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Building Research Institute, Japan

Preliminary Reconnaissance Report of the Chile Earthquake 2010

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Preface

A great earthquake of magnitude 8.8 struck on the Pacific coast of Chile, at 3:34a.m. local time on February 27, 2010, and the earthquake and Tsunami caused widespread damage in Chile.

After the earthquake, Ministry of Housing and Urbanism of Chile appealed Japan to dispatch experts who have superior technology and experience on inspection of damaged buildings. Japanese government decided to dispatch experts through JICA [#1] on the request of them. Three researchers of Building Research Institute took part in the expert team (JICA expert team) and conducted disaster investigation especially for buildings from March 13 to 23, 2010.

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#1 Name of investigation team: Expert team for inspection of damaged buildings in Chile earthquake, 2010
Principal purpose of the investigation team are as follows:
1) Conduct and support on damaged building inspection technically with jointly established team from Universidad Católica de Chile (Católica University) and Universidad de Chile (University of Chile) requested by Servicio de vivienda y urbanismo (Housing Service and Urbanism of Chile).
2) Confirm assignments of damaged building inspection, decreasing the earthquake damage and further needs through the investigation.

** Belong to Government Building Department of Ministry of Land, Infrastructure, Transport and Tourism from April, 2010

1. Earthquake data and summary of damage

Earthquake details reported by US Geological Survey (USGS) [1] are as follows:

Date: February 27, 2010 at 06:34:14 UTC, 03:34:14 local time
Earthquake Center: 35.9°S, 72.7°W, 35 km (21.7 miles) depth
95 km (60 miles) NW of Chillan
115 km (70 miles) WSW of Talca
105 km (65 miles) NNE of Concepcion
335 km (210 miles) SW of Santiago
Magnitude: Mw8.8

It was approximate five hundred thousand (500,000) people living within 100-kilometer radius and three million (3,000,000) people within 200-kilometer radius from the earthquake source and the strong seismic vibration affected and caused extensive damage to wide area in particular following four states: Libertado, Maule, Biobio and Metropolitana (Santiago).

Summary of damage caused by the earthquake based on OCHA and USAID report is as follows:

Dead : 432 people (by Chile government as of March 27)
Missing : 98 people (OCHA) [2]
Victims : More than 1.8 million (by OCHA as of March 29) [2]
Damaged houses : Approx. 810,000 houses (More than 160,000 houses were seriously damaged or collapsed, More than 93,000 houses are need damage inspection) [2]
The total amount of damage : Approx. US$30 billion

Abbreviated expressions used in this report:

USGS	U.S. Geological Survey
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
USAID	United States Agency for International Development
MINVU	Ministerio de Vivienda y Urbanismo (Ministry of Housing and Urbanism)
SERVIU #2	Servicio de vivienda y urbanismo (Housing Service and Urbanism)
IDIEM	Instituto de Investigación Ensayos de Materiales, Universidad de Chile (Institute of Investigation Specification tests, University of Chile)
DICTUC	Dirección de Investigaciones Científicas y Tecnológicas de la Pontificia Universidad Católica de Chile (Direction of Scientific and Technological Investigations of the Papal Catholic University of Chile)

#2 SERVIU constructs large number of apartment houses for low-income group in Chile. JICA expert team could not obtain the detailed information of the damage, i.e. number of buildings and damage degree. According to the hearing from Chief of SERVIU Biobio state, initial evaluation of 26,000 buildings under the jurisdiction of SERVIU had completed and of those 7,000 buildings were still conducted detailed investigation. So far, they estimated approximate 1,800 buildings would be demolished. After the earthquake, SERVIU and local government officials conducted initial damage inspection of buildings and ordered inhabitants to vacate from dangerous housings. Detailed damage inspection has been conducting by DICTUC and IDIEM, around 30-40 experts who were professors of universities, structural engineers and students were engaged in the inspection works. They contracted for the inspection from private sectors other than SERVIU. At the stage of hearing on March 19, they completed the inspection of 50 buildings of SERVIU, 50 high-rise buildings and 200 houses.

In Chile, they have not prepared the normalized method for damage inspection of buildings and the blank form. Some institutes used an inspection method that was imported from Colombia and revised, and others used their own way. JICA expert team advised technically on the damage inspection of buildings, regarding the apartment houses for low-income group by request of MINVU.

2. Damages in affected areas

Investigated locations by JICA expert team are shown in Figure 1 with editing the map created by OCHA. Investigated locations are eight cities: Santiago, Constitucion, Talca, Cauquenes, Pelluhue, Dichato, Penco, and Concepcion. In addition, Chillan is just for reference.

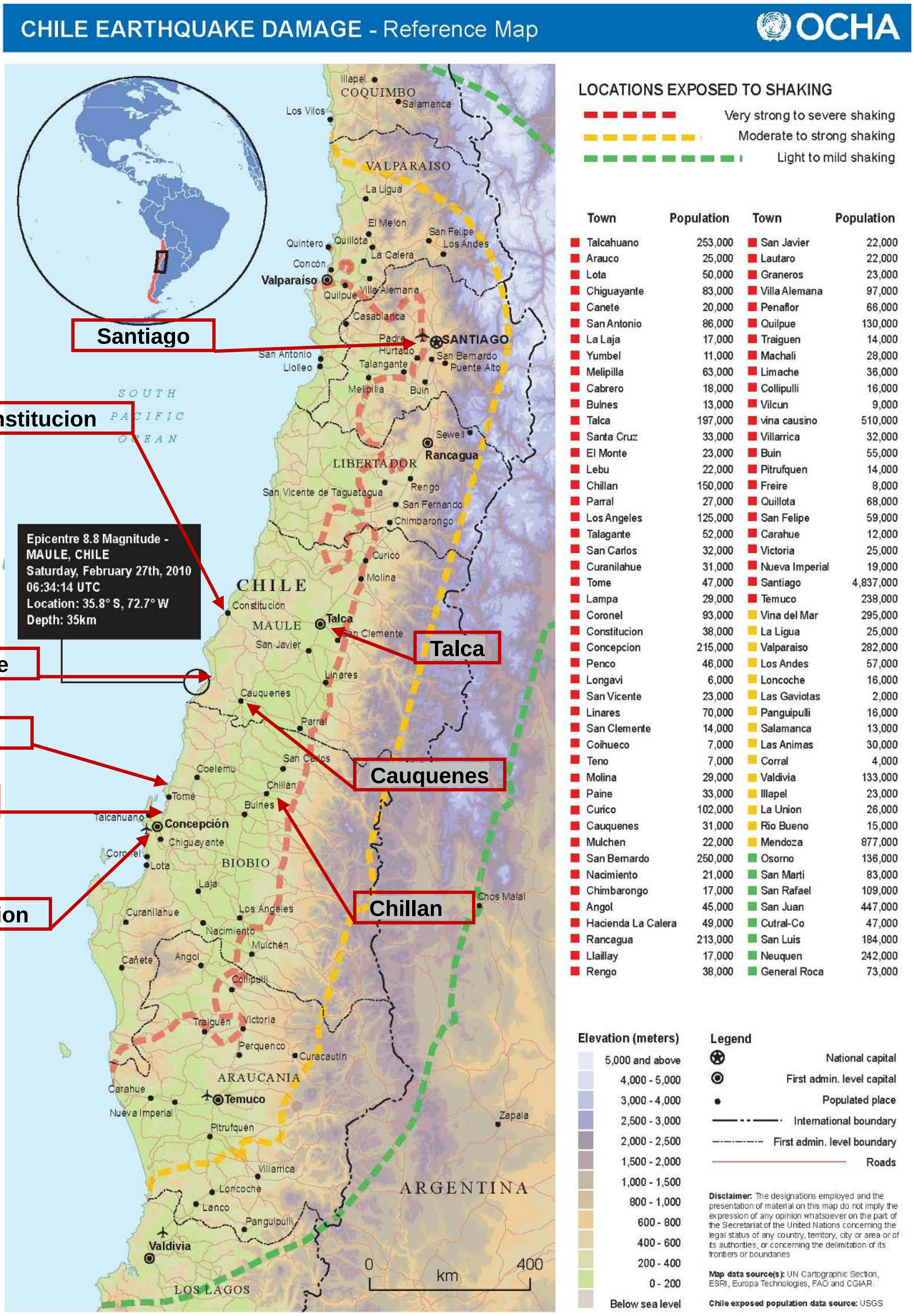

Figure 1 Investigated locations by JICA expert team (edit the map created by OCHA)

2.1 Santiago

Damaged building inspections shown in Figure 2 were conducted in Santiago. They are relatively new private buildings (condominiums) and apartment houses constructed by SERVIU.

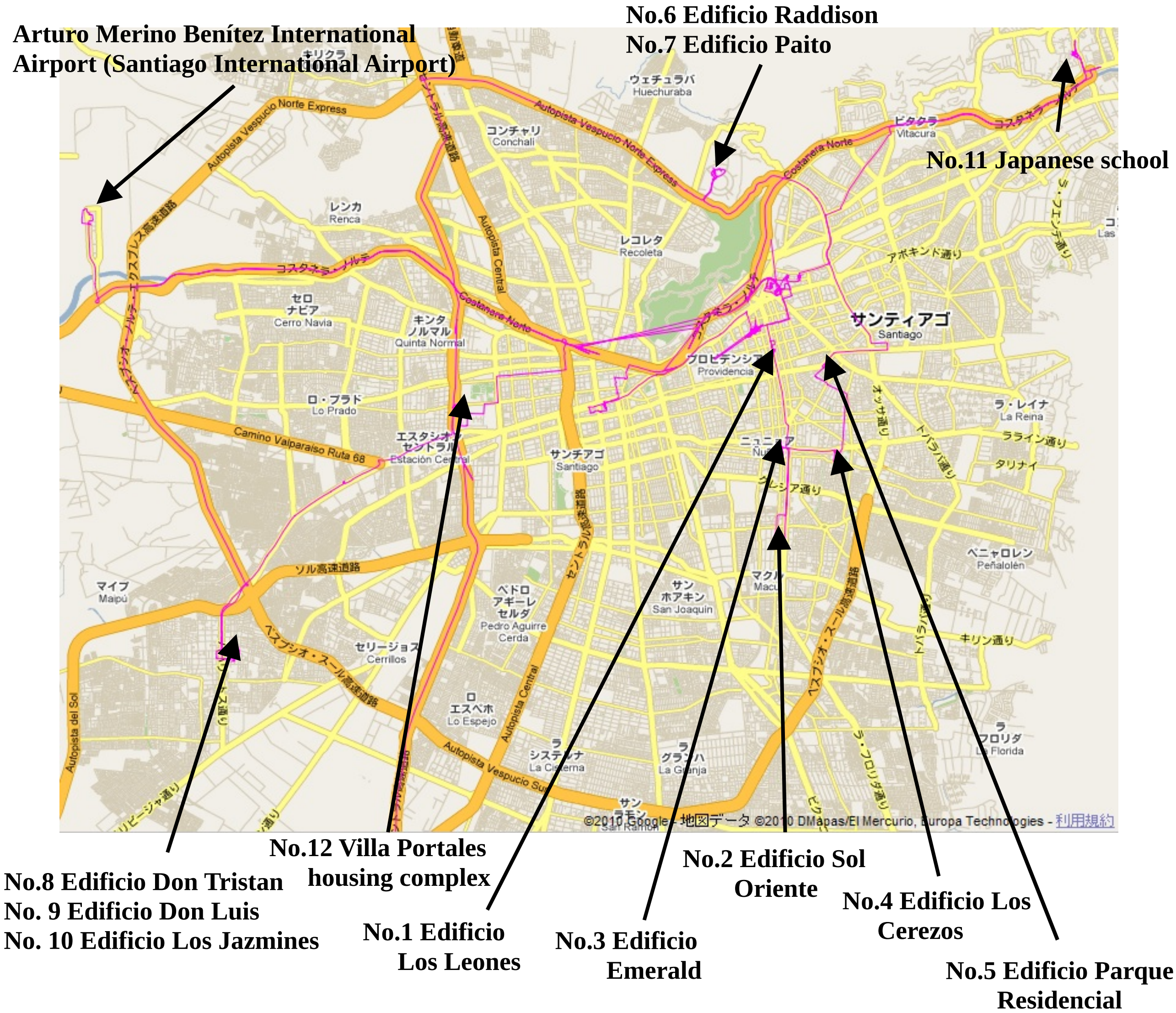

Figure 2 Investigated buildings in Santiago (tack building number on the google map)

No.1 Edificio Los Leones

A condominium was completed in 2009 and has 12 floors (2 basements) with reinforced concrete (RC) wall construction (Photo 1-1). The basements are parking garage and span direction wall of the first basement was smashed up as Photo 1-2, and axially compressed. Wall thickness was 150mm.

Photo1-1 Appearance

Photo1-2 Smashed RC wall

No.2 Edificio Sol Oriente

A condominium has 18 floors (2 basements) with RC wall construction. A similar building is in front of Photo 2-1 and the basements for parking garage are between two buildings. Most of RC walls in span direction were smashed at the upper part of walls on the first level basement (Photo 2-2 and Photo2-3). Axial reinforcement is D25 and hoop is D8 [#3]. Extensive damage happened on a part of capitals and streamed through the slab at the first floor (Photo 2-4).

Photo 2-1 Appearance

Photo 2-2 Smashed RC wall

Photo 2-3 Close-up of wall column

Photo 2-4 Damaged RC column

No.3 Edificio Emerald

This is a high-rise condominium with slender form and has 20 floors. Although it was informed that the whole building was slightly sloped, internal building could not be investigated without permission. This building was already determined uninhabitable by the municipal authorities (Photo 3-1 and Photo 3-2).

#3 This notation does not mean the deformed reinforcement established by Japanese Industrial Standard, but used considerable diameter as deformed reinforcement. The similar manner will be applied in following descriptions.

Photo 3-1 Appearance

Photo 3-2 Determination by the municipal authorities

No.4 Edificio Los Cerezos

Photo 4-1 is a high-rise condominium of RC wall construction with 26 floors (1 basement). The bottom of RC wall column next to the entrance was crushed as shown in Photo 4-2 (axial rebar is D35 and hoop is D13). Photo 4-3 shows the internal view of the column. Additionally, the beam-column joint of relevant wall at the first level basement was severely damaged (Photo 4-4). This possible causes are multistory shear wall is lost at the underground.

Photo 4-1 Appearance

Photo 4-2 Crushed column bottom

Photo 4-3 Internal view of Photo 4-2

Photo 4-4 Underground portion of Photo 4-2

No.5 Edificio Parque Residencial

Photo 5-1 shows a high-rise condominium with RC construction and the number of floors is 22 with 38 years after construction. The exterior of nonstructural brick walls were cracked almost all floors as shown in Photo 5-2. Notable damages could not be seen in structural members.

Photo 5-1 Appearance

Photo 5-2 Damaged outer wall with bricks

No.6 Edificio Raddison

This is an accommodation with 12 floors and only appearance was investigated since access to this building was prohibited (Photo 6-1). The beam-ends of low-rise building, the joint part with high-rise building, and the joint parts of column capital were damaged (Photo 6-2). According to an investigator of this internal building, some crush occurred on RC angle posts at the basement.

Photo 6-1 Appearance

Photo 6-2 Damaged wall beam

No.7 Edificio Paito

This building group is a commercial establishment with five floors and with other four (Photo7-1). The blindfold wall of external staircase was crumbled. The short spanned wall beams because of nonstructural wall were severely damaged and a part of beam-column joint were broken (Photo 7-2). The penthouse was inclined because of the slab just below was crumbled (Photo 7-3). Earthquake induced ground deformation could be seen on its property (Photo 7-4).

Photo 7-1 Appearance (crumbled external staircase)

 

Photo 7-2 Damage on beam and beam-column joint

Photo 7-3 Crumbled penthouse

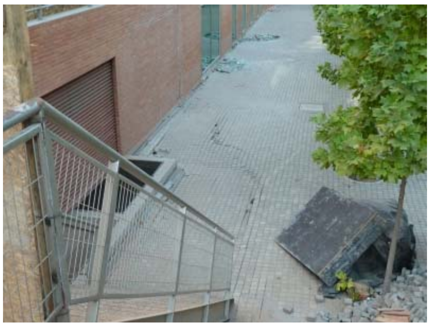

Photo 7-4 Ground deformation

No.8 Edificio Don Tristan

Photo 8-1 is the situation of a five-story building with RC construction for residence. The site is sloped along span direction of building (right side in Photo 8-2). The wall columns in longitudinal direction were in destruction and story collapse was confirmed at first story.

Photo 8-1 Appearance (longitudinal direction)

Photo 8-2 Appearance (span direction)

No.9 Edificio Don Luis

The building is a condominium of RC construction with five floors and soft first story (Piloti). Number of bearing wall is lacking at the first story; parking garage (Photo 9-2). Hinges occurred on capital and bottom of wall columns because of tensile axial force and bending, further story collapse was confirmed at the first story (Photo 9-3). The bearing walls without lateral columns showed shear failure (Photo 9-4).

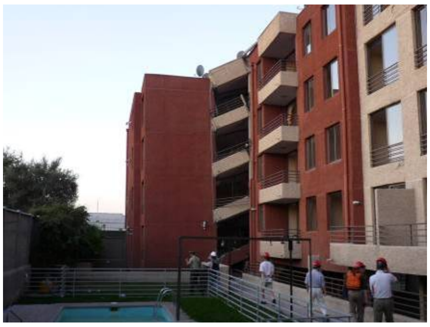

Photo 9-1 Appearance

Photo 9-2 First floor parking garage (Piloti)

Photo 9-3 Wall column with bended hinge

Photo 9-4 Shear failure

No.10 Edificio Los Jazmines

This building is a condominium of RC construction with soft first story (Piloti) and has four floors (Photo 10-1). Outer parts of building at the first floor are composed of T-shaped wall columns and multistory shear walls construct center part. T-shaped wall columns were severely damaged around 500-600mm high as Photo 10-2 shown and concrete of them were fallen off and could not bear the axial force. Concrete of bearing walls at the first story dropped and damage was severe. Fillers like polystyrenes were found at the top of wall at left side of the entrance, therefore it is estimated that the bearing wall at periphery does not work effectively against earthquake force.

Photo 10-1 Appearance

Photo 10-2 Damaged T-shaped wall columns and bearing walls

Photo 10-3 Fillers like polystyrenes

No.11 Japanese school

The building in Photo 11-1 is the auditorium of Japanese school in Chile and has two floors with concrete block construction. Minimal crack was observed in joint part of block walls and cantilever walls which thrown out from the building frame (Photo 11-2). Small gap was found in a part of ceiling panel, but they were small damage as a whole (Photo 11-3).

Photo 11-1 Appearance

Photo 11-2 Crack of cantilever walls

Photo 11-3 Ceiling gap

No.12 Villa Portales housing complex (BLOCK-4)

An apartment house for low-income group constructed by SERVIU, it has four floors with double-loaded corridor and 54 years after completed (Photo 12-1). The structure is moment resisting frame with RC bearing walls and nonstructural brick walls (Infilled Wall structure [#4]).

SERVIU requested IDIEM for damage investigation and already completed. A document posted at the entrance shows the inspection results and precaution statement (Photo 12-2). Cracks were appeared on masonry walls in double-loaded corridor and party wall, and some parts were completely fallen off (Photo12-3). This building was kept using through earthquakes happened in Chile in 1960 (Mw9.5) and in 1985 (Mw7.8). Renovation of cracks was found on masonry walls. Meanwhile, some cracks occurred on beam elements, which support the external staircase landing, and vertical deformation with long-term loadings on them were observed (Photo12-4). In other building, a roller supported beam at roof was fallen off because of the earthquake (Photo 12-5), and should be taken measures as a part of reinforcement work.

Minister of Housing and Urbanism of Chile visited the building in time with the investigation of JICA expert team and held a press conference, since she assumed the post. Japanese ambassador to Chile, Mr. Wataru Hayashi and JICA expert team also joined it and televisions and newspapers reported those [#5].

Photo 12-1 Appearance

Photo 12-2 Inspection results

#4 These structures are sometimes indicated as Infilled Wall structure to distinguish in particular. The details will be shown in Chapter 3.

#5

Visit at the site and press conference with Minister of Housing and Urbanism of Chile, Ms. Magdalena Matte Lecaros


Photo 12-3 Damages of masonry walls

Photo 12-4 Cracks and deflection of beam at external staircase landing


Photo 12-5 Fallen beam from roof

No.13 Others

In most cases, old masonry buildings (stone masonry or brick construction) in the investigated areas of Santiago did not show damages. Some minor problems as door was not opened might happen in many ordinary buildings however, apparent damages were not seen [#6]. Adobe structure buildings did not exist anymore in Santiago. Furthermore, it is explained that construction of Adobe structure buildings will not be allowed in the future even if in local areas.



Photo 13-1 Masonry structure buildings in Santiago (No damage)

Photo 13-2 General buildings in Santiago (No damage)

2.2 Constitucion, Región del Maule

Constitucion is a seafront small city with a population of 38,000 and located at the mouth of Maule River, where flat land is few and mountains are behind. JICA expert team investigated apartment houses of SERVIU and the city, and Tsunami disaster near the seashore was inspected at the points shown in Figure 3. The outline of Tsunami disasters will be described in Chapter 2.9.

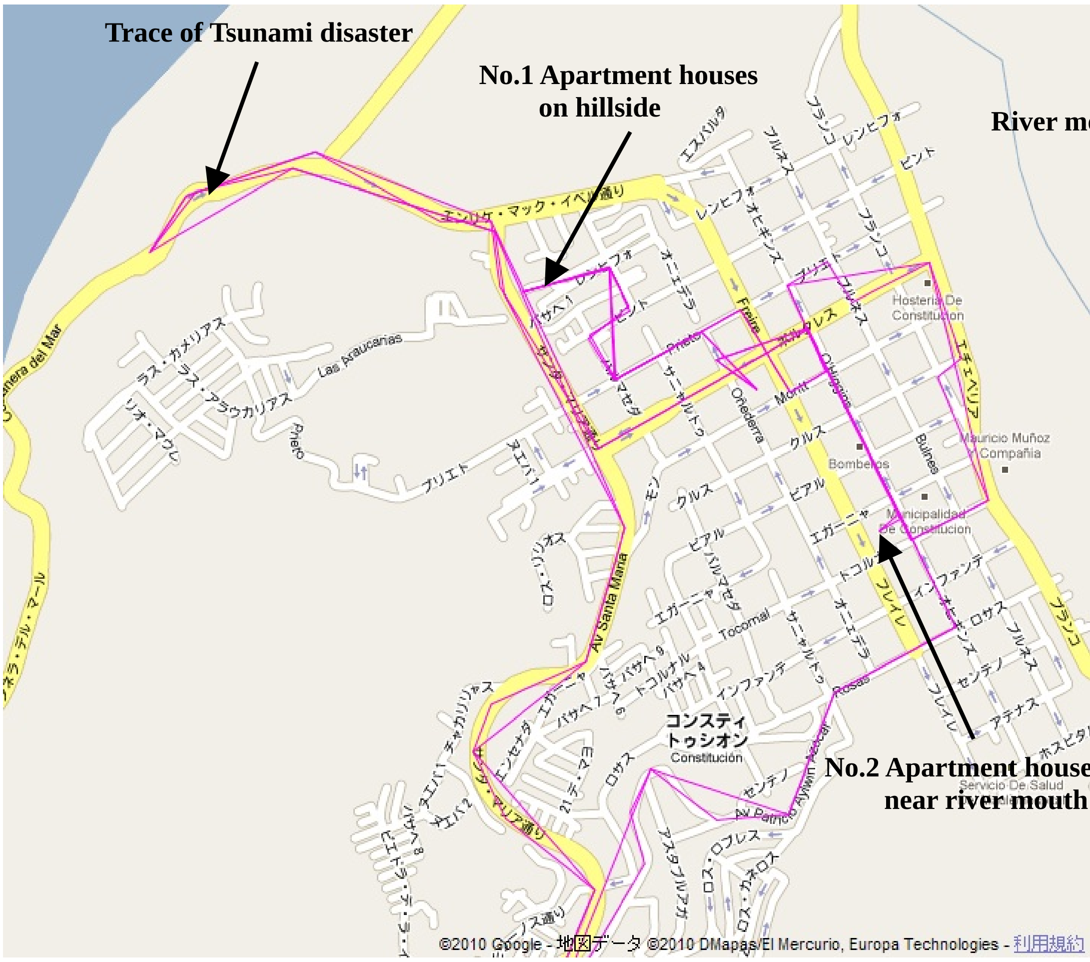

Figure 3 Investigated buildings in Constitucion (tack building number on the google map)

#6 According to the announced strong motion observation record [3], the acceleration of surface in Santiago was 0.2g-0.3g except a few points and it is imagined the scale was intensity 5+ to 6- in Japan Meteorological Agency Seismic Intensity Scale.

No.1 Apartment houses on hillside

Apartment houses of Confined Masonry (CM) structure with three floors exist on hillside, which were constructed by SERVIU around 10-15 years ago for low-income group (Photo 14-1). Dimensions of columns are 200x300mm. Axial reinforcement is D10 and hoop is φ4 with about 150mm spacing. Hollow bricks composed walls and horizontal rebar at masonry joint reinforced the wall every 4-5 layer of bricks, but no vertical reinforcing bars (Photo14-2).
Story collapse at the first story was confirmed in a building built in the highest place near the cliff (Photo 14-3), and two families with eight people were dead. Cracks appeared on the upper of the cliff and it might be banking structure. There was no hoop in beam-column joint (Photo 14-4).

Photo 14-1 Appearance


Photo 14-2 Columns and walls with CM structure

Photo 14-3 Buildings with story collapse at first story

Photo 14-4 Beam-column joint

No.2 Apartment houses near river mouth

Apartment houses constructed by SERVIU are near the river mouth. The buildings were CM structure with bricks and have four floors after 20 years construction (Photo 15-1). Tsunami marked a trace at about 400mm high of floor.
Shear failures of transverse wall were found, and the floor height was down in a building out of four (Photo 15-2). There were rock pockets and rusted reinforcing bars in the broken part. Beam of top of transverse wall came down in another building (Photo 15-3 and Photo 15-4).


Photo 15-1 Appearance


Photo 15-2 Shear failure of transverse wall

Photo 15-3 Damaged beam for top of transverse wall

Photo 15-4 Fallen beam

No.3 Damages of old brick construction and Adobe structure

Buildings with old brick construction and Adobe structure were damaged in many places in Constitucion, while the damage of new low-rise houses built on mountainside were slight.

Photo 16-1 Damages of old brick structure and Adobe structure

2.3 Cauquenes, Región del Maule

Damage inspections for apartment houses of SERVIU were conducted in Cauquenes. Location of investigated buildings is shown in Figure 4.

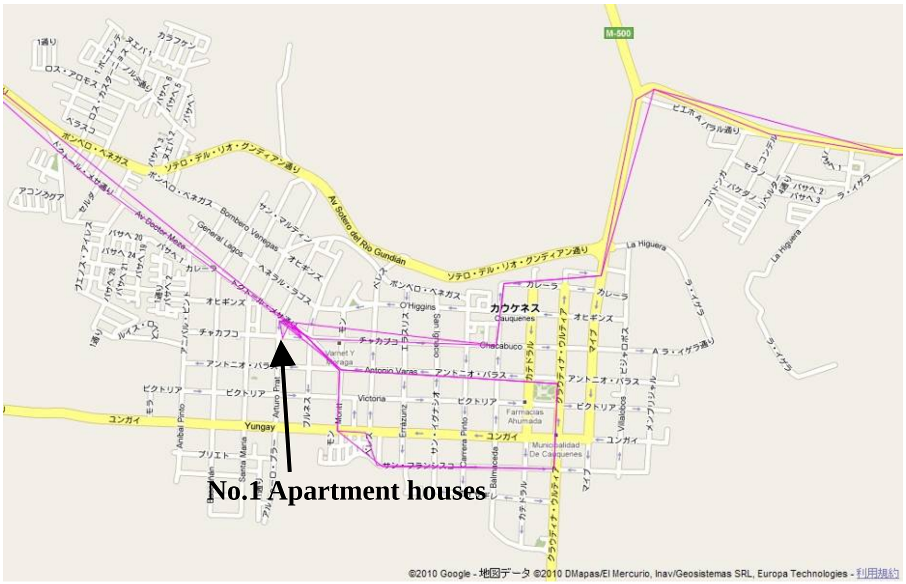

Figure 4 Investigated buildings in Cauquenes (tack building number on the google map)

No.1 Apartment houses

There are four apartment houses of SERVIU with CM structure and three floors constructed 16 years ago on a gentle hillside. Hollow bricks composed the walls, and horizontal reinforcements were arranged in masonry joint every 4-5 layer in longitudinal direction, but nothing in span direction. Walls at the first story suffered from shear failure at the highest building, and almost all columns were severely damaged and smashed (Photo 17-1). Shear cracks were found in one building out of two which separated by Expansion Joint (EXP.J, almost no space), but not so big damage (Photo 17-2).

Photo17-1 Damaged transverse wall and longitudinal direction wall

Photo 17-2 Shear cracks of longitudinal direction wall (Another building)

2.4 Talca, Región del Maule

Talca is a medium-size city with a population of 200,000 and located about 115km away from the earthquake source. Here we investigated the damage of apartment houses with CM structure, SERVIU office building and construction site of low-rise houses with CM structure. Figure 5 indicates the points of investigated buildings.

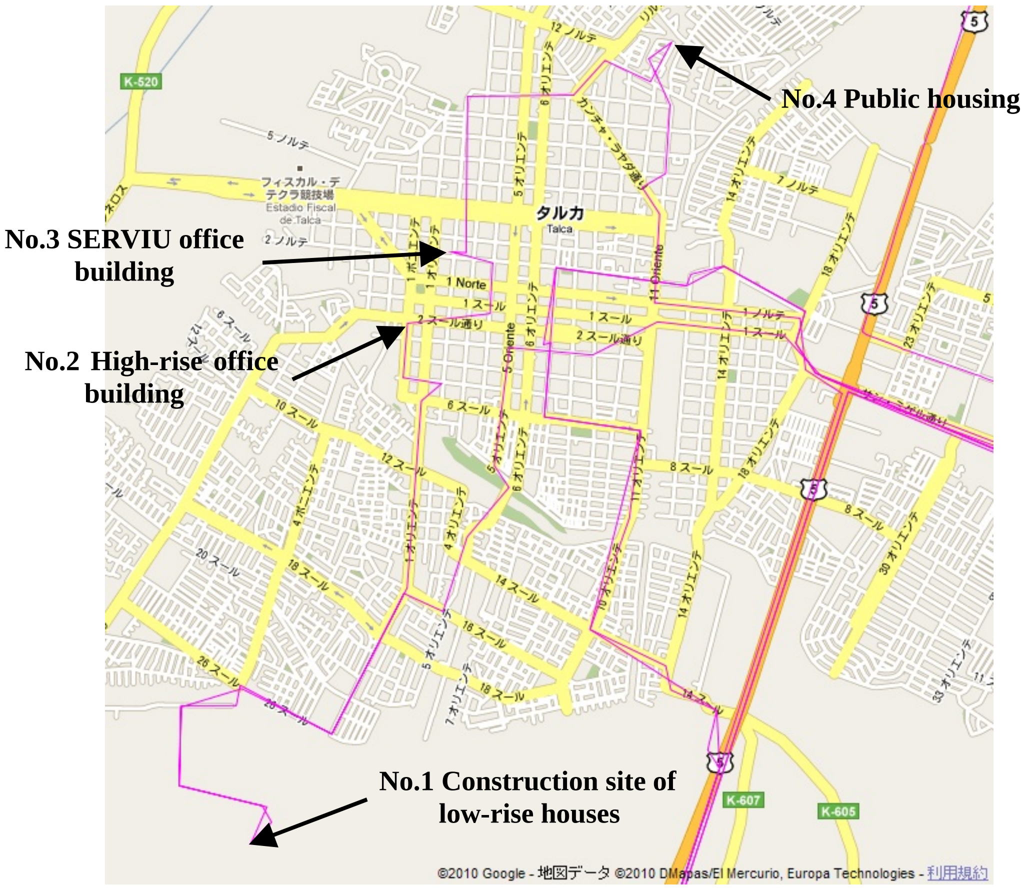

Figure 5 Investigated buildings in Talca (tack building number on the google map)

No.1 Construction site of low-rise houses

Photo 18-1 shows construction work of low-rise houses with two-story of which the first floor is CM structure and the second floor is wooden structure. Vertical reinforcements of columns, and those of walls (500mm spacing) were arranged on concrete foundation, and hollow bricks were subsequently stacked as walls. The walls contain horizontal reinforcing steels, and the top of walls and columns were unified by cast-in-place concrete beam. Main reinforcements in column and footing beam were straightly anchored in the joint, and corner bars of 90-degree bend with 400mm (40d) length were arranged on main reinforcement (Photo 18-2). The spacing of hoops in column was around 200mm, but the angle of hook end was not 135-degree. The slab was one-way joist slab using concrete blocks (Photo 18-3). Masonry walls were collapsed to out-of-plane direction before concrete was casted in columns (Photo 18-4).

Photo 18-1 CM structure house under construction

Photo 18-2 Bar arrangement of footing beam and corner

Photo 18-3 Joist slab

Photo 18-4 Fallen Masonry walls

No.2 High-rise office building

Nonstructural elements of an office building with RC structure were fallen off (Photo 19-1). Granular foamed polystyrene were contained in concrete materials (Photo 19-2).

Photo 19-1 Appearance

Photo 19-2 Foamed polystyrene contained in concrete

No.3 SERVIU office building

A SERVIU office building of RC structure in Talca with 30 years after construction had six floors (top three floors are apartment), and steel columns composed the outer frames in longitudinal direction (Photo 20-1). Broken windows were scattered on outdoor passage (Photo 20-2). Shear failure of masonry walls at the front, RC bearing walls, and most short span beams of top of the door were observed (Photo 20-3). Four axial reinforcements were arranged in wall edge, but the spacing of reinforcement was narrow (Photo 20-4).

Photo 20-1 Appearance

Photo 20-2 Longitudinal direction outer and broken windows

 

Photo 20-3 Shear failure of bearing walls and short span beam

Photo 20-4 Bar arrangement in wall edge

No.4 Public housing

This is a public housing for low-income group with 50 years after construction, and the dimension is long side 47.4m x short side 7.7m and five floors with RC construction (Infilled Wall structure, Photo 21-1). Back of the front wall in Photo 21-2 is an adjacent house, and those were built with EXP.J without any space, so masonry structure walls were damaged because of shock and vibration of the earthquake and almost fallen from the RC structure. Other than above, damages of nonstructural brick walls, and exposure of reinforcing bars of transverse wall edges were found (Photo 21-3). Damages seem moderate, but SERVIU officials told this housing would be demolished.

Photo 21-1 Appearance

Photo 21-2 Damaged masonry wall

Photo 21-3 Damaged corner columns

No.5 Others

Old brick constructions and Adobe structures everywhere in the city were severely damaged (Photo 22-1). Comparatively new buildings and houses did not receive so much damage (Photo 22-2).

Photo 22-1 Damages of brick and adobe structures

Photo 22-2 Comparatively new buildings and houses

2.5 Concepcion, Región del Biobío

Concepcion is a city with a population of 220,000 and located about 105km away from the earthquake source. Here we investigated the damage of new-built office buildings and fallen condominium. Locations of investigated buildings are shown in Figure 6.

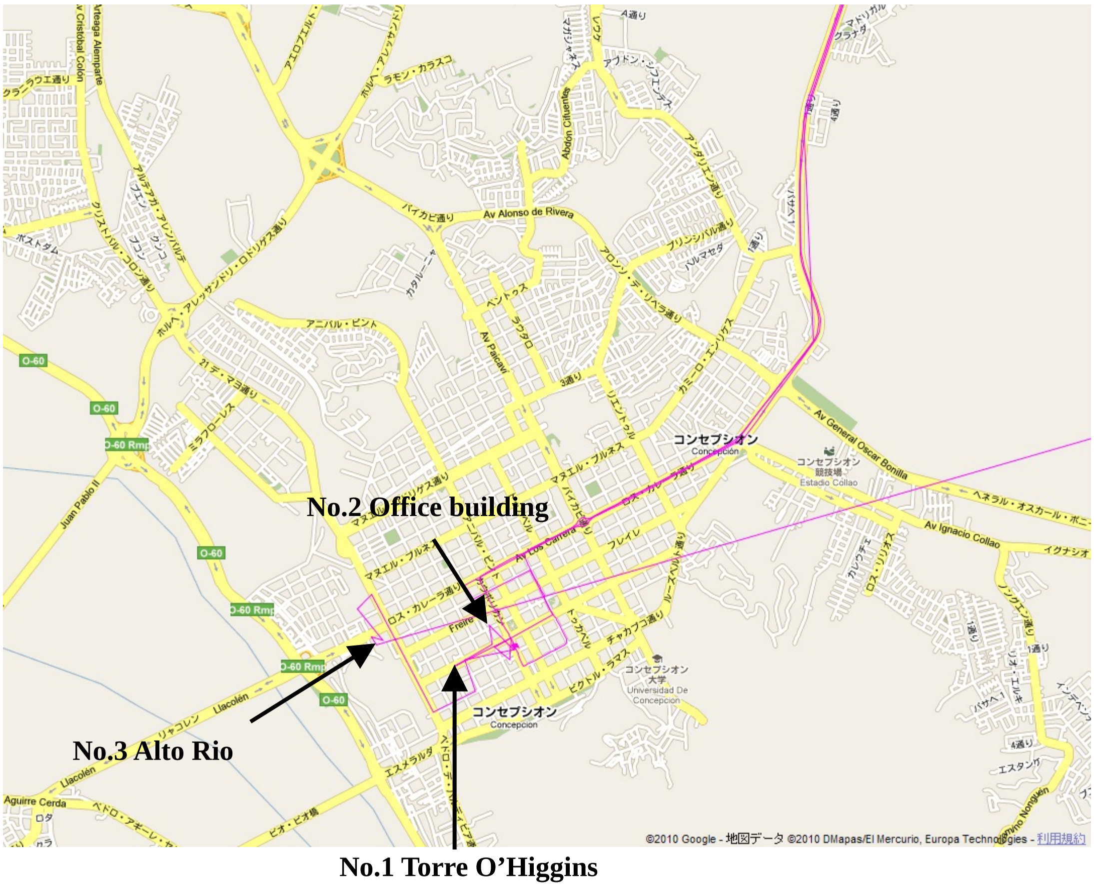

Figure 6 Investigated buildings in Concepcion (tack building number on the google map)

No.1 Torre O'Higgins

A high-rise office building of 21 floors with RC structure constructed in 2008 was in urban area (Photo 23-1). Story collapse occurred in the middle story near the 12th floor at the front of the building (Photo 23-2). Upper stories were inclined to roadside, and the front street was impassable. Setback was found near the story-collapsed floor. There were multistory bearing walls in backside of the building, and no remarkable damage. According to SERVIU officials, the owner will plan to demolish only the upper stories of the story-collapsed and continue to use the building.

Photo 23-1 Appearance

Photo 23-2 Story collapse near 12th floor

No.2 Office building

This is an office building constructed by SERVIU and has four floors with RC structure (Photo 24-1). Masonry walls of inside and stairway were smashed (Photo 24-2) and documents were scattered. Bending-shear cracks occurred at regular interval on the capital of circular RC columns of 3rd and 4th floor (Photo 24-3). Nonstructural walls had severe damages, but the building will be able to use after adequate restoration.

Photo 24-1 Appearance

Photo 24-2 Damage of masonry e wall

Photo 24-3 Bending-shear cracks of circular column

No.3 Alto Rio

This condominium was built in 2008, had 15 floors and 2 basements (parking garage) with RC structure. The building had a fall from the bottom of the first story (Photo 25-1). Destructions of walls on the Photo 25-1 were openings for rescue works. According to the hearing from a resident who lived in the 5th floor at the earthquake, the building sank about one minute after the earthquake and began collapsing. Photo 25-2 shows that all reinforcements of columns and bearing walls were drawn out or cut at the first floor when collapsing. There was no damage in the basement walls for the gable plane of structure (Photo 25-3).

Photo 25-1 Appearance

Photo 25-2 Torn wall columns and bearing walls

Photo 25-3 Walls at basement

No.4 Others

A lot of old brick construction and Adobe structure buildings were damaged in Concepcion. Many buildings suffered from damage in some parts or glasses were under renovation, but not so many middle and low-rise buildings with RC structure were damaged. Photo 26-1 shows devastated details in the city.

Photo 26-1 Concepcion

2.6 Dichato, Región del Biobío

Dichato is a small fishing village on the sea, and located northern 30km away from Concepcion. Devastated investigation for low-rise houses of SERVIU was conducted. Locations of investigated buildings in Dichato and Penco are shown in Figure 7.

Figure 7 Investigated buildings in Dichato and Penco (tack building number on the google map)

No.1 Detached houses

Those are houses constructed by SERVIU in 2008, which steel frame and precast RC construction are mixed (about 4.8m eave height, Photo 27-1 and Photo 27-2). Most damage of buildings was caused by Tsunami, not the earthquake as itself.

Photo 27-1 Appearance

Photo 27-2 Precast RC construction

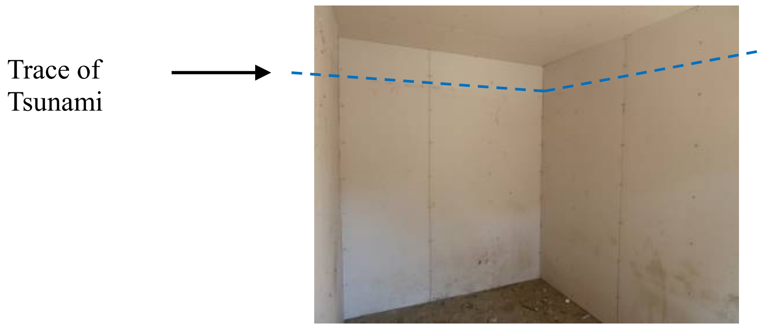

Photo 27-3 Trace of Tsunami (Wall at the second floor)

Photo 27-3 shows the trace of Tsunami which remained on the wall. It is imagined that the height of Tsunami was about 9m because, the altitude of the nearest house from the seashore is about 5m and the trace of Tsunami was near the ceiling of the 2nd floor.

No.2 Miramar houses

They are houses constructed by SERVIU in 2008. The 1st story was masonry structure with bricks and the 2nd story was wooden structure (Photo 28-1). Not so big damages received by the earthquake, but the most damage was because of Tsunami, and wooden structure parts of the 2nd story were swept away (Photo 28-2). Damages of northern part of houses were severe, and wooden structure part of the 2nd story was deformed to south side, so it is imagined Tsunami was attacked from the north. There were foundations and girders, but not columns at the 1st story, and vertical and horizontal reinforcements were arranged in the walls. The size of the vertical reinforcement was about D10 (Photo 28-3).

Photo 28-1 Appearance

Photo 28-2 2nd story were swept away by Tsunami

Photo 28-3 Vertical reinforcement

2.7 Penco, Región del Biobío

Penco is a small fishing village on the sea same as Dichato, and apartment houses constructed by SERVIU were investigated. Investigated buildings are shown in Figure 7.

No.1 Apartment houses

This is an apartment house offered by SERVIU and has four floors (Photo 29-1). The structure is light-steel frames and braces, and exterior walls were composed of steel folded plates. Some residents used to remove the brace or column in a part of houses, but there was no big damage by the earthquake. Steel folded plates of exterior walls were deformed in some parts as Photo 29-2, and it is imagined that they worked properly as earthquake resistant elements.

Photo 29-1 Appearance

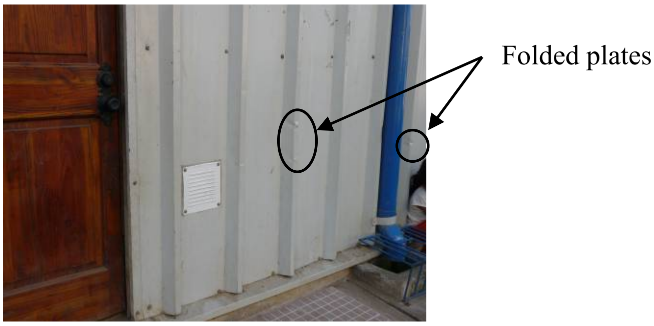

Photo 29-2 Deformation of folded plates

2.8 Chillan, Región del Biobío

Investigation in Chillan was not conducted, but the church near the hotel was severely damaged (Photo 30-1). Building frame is RC structure, but the steeple penetrated the roof and came down. The top of colonnade of a chapel and walls were also damaged (Photo 30-2 and Photo 30-3).

Photo 30-1 Church

Photo 30-2 Inside of church

Photo 30-3 Fallen steeple

2.9 Tsunami disaster

(1) Constitucion, Región del Maule

The traces of Tsunami in Constitucion were shown in Photo 31-1 and Photo 31-2.

The trace of Tsunami

Photo 31-1 Apartment house of SERVIU near estuary region (About 400mm high)

Photo 31-2 City area

All of restaurants built at the seacoast were destroyed. Discolored plants by seawater were up to halfway of the cliff, and it estimated that Tsunami reached about 20 to 30m (Photo 31-3). All streetlights on the coast were turned over from the foot to same direction (to the south). A wood chips factory near the seacoast also received damages (Photo 31-4).

Photo 31-3 Trace of Tsunami

Photo 31-4 Seacoast area

(2) Pelluhue, Región del Maule

Pelluhue is a small settlement facing the Pacific Ocean, and located the closest point to the earthquake source. This area was severely damaged by Tsunami, and most buildings near the coast were swept away, except for concrete foundation and a part of walls remained (Photo 32-1). According to the residents, there was no human suffering because they evacuated voluntarily on the hill by cars immediately after the earthquake. It is assumed that emergency drills were conducted on a routine basis, and awareness of disaster prevention was raised. It is reported that Tsunami was not so large in the earthquake in 1960. Signs to indicate the evacuation direction and safe places from Tsunami were settled on the road, not only in this district but also in many places.




Photo 32-1 Seacoast area

(3) Dichato, Región del Biobío

Wooden structure buildings were destroyed by Tsunami and received extensive damages, and rubbles were piled up near the seacoast (Photo 33-1). As described in 2.6, the trace of Tsunami was seen in RC and brick construction buildings, but building frames remained without big damages. Residents evacuated on the hill after the earthquake and were safe, but there were some victims who went back to their houses to bring baggage after the first wave went out, and who stayed in the vacation houses near the seacoast as tourists. This district was under control of the military at the point of this investigation (Photo 33-2).




Photo 33-1 Seacoast area



Photo 33-2 Tent of refugees and military

3． Features of damaged buildings

Extensive damages were observed on buildings with masonry structure as brick constructions and Adobe structures including CM and Infilled Wall structures [#7] in this earthquake. Though the masonry structure is one of the most popular construction method around the world, not only in Central and South America but in Asia and European countries, they have not always been excelled in performance for the earthquake resistant, so it is reported many damages by earthquakes in the past.

As some featured cases, damages of RC wall structures were investigated. In Chile, RC wall structure is in widespread use for building constructions, which is uncommon in Central and South America area. The structure is similar to Japanese RC wall moment frame structural system, of which the applicable limitation is less than 15 stories and 45m high. Other than the above, there are common damage cases in urban buildings as collapse of the soft first story buildings, and story collapse of intermediate story in high-rise buildings. Numbers of these damaged buildings are attributive, but those occurred in relatively new buildings, and should be constructed based on the current seismic design standard of Chile (1996), so further detailed investigations will need to be executed for solving the cause of the phenomena.

Chile always focus on seismic design of buildings and it is estimated that damages of the earthquake this time is not big scale as Mw8.8, which seismic design force of Chilean code is about half of Japanese standard [4]. It follows in general that the current seismic design method has performed effectively to mitigate the damage of buildings. Here we indicate the classification of investigated damage patterns comparing with past typical damages.

3.1 Damages of whole buildings

(1) Overturned building

This is a case of a RC condominium collapsed, which had 15 floors (Photo 34-1, reprinted photos shown in Chapter 2). The basements are parking garage (3.3(1) is the similar case) and the length of bearing walls are shorter (smaller) than upper floors, so it seemed the damage at this portion brought on the overturn of the building (refer to Photo 39-1and Photo 39-2). A schematic illustration of multistory bearing wall that has a large opening at basement is shown in Figure 8. The cause of collapse needs to be considered in detail.

Photo 34-1 Damage of collapse (Photo 25-1 reprinted)

#7 Confined Masonry (CM) structure
After arranging reinforcements of column and stacking bricks of wall, concrete are casted in column using the form. Upper beam of RC is consequently built, and then masonry wall is unified with RC tie-columns and tie-beams. Reinforcements are usually arranged in masonry walls but sometimes without rebar. In both cases, masonry walls of CM structures are designed as structural elements against vertical load and seismic force.

Infilled Wall structure
After framing RC columns and beams, bricks are piled up in the frame. Wall has no reinforcement in most cases. Structural element against load and external force is RC moment resisting frame but masonry wall.

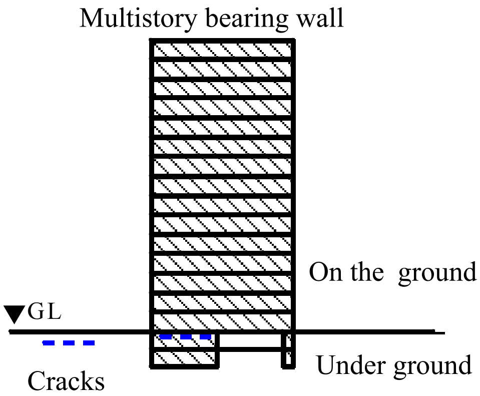

Figure 8 Schematic illustration of multistory bearing wall with large opening at basement

(2) Collapse of intermediate story in high-rise building

This is an example that the intermediate story in RC high-rise building was collapsed (Photos 35-1 and 35-2). Entire story collapse was observed in the front of the building, but the backside of it was a multistory bearing wall with small opening, and the damage was small. Story collapse occurred at the floor with setback. Information of the building structures and the investigation results did not be obtained yet, so the cause of damages should be considered after time.

Photo 35-1 Collapse of the intermediate story (Photo 23-1 reprinted)

Photo 35-2 12th floor (Photo 23-2 reprinted)

In the Great Hanshin-Awaji Earthquake, Japan, 1995, similar cases of the collapse of intermediate story were reported (Photo 35-3). As for the cause of them, the change of structural system from SRC to RC was pointed out.

Photo 35-3 Collapses of intermediate story (The Great Hanshin-Awaji Earthquake, Japan, 1995)

(3) Collapse of first story in RC mid-rise building

This is an instance that the first story in RC mid-rise building (condominium) was collapsed (Photos 36-1 and 36-2). The building shown in Photo 36-2 is the soft first story (Piloti) structure and the deformation in the earthquake centered on the first story.

Collapse of the soft first story has been frequently reported as earthquake damages, Photo 36-3 indicates the case in the Great Hanshin-Awaji Earthquake, Japan, 1995, and Photo 36-4 is the case in L'Aquila Earthquake, Italy, 2009.

In Japan, after the Great Hanshin-Awaji Earthquake, the provisions for story stiffness ratio, i.e. the evaluation for distribution of stiffness belong to the building height; have been strengthen. Additionally, the points to consider in seismic design of the soft first story structure are published in a technical handbook [5], [6].

Photo 36-1 Collapse of soft first story (Photo 8-1 reprinted)

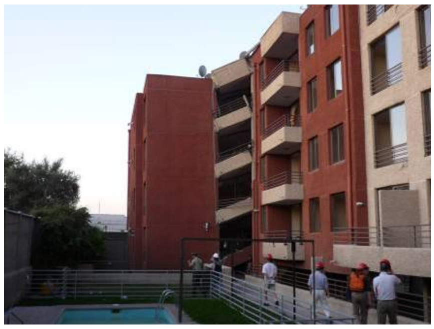

Photo 36-2 Collapse of soft first story (Piloti) (Photo 9-1 reprinted)

Photo 36-3 Collapse of soft first story structure (The Great Hanshin-Awaji Earthquake, Japan, 1995)

Photo 36-4 Collapse of soft first story structure (L'Aquila Earthquake, Italy, 2009)

(4) Story collapse of CM low-rise building

Photo 37-1 indicates a case that an apartment house of CM structure collapsed at the first story, and upper stories fell down. These structures have a tendency to use same member section, bar arrangement, and wall quantity in every story; that causes the shortage of wall at the first story compared to upper, because large opening is set to the entrance. Seismic force against building generally acts on the first story the most, so it leads to the first story relatively breakable. Damages of CM buildings are reported in many earthquakes, and here let me introduce a case in Pisco Earthquake, Peru, 2007 (Photo 37-2).


Photo 37-1 Collapsed first story of CM building (Photo 14-3 reprinted)


Photo 37-3 Collapsed CM buildings (Pisco Earthquake, Peru, 2007)

(5) Damages of masonry structure building

Photos 38-1 and 38-2 show examples of damages of masonry structure buildings as brick constructions and Adobe structures. As cases of recent earthquakes, for example, damage of brick construction buildings in Sichuan Earthquake, China, 2008 (Photo 38-3), and masonry structure buildings in L'Aquila Earthquake, Italy, 2009 (Photo 38-4) are quoted.


Photo 38-1 Damage of Adobe buildings (Photo 16-1, Photo 22-1 reprinted)


Photo 38-2 Brick construction buildings (Photo 22-1, Photo 26-1 reprinted)

Photo 38-3 First floor collapsed brick construction building
(Sichuan Earthquake, China, 2008)

Photo 38-4 Masonry structure
(L'Aquila Earthquake, Italy, 2009)

3.2 Damages of structural members

(1) Failure of RC bearing wall

Photo 39-1 shows a case that RC multistory bearing wall of a 12-story building was smashed at the first basement level. Photo 39-2 also shows RC multistory bearing wall was smashed at the first basement level in a building, which has 18 floors and 2 basements. These cases are unknown in past other earthquake, and it might be the specific failure type in this earthquake. In general, the common failure type of RC bearing wall is diagonal shear crack.

Photo 39-1 Smashed RC wall
(Photo 1-2 reprinted)

Photo 39-2 Smashed RC wall
(Photo 2-3 reprinted)

Apartment houses newly-built in urban city area are designed to set up the opening in a part of multistory bearing wall to secure the drive zone at the basement which is used as parking garage (Figure 8). Photo 39-1 is corresponding to the left-side wall underground shown the image in Figure 8. Failure on the Photos occurred because large tensile axial force and shear force were affected on.

(2) Flexural failure of RC column (wall column)

Photo 40-1 shows wall columns (flat shaped columns) of RC mid-rise building, and the big damage occurred on the capital. These wall columns are imagined that deformation centered to the capital after bending to weak axis direction, and could not support the vertical load with losing the horizontal strength. Similar damages of columns are confirmed in Sichuan Earthquake, China, 2008 (Photo 40-2), but the damage of wall column is presumed the specific failure type in Chile.

Photo 40-1 Flexural hinges on wall columns (Photo 9-3 reprinted)

Photo 40-2 Flexural hinge on column capitals (Sichuan Earthquake, China, 2008)

(3) Failure type of RC beam

a. Shear failure of beam

Photo 41-1 shows a example that beams on the top of the door opening in RC mid-rise building failed in shear. The causes of the failure are presumed that stress is easy to be concentrated at short spanned beam in earthquake, and flexural strength of it become strong.
Similar failure of short spanned beam at the stairway of a hospital was confirmed in Niigata-ken Chuetsu Earthquake, Japan, 2005 (Photo 41-2).

Photo 41-1 Shear failure of short spanned beam (Photo 9-3 reprinted)

Photo 41-2 Shear cracks of short spanned beam (Niigata-ken Chuetsu Earthquake, Japan, 2005)

b. Failure of anchorage of beams

Photo 42-1 shows a beam at the top story of CM building failed around the lap joint of reinforcements and fallen down to out-of–plane. This building was constructed more than 20 years ago and, the standard for design and construction at that time are not recognized. In general, the location and length of the lap joint should be designed so that tensile stresses of which main reinforcements carry can be transmitted. It is imagined that the location and length of lap joint in the fallen beam are not appropriate and the stress transmission is not performed adequately (Photo 42-2).

Photo 42-1 Failed beam at the top of the transverse wall (Photo 15-3 reprinted)

Photo 42-2 Main reinforcement at same joint point (Photo 15-4 reprinted)

(4) Failure of RC beam-column joint and others

a. Failure of RC beam-column joint

Photo 43-1 shows the failure of beam-column joint in RC mid-rise building, and Photo 43-2 is the same of CM building. In both cases, hoops were not used in the joint, and the section of it was small, then they led to the failure.

Similar damages of beam-column joint were investigated in Sichuan Earthquake, China, 2008 (Photo 43-3), and in L'Aquila Earthquake, Italy, 2009 (Photo 43-4).

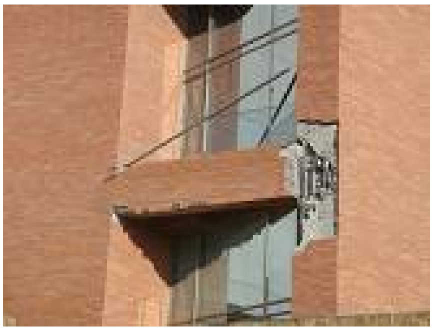

Photo 43-1 Failure of beam-column joint (Photo 7-2 reprinted)

Photo 43-2 Failure of beam-column joint (Photo 14-4 reprinted)

Photo 43-3 Failure of beam-column joint (Sichuan Earthquake, China, 2008)

Photo 43-4 Failure of beam-column joint (L'Aquila Earthquake, Italy, 2009)

b. Failure of joint among buildings

Photo 44-1 shows the failure of joint among buildings, one is 12-story building and another is 2-story building. Vibration of building in earthquake is depending on the natural period, so if adjacent buildings, which have different height, are situated, they are crashed each other and become the cause of the failure.

Expansion joint is laid on among buildings ordinarily in Japan.

Photo 44-1 Joint among buildings (Photo 6-2 reprinted)

3.3 Nonstructural materials

(1) Damage of brick wall

Photo 45-1 is the damage of brick walls in RC high-rise building (Infilled Wall structure). These walls are designed as nonstructural wall, so some damages must be allowed, but measures should be taken in order to prevent falling off in out-of-plane direction even if cracks occurred by earthquake. Similar damages are reported in many earthquakes, Photo 45-2 is seen in Sichuan Earthquake, China, 2008 and Photo 45-3 is seen in L'Aquila Earthquake, Italy, 2009.

Photo 45-1 Cracks on brick walls (Photo 5-2 reprinted)

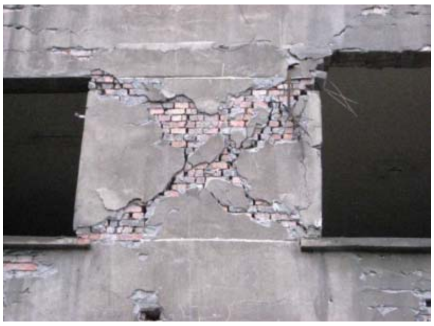

Photo 45-2 Collapse of nonstructural wall (Sichuan Earthquake, China, 2008)

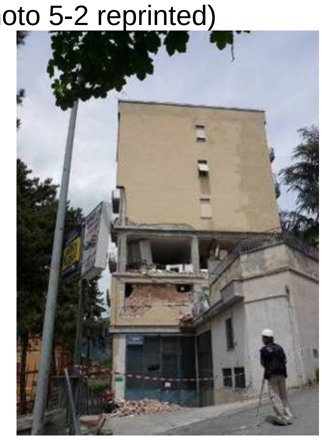

Photo 45-3 Collapse of brick walls (L'Aquila Earthquake, Italy, 2009)

(2) Damages of RC nonstructural materials

Photo 46-1 shows a roller-supported beam at one end fell down the place 7 to 8m away because of the earthquake. Photos 46-2 and 46-3 are the nonstructural walls of RC office buildings dropped. In both cases, heavy RC materials are used, and such phenomena bring a risk to get passer-by and vehicles involved in accidents. Many decoration materials are attached to the external walls on buildings in this investigation.

Further caution should be needed in design and construction from here on.

Photo 46-1 Drop of beam (Photo 12-5 reprinted)

Photo 46-2 Collapse of External wall (Photo 7-1 reprinted)

Photo 46-3 Collapse of External wall (Photo 19-1 reprinted)

(3) Damages of glasses and ceiling

Photo 47-1 shows the situation of broken and scattered windows of outer plane in a mid-rise building.

Ceiling materials fell down in the terminal building of Santiago international airport (Arturo Merino Benítez International Airport, Photo 47-2). A part of the terminal was unusable due to those phenomena and damages on facilities, then some operation were conducted in an outdoor camp at the time of the investigation.

Fallen ceiling materials at the large-scale building were also reported as the terminal building damage in Kushiro airport at the Tokachi-oki Earthquake, Japan, 2003 (Photo 47-3).

Photo 47-1 Broken and scattered windows (Photo 20-2 reprinted)

Photo 47-2 Fallen ceiling panels at Santiago international airport

Photo 47-3 Fallen ceiling panels at Kushiro airport
(Tokachi-oki Earthquake, Japan, 2003;
photo offered by Kushiro Airport Terminal Building Co. Ltd. [7])

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