World Housing Encyclopedia
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Seismically Active Areas of the World

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HOUSING REPORT
Concrete Shear Wall Buildings

Report #	4
Report Date	05-06-2002
Country	CHILE
Housing Type	RC Structural Wall Building
Housing Sub-Type	RC Structural Wall Building : Moment frame with in-situ shear walls
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Summary

This housing type is mainly characterized by reinforced concrete shear walls that are built in both directions along the entire height. Some of the walls may be perforated with openings (coupled walls). These buildings are multiple housing units and are found in the major urban areas in Chile. Stiffness and mass distribution are regular and most of them may have a symmetry axis in at least one direction of the plan. In general, these buildings are quite stiff

because they must resist a base shear of 5-6.7% (depending on the seismic zone) and the story drift must be equal to or less than 0.002. Seismic performance is very good, strength and stiffness are controlled, and torsional effects are minimal. The buildings may have one or two basement floors. Problems that may appear in the future include reduction in the wall density, introduction of soft floor, or torsional effects.

1. General Information

Buildings of this construction type can be found in all main cities of the country: Iquique, Antofagasta, Concepción, Temuco, Valparaíso, Viña del Mar and Santiago. 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 1: Typical building

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They do not share common walls with adjacent buildings. According to NCH433.of96 the distance must be at least 1.5 cm or 0.002 x total height of the building. In addition there are some dispositions about the distance to the neighboring site or free space for parking. So, individual buildings in a block may be separated up to 10 m When separated from adjacent buildings, the typical distance from a neighboring building is 10 meters.

2.2 Building Configuration

These buildings in general have rectangular plan shapes. Not Applicable. In this country there is no standardization for any element: window, door, etc, so it is not possible to provide an estimate of number or size of openings.

2.3 Functional Planning

The main function of this building typology is multi-family housing. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. Modern buildings have pressurized stairs and the taller ones also have a helicopter landing strip on the top.

2.4 Modification to Building

The most popular modifications to the buildings may be infill balconies.

Figure 2A: Plan of a typical building

Figure 2B: Plan of a typical building

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	☐
Structural concrete	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	☐
		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)	☐

3.2 Gravity Load-Resisting System

The vertical load-resisting system is reinforced concrete structural walls (with frame). Shear walls act as lateral as well as gravity load-bearing elements. Beams and slabs carry floor loads.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is reinforced concrete structural walls (with frame). Shear walls provide adequate strength and stiffness to control lateral displacements. In some cases, lintel beams couple some walls, thus resulting in the reduced lateral displacements. If designed and detailed properly, those coupling beams dissipate energy when subjected to severe earthquakes and are easily repaired after an earthquake.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 20 and 20 meters, and widths between 20 and 20 meters. The building has 4 to 30 storey(s). The typical span of the roofing/flooring system is 6 meters. Typical Plan Dimensions: - Average area: 487 m². - Typical Number of Stories: In recent years the average is 13 stories. - Typical Story Height: Variation of story height is 2.6 - 2.8 m. - Typical Span: Usually span is limited to 4.0 - 8.0 m. The typical storey height in such buildings is 2.7 meters. The typical structural wall density is none. Total wall area/plan area (for each floor) For the 95% of the buildings, the wall density is greater than 1.5% in each direction, average value = 2.8% Figure 5A shows the variation on time of the wall density which has remain almost constant.

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	☑	☑

The floors and the roof are considered rigid in seismic analysis. Post-tensioned slab are used less often than cast in place, but there are some buildings designed by important engineers firm that do have it. VSL has an office in Chile and they are trying to introduce it.

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	☐

Strip footings are used in firm soil for middle height buildings (6-10 stories), but in softer soils or when there are basement for parking mat footings are used.

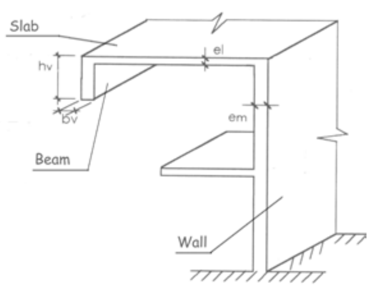

Figure 3: Key load-bearing elements

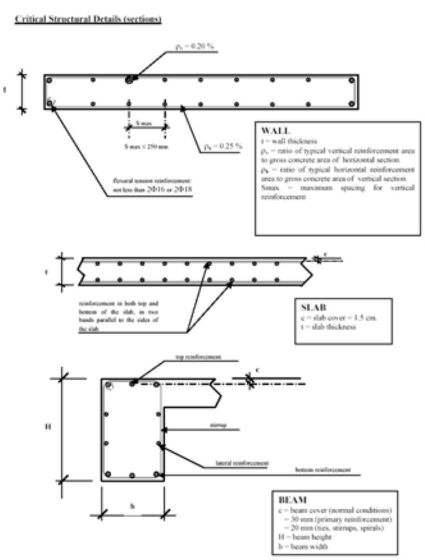

Figure 4: Typical wall section, slab and beam

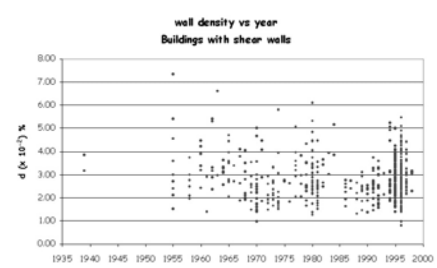

Figure 5A: Wall density: a key seismic feature

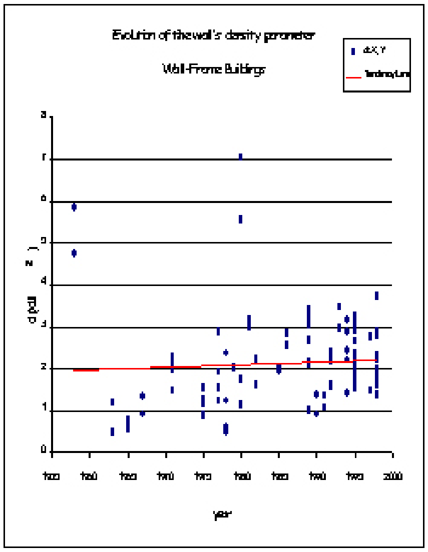

Figure 5B: Wall density

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 51-100 housing unit(s). 70 units in each building on average. 10 to 100 units may be in the building and 4 to 10 units on each floor. The number of inhabitants in a building during the day or business hours is more than 20. The number of inhabitants during the evening and night is more than 20. During the day the inhabitants may be one fourth of those that reside in the night. Each unit may have 4-8 inhabitants.

4.2 Patterns of Occupancy

One family occupies one housing unit.

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)	☑

The prices are expressed in US$. In Chile the income is very non-uniformly distributed, and the rich constitute less than 10% of the population. Middle class apartments may cost 1500-4000 UF (US$ 37.500-100.000), and the annual income for a family of 4 people may be US$ 20.000. Larger apartments may cost 7000-10.000 UF (US$ 175.000-250.000), and the annual income for a family of 4 people may be US$ 120.000. Economic Level: For Middle Class the Housing Price Unit is 50,000 and the Annual Income is 20,000. For Rich Class the Housing Price Unit is 250,000 and the Annual Income is 120,000.

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)	☐

In each housing unit, there are 1 bathroom(s) without toilet(s), no toilet(s) only and 1 bathroom(s) including toilet(s).

Single bathroom in one or two bedroom apartments. Larger apartments may have 2 or 3 bathrooms. .

4.4 Ownership

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

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.	☑	☐	☐
	The roof diaphragm is considered to be rigid and it is			

Roof construction	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				

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	none	High wall density, regular on height lead to story drift under control, negligible P-D effect, less sensible to non-structural elements, plasticity uniformly distributed. In case of damage are easily repaired	Small shear cracks
Frame (columns, beams)			
Roof and	Some damage has been reported in slab with openings, i.e.		Shear crack

floors	between stairs and elevators, when there are not lintels and the slab works as a coupling element and no special reinforcements have been provided.		in lintels

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is F: VERY LOW VULNERABILITY (i.e., excellent seismic performance), the lower bound (i.e., the worst possible) is E: LOW VULNERABILITY (i.e., very good seismic performance), and the upper bound (i.e., the best possible) is F: VERY LOW VULNERABILITY (i.e., excellent 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
1960	Valdivia, X Region	9.5	XI-MMI
1985	Llolleo	7.8	VIII

Not many buildings existed in southern Chile in 1960, the only damage cited in the literature is the hospital in Valdivia. In 1985 only one building partially collapsed in Santiago (Villa Olímpica) and one had to be demolished in Viña del Mar (El Faro de Reñaca). Important damages occurred in 5 stories buildings (Canal Beagle) that were located on the top of a hill in Viña del Mar where important acceleration amplification have been measured. A few others buildings in Viña del Mar had some walls damaged and some others had non-structural damage. FIGURE 6 shows the Edificio Acapulco building in Viña del Mar, after the 1985 Llolleo earthquake. This building suffered some damage in lintels during 1971 earthquake, that was not properly repaired, so during 1985 new cracks appeared.

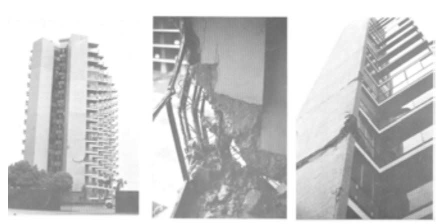

Figure 6: Edificio Acapulco, Vina del Mar, 1985 Llolleo earthquake

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Reinforced concrete, H25-H35 steel	1.5-4.0/25-35/1.5-2.0 A63-42H or A44-28H	3:1:0.5, 6:1:0.5 (sand:cement:water)	
Foundation				

Frames (beams & columns)				
Roof and floor(s)	Reinforced concrete	H25-H30		

6.2 Builder

It is built by developers and sold to the people who will live in this construction type.

6.3 Construction Process, Problems and Phasing

The owner of the land and a construction firm will hire an architectural office and structural engineer to design the building. They will use modern equipment, crane, premix concrete, etc. 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. There is no compulsory inspection during the construction and no peer revision of the structural project. The designer may visit the construction site one or two times during the construction. Yes, of course they play a role as is explained in Building Expertise.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. NCh433.of96 Seismic Design of Buildings. The year the first code/standard addressing this type of construction issued was Until 1993 the NCh433.of72 was in force. The last two numbers indicates the year since the code is in force. Provisionally dispositions to design this type of buildings existed since 1966. NCh433.of96. In addition, ACI318-95 is used for design reinforced concrete elements, with some exceptions: the minimum compressive strength is 16 MPa, confinements at wall end or diagonal bars in couple beam are rarely used and a reduced reinforcement cover is allowed. The appendix of the NCh433.of96 states that "the shear wall design doesn't need to follow dispositions 21.6.6.1 to 21.6.6.4 of ACI 318-95. The most recent code/standard addressing this construction type issued was 1996. NCh433.of96 Seismic Design of Buildings Year the first code/standard addressing this type of construction issued: Until 1993 the NCh433.of72 was in force. The last two numbers indicates the year since the code is in force. Provisionally dispositions to design this type of buildings existed since 1966. National building code, material codes and seismic codes/standards: NCh433.of96. In addition, ACI318-95 is used for design reinforced concrete elements, with some exceptions: the minimum compressive strength is 16 MPa, confinements at wall end or diagonal bars in couple beam are rarely used and a reduced reinforcement cover is allowed. The appendix of the NCh433.of96 states that "the shear wall design doesn't need to follow dispositions 21.6.6.1 to 21.6.6.4 of ACI 318-95. When was the most recent code/standard addressing this construction type issued? 1996.

The building design must follow the NCh433.of96 code, although no one verifies. 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) and Tenant(s).

6.8 Construction Economics

A unit construction may cost 15-35 UF/m² (500-1200 US$/m²). Nowadays, the progress in construction is quite rapid, probably one or two floors per month.

7. Insurance

Earthquake insurance for this construction type is typically available. 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 an additional to insurance against fire. In this case the premium cost is almost doubled. In case of damage this insurance will cover repair work.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Lintels damage	Rebuilt the lintel or fixed with epoxy.
Shear cracks in walls	The wall is thickened with a new mesh or confined element are added at the extremes.

This is not a common activity in Chile. FIGURES 7A and 7B show strengthening of earthquake damaged building shown on FIGURE 6. Columns have been added to the extreme of one wall.

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?
No.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
Only after an earthquake some buildings have been repaired, when some constructive deficiencies appeared. Edificio Acapulco in Viña del Mar, suffered some damage in lintels during 1971 earthquake, that were not properly repaired, so during 1985 new cracks appeared. FIGURES 6 and 7A show the Acapulco building after the 1985 earthquake and after repaired work was done.

8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?
Probably not.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?
A contractor and an engineer were involved hired by the owner/user.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?
No earthquakes have occurred in Central Chile since 1985.

Figure 7A: Seismic strengthening (Edificio Acapulco building damaged in the 1985 Llolleo earthquake). A column has been added to the wall exterior.

Figure 7B: Seismic strengthening (Edificio Acapulco building). The exterior wall has been thickened with a new steel mesh.

Reference(s)

1. Criterios tradicionales utilizados en Chile en el diesno de muros de hormigon armado
   Julio Dufflocq
   Civil Engineer Thesis, Universidad de Chile 1998

2. Caracterizaci
   Cristi
   Civil Engineer Thesis, Universidad de Chile 2001

3. Caracterizaci
   M. Guzm
   Civil Engineer Thesis, Universidad de Chile 1998

4. Apuntes para el curso CI52G, Proyecto de Hormig
   M. Kupfer and R. Lagos
   Deplo de Ing. Civil, Universidad de Chile 1999

5. Evoluci
   M. Moroni, and M. Guzm
   Bolet 1998

6. History of Chilean Seismic Regulations
   M. Sarrazin
   Bulletin of IISEE 1992 26

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