Paper No. 113

Chile Resiliency: a Review of the Housing and Health Sectors

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INTRODUCTION

Chile is one of the countries with the highest seismic activity in the world, primarily due to the subduction process of the Nazca Plate below the South American continent. From the late 16th century to the present, there has been a high-magnitude damaging earthquake (M_w>7.5) every 8 to 10 years on average throughout the Chilean territory. Figure 1 shows the statistics of seismic events with Modified Mercalli Intensities IMM greater than V occurred between 2007 and 2014 in the Chilean territory.

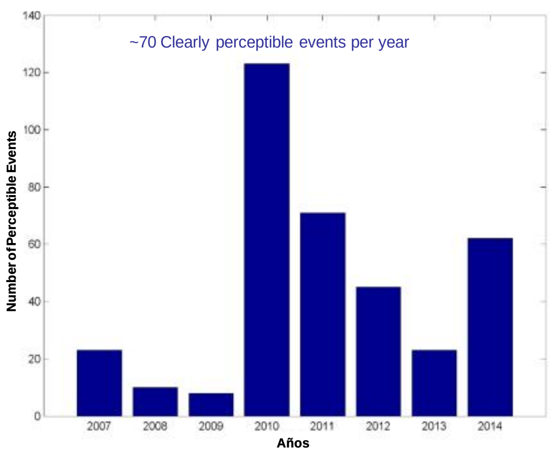

Figure 1. Number of events IMM>V.

DESIGN/CONSTRUCTION TECHNIQUES

The Chilean traditional design and construction practices consider the application and enforcement of strict seismic design codes. The present design practices for dwellings mainly consider the use of reinforced concrete or confined masonry walls. The use of non-seismic materials such as adobe or unreinforced masonry has decreased systematically since 1920, as illustrated in Figure 2. Non-engineered adobe and unreinforced masonry structures been severely damaged in all major earthquake in Chile, Mw> 8 every 10 years in average, and the have been demolished and not reconstructed after past earthquakes, reducing the existing stock of risky structures (Figure 3). On the other hand, the good performance observed in engineered structures designed according to the Chilean code requirements during M_w>8 earthquakes is attributed to the used of structural walls, strict code compliance by the designer and contractor and mandatory peer review requirement for all structural design projects with more than 4 stories high. Additionally, the code strict inter-story drifts limits, which typically results in the need for using reinforced concrete shear walls or mixed systems composed by moment resistant frames and shear walls has contribute to a very low damage level. Moment resistant frames without shear walls are not feasible in the Chilean practice. Figure 4 shows the evolution with time of the ratio between the in-plan shear wall area and the total floor area, and the evolution with time of total building heights (after Calderon 2007). It is observed historically the wall density ratio has fluctuated between 2 and 4%.

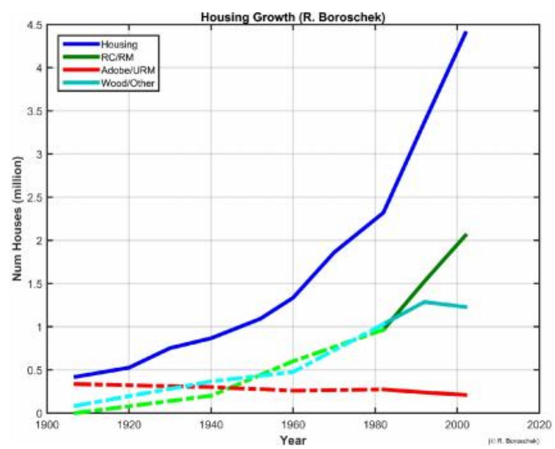

Figure 2. Housing growth per construction material.

Figure 3. Typical damage non engineered structure.

Figure 5 shows a plan view of a typical office building, the Chilean Chamber of Construction, a high rise 24-story building, 78 m in height, with wall density ratios equal to 2.3 and 4.6% in the longitudinal and transverse directions, respectively. The typical story

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height is 3.3 m. The fundamental period of the structure is 0.95 seconds. This building has been instrumented by the University of Chile (http://terremotos.ing.uchile.cl/) since the mid 90's, recording data during more than 80 strong motion events.

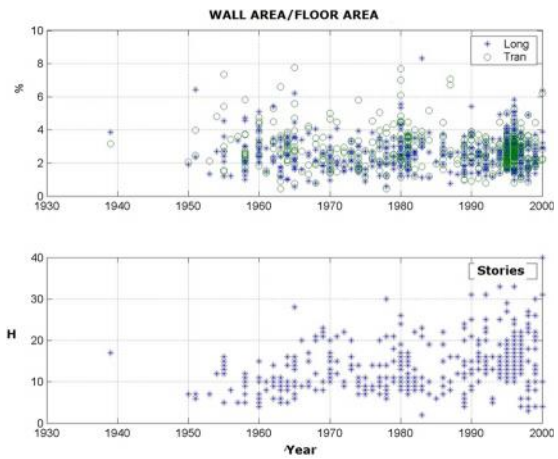
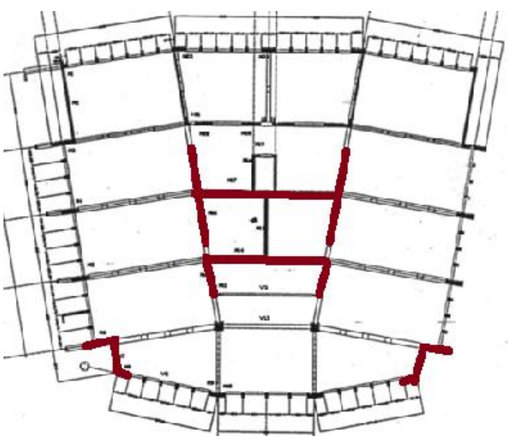


Figure 4. Evolution with time of wall area to floor area ratio and total building height (after Calderon 2007).



a) Plan view structural system (Lagos Contreras)

b) Photo modern construction

Figure 5. Chilean Chamber of Construction building. (S. Contreras)

THE 2010 M_w 8.8 MAULE EARTHQUAKE

The February 27, 2010 M_w 8.8 Maule earthquake (Figure 6) affected a significant portion (65% of stock, approximately) of housing and health infrastructures, causing economic losses exceeding 33 billion US dollars, equivalent to 15% Chile's 2010 GDP. Ninety percent of those losses were associated to nonstructural damage (Figure 7).

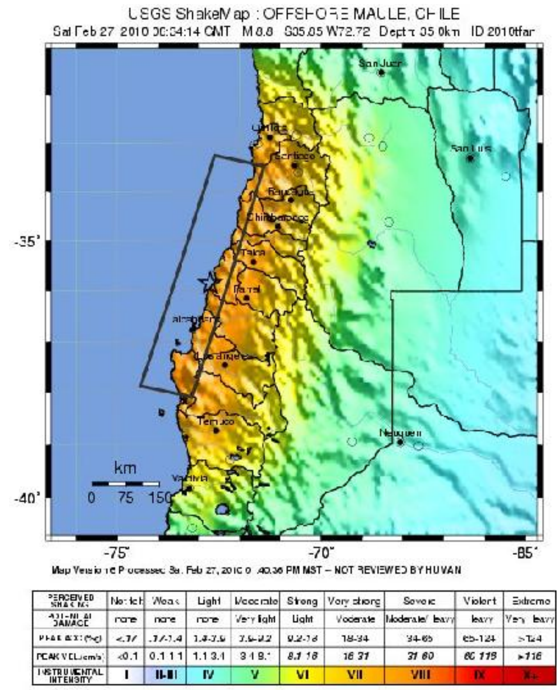


Figure 6. Zone affected by 2010 Maule Earthquake (Source: USGS).

Figure 7. Example of generalized damage to non-structural components and systems (Miranda et al., 2012).

Structural damage was observed in approximately 0.5% of buildings, including damage to shear bearing walls due to deficient confinement detailing, excessive slenderness of the walls, low cycle fatigue of longitudinal rebar, excessive vertical compression loads, walls discontinuities and wall/slab interactions (Boroschek et al. 2014). Figure 8 shows examples of the observed structural damage. Ten percent of the losses (3.3 billion US dollars) resulted from direct damage to the 130 public health facilities affected.

Among these hospitals, 83% lost partially or completely its functionality exclusively due to damage to nonstructural systems and components, such as architectural elements, contents and electrical, and mechanical and medical equipment. Five hospitals needed to be evacuated due to severe structural and nonstructural damage, twelve had greater than 75% loss of function due to nonstructural damage, eight were operating only partially after the main shock, and eighty needed repairs or replacement. Figure 9 shows the statistics of damage in hospitals located in the epicentral area. Twenty two percent of the 19,179 beds in public hospitals were lost during the main shock and 18% continued out of service one month after the earthquake. Although structural damage was minimal in hospitals, most suffered nonstructural damage and loss of utilities.

a) Damage in slender shear bearing walls

b) Low cycle fatigue longitudinal rebar (Photo: J Restrepo)

c) Damage due to wall/slab interaction

Figure 8. Damage to structural components.

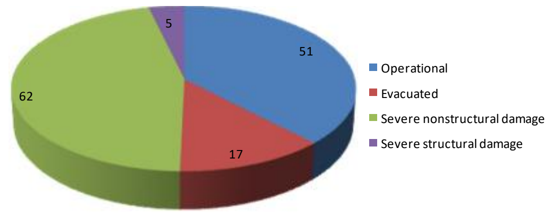


Figure 9. Statistics of damage in hospitals (Ministry of Health)

Figure 10 shows the recovery function of the number of beds available in the affected area. In Figure 10 it is observed that recovering the number of beds available before the M_w 8.8 earthquake took 14 months.

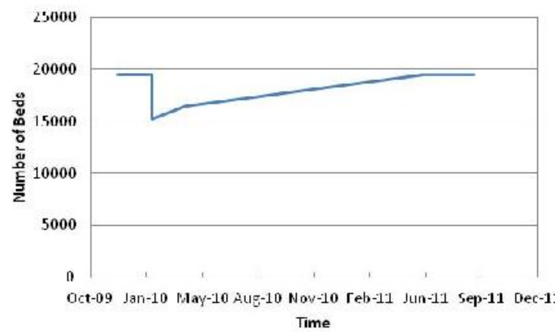
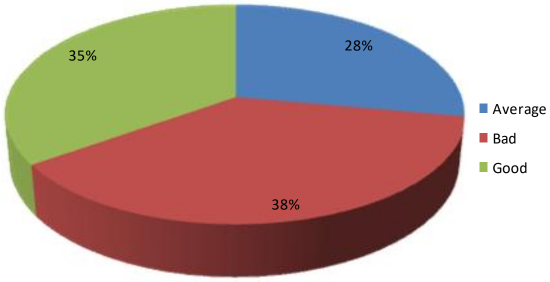


Figure 10. Recovery process for beds in affected area. (after MINSAL)

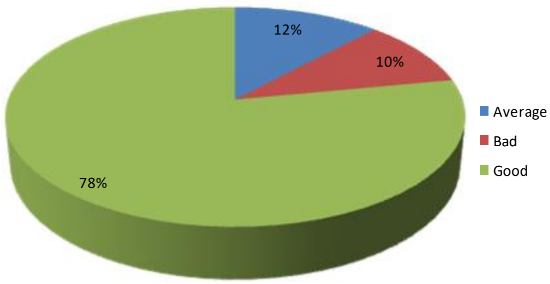
CURRENT AND FUTURE TRENDS

Following the 2010 Maule earthquake, significant efforts were made to introduce modifications into design codes and standards in order to improve seismic design practices, disseminate the use of seismic protection technologies, such as seismic isolation and energy dissipation (Retamales and Boroschek, 2014), promote the seismic design of nonstructural components and systems, and define minimum requirements for utilities, communication and access redundancy for critical facilities. All these actions aimed at improving the seismic resilience of new housing and health facilities. Figure 11 shows the condition in 2013 and the projected condition by 2018 of the public health infrastructure.

Currently, public investment plans for the next 5 years consider the construction of 8 new hospitals, with a total investment about 1.4 billion US dollars and 770,000 square meters to be built. All of them consider measures such as the use of seismic isolation, seismic design of nonstructural components and system, and an extensive instrumentation and monitoring plan, oriented to increase the seismic resiliency of the public health net. The codes used for designing residential buildings have been also updated to include the lessons learned from the recent earthquakes.



a) Condition in 2013



b) Projected condition in 2018

Figure 11. Current (2013) and projected condition of public health infrastructure (after MINSAL)

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