings; all of them had some type of damage. The following characteristic damage patterns were observed:- perimeter walls with shear cracks, out of plane movements and separations at the corners. - crushed at the wall bottom due to compression failure- interior walls usually confined had only small cracks.Some damage occurred in houses located in Illapel during 1997 earthquake due to differential settlement on a slopped terrain.During the 2010 earthquake, the behavior was even worse, two buildings collapsed killing 10 people and several buildings in different cities were demolished after the earthquake, most of them built with concrete hollow blocks. Detailed information can be found in Astroza et al. [2012]
	Overall damage patterns observed in past

Additional comments on earthquake damage patterns	earthquakes for this type of construction included perimeter walls with shear cracks, out of plumb and separations at the corners, crushing at the wall bottom due to compression failure and interior walls, usually confined, with only small cracks.

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 ½ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; For precast concrete wall structures: less than 3/4 of the length of a perimeter wall.

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	TRUE

	area.	
Foundation Performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.	FALSE
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 doweled 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).	FALSE
Quality of Workmanship	Quality of workmanship (based on visual inspection of a few typical buildings) is considered to be good	FALSE

	(per local construction standards).	
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).	FALSE

Building Irregularities

Additional comments on structural and architectural features for seismic resistance	Usually the roof is made of wood planks or beams that support slate, metal, asbestos-cement or plastic corrugated sheets or tiles.
Vertical irregularities typically found in this construction type	No irregularities
Horizontal irregularities typically found in this construction type	No irregularities
Seismic deficiency in walls	Unknown 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 tie-post may cause shear failure and out-of-plane bending effects. The tensile steel bar in one end does not represent a proper tie-post. Lack of appropriate reinforcement at opening edges.
Earthquake-resilient features in walls	The seismic behavior of this type of building is inadequate.
Seismic deficiency in frames	
Earthquake-resilient features in frame	
Seismic deficiency in roof and floors	
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	-|			

Photograph illustrating typicalearthquake damage (1997 Punitaqui earthquake)

Earthquake damage (1997 Punitaquiearthquake)

Earthquake damage (1997 Punitaquiearthquake)

Aerial view of building complex in Santa Cruz, 2010

Collapsed three-story partially confined building in Santa Cruz, 2010

Stair-stepped cracking and masonry disintegration

Improper detailing of tie-beam-to-tie-column joint

Shear failure of tie-column

Collapse of building in construction, door opening at the second floor

In-plane shear failure

Out of plane cracking in the longitudinal wall

Absence of ties in the joint region

Retrofit Information

Description of Seismic Strengthening Provisions

Structural Deficiency	Seismic Strengthening
Lack of appropriate confinement	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. After the 2010 earthquake, set of buildings were demolished although some of them could be repaired.

Additional comments on seismic strengthening provisions	
Has seismic strengthening described in the above table been performed?	Only after the March 3, 1985 earthquake.
Was the work done as a mitigation effort on an undamaged building or as a repair following earthquake damages?	As repair following earthquake damage.
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?	A contractor hired by the Ministry of Housing
What has been the performance of retrofitted buildings of this type in subsequent earthquakes?	The performance of retrofitted buildings was appropriate during 2010 earthquake,
Additional comments section 6	

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