Building Damage Investigation of the 2010 Chile Earthquake and Tsunami Disaster

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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. The group of Japanese and Peruvian researchers conducted disaster investigation especially for buildings from 26 April to 3 May, 2010.

Key Words : *Chile Earthquake, building damage, reinforced concrete, RC quake resisting wall*

1. INSTRUCTION

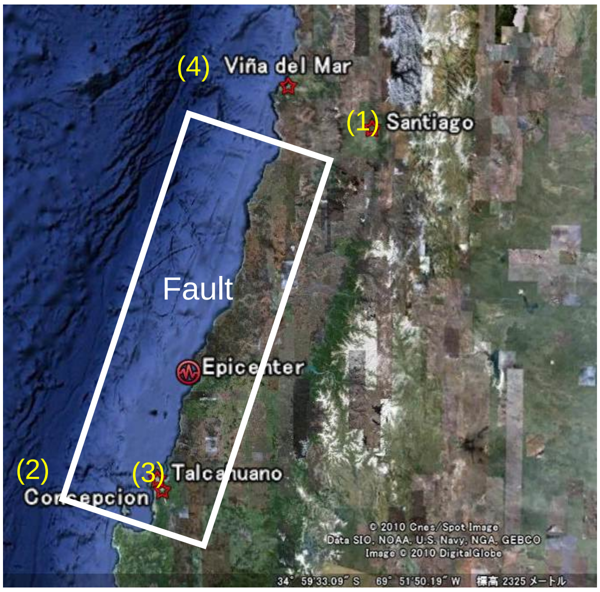
A great earthquake of Mw8.8 occurred at 3:34 A.M. on February 27, 2010 local time with the Pacific coast of Chile as the hypocenter. This earthquake collapsed or destroyed more than 810,000 buildings etc., resulting in more than 1.8 million victims including 432 deaths (as of March 27). When the earthquake occurred, in Peru, which a neighboring country of Chile, the Japan-Peru international joint research project, “Project for Enhancement of Earthquake and Tsunami Disaster Mitigation Technology in Peru” (JST-JICA Science and Technology Research Partnership for Sustainable Development Project, representative researcher: Fumio Yamazaki, professor at Chiba University, 2009-2014) was under way. Given that Peru and Chile are closely related to each other in terms of the seismotectonic and natural/social environments, and hence the findings obtained from the study on the great earthquake of Chile are expected to be mostly applied to Peru, with considerable ripple effects on other Latin-American countries, it was decided to perform investigation and information gathering on the damage caused by the earthquake and Tsunami that hit Chile, jointly with the counterpart from Peru. In addition, it was also decided that the second investigation team (team leader: Susumu

Kawano) would be dispatched from the Architectural Institute of Japan to the site around the same period to perform a joint investigation.

The investigation was performed from April 26 to May 3, approximately two months after the earthquake. Given the JICA Study Team (March 13 to 23) and a joint study team comprised of four societies (Japan Association for Earthquake Engineering, Japan Society of Civil Engineers, Japanese Geotechnical Society, and Architectural Institute of Japan) (March 27 to April 8) already dispatched from Japan and the limited investigation days, this investigation was devoted chiefly to performing on-the-spot inspection of disaster-stricken buildings, acquisition of design documents, hearing with relevant parties, and so on, with the objective of elaborately investigating reinforced concrete buildings. While our activities included the investigation of buildings equipped with a base isolation or seismic control structures, we would like to report in this paper our investigation results on the damage to reinforced concrete structures.

2. OUTLINE OF INVESTIGATION

The investigation was performed chiefly in principal cities (Santiago, Concepcion, and Viña del Mar) of Chile and the surroundings. Figure 1 was the investigation points and the locations of faults. Table 1 shows the list of the investigated buildings. The results of our detailed investigation on the underlined buildings of those listed in the table are as follows.



4/27	(1)	Santiago
4/28	(1)	Santiago
4/29	(2)	Concepcion
4/30	(2)	Concepcion, (3) Talcahuano
5/1	(4)	Viña Del Mar

Figure 1 Investigation points and locations of fault

Table 1 Investigated buildings

(Santiago)
B1. Torre Titanium (vibration control)
B2. Ciudad Empresarial
B3. Edificio Leones 1300
B4. Sol Oriente 1 and 2
B5. Edificio Don Luis
B6. Edificio Don Tristan
B7. Edificio Don Luis
B8. Hall Arnoldo Hax (Catolica Univ., seismic isolation)
B9. Comunidad Andalucia (seismic isolation)

(Concepcion)
B10. Torre O'Higgins 241
B11. LINCOYAN 440 (Torre Livertad)
B12. CAUPOLICAN 518
B13. Alto Rio
B14. SALAS 1343
B15. LOS CARRERAS 1535
B16. ROZAS 1145 (Edificio Don Feodra)
B17. FREIRE 1965 (Edificio Centro Mayor)
B18. Plaza Mayor
B19. BARROS ARANA 272

(Talcahuano)
B20.Edificio de Biblioteca Municipal de Talcahuano

(Viña del Mar)
B21. Building Festival
B22. ACHS (Asociacion Chilena de Seguridad) (seismic isolation)
B23. Efidicio Rio Petrohue

3. INVESTIGATION RESULTS OF BUILDING DAMAGE

(1) Damaged buildings in Santiago City

a) B4. Sol Oriente 1 and 2

It is an apartment complex constructed of box-frame-type reinforced concrete in 2007 with 18 stories above ground (2 stories underground) (Photo 1). The building was damaged particularly on the first basement level of the underground self parking lot (Photos 2, 3). The structural features and the summary of damage are follows:

- Multi-story shear wall structure connected by flat slabs.
- Flexural tension failure occurred in three structure planes out of five 4-span ones on the first basement. An end main reinforcement ruptured.
- The height of the north side multi-story shear wall on the basement is shorter by 1200 mm than on higher floors. In addition, only the northern end of the north side multi-story shear wall lacks an orthogonal wall (Figures 2, 3). Accordingly, the flexural strength of the north side multi-story shear wall is low on the first basement, likely resulting in the flexural tension failure in the south direction on the north side multi-story shear wall.

Photo 1
Appearance of the building

Photo 2
Underground parking lot

Photo 3
Shear wall on the first basement

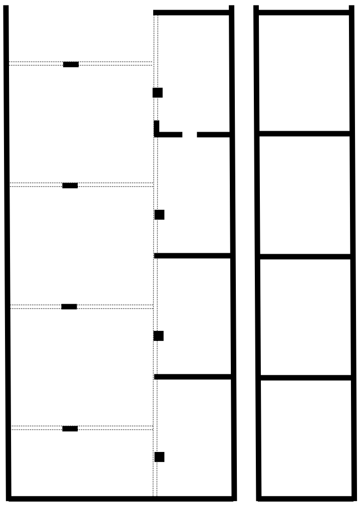


Figure 2 Basement plan view

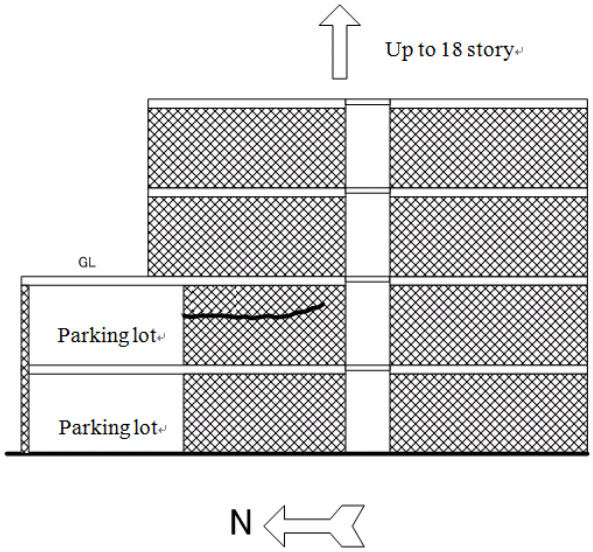


Figure 3 Building section view (sketch)

(2) Damaged buildings in Concepcion City

Concepcion City is a city located approximately 105 km away from the hypocenter with a population of approximately 220 thousand. The earthquake brought eight buildings into serious damage, of which one was completely collapsed. We could obtain entry permits to and design documents of several buildings thanks to the cooperation of the Urban Development Bureau and the Police Bureau of Concepcion City.

a) B11. LINCOYAN 440 (Torre Livertad)

It is an RC wall flat slab structure constructed in 1973. The building has 17 stories above ground and one basement (with no underground car park), of which the three lower floors are occupied by commercial tenants and the fourth and above floors are used for housing (Photo 4). The machine room on the first basement was hardly damaged. The non-structural brick wall collapsed more seriously on upper floors. The walls on the first and second floors failed in flexural tension with the wall-end main reinforcement fractured or buckled (Photo 5). While the building was damaged particularly on the walls in the northeast and southwest directions, little damage was observed on the walls in the orthogonal direction. The damage concentrated on the wall footing is likely attributable to the lack of flexural strength of the T section web resulting from the respective bending deformation of two multi-story shear walls arranged in parallel due to the limited floor slab area in the staircase (Figures 4, 5, 6).

Photo 4
Appearance of the building

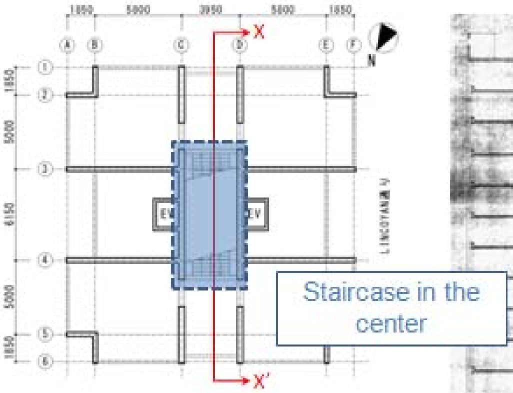


Figure 4
Building plan view

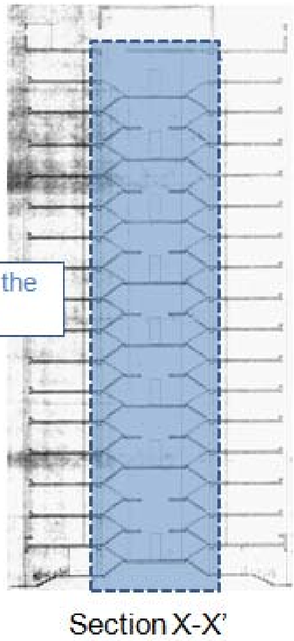


Figure 5
X-X' section view

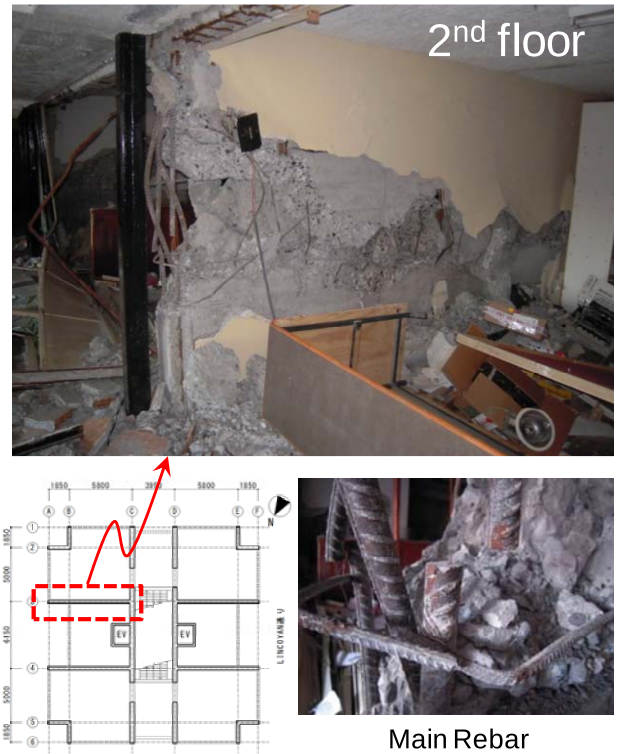


Photo 5
Wall fracture

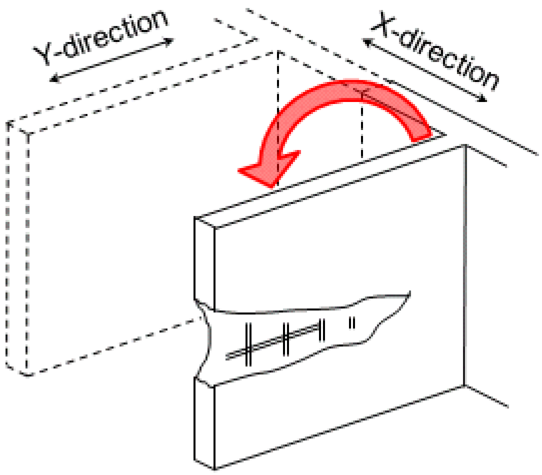


Figure 6
Failure mechanism of T-shaped section wall

b) B13. Alto Rio

It is a reinforced concrete apartment complex constructed in 2008 with 15 stories above ground and two stories underground (parking lot). The building completely fell down from the base on the first floor (Photo 6, 7). Photo 7 shows the appearance of all the reinforcing bars on the first floor having been pulled out or cut down from the wall pillars and load-bearing walls on the first floor during the overturning of the building. Conversely, little damage was observed on the underground end plane walls. As shown in the plan view of Figure 7, the walls on the first floor and the basements (parking lot) are smaller than those on the second and above floors in both length and volume. This fact may have resulted in the damage particularly on the wall footing on the basements.

Photo 6
Photo of the building before collapsed
(excerpted from the Web Page)

Photo 7
Collapsed building

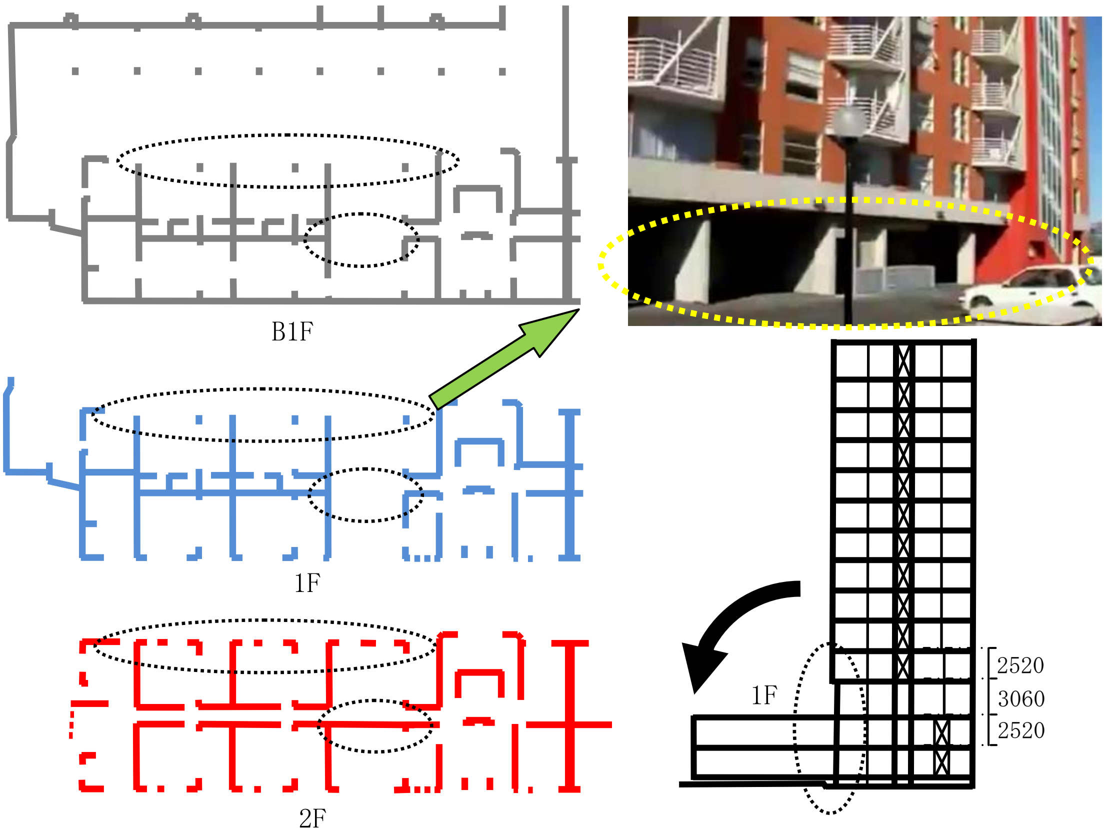


Figure 7 Difference in wall volume and layout among basement, first floor, and second floor

c) B14. SALAS 1343

It is an apartment complex constructed in 2007 with 13 stories above ground and an underground car park provided beside the building. It consists of two buildings arranged in L shape and connected with an expansion joint (Photo 8, Figure 8). It is constructed with a middle corridor in planar shape with more wall volume in the ridge direction. While the south side building was seriously damaged, the north side building was slightly damaged. The south side building seems to have suffered torsional vibration caused by stiffness eccentricity resulting from the many walls in the surrounding of elevators and staircases.

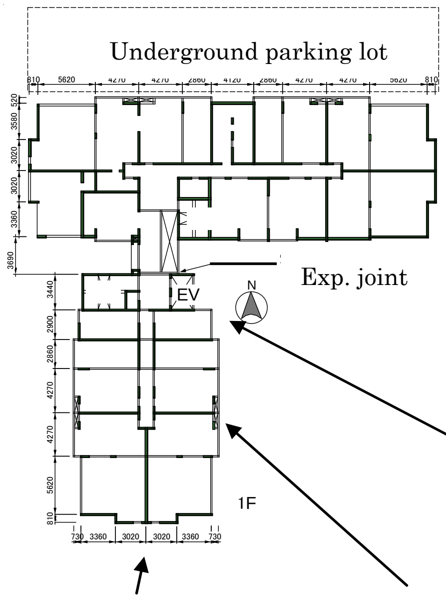


Photo 8
Appearance of the building

Figure 8 Plan view and damage

(3) Damaged buildings in Viña del Mar City

Viña del Mar City is a city with a population of approximately 300 thousand. The 1985 Chile Earthquake (magnitude 7.8, 150 deaths) damaged many high-rise RC buildings within the city.

a) B21. Building Festival

It is an apartment complex (wall-type flat slab structure) with 14 stories above ground and one basement. It was severely damaged (Photo 9). The building had undergone seismic retrofitting such as the placement of additional concrete for walls and beams and the additional installation of walls in response to the earthquake in 1985, but suffered damage in the recent earthquake such as flexural tension failure and separation of concrete-added walls in the wall footing (Photo 10, Figure 9).

Photo 9
Appearance of the building

Photo 10
Appearance of the building

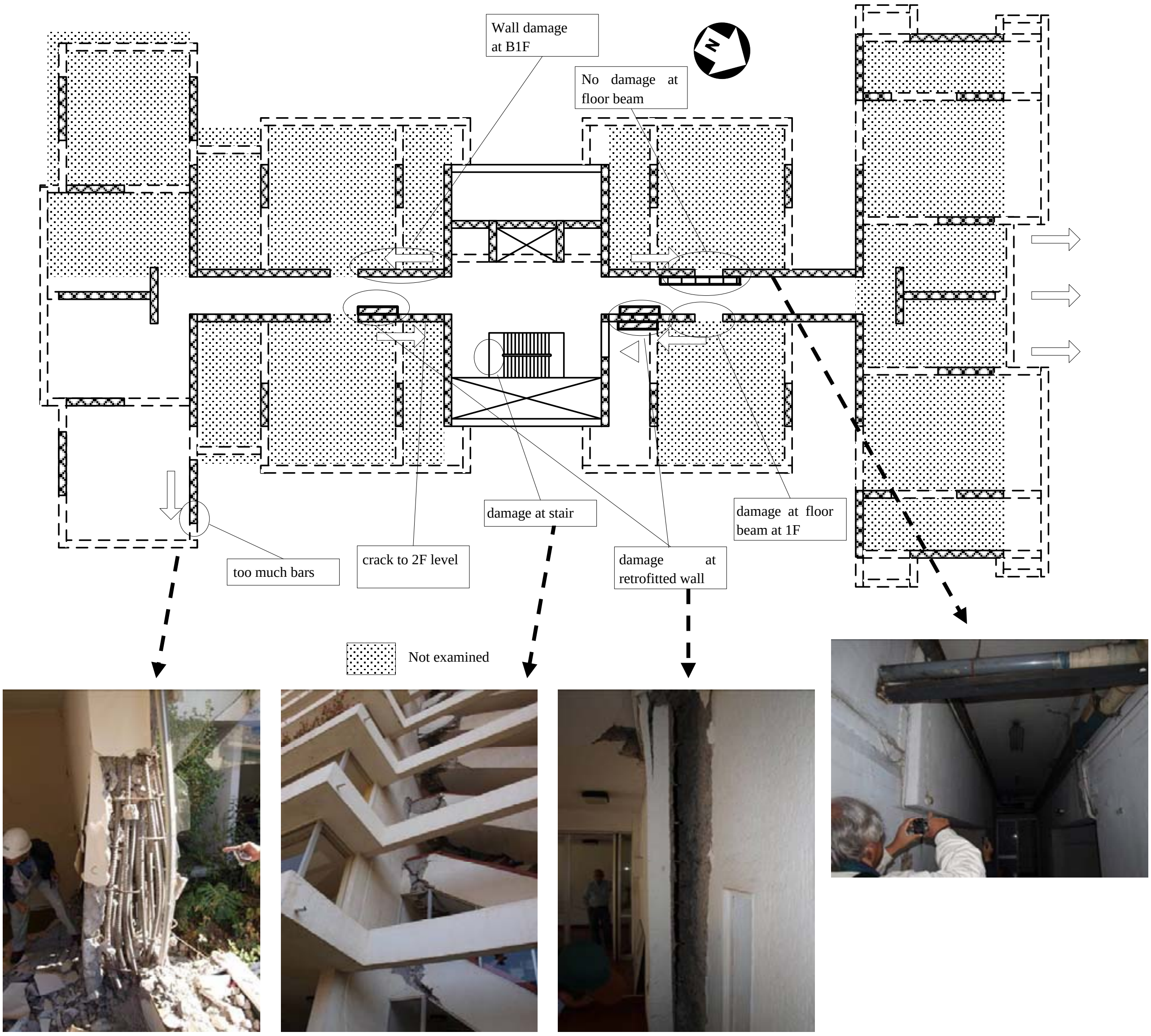


Figure 9　Plan view and damage

4. SUMMARY

The characteristics of the damaged buildings are as summarized below.

- Many of the damaged buildings are flat slab structures with no beam or frame column on the wall.
- The standard size of wall reinforcement is D10@250-D.
- At the wall end, confinement steel (or supplementary cross ties) is installed as well as bending reinforcement.
- The wall pillars, which are provided in place of pillars, are arranged longitudinally in the span direction for reasons of the layout of the parking lot. This fact may result in lower flexural strength and stiffness in the ridge direction.
- The length of a multi-story shear wall may be reduced in the underground parking lot space for the sake of vehicular traffic.
- A parking lot in the underground of the building may be constructed in a shape protruded in one direction. In this case, the parking lot is enclosed only by the three-side retaining walls immediately below the building, with the other side of wall set back in the ridge direction.
- Some walls or wall pillars in the span direction are not connected to orthogonal walls. Such walls include a wall extending in the span direction on the side without a retaining wall and a piloti-type wall pillar (ground parking lot). They were damaged probably due to the low flexural strength when the tensile load was exerted to the side with no orthogonal wall.
- The buildings have a relatively large number of stories and a high slenderness ratio. As a result, the walls of such buildings mostly underwent flexural tension failure. In addition, lack of enough strength to bear the story shear force on the compression side may result in collapse of the building.

Most of the severely damaged or collapsed buildings were high-rise constructions with 13 or more stories and damage concentrated on the footing of the multi-story shear wall observed as a common characteristic. Conversely, most buildings in cities appeared to be sound and few buildings suffered intermediate damage, e.g. slight or medium damage. This may be a characteristic of damage to box frame constructions without plastic deformability. The damage can be considered generally minor, in view of the great magnitude of the recent earthquake at 8.8. While elaborate analysis is still required as to the extent of the seismic force applied to the buildings, given the fact that the damage remained so modest after the great earthquake, the Chilean Seismic Code seems to have functioned extremely well. One of the factors behind the major lack of damage to buildings in the recent earthquake was the positive introduction of the load-bearing wall.

The Chilean Seismic Code includes a provision likely encouraging the positive introduction of the load-bearing wall such as a strict restriction of deformation and reduction of the design seismic force according to the load ratio of the load-bearing wall. In Japan, the height of wall-type rigid-frame structures is limited to 15 stories. Given the modest damage to buildings in the recent Chile Earthquake and the continuous usability of post-earthquake buildings, Japan may also need to recognize anew the benefits of box frame constructions.
From the research perspective, a design method needs to be established to prevent such brittle failure after flexural yielding as observed in the recent seismic damage. Structural testing on flexural failure of load-bearing walls is not common in Japan and future research and development is awaited.

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