# World Housing Encyclopedia

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

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

# HOUSING REPORT
# Concrete Frame and Shear Wall Building

| | |
|---|---|
| **Report #** | 6 |
| **Report Date** | 05-06-2002 |
| **Country** | CHILE |
| **Housing Type** | RC Moment Frame Building |
| **Housing Sub-Type** | RC Moment Frame Building : Dual System - Frame with Shear Wall |
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**Important**
This encyclopedia contains information contributed by various earthquake engineering professionals around the world. All opinions, findings, conclusions & recommendations expressed herein are those of the various participants, and do not necessarily reflect the views of the Earthquake Engineering Research Institute, the International Association for Earthquake Engineering, the Engineering Information Foundation, John A. Martin & Associates, Inc. or the participants' organizations.

## Summary

Buildings of this type are used mainly for offices or hotels, and they are found in large cities throughout the country. At the present time this building type represents about 15-20% of the high-rise building stock in Chile (building with more than 10 stories). The structural system consists of reinforced concrete frames and shear walls. The walls are typically located around the staircases and the elevators, while the frames may be uniformly distributed in plan or at the perimeter only. Most of the lateral load-bearing elements exist along the full building height in the elevation and in both directions of the building plan. In some buildings the walls are perforated with openings and

coupled with lintel beams. Some buildings of this type have one or more basement floors. In general, these buildings are quite stiff. Seismic performance is very good, strength and stiffness are controlled, and torsion effects are minimal. Problems that may occur in the future are related to the reduction in the wall density, and introduction of soft-story 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 1A:Typical building

Figure 1B: 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 distance to neighbor site or free space for parking. So, individual buildings in a block may be separated up to 10 meters. They are typically located close together in some specific neighborhoods. In Santiago there are some new developed neighborhood where corporate buildings are widely spaced When separated from adjacent buildings, the typical distance from a neighboring building is 10 meters.

## 2.2 Building Configuration

Plan shapes range from rectangular to octagonal. In this country there is not standardization for any element: window, door, etc, so it is not possible to provide any number or size of openings.

### 2.3 Functional Planning

The main function of this building typology is mixed use (both commercial and residential use). In some buildings commercial ground floor includes a big hall. 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 may be infill balconies.

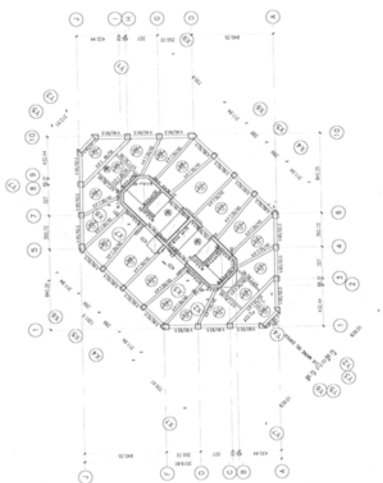

Figure 2A: Plan of a typical building

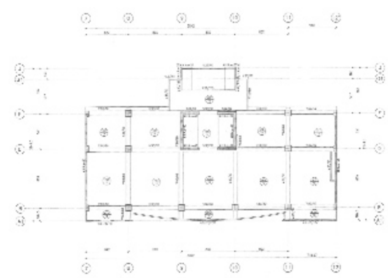

Figure 2B: Plan of a typical building

## 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 | |
| | | | Stone masonry in cement | |

| | | | | |
|---|---|---|---|---|
| | | 14 | mortar | |
| | Reinforced masonry | 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 and frames play both role as both the lateral and gravity load-bearing elements. In addition, gravity load-resisting beams may exist.

## 3.3 Lateral Load-Resisting System

The lateral load-resisting system is reinforced concrete structural walls (with frame). Shear walls provide enough strength and stiffness to control displacements in the lower floors while the frames control displacements in the upper floors. In some cases the walls are coupled with lintel beams, which are able to dissipate energy when subjected to severe earthquakes and are easily repairable afterwards. 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 or less than 0.002. The façade frames may not be linked to the stair or elevator walls, in which case the slab must transfer lateral loads from one element to the other. Stiffness and mass distribution are regular in plan but some irregularities may appear at the top floors due to reduction in floor area. Most of them may have symmetry axes in at least one direction of the plan. The ratio Total Height/Period (H/T) has been defined as representative of building stiffness, being normal values between 40 to 70 m/sec. However, in the last decade this value had diminished and about 7% of the buildings have H/T between 20 to 40 m/sec. This may lead to larger story drift and damage due to earthquakes.

## 3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 20 and 20 meters, and widths between 40 and 40 meters. The building has 10 to 30 storey(s). The typical span of the roofing/flooring system is 8 meters. Typcial plan dimensions: Vary from case to case, average area is 750 m². Typical story height: Average story height is 3.2 m. Story height varies from 2.9 to 3.5 m. Typical span: Variation of typical span is 6 - 10 m. The typical storey height in such buildings is 3.2 meters. The typical structural wall density is none. Ranges from 1.5% to 2.5% in each direction. Only 25% buildings of this type have wall density less than 1.5% but larger than 0.5%. Figure 5 shows the variation on time of the wall density.

## 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 as rigid diaphragms for seismic analysis. With post-tensioned slabs larger span between the central core walls (elevators and stairs) and some frames can be used.

### 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 | |

Probably the mat foundation is more typical as most of these buildings possess a basement.

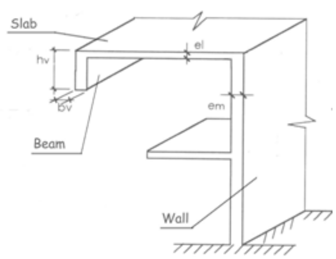


Figure 3: Key load-bearing elements

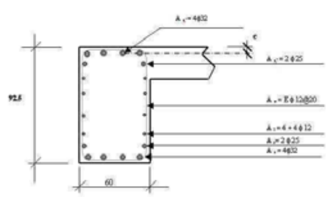

Figure 4A: Critical structural details: design of beams and columns

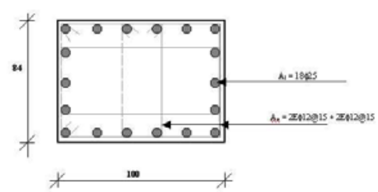


Figure 4B: Typical structural details: columns

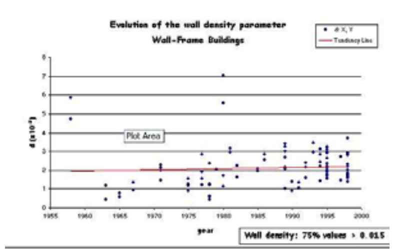


Figure 5: Variation of wall density

# 4. Socio-Economic Aspects

### 4.1 Number of Housing Units and Inhabitants

Each building typically has 21-50 housing unit(s). One institution may own one or more floors. 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 5-10. During the day will have complete occupancy, however some buildings may also be occupied in the night (night shifts).

## 4.2 Patterns of Occupancy

These are mainly office buildings and therefore nobody resides in them with the exception of some administrative workers unless the building is used as an hotel.

## 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) | |

We are identifying the entrepreneurs or the owners of the offices, not the people working in these buildings.

| 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) | |

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

Maybe 5 to 10 bathrooms per floor. .

## 4.4 Ownership

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

| Type of ownership or | Most appropriate type |
|---|---|

| | |
|---|---|
| **occupancy?** | |
| 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:<br><br>Less than 25 (concrete walls);<br><br>Less than 30 (reinforced masonry walls);<br><br>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:<br><br>For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls;<br><br>For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls;<br><br>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) | | | |
| Other | | | | |

## 5.2 Seismic Features

| Structural Element | Seismic Deficiency | Earthquake Resilient Features | Earthquake Damage Patterns |
|---|---|---|---|
| Wall | None | The main characteristic of Chilean buildings is the high wall density ratio | |
| Frame (columns, beams) | Non-structural elements not properly separated from the structures. | | Tilt out of plane of non-structural elements; short column failures |
| Roof and floors | Some damage has been reported in slab with openings, i.e. between stairs and elevators, when there are not lintels and the slab works as a coupling element and no special reinforcements have been provided. | | |
| | | | |

## 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 (MMI) |

In the southern part of Chile, buildings of this type did not exist at the time of the 1960 earthquake, and the only reported example of damage is the hospital in Valdivia. In the 1985 earthquake, structural damage was not reported in buildings of this type with the exception of the San Antonio Hospital, located very close to epicenter. Out of plane tilting occurred in some non-structural masonry walls at the third floor level (FIGURE 6A) and some columns, not properly confined, in the first floor were damaged at the top. (FIGURE 6B and FIGURE 6C). In fact there were two building blocks-one of them was 3-story high and one basement with no damage, whereas the other one was 4 story high with a flower stand on the top floor that was damaged. The other photo (FIGURE 6D) represents a 4-story building at Valparaiso that had experienced some damage in interior panel and contents.

Figure 6A: San Antonio Hospital, March 3, 1985 Llolleo earthquake

Figure 6B: San Antonio Hospital. First floor columns damaged in the 1985 Llolleo earthquake

Figure 6C: San Antonio Hospital, close-up damaged in the 1985 Llolleo earthquake

Figure 6D: Medicine School, University of Valparaisos, 1985 Llolleo earthquake, damage in interior panels and contents

# 6. Construction

## 6.1 Building Materials

| Structural element | Building material | Characteristic strength | Mix proportions/dimensions | Comments |
|---|---|---|---|---|
| Walls | Reinforced concrete | Tensile strength of concrete: 1.5-4.0 MPa, Cylinder compressive strength of concrete: 25-35 MPa, Shear strength of concrete: 1.5-2.0 MPa | 3:1:0.5 | st/f'c/shear strength |
| Foundation | Reinforced concrete | Tensile strength of concrete: 1.4-2.2 MPa, Cylinder compressive strength of concrete: 25 MPa, Shear strength of concrete: 1.5 MPa | 3:1:0.5 | |
| Frames (beams & columns) | Reinforced concrete | Tensile strength of concrete: 1.5-4.0 MPa, Cylinder compressive strength of concrete: 25-35 MPa, Shear strength of concrete: 1.5-2.0 MPa | 3:1:0.5 | |
| Roof and floor(s) | Reinforced concrete | Cylinder compressive strength of concrete: 25-30 MPa | | |

## 6.2 Builder

It is built by developers or as initiative of a firm or a hotel.

## 6.3 Construction Process, Problems and Phasing

The building design must follow the NCh433.of96 code, although nobody checks this. In case of damage an arbitrage process may take place at the court of justice. The landowner and a construction firm (developer) hire an architectural office and structural engineer to design the building. Modern equipment such as crane, premix concrete, industrial formwork etc. is used in the construction. 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 typically has a background consisting of 6 years of academic 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. The inspection during the construction is not mandatory and there is no peer review of the structural project. The designer may visit the construction site once or twice during the construction.

### 6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. Title of the code or standard: Nch433.of96 Seismic Design 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: Nch 433.of96 Seismic design of Buildings. The design of structural elements follows ACI 318-95, with some exceptions: reduced reinforcement cover, non-confinement at the wall ends, 16 MPa minimum compressive strength. B.2.1 Appendix of the NCH433.0f96 Seismic Design of Buildings says: "The design of frames in buildings with "Frame with concrete shear walls-dual system", must follow at least ACI318-95 dispositions 21.8.4 and 21.8.5 when the 75% or more of the story shear in any direction of analysis is resisted by the shear walls and any frame individually resists less than 10% of the story shear. The same may apply when the seismic forces acting on the building are calculated with a reduced modification factor". B.2.2 says: "The Page 12 shear wall design doesn't need to follow dispositions 21.6.6.1 to 21.6.6.4 of ACI318-95. When was the most recent Code/standard addressing this construction type issued? 1996.

The building design must follow the NCh433.of96 code, although nobody checks this. In case of damage an arbitration 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 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

For an standard building construction may be 15 - 30 UF/m² (400 - 800 US/m² ). Selling price will be 40 - 50 UF/m² (1,050 - 1,400 $US/m²). In the last years, "intelligent buildings" had been constructed that include air conditioning, computer, energy-savings devices, etc. For this case the construction cost may be up to 30-45 UF/m² (800 - 1,225 $US/m²). Selling price will be 50 - 70 UF/m² (1,400 - 1,850 $US/m²). Nowadays this 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 are optional added to fire insurance. In case of damage, this insurance will cover repair work and contents.

# 8. Strengthening

## 8.1 Description of Seismic Strengthening Provisions

**Strengthening of Existing Construction :**

| Seismic Deficiency | Description of Seismic Strengthening provisions used |
|---|---|
| Short column | To separate the non-structural elements from the column |
| Non-structural elements connections | To provide support against out of plane deformations |

## 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?

The hospital at San Antonio was repaired however the details are not available.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
This is not a common activity in Chile. The only situation when buildings are repaired is after an earthquake, when some constructive deficiencies appeared. It is normal to observe some small cracks in the concrete.

## 8.3 Construction and Performance of Seismic Strengthening

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

I suppose so.

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

A contractor performed the construction, of course an architect and engineer were involved.

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

Non subsequent earthquake had occurred in central zone of Chile until this report was submitted (2001).


Figure 7A: Illustration of seismic-strengthening techniques

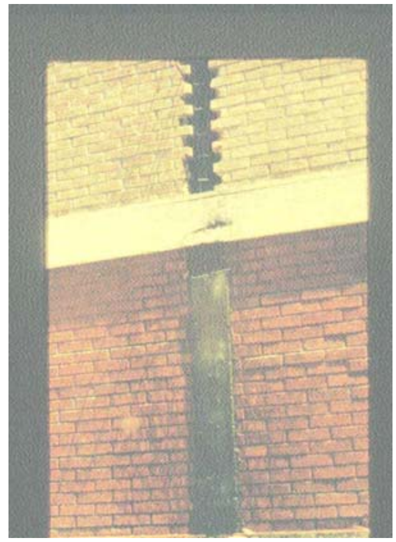
Figure 7B: Illustration of seismic-strengthning techniques

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