World Housing Encyclopedia

an Encyclopedia of Housing Construction in
Seismically Active Areas of the World

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HOUSING REPORT
Buildings with hybrid masonry walls

Report #	8
Report Date	05-06-2002
Country	CHILE
Housing Type	Confined Masonry Building
Housing Sub-Type	Confined Masonry Building with Concrete blocks, tie-columns and beams
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Summary

This housing type represents a common multi-family urban construction in Chile. Practice of this construction "mainly used for dwellings and for up to 4-story apartment buildings" began in the 1980s. The main load-bearing system consists of masonry walls in the transverse direction and reinforced concrete walls in the longitudinal direction. In some cases, longitudinal walls are of reinforced masonry construction (instead of concrete construction).

Masonry walls in the transverse direction are usually confined with concrete posts at the ends (such as is found in confined masonry construction). Buildings are usually regular in plan and in elevation. The seismic design code does not address this building type. However, the Chilean Ministry of Housing has issued specifications for 1- and 2-story dwellings, which have mainly been followed in the design (even in taller buildings of this type). Performance in the 1985 Llolleo earthquake was rather poor, with most buildings experiencing structural damage.

1. General Information

Buildings of this construction type can be found in all parts of Chile. This type of housing construction is commonly found in urban areas. This construction type has been in practice for less than 50 years.

Currently, this type of construction is being built. .

Figure 1A: Typical building (photo)

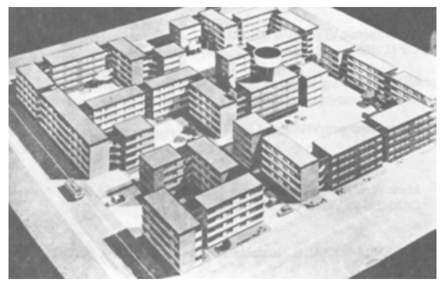

Figure 1B: Typical housing complex

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They do not share common walls with adjacent buildings. When separated from adjacent buildings, the typical distance from a neighboring building is 5-10 meters.

2.2 Building Configuration

The typical shape of a building plan is rectangular. These buildings are characterized with a regular structural layout, symmetrical with respect to at least one axis. As a result, there is a uniform distribution of stiffness both in plan and in elevation. In each longitudinal façade may be 3 to 4 openings of 0.8 to 1.5 m width probably equally spaced. The ratio for the overall window and door areas over the wall surface area is about 25 - 30%.

2.3 Functional Planning

The main function of this building typology is multi-family housing. Buildings of this type may be used for single-family houses, too. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. If single-story building, there is an additional door besides the main entry. If more than one floor, there is not an additional exit stair besides the main stairs.

2.4 Modification to Building

Typical patterns of modification observed are infill balconies or hillock on the top floor.

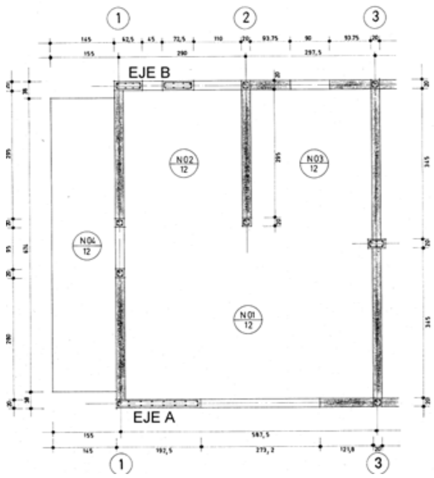

Figure 2A: Plan of a typical building

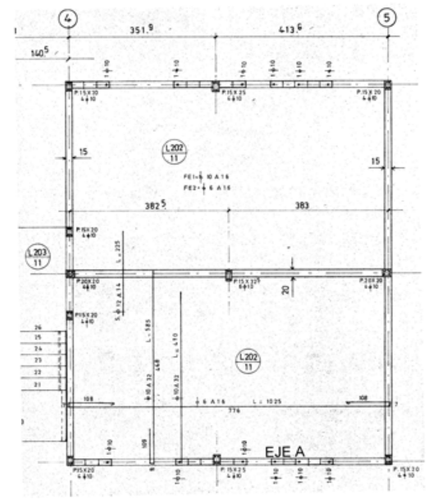

Figure 2B: Typical building plan

3. Structural Details

3.1 Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
Masonry	Stone Masonry Walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	☐
		2	Dressed stone masonry (in lime/cement mortar)	☐
	Adobe/ Earthen Walls	3	Mud walls	☐
		4	Mud walls with horizontal wood elements	☐
		5	Adobe block walls	☐
		6	Rammed earth/Pise construction	☐
	Unreinforced masonry walls	7	Brick masonry in mud/lime mortar	☐
		8	Brick masonry in mud/lime mortar with vertical posts	☐
		9	Brick masonry in lime/cement mortar	☐
		10	Concrete block masonry in cement mortar	☐
	Confined masonry	11	Clay brick/tile masonry, with wooden posts and beams	☐
		12	Clay brick masonry, with concrete posts/tie columns and beams	☐
		13	Concrete blocks, tie columns and beams	☑
	Reinforced masonry	14	Stone masonry in cement mortar	☐
		15	Clay brick masonry in cement mortar	☐
		16	Concrete block masonry in cement mortar	☐
	Moment resisting frame	17	Flat slab structure	☐
		18	Designed for gravity loads only, with URM infill walls	☐
		19	Designed for seismic effects, with URM infill walls	☐

Structural concrete		20	Designed for seismic effects, with structural infill walls	☐
		21	Dual system – Frame with shear wall	☐
	Structural wall	22	Moment frame with in-situ shear walls	☐
		23	Moment frame with precast shear walls	☐
	Precast concrete	24	Moment frame	☐
		25	Prestressed moment frame with shear walls	☐
		26	Large panel precast walls	☐
		27	Shear wall structure with walls cast-in-situ	☐
		28	Shear wall structure with precast wall panel structure	☐
Steel	Moment-resisting frame	29	With brick masonry partitions	☐
		30	With cast in-situ concrete walls	☐
		31	With lightweight partitions	☐
	Braced frame	32	Concentric connections in all panels	☐
		33	Eccentric connections in a few panels	☐
	Structural wall	34	Bolted plate	☐
		35	Welded plate	☐
Timber	Load-bearing timber frame	36	Thatch	☐
		37	Walls with bamboo/reed mesh and post (Wattle and Daub)	☐
		38	Masonry with horizontal beams/planks at intermediate levels	☐
		39	Post and beam frame (no special connections)	☐
		40	Wood frame (with special connections)	☐
		41	Stud-wall frame with plywood/gypsum board sheathing	☐
		42	Wooden panel walls	☐
Other	Seismic protection systems	43	Building protected with base-isolation systems	☐
		44	Building protected with seismic dampers	☐
	Hybrid systems	45	other (described below)	☐

Multiple Sub-Types exits such as 'Confined Masonry Building' or 'Reinforced Masonry Building'. The structural system is a RC wall in one direction and masonry.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is reinforced concrete structural walls (with frame). Shear walls in both directions. Reinforced concrete slab. Average thickness 11 cm.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is reinforced concrete structural walls (with frame). The main lateral load-resisting system in the buildings of this type consists of a hybrid system. In the transverse direction, the masonry walls it consists of 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). These shear walls are tied together at floor levels by means of reinforced concrete beams. The reinforced masonry walls have a

10 mm diameter bar at each end plus 8 mm diameter 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 diameter) for dwellings higher than 2 story. Horizontal reinforcement does not meet the minimum steel ratio requirement of 0.06. The brick thickness in the exterior (façade) 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.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 6 and 12 meters, and widths between 10 and 20 meters. The building is 4 storey high. The typical span of the roofing/flooring system is 6 meters. Typical Plan Dimension: Unit average areas are 35-40 m². The typical storey height in such buildings is 2.3 meters. The typical structural wall density is none. 1.5 to 7.0 % in each direction. The average is about 3.2 % in each direction. 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 Figure 5A, 5B and 5C.

3.5 Floor and Roof System

Material	Description of floor/roof system	Most appropriate floor	Most appropriate roof
Masonry	Vaulted	☐	☐
	Composite system of concrete joists and masonry panels	☐	☐
Structural concrete	Solid slabs (cast-in-place)	☑	☐
	Waffle slabs (cast-in-place)	☐	☐
	Flat slabs (cast-in-place)	☐	☐
	Precast joist system	☐	☐
	Hollow core slab (precast)	☐	☐
	Solid slabs (precast)	☑	☐
	Beams and planks (precast) with concrete topping (cast-in-situ)	☐	☐
	Slabs (post-tensioned)	☐	☐
Steel	Composite steel deck with concrete slab (cast-in-situ)	☐	☐
Timber	Rammed earth with ballast and concrete or plaster finishing	☐	☐
	Wood planks or beams with ballast and concrete or plaster finishing	☐	☐
	Thatched roof supported on wood purlins	☐	☐
	Wood shingle roof	☐	☐
	Wood planks or beams that support clay tiles	☐	☐
	Wood planks or beams supporting natural stones slates	☐	☐
	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	Described below	☑	☑

In the analysis the floor is considered to be a rigid diaphragm.

3.6 Foundation

Type	Description	Most appropriate type
Shallow foundation	Wall or column embedded in soil, without footing	☐
	Rubble stone, fieldstone isolated footing	☐
	Rubble stone, fieldstone strip footing	☐
	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	☐
	Steel skin friction piles	☐
	Wood piles	☐
	Cast-in-place concrete piers	☐
	Caissons	☐
Other	Described below	☐

Usually the foundation does not have reinforcement, unless the soil is day or silt. Concrete strip footing are used only under the walls plus reinforced tie beams in between.


Figure 3: Key load-bearing elements

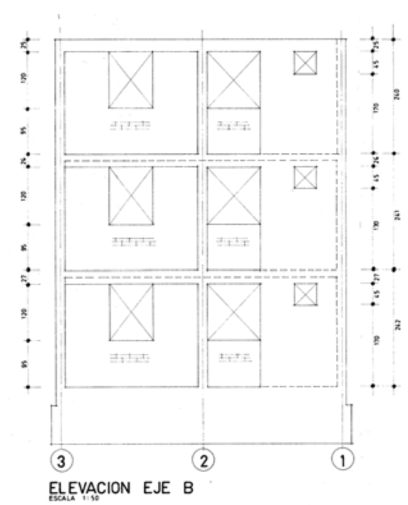

Figure 4A: Critical structural details: elevation of a confined masonry wall

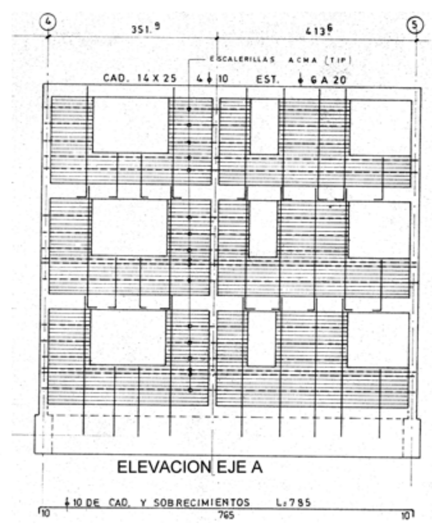

Figure 4B: Critical structural details: elevation of a confined masonry wall showing reinforcement details

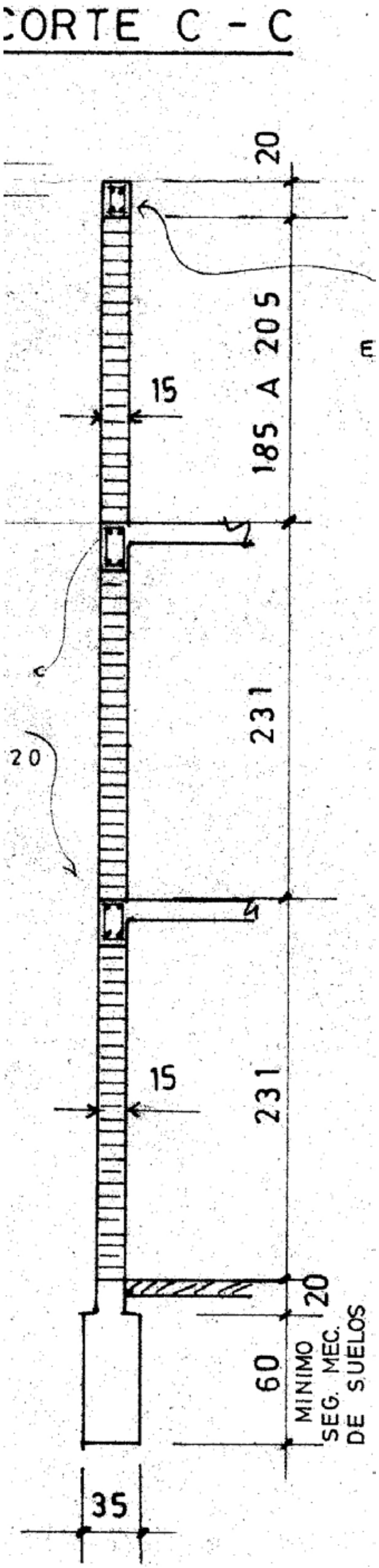

Figure 4C: Critical structural details: vertical section through the wall showing reinforced concrete beams at floor levels

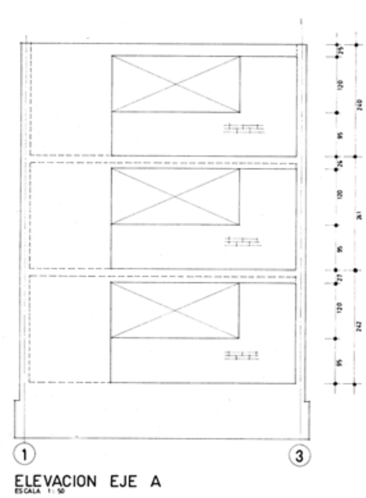

Figure 4D: Critical structural details: elevation of a confined masonry wall

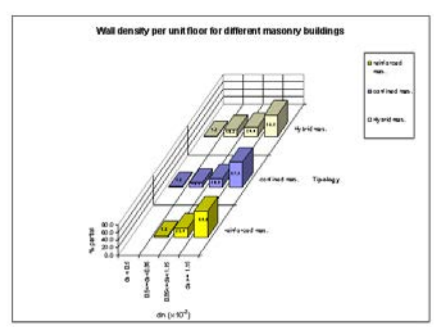

Figure 5A: Wall density per floor area for different masonry buildings

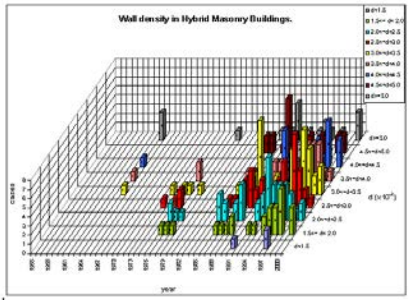

Figure 5B: Wall density for hybrid masonry buildings

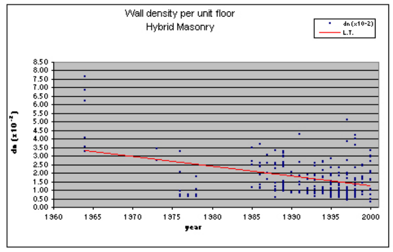

Figure 5C: Wall density per unit floor: hybrid masonry

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 5-10 housing unit(s). 8 units in each building. 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. The number of inhabitants in a building during the day or business hours is less than 5. For larger buildings the daytime occupancy may be between 5-10. The number of inhabitants during the evening and night is 11-20. 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.

4.2 Patterns of Occupancy

Typically one family occupies one housing unit. However, poor families may shelter 1 or 2 families, so-called "allegados".

4.3 Economic Level of Inhabitants

Income class	Most appropriate type
a) very low-income class (very poor)	☑
b) low-income class (poor)	☑
c) middle-income class	☑
d) high-income class (rich)	☐

Economic Level: For Very Poor Class, the Housing Unit Price is 8,000 and the Annual Income is 2000. For Poor Class, the Housing Unit Price is 25,000 and the Annual Income is 6,000. For Middle Class, the Housing Unit Price is 50,000 and the Annual Income is 12,000.

Ratio of housing unit price to annual income	Most appropriate type
5:1 or worse	☐
4:1	☑
3:1	☐
1:1 or better	☐

What is a typical source of financing for buildings of this type?	Most appropriate type
Owner financed	☑
Personal savings	☑
Informal network: friends and relatives	☑

Small lending institutions / micro-finance institutions	☑
Commercial banks/mortgages	☑
Employers	☐
Investment pools	☑
Government-owned housing	☐
Combination (explain below)	☐
other (explain below)	☐

This type of dwelling for poor and very poor people is subsidized by the State. In each housing unit, there are 1 bathroom(s) without toilet(s), no toilet(s) only and 1 bathroom(s) including toilet(s).

4.4 Ownership

The type of ownership or occupancy is renting, outright ownership and ownership with debt (mortgage or other).

Type of ownership or occupancy?	Most appropriate type
Renting	☑
outright ownership	☑
Ownership with debt (mortgage or other)	☑
Individual ownership	☐
Ownership by a group or pool of persons	☐
Long-term lease	☐
other (explain below)	☐

5. Seismic Vulnerability

5.1 Structural and Architectural Features

Structural/ Architectural Feature	Statement	Most appropriate type		
		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 from the building to the foundation.	☑	☐	☐
Building Configuration	The building is regular with regards to both the plan and the elevation.	☑	☐	☐
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.	☐	☐	☑
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.	☑	☐	☐
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.	☐	☑	☐
Wall and frame structures-redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	☑	☐	☐

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);	☑	☐	☐
Foundation-wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	☑	☐	☐
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps	☐	☐	☑
Wall openings	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.	☑	☐	☐
Quality of building materials	Quality of building materials is considered to be adequate per the 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).	☐	☑	☐
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber)	☐	☑	☐
Additional Comments	Usually the roof is made of wood planks or beams that support slate, metal, asbestos-cement or plastic corrugated sheets or tiles.			

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	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.	High wall density.	Perimeter walls with shear cracks, out of plumb and separations at the corners. Crushed at the wall bottom due to compression failure-interior walls usually confined had only small cracks.
Frame (columns, beams)			
Roof and floors			

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is B: MEDIUM-HIGH VULNERABILITY (i.e., poor seismic performance), the lower bound (i.e., the worst possible) is A: HIGH VULNERABILITY (i.e., very poor seismic performance), and the upper bound (i.e., the best possible) is C: MEDIUM VULNERABILITY (i.e., moderate seismic performance).

Vulnerability	high	medium-high	medium	medium-low	low	very low
	very poor	poor	moderate	good	very good	excellent
Vulnerability Class	A	B	C	D	E	F
	☑	☐	☑	☐	☐	☐

5.4 History of Past Earthquakes

Date	Epicenter, region	Magnitude	Max. Intensity
1971	La Ligua	7.5	IX
1985	Llolleo	7.8	VIII
1997	Punitaqui	6.8	VI-VII

Due to 1971 earthquake, about 1000 one-story houses at Choapa Valley partially collapsed. The masonry walls had tie-reinforced concrete beam and some tensile bars at the extremes of the walls or at the corners of joint 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, being 2.6% of it hybrid reinforced masonry 3 or 4 story buildings and all of them had some type of damage. The following characteristic damage patterns were observed: (1) perimeter walls with shear cracks, out of plumb and separations at the corners, (2) crushed at the wall bottom due to compression failure, (3) 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.

Figure 6A: Photograph illustrating typical earthquake damage (1997 Punitaqui earthquake)

Figure 6B: Earthquake damage (1997 Punitaqui earthquake)

Figure 6C: Earthquake damage (1997 Punitaqui earthquake)

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Clay brick, Artisan brick	6-12 / 2-8	14 x 29 / 20 x 30	10-20 / 15-40
Foundation	Concrete block	3-10	39x19x9 / 39x14x9	5-12
Frames (beams & columns)	Beams: Concrete Steel A44-28H	18 - 20		
Roof and floor(s)				

6.2 Builder

Construction companies, which are hired by the state are constructing this type of buildings.

6.3 Construction Process, Problems and Phasing

One contractor builds large quantities of this type of buildings, so project management and control techniques are used in order to increase productivity and to diminish cost. However, inspection and supervision is difficult because too many activities are done simultaneously. 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. For confined walls the brick are laid in first place and then the columns and beams are concrete 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, traveling crane, winch. The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size.

6.4 Design and Construction Expertise

The structural engineer will have 6 years of studies and more than 3-5 years of experience. The construction engineer may have 6 years of studies and less experience than the structural engineer. For private projects there is not compulsory inspection during the construction and no peer revision of the structural project, but when inspection does exist larger masonry compression strength are 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. See 'Construction process'.

6.5 Building Codes and Standards

This construction type is not addressed by the codes/standards of the country. The seismic loads are determined based on the NCh433.of96 "Seismic Design for Buildings". 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. A specific code addressing this type of construction does not exist. Designers follow some requirements of NCh1928.Of93 (Reinforced Masonry Design Code) or NCh 2123.Of97 (Confined Masonry Design Code) which are too strict. In general, designers follow guidelines prepared by the Ministry of housing for 1 or 2 storied houses, independently of the number of floors of the project. The building design must follow the NCh433.of96 code. SERVIU, a governmental office which is 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.

6.6 Building Permits and Development Control Rules

This type of construction is an engineered, and not authorized as per development control rules. Building permits are required to build this housing type.

6.7 Building Maintenance

Typically, the building of this housing type is maintained by Owner(s), Tenant(s) , No one and others. As it was pointed out, after the 1985 earthquake a committee was appointed by the Ministry of Housing, in order to review the damaged buildings, to prepare restoration projects, and to supervise its execution.

6.8 Construction Economics

The total cost of this type of building can be blotted out in main structure 62%, finishing work 25%, urbanization, operating cost and profit 13%. The cost of one unit is 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). At present, depending on the technology used, the construction may take 2 - 3 stories per month of several units simultaneously built.

7. Insurance

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. Earthquake insurance is available as a supplement of other insurances (fire, robbery, etc.) and people living in these buildings do not have money to pay for that. Repair costs in order to bring the building into the same condition as it was before the earthquake.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
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.

8.2 Seismic Strengthening Adopted

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

Only after the earthquake on March 3, 1985.

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

As a repair following earthquake damage.

8.3 Construction and Performance of Seismic Strengthening

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

Yes.

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

A contractor hired by the Ministry of Housing.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?

No subsequent earthquakes has hit that zone yet.

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