World Housing Encyclopedia

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

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HOUSING REPORT
Steel Frame Buildings with Shear Walls

Report #	3
Report Date	05-06-2002
Country	CHILE
Housing Type	Steel Structural Wall Building
Housing Sub-Type	Steel Moment Frame Building : Cast in-situ concrete walls
Author(s)	Elias Arze-L.
Reviewer(s)	Ofelia Moroni

Summary

These buildings are modern steel composite structures ranging from 3 to 24 stories. The buildings have a rigid steel frame with floor diaphragms made of post-tensioned concrete slabs or composite steel decking, with or without a concrete slab covering. Additional lateral force-resisting elements are added to the steel moment-resisting frame to stiffen the structure and enhance the seismic performance. These elements are steel #X# or concentric braces and

reinforced concrete shear walls. The seismic performance for these composite structures is very good. Most of these buildings are used as apartments or offices.

1. General Information

Buildings of this construction type can be found in mainly large cities like Santiago, Concepcion, Valdivia, Temuco, Villarrica. Percentage of total area built is below 2 %. This type of housing construction is commonly found in urban areas. This construction type has been in practice for less than 100 years.

Currently, this type of construction is being built. Since 1965-70.

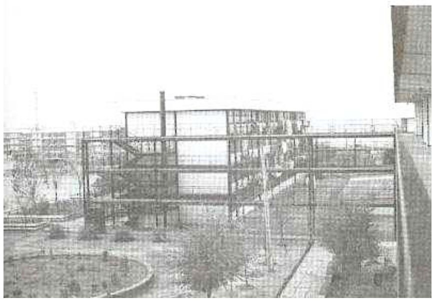

Figure 1A: Typical building located in Vina del Mar, an area affected by the March 3, 1985 earthquake. These buildings suffered no damage.

Figure 1B: Typical building located in Vina del Mar, an area affected by the March 3, 1985 earthquake. These buildings suffered no damage.

2. Architectural Aspects

2.1 Siting

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

2.2 Building Configuration

Rectangular plan shapes. 20 to 30%.

2.3 Functional Planning

The main function of this building typology is multi-family housing. Some buildings include commercial ground floor 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 6-8 floor there is an additional exit stair besides the main stairs, probably pressurized.

2.4 Modification to 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)	☐

Typical buildings have shear wall, light weight partitions and some concentric brace frames.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is steel braced frame. Steel deck slabs, prestressed concrete slabs, reinforced concrete slabs. Steel beams, normally composite. Steel columns and shear walls.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is steel structural walls. Dual construction, shear walls combined with rigid steel frame. Up to 5 stories x or v or ^ braced shear walls. Over 5 stories - reinforced concrete slip or jump formed walls.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 10 and 20 meters, and widths between 20 and 30 meters. The building has 3 to 24 storey(s). The typical span of the roofing/flooring system is 7.5 meters. Values are for buildings with number of story up to 5 floors. For high-rise buildings the typical plan dimensions range from 20 x 20 m to 30 x 30 m. Typical number of stories: 3 to 5 and 6 to 24. Typical story heights: from 2.7 to 3.0 m. Typical spans: from 7.5 - 10.0 m. The typical storey height in such buildings is 3.0 meters. The typical structural wall density is none. 1 to 2 % in each direction.

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	☑	☑

Composite steel deck with concrete slabs. Post-tensioned slabs. Composite steel deck without concrete slab. Floors and roofs are considered as rigid diaphragms.

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	☐

It consists of reinforced concrete end-bearing piles and steel end-bearing piles. Reinforced concrete isolated footing. Reinforced concrete strip footing. Mat foundation. Reinforced concrete bearing piles. Steel bearing piles. Floating deep foundations.

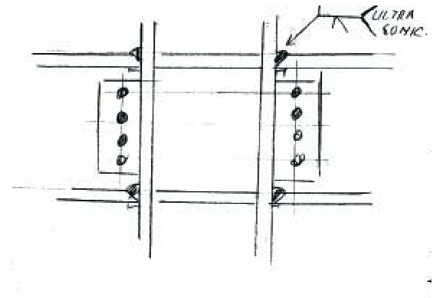

Figure 2A: Critical structural details

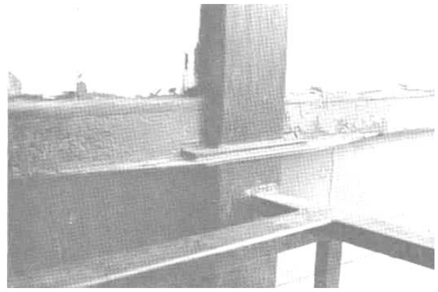
Figure 2B: Critical structural details: beam-column connection. THe beam stringer is welded to the column at the top, so that onsite welding is done outside high risk zones.

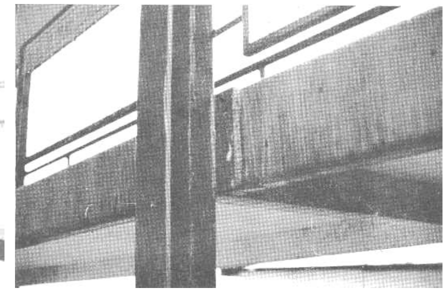
Figure 2C: Critical structural details: connections

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 51-100 housing unit(s). For buildings up to 5 floors: 15 - 20 units. For those up to 20 floors: 150 - 200 units. 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.

4.2 Patterns of Occupancy

1 family per 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)	☑

House Unit Price/Annual Income Ratio: 4.0 - 4.5 for Poor, 2.5 - 3.0 for Middle Class, 2.5 - 3.0 for Rich.

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)	☑

Ministry of Housing gives low interest loans for poor or low middle class owners. In each housing unit, there are 2 bathroom(s) without toilet(s), no toilet(s) only and no bathroom(s) including toilet(s).

2 bathrooms are widespread. Often there are 1 or 2 bathrooms in apartments up to 60 m², and 3 or 4 bathrooms in apartments over 60 m². .

4.4 Ownership

The type of ownership or occupancy is renting, ownership with debt (mortgage or other) , individual ownership and ownership by a group or pool of persons.

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)	☐

Some buildings may belong to institution.

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	The number of lines of walls or frames in each principal			

structures-redundancy	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	Regular building in plan and height good design and construction practice	No damage in serious earthquakes in 1960 (M9.5) and in 1985 (M7.8)
Frame (columns, beams)	none		
Roof and floors	none		

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
1985	Llolleo	7.8	VIII (MMI)
1960	Valdivia	9.5	XI (MMI)

There were many connections of the type that failed in Northridge, Loma Prieta and Kobe. No damage in any of them. Probable causes: # Chilean Building Code allows maximum drift about 1/2 of USA. # Periods are approximately 0.05N instead of 0.1N (N=floors) # No jumbo W sections are used # Beams and columns are welded to stress relieved plates. A good example of good behavior are the seven 4 story-buildings from Poblacion Republica Popular China, located in Viña del Mar. They are 46 X 10.6 m in plan, have moment resisting frames in both directions and 12 cm reinforced concrete slab. In the longitudinal direction the span is 4.6 cm. The buildings were designed according to NCh428.Of 57 with A42-27ES steel.

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Reinforced concrete rebars	25-30 MPa 420-280 MPa		
Foundation				
Frames (beams & columns)	Structural steel	250 MPa (36 ksi)		
Roof and floor(s)	RC slabs Steel beams	25-30 MPa 250 MPa		

6.2 Builder

No information is available .

6.3 Construction Process, Problems and Phasing

Developer hires architects, engineers and construction firms. The construction of this type of housing takes place incrementally over time. Typically, the building is originally designed for its final constructed size.

6.4 Design and Construction Expertise

Architects have 5 university years and typically over 5 years of experience. Engineers have 6 university years and typically over 5 years of experience. Construction companies are headed by engineers or architects. Experience about 10 years.The same for fab shops. In steel frame buildings, review of design and independent inspection are typical. Architects and engineers must visit the job and provide general supervision. They usually must approve construction contracts.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. Chilean seismic codes NCh433.Of96 and NCh2369 are mandatory. AISC and ACI codes corrected to meet seismic codes are applied. The year the first code/standard addressing this type of construction issued was 1957. NCh433.Of96, seismic design for buildings; NCh2369.Of01 seismic design of industrial buildings, NCh428.Of57code design for steel structures. The most recent code/standard addressing this construction type issued was 1957, but now there is a draft to modify that code that partially follows AISC and AISI. Chilean seismic codes NCh433.Of96 and NCh2369 are mandatory. AISC and ACI codes corrected to meet seismic codes are applied. Year the first code/standard addressing this type of construction issued: 1957 National building code, material codes and seismic codes/standards: NCh433.Of96, seismic design for buildings; NCh2369.Of01 seismic design of industrial buildings, NCh428.Of57code design for steel structures. When was the most recent code/standard addressing this construction type issued? 1957, but now there is a draft to modify that code that partially follows AISC and AISI.

Design review by peers (may belong to design firm) is normal. Independent inspection is normal in steel framed buildings.

6.6 Building Permits and Development Control Rules

This type of construction is an engineered, and 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

Low cost apartments, up to 5 floors, UF 10/m² (US $300/m²). Normal, up to 5 floors, UF 20/m² (US $600/m²). High-rise, 30/m² (US$ 900/m²). 1.5 to 2.5 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. Repairs to same conditions before the earthquake. Occasionally time lost.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

It has not been required in steel framed buildings.

8.2 Seismic Strengthening Adopted

8.3 Construction and Performance of Seismic Strengthening

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Author(s)

1. Elias Arze-L.
   President, ARA Consulting Engineers
   Av. J.P. Alessandri 1495, Nunoa Santiago , CHILE
   Email:amarquez@ara.cl FAX: (562) 238-9398

Reviewer(s)

1. Ofelia Moroni
   Civil Engineer/Assistant Professor
   , University of Chile
   Santiago , CHILE
   Email:mmoroni@cec.uchile.cl FAX: 562-6892833

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