14.0 GEOLOGIC AND TSUNAMI HAZARDS, URBAN PLANNING, AND RECONSTRUCTION

14.1 Introduction

The February 27 earthquake and tsunami resulted in substantial geotechnical and structural damage as well as loss of life. The geologic setting and patterns of damage offer a variety of challenges to rebuilding in Chile. There are also several important lessons for geologic hazards mitigation and planning in earthquake and tsunami-prone regions of the U.S. and Canada, particularly in the Cascadia subduction zone area of the West Coast, and elsewhere.

The purpose of the urban planning mission of the GEER team was to assess the geologic and tsunami impacts of the February 27 earthquake and identify urban risk management lessons for the U.S. Another key purpose was to identify candidate areas for potential long-term monitoring of post-disaster rebuilding actions in Chile.

Field reconnaissance between March 14 and 18, 2010 covered over 350 km of the central Chilean coastline between Pichilemu and Laraquete. The coastal region experienced some of the most significant damage from the tsunami, vertical deformation (uplift versus subsidence), and other geologic effects. Much more limited assessments were made of damage-affected areas in the central Chile Valley region, Santiago, Vina del Mar, and Valparaiso. Other information has been gleaned from media accounts and other reconnaissance reports, as well as collaborations with other investigators including members of the GEER team, as well as Nicholas Zoa, and William Siembieda – a member of the Earthquake Engineering Research Institute's Learning from Earthquakes reconnaissance team.

14. 2 Earthquake Impacts

The M8.8 earthquake occurred at 3:34 am in the early morning hours of Saturday, February 27, 2010. Given the time of day and day of the week, few people were driving, on the streets or at work, and thus were not much affected by falling debris or damage to highways, bridges, and roadways. Instead, most were sleeping, and because it was the end of summer, many people were camping and staying in tourist facilities along Chile's central coast. A major tsunami struck much of the epicentral coast within minutes of the mainshock.

A "state of catastrophe" was declared in 6 of Chile's 15 regions – Valparaiso, Metropolitana, Libertador O'Higgins, Araucania, Biobio and Maule. As of April 7, the Government of Chile's (GoC's) official death toll was 486 people, with 79 still reported as missing (U.S. AID 2010). The GoC confirmed that the earthquake and tsunami affected more than 1.8 million people in the four most affected regions – almost 1/8th of the country's population (U.S. AID 2010). At least 30 cities and towns were badly damage. Infrastructure, including roads, bridges, ports, airports, utilities and communication networks also sustained significant damage, with the most severe damage along the coast and in parts of the central valley; see Figure 14.1. As of March 29, the GOC is reporting that approximately 370,000 housing units were damaged by the February 27 earthquake (U.S. AID 2010); see Table 14.1.

The major industries of the region – fishing, shipping, mining, refineries, forestry, winemaking, and agriculture – were all disrupted by the earthquake, some with long-term consequences for local and, in some instances, regional economies. Details are still forthcoming. Schools, including colleges and universities, were on summer break at the time of the earthquake, so damages have not been as well reported. However, school damage was extensive across central Chile. To avoid delaying the start of the school year, the Government of Chile is merging schools and installing portable classrooms while repairs take place (Burgoine 2010). Chile's healthcare system also sustained heavy damage. Chile's Minister of

Health reports that 7 hospitals in south central Chile were not operational and another 11 are severely damaged (Burgoine 2010). They estimate that hospital rebuilding will cost USD 3.6 billion - four times the national hospital investment plan that was just launched in November 2009 (Burgoine 2010).

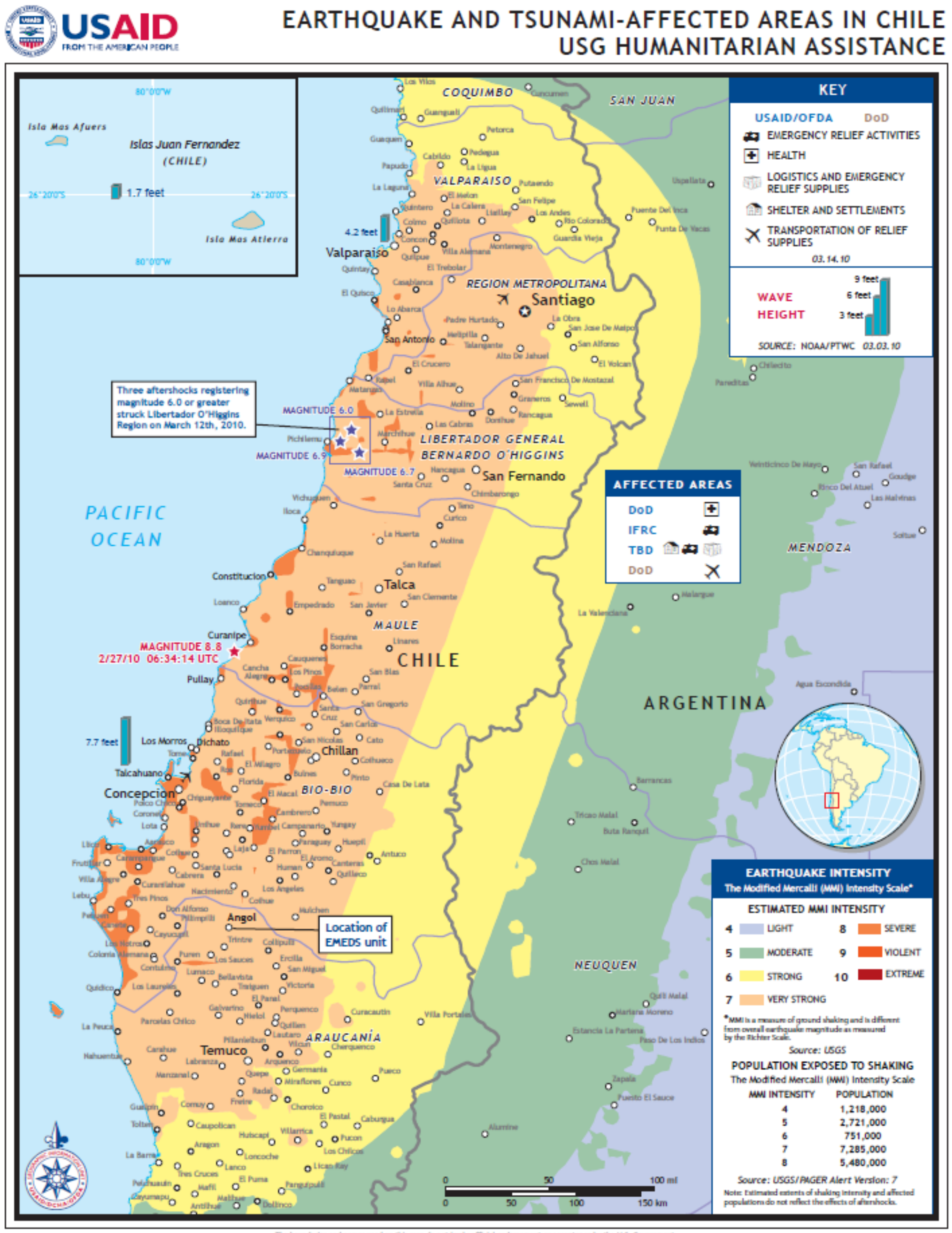

Figure 14.1. Extent of Earthquake and Tsunami Affected Area in Chile
(Source: U.S. AID, March 14, 2010)

Table 14.1. Estimate of Housing Damage (As of March 29, 2010)

	Housing Units Destroyed	Housing Units Significantly Damaged	Housing Units with Minor Damage	Total Housing Units
Coast	7,931	8,607	15,384	31,922
Urban Adobe	26,038	28,153	14,869	69,060
Rural Adobe	24,538	19,783	22,052	66,373
Multi-unit Public Housing	5,489	15,015	50,955	71,459
Multi-unit Private Housing	17,449	37,356	76,433	131,238
Total	81,444	108,914	179,693	370,051

(Source: Government of Chile)

Total economic loss estimates range from USD15 to 30 billion which, at a conversion rate of 520 Chilean Pesos (CLP), translates to 8 to 16 trillion CLP (10% to 15% of Chile's real GDP (EQECAT 2010). EQECAT expects that most of the damage, 55% to 65%, would be to residential structures, with commercial damage accounting for 20% to 30% of the total and industrial damage making up 15% to 20%. As of March 8, 2010, insurance industry estimates ranged from USD2 to 8 billion (or as much as 25% of total economic losses) (EQECAT 2010). A large degree of uncertainty in the loss estimate mainly accounts for the extent of infrastructure damage which in some cases is still unknown. While electricity and telecommunication systems are being restored fairly rapidly, water, wastewater, and transportation damages are going to take much longer to repair which can significantly escalate business interruption losses.

14.3 Urban Planning and Risk Reduction Overview

After a large-scale disaster like the February 27 earthquake, there are immense psychological, economic and political pressures to enable repairs and reconstruction as quickly as possible. Taking time to evaluate damage causes and patterns, assess future risks, and consider actions to reduce future risk may be seen as interfering with rapid recovery. However, the post-disaster period can provide unprecedented financial resources and other opportunities to reduce future risk and make other improvements. Given the relatively high level of awareness of seismic risk in Chile, and its advanced building codes and emergency preparedness systems, this earthquake provides an important case study as to how risk reduction or other improvements are made as part of the recovery.

In their landmark study, Land Use Planning After Earthquakes, William Spangle et al. studied the factors influencing rebuilding decisions following damaging earthquakes in Alaska (1964); Santa Rosa, California (1969); San Fernando, California (1971), Skopje (former Yugoslavia) (1963), and Managua, Nicaragua (1972), as well as Laguna Beach, California after a major landslide (1978) (William Spangle and Associates et al. 1980). Their interest was in understanding the effectiveness of post-disaster land use planning for achieving risk reduction in the rebuilding. They found that improved safety, post-disaster, is more easily achieved through improved structural design and construction than through changing land use. However, in specific instances, changing land use is the best response (William Spangle and Associates et al. 1980, 11).

Chile has had seismic design provisions in its codes since 1935, and the standards are comparable with the U.S. Generally, seismic codes get stricter with time and most of the recent construction in Chile follows the 1996 and 2003 updates to Chile’s Seismic Design Code. The codes apply to new construction, but it is unclear how the codes guide building retrofits or the extent to which seismic retrofitting has been required. Chilean engineers estimate that about 25% of the country's building stock is older without any seismic design provisions, and that only about 3% of the country's new construction is not to code; these are usually informal or illegal housing and non-engineered structures.

Possible structural and building code related responses that Chile may undertake in the aftermath of the 2010 earthquake include: enhanced seismic provisions for new construction, seismic retrofit requirements for existing construction, and structural hardening for storm surge and tsunami loading. It is not yet clear how storm surge and tsunami loading are addressed in Chile's current codes.

Chile also has a multi-governmental framework of land use planning with a National Ministry of Planning; strong regional planning offices that provide broad-based regional planning; and local planning agencies that are more directly involved in the siting and permitting of development and actual land use decision making. More research is needed to fully understand Chile's planning system, but input from local engineers and architects, and fellow planning researchers, revealed the following preliminary information:

- Chile has the regulatory framework to support land use planning and zoning. Recent (2006/2007) changes in national planning law have required regional and local planning agencies to update plans but many have not done so yet.
- Chile has had an active housing and urban development program focused on providing housing to replace informal settlements throughout the country.
- Chile has a coastal zone management act that provides a framework for planning and specifying desired land uses in coastal areas.
- Starting around 2004/2005, the Chilean Navy has been developing tsunami inundation flood maps for coastal areas. They are published on the Navy's website (SHOA website address still unconfirmed). While this information may have been available, it is not believed to be widely known, nor have most coastal cities incorporated the information into local plans, planning policies, and planning and building practices.
- The availability of hazard mapping for flooding, known faults, earthquake-induced landslides, vulnerable soils, areas of strong shaking, and areas of liquefaction is unknown. Its use in siting structures and building design is also unknown. Local architects do not feel that they receive adequate academic training on how to apply such information if it exists. Hazard zonation does not appear to be a part of local planning practice.
- Chile has planning and building inspection procedures, in addition to stringent building codes, but code violations and lax enforcement by local governments have been raised as issues of concern in light of the spectacular failures of some newer buildings.

As part of the restoration and rebuilding, there are also a range of possible land use responses that Chile's national government, as well as local and regional governments, may pursue in the restoration and rebuilding. They include:

- Changes in land use plans and regulations
- Changes in land use or occupancy
- Relocation of facilities
- Redevelopment
- Land acquisition

In additional to structural and land use decisions, there are other possible risk reduction responses that Chile may choose to pursue. They include public education about hazards and risk, and enhanced warning and response planning.

According to William Spangle et al (1980, 11), the key factors influencing post-disaster risk reduction decisions are:

- The cause and extent of damage
- The ability to delineate hazardous areas and evaluate the level of risk pertaining to potential uses in those areas
- Post-earthquake authority and capabilities of local government to impose building and land use limitations
- Availability of, and conditions for the use of, any large blocks of funding, such as from the national government, for post-earthquake recovery.

The following parts of this section of the report explore these issues in further detail with an emphasis on identifying causes and extent of damage in areas that are likely to have long-term rebuilding challenges, as well as opportunities for significant risk reduction and other improvements as part of the rebuilding.

14.4 Causes and Extent of Damage

This section summarizes observations made from the entire GEER team on the extent of damage from tsunami inundation as well as the following geologic effects:

- Severe shaking and site amplification of ground motions
- Coastal uplift and subsidence
- Liquefaction and lateral spreading
- Landsliding

More details on the causes and extent of damage can be found in the other, referenced sections of the GEER report. By no means is this an exhaustive analysis. Instead, its main purpose, at this early stage post-disaster, is to identify candidate areas to continue to monitor as part of the recovery as well as issues for further study.

14.4.1 Severe shaking and site amplification of ground motions.

Strong shaking lasted for over ninety seconds in some areas and shaking intensities of VII and greater were felt over a vast area, affecting 12 million people (USGS, 2010). As a result, subsequent damage and ground-surface effects occurred over a north-south length of more than 600 km (375 mi). This is roughly equivalent to the entire coastline for the states of Washington and Oregon along the Cascadia subduction zone, or the distance between Los Angeles and San Francisco along the San Andreas system in California. Long duration ground motions and their effects on buildings and infrastructure are directly relevant to rupture scenarios for a Cascadia megathrust earthquake in the Pacific Northwest as well as to a large San Andreas Fault event, like the M7.8 Great Southern California Shakeout scenario.

According to zoning in Chile’s seismic building code, buildings in the earthquake-affected region must be constructed to withstand up to 0.4 g (force of gravity) in peak ground accelerations. Available ground motion records are showing ground motions that are less than 0.4 g. And, commensurately, shaking damage was minimal in most modern, engineered structures. However, the strong shaking was particularly harmful to adobe, unreinforced masonry, and other non-engineering buildings. As the housing damage statistics show, 50,576 (62 %) of the 81,444 housing units that were totally destroyed were adobe structures. About half of these structures were in more urban settings, while others are classified as rural dwellings. It is unclear how the GoC is making its urban-rural distinction. It is also unclear how the GoC is treating coastal adobe structures, since it has a separate count for coastal dwellings (see Table 14.1).

Concentrations of collapsed and heavily damaged structures due to strong shaking were observed in both the central valley and coastal areas during the reconnaissance. Chile's central valley is a basin of young alluvial soils. Towns are typically built alongside rivers and the young sediments likely influenced strong ground motions. Further study is needed to characterize whether soft alluviums or other site affects contributed significantly to the damage patterns and may need to be considered as part of the rebuilding. Some of the localities with significant concentrations of shaking-related damage are shown (in roughly north to south order) in Table 14.2. Strong shaking related damage occurred throughout the coastal areas; however, much of it was erased by the tsunami. Pockets remain, particularly in areas of older building stock that were not within the tsunami's path.

Areas of concentrated damage in older and more vulnerable building stock are potential areas where changes in land use or large-scale redevelopment may be likely. It has been reported that the city of Chillan, in the central valley area, experienced heavy damage in a 1939 earthquake. It has been an explanation for why there was less damage in Chillan in the 2010 earthquake. Subsequent investigations of Chillan should verify post-1939 reconstruction, structural and land use risk reductions made as part of the rebuilding, and building performance in the 2010 earthquake. Chillan could be a good comparative case study with Talca or other central valley cities that had a higher percentage of older buildings that suffered extensive damage in 2010.

Section 5 details observations of soft soil related ground amplification and damage in select areas of Santiago, Vina del Mar, and Talca. The Santiago and Vina del Mar observations focused on site effects at modern, engineered structures. Additional pockets of heavy damage also exist in the older parts of several other central valley and coastal area cities. Two examples are Parral (37,822 population) and Cauquenes (41,217 population) located on the western side of the central valley. In these two localities, local commerce was functioning and much of the town was inhabited and active. These areas are less likely to consider substantive land use changes or redevelopment. It is unclear at this time whether building owners will be required to repair or rebuild to higher seismic standards.

14.4.2 Tsunami Inundation

The February 27, 2010 earthquake in Chile generated a tsunami that arrived within 30 minutes of the earthquake in the epicentral region of the Chileans coast. Towns in this region of the coast, such as Talcahuano, Constitucion, and Curanipe, had wave heights of 3 to 4 meters. Within an hour, the tsunami struck further north near the ports of San Antonio and Valparaiso with heights of 0.75 to 2.5 meters, as well as to the south. Tsunami inundation extended over 1 kilometer inland in some areas and also propagated much further up the mouths of rivers and streams.

Section 13 details the impacts of the tsunami along Chile's coast, and Section 4 provides details on wave measurements taken as part of the investigations of coastal deformation. This section of the report focuses on areas of the coastline where tsunami damage was most extensive. Table 14.3 lists from north to south, the most heavily impacted localities where risk reduction measures, such as changes in building codes and land uses, may be implemented as part of the recovery. In particular, the towns of Bucalemu, Constitucion (see Figures 14.2 and 14.3), Curanipe (see Figures 14.4 and 14.5), Dichato, and Talcahuano (see Figure 14.6) sustained extensive damage. Some cases also had pre-existing economic challenges and substantial life loss resulting from the tsunami. These conditions may make these areas likely candidates for post-disaster risk reduction and other improvement efforts.

Table 14.2 Areas of Concentrated Shaking-Related Damage

Central Valley area	• Santa Cruz. Extensive damage to masonry and adobe structures. • Marchihue (small town approaching the Coast Range). Nearly all adobe and masonry buildings collapsed or severely damaged, but the few modern buildings appeared undamaged. • Curico (population 119,585). The downtown commercial district (about 20 city blocks) sustained heavily damage. As of March 17, much of the debris had been cleared in the downtown district, remaining damaged structures were gutted, and the district was devoid of business activity. • Talca (population 210,797). There was significant damage to older masonry and adobe structures. Media report of 1,800 housing units being demolished the week of March 14 – 18. • Curepto (population 10,812). Damage reported to be extensive. • Maule. Damage reported to be extensive.
Coastal area	• Chanco (population 9,457). Much of the adobe and masonry buildings are seriously damaged. Chanco is well away from the coast so all the damage is from shaking, not tsunami. Paredones. Damage reported to be extensive. Away from the coast so all damage is from shaking, not tsunami. • Constitucion (population 46,081). Significant adobe and masonry building damage in the downtown area surrounding the main plaza. The shaking damage merges with the tsunami damage that extends inland along the Maule River. (This example is discussed further in section 14.3.2) • Talcahuano (population 250,348). Adobe and masonry building damage merges with tsunami damage in the older downtown area near the bay and ocean ports. • Concepcion (population 216,061). Adobe and masonry building damage in older areas of the city, such as the city center. Site of two severely damaged high-rise structures; the cause of those damages is still uncertain.

Figure 14.2. Constitucion. Debris removal and road clearing still underway in the tsunami inundation zone along the Maule River. (S35.340323°, W72.396772°; 16:54 hours on 3/15/2010).

Figure 14.3. Constitucion. Tsunami damage merges with shaking related damage in the older section of the city center with its many adobe and unreinforced masonry buildings.
(S35.335383°, W72.410055°; 17:25 hours on 3/15/2010).

Figure 14.4. Curanipe. Main beach and much of town’s debris has been completely cleared.
(S35.843823°, W72.6385°; 15:58 hours on 3/17/2010)

Figure 14.5. Curanipe. According to locals, hundreds were at a campground in this grove of trees. Many ran to the beach to avoid falling trees and were swept away by the tsunami.
(S35.843957°, W72.69647°; 15:59 hours on 3/17/2010)

Figure 14.6. Tsunami damage near Navy facilities and bayside port of Talcahuano.
(S36.711305°, W73.114808°; 12:39 hours on 3/16/2010)

14.4.3 Coastal Uplift and Subsidence

As the earthquake ruptured, it uplifted the central Chilean coast (as much as 3 meters) and also subsided elsewhere (as much as 2 meters). It also permanently displaced much of the South American continent. Buenos Aires moved 4 centimeters closer to Chile. The city of Concepcion, near the epicenter, moved 3 meters to the west. The uplift and subsidence have had immediately visible impacts to shorelines, beaches, ports, and harbors. The subsurface deformation may have resulted in more hidden damage to subsurface pipelines, infrastructure, foundations, and other elements vulnerable to differential displacements.

Section 4 details the measurements and evidence of uplift and subsidence observed along the coast. The towns of Bucalemu and Lebu are featured in that section and also here. Both towns have experienced substantial deformation that may result in land use changes and risk reduction efforts.

Bucalemu (S34.642627°, W72.043017°) (approximate population 1,500) is part of the coastal region north of Constitucion that appears to have had substantial tsunami inundation of over 3 meters at the shore, coupled with vertical subsidence of 0.5 meters. There was limited evidence of shaking-related damages to non-tsunami impacted structures. The small resort and fishing village is a popular tourist destination with lodging, restaurants, discos, and shops all nestled in and around an inland estuary and lagoon. In the summertime, the town's population doubles to about 3,000 with tourists.

Table 14.3 Areas of Concentrated Tsunami-related Damage

Pichelemu (25,000 approx. pop.)	The dunes, bluffs, and levees protected much of the town. Tsunami damage extended across the main beach road and also propagated up a channel on the north end of town. Beach front redevelopment is likely and may involve structural and land use changes, such as building elevations, setbacks and reductions in occupancies.
Bucalemu (1,500 approx. pop.)	The tsunami inundated the small lagoon area and propagated up the channel, depositing fishing boats more than 100 meters to the east of the coast highway bridge (and more than 1 kilometer from the shoreline). Houses, discos, cabanas, and campgrounds were destroyed. (This example is discussed further in section 14.4.3)
Boyeruca	Small village with reportedly substantial tsunami damage. It was not part of this investigation.
Lipimavidia	Small village where tsunami damage appears to have been reduced somewhat by the dunes. But, it still crossed the road in lower-lying areas and inundated structures along the inland side of the coast road as well.
Iloca	The town was heavily damaged by the tsunami. The north end of the town sustained less damage than the south side.
Constitucion (46,081 pop.)	Tsunami damage is quite extensive. The tsunami reportedly traveled more than 4 kilometers up the Maule river. Damage also extends inland for several blocks from the river and the beach front (e.g., 10 blocks long and 3 to 4 blocks inland).
Los Pellines	A small village that may have been suffering economically before the earthquake due to a nearby paper pulp plant closing. Tsunami damage impacted the beachfront and streamfront structures.
Pelluhue	A resort and fishing village. Low-lying areas, around beaches, coves, and the mouths of streams, were hit hard by the tsunami. There were tsunami-related deaths in beachfront motels.
Curanipe	A resort and fishing village with an extensive beach that had camping grounds, discos, tourist accommodations, and housing. Low-lying areas, around beaches, coves, and the mouths of streams, were hit hard by the tsunami. There were tsunami-related deaths in the campgrounds and beachfront hotels and discos. Locals reported that local government considerations of changes in land use were already underway.
Dichato	One of hardest hit towns. Only buildings on higher ground were undamaged. A number of stronger structures also survived, but with substantial first floor damage. A boat was swept inland over 3 kilometers.
Penco	Tsunami damage both in the town and the port. Penco received substantive debris from neighboring Talcahuano port, including containers and a marine ship.
Talcahuano (250,348 pop.)	Tsunami damage is extensive at the Navy port, bayfront and oceanfront port facilities, and in the older downtown area near the bay and port. The ocean front and downtown areas may have been in decline prior to the earthquake and may be a focus for post-earthquake redevelopment.

Local policeman say that there were many cabanas, campgrounds, and discos along the estuary, and about 500 people were in this low-lying area when the earthquake hit (see Figures 14.7a and 14.7b). There was a lot of moonlight and many people were out dancing. There was no tsunami alarm. But, many of the local people, firemen and police shouted to get out knowing that a tsunami might strike after the earthquake shaking stopped. Some saw the ocean receding and knew it was a forewarning of tsunami. Vacationers jumped into their cars and drove inland and up into the hills above the town. The tsunami was up to 2 meters deep in the estuary valley area and penetrated nearly 1 kilometer up the river, pushing fishing boats upstream under the coast highway bridge.

Prior to the earthquake, the town had been embarking in a fairly significant capital improvement project that included expansion of the lagoon and construction of a boardwalk along the shore (see Figures 14.8 and 14.9). Local residents say that the lagoon used to be only 10 meters wide and did not have a permanent opening to the sea and the rough waves like it does now. They say the beach extended about 20 meters beyond the arched, orange bridge out next to the pub building at the rocky point. Now the waves are crashing up against the pub building (see Figure 14.10). The cement boat launch ramp next to the pub building is now under water and the beach that local fisherman used to pull their boats up onto is gone.

Bucalemu's physical geography has been dramatically altered by the earthquake and tsunami. High-density tourist-oriented uses that were previous adjacent to the estuary may be much more vulnerable to flooding, storm surge, and tsunami hazards. As part of the rebuilding, changes in land use, reductions in allowable densities, and condemnation or acquisition of low-lying areas both along the estuary and the adjusted shoreline, may be considered in addition to other risk reduction and community improvement measures.


Figure 14.7a and 14.7b Bucalemu.. Much of the tsunami debris and damaged structures had already been removed from the low-lying area along the estuary that had campgrounds, hotels, restaurants, and discos. As many as 500 people were in this area when the earthquake struck. (S34.62552°, W72.038395°; 09:05 hours on 3/15/2010)

Figure 14.8. Bucalemu. Prior to the earthquake, the town had been expanding the lagoon and constructing a boardwalk along the shore. (S34.642367°, W72.040965°; 09:06 hours on 3/15/2010)

Figure 14.9. Bucalemu. Local residents say the beach extended about 20 meters beyond the arched, orange bridge out next to the pub building at the rocky point. (S34.641713°, W72.043115°; 09:09 hours on 3/15/2010)

Figure 14.10. Bucalemu. Waves crashing up against the pub building. The cement boat launch ramp and former beach are now submerged after the tsunami. (S34.474325°, W72.023918°; 10:42 hours on 3/15/2010)

Lebu (S37.591897°, W73.668353°) is part of the coastal region that had as much as 2 meters of uplift in the February 27 earthquake. Lebu is the capital of the province of Arauco. Its economy centers on fishing, forestry, trade, and services. It is also home Lebu mine (Carvil), the last coal mine in the area following the closure of Lota, Schwager and Trongol; it has been kept open with state subsidies.

Coseismic uplift has stranded boats in Lebu's harbor (see Figure 14.11). The lighthouse northwest of the Lebu Harbor inlet is on an island that was uplifted enough to almost form a peninsula. Lebu will likely have significant land use planning issues as part of the rebuilding that may include relocation and construction of the harbor and appropriation of rights to the newly-created land. This area was also uplifted in the 1960 earthquake, so there are historic decisions and ongoing risk management issues to be studied as well.

14.4.4 Liquefaction and Lateral Spreading

Evidence of ground cracking, liquefaction, and lateral spreading have been documented across a vast region that is roughly 600 kilometers long and 100 kilometers wide. River sediments were especially vulnerable to ground deformation, and observations were made along many of the regions large, east-west trending watersheds the flow into the Pacific Ocean. Areas alongside lakes, bays, and ports were also especially vulnerable. Section 6 documents in much greater detail the ground deformation observations made as part of the GEER reconnaissance.

Figure 14.11. Boats stranded in Lebu’s Harbor. (S37.603694° W73.654372°; 1800 hrs on 03/10/2010).

For the most part, these deformations are fairly distinct occurrences and were not a significant contributor to the overall damage levels. However, there are some potential areas for more focused study. A key concern is ports and bridges, where ground deformations were a consistent cause of damage; sites should be remediated as part of the repairs. There were also a few instances where the future stability and suitability of building sites may be questioned as part of the rebuilding. Two such observations are briefly discussed below, and are good candidates for long-term observation.

Lateral spreading along the banks of Lago Vichuquen (S34.796068^{o}, W72.078810^{o}), near the Laguna Torca National Reserve, severely impacted the road bed, underground utilities, and lakeside properties (see Figures 14.12, 14.13, and 14.14). Much of the ground underlying a small lakeside cabana hotel has been affected. Over 50 feet of shoreline was submerged and there was evidence for submarine landsliding as well. Sections of lawn, trees, and boat docks were all submerged. The shore side piers of several cabanas were also submerged and there was evidence of structural damage as well. The future viability of this property is definitely in question since there is not adequate land area between the cabanas and the road to setback and reconstruct. Ground deformation was observed in another location along the lake road but did not appear to be a consistent feature along the shoreline. Other boat docks along the shoreline did not appear damaged or submerged, but further study is needed.

Figure 14.12. Lago Vichuquen,. Lateral spreading on the inland side of the lakefront road. (S34.39097°, W72.077815°; 12:46 hours on 3/15/2010)

Figure 14.13. Lago Vichuquen. Lateral spreading has affected much of the ground underlying a small lakeside cabana hotel. Some shore side piers of the cabanas were submerged and there was evidence of structural damage as well. (S34.796345°, W72.07885°; 12:58 hours on 3/15/2010)

Figure 14.14. Lago Vichuquen, March 15. The lawn, trees, and boat docks are all submerged and there was evidence for submarine landsliding as well. (S34.79634°, W72.078852°; 12:52 hours on 3/15/2010)

Several port side properties at Port San Vicente in Talcahuano were also significantly damaged by lateral spreading and ground deformation (S36.72593^{o}, W73.12872^{o}). Two fish processing plants, Alimentos Marinos and Concession Maritima, were both severely damaged and not in operation on March 15 (see Figures 14.15 and 14.16).

Port San Vicente is a major fish processing facility and the two plant closures are likely to have prolonged impacts on the region's fishing economy. On March 14, fishing boats were observed dropping their loads in the harbor since the plants were not operational. Alimentos Marinos employed 300 people directly and another 300 indirectly. Insurance adjustors were onsite on March 15 and the former plant manager said the facility will likely not be rebuilt in this location. This type of relocation could have significant local economic ripple effects. The suitability of the port side land for rebuilding is also a major question. Across the port road from the two damaged plant is a tank farm facility that had no observable damage (see Figure 14.17). Perhaps, the tank farm had better site preparations as part of its construction. Also, the port road was slightly elevated from surrounding lands and may be part of a levee system along a former shoreline. The fish processing facility may be sited on much more vulnerable bay fills than the tank farm. Additional study is needed to clarify these concerns.

Figure 14.15. Port San Vicente, Talcahuano. The damaged Alimentos Marinos fish processing plant will likely not be rebuilt at this port. (S36.725983°, W73.128817°; 11:45 hours on 3/16/2010)

Figure 14.16. Port San Vicente, Talcahuano. The damaged Concession Maritima fish processing plant. (S36.725892°, W73.128678°; 11:50 hours on 3/16/2010)

Figure 14.17. Port San Vicente, Talcahuano. View of two damaged fish processing plants and nearby tank farm. (S36.724605°, W73.136475°; 12:18 hours on 3/16/2010)

14.4.5 Landsliding

Earthquake-induced landsliding was not prevalent in this earthquake. Section 12 documents the landsliding observations made as part of the GEER reconnaissance. Rockfalls and slides were observed in highway road cuts traversing the coast ranges (see Figure 14.8). Slumping was also observed along coastal bluffs and river banks. While, there do not appear to be any large-scale landslides that would have significant long-term rebuilding issues, landsliding may have some important near- to medium-term implications for recovery.

The February 27 earthquake occurred at the end of the dry, summer period and ground water tables were low. Slope instability may significantly increase into the rainy season, with more significant episodes of landsliding possible as future earthquake sequences occur. Access across the coast ranges to coastal areas could be significantly affected by rain-induced slope failures.

Also, many temporary settlements were observed in hillsides and on coastal bluffs (see Figure 14.19). The site selection of both informal and formal (organized) encampments is likely being driven by tsunami-hazard related concerns. Formal encampments established by the government and non-governmental organizations seem to have included some site preparations. However, informal settlements did not. These encampments may be vulnerable to landsliding in future aftershocks or with increased rainfall and soil moisture conditions. Local architects report that there is a history of temporary encampments becoming permanent, low-cost housing.

Figure 14.18. Lota Alto, Bio Bio region. Failures on the road cuts along one of two main highways leading to the Port of Coronel and surrounding coastal cities. (S37.047677°, W73.061597°; 15:30 hours on 3/16/2010)

Figure 14.19. Temporary housing settlement being established in the hills above the coast near the town of Lipimavidia. (S34.853393°, W72.135148°; 13:41 hours on 3/15/2010)

14.5 Post-Earthquake Evaluations of Hazards and Risk

There is a tremendous need for timely and credible evaluations of the hazards as well as future risks throughout the region affected by the February 27 earthquake. Low-lying coastal, bay, and riverine areas that had tsunami inundation, as well as areas with concentrated building damage, should be given priority for evaluation. Priority areas for mapping might include, put should not be limited to, Bucalemu, Constitucion, Curanipe Dichato, Talca, and Talcahuano, as well as specific sites in Santiago, Valparaiso, and Vina del Mar.

As a first step, high hazard areas should be delineated and followed by more detailed studies. Areas with problems for tsunami evacuation also should be identified to assist with evacuation route design and education efforts. Hazard delineation can be accomplished fairly readily, but evaluating future risk is far more difficult. The earthquake affected region has experienced many large earthquakes in the past century, including the Chillan Earthquake (M7.7) of 1939, which damaged an area covering 45,000 square kilometers and killed 30,000 people; and the catastrophic series of earthquakes and tsunamis in May and June of 1960 that killed hundreds, displaced about 1 million people, destroyed over 400,000 houses, and resulted in damage totaling over $417 million (1960 U.S. dollars) (RMS 2009). The risk of future earthquakes and tsunamis, and their consequence, need further study, particularly in light of geologic and tsunami impacts of the 2010 earthquake and the improved building stock that will likely result from the rebuilding.

It is hoped that the series of tsunami inundation flood maps developed prior to the earthquake will be widely distributed to local governments and private landowners in the most heavily affected areas. Additional damage and hazard mapping efforts are reportedly underway in some of the most heavily impacted areas, like Constitucion and Dichato.

14.6 Post-earthquake Authority and Capacity of Local Governments for Risk Reduction

Initial investigations suggest that local governments will have authority for post-earthquake land use and rebuilding considerations, but there capacity to deal with technical issues of hazards evaluation and risk reduction is uncertain. Technical assistance may be needed for hazards mapping, risk evaluation, policymaking and decision making, and enforcement.

More education and training is needed, particularly with local government decisionmakers, architects, planners, as well as landowners. These stakeholders need to understand the process and purpose of hazard and risk evaluations, as well as how to interpret and use the resulting information in decision making. Such education and training will be critical if there is political will and the desire to reduce future risk as part of the rebuilding process.

In rebuilding, local governments should consider reconstructing easily accessible and well-marked tsunami evacuation routes and shelters in areas where access may have been more limited prior to the earthquake. Additional consideration should be given as to whether to allow high-density and tourist related uses in tsunami hazard areas. Such uses include campgrounds, hotels, and nightclubs. The public also need to be involved in post-earthquake planning and decision making. It is unclear how versed Chile’s local governments are in public involvement processes.

Priority localities for monitoring recovery and rebuilding decision making are: Bucalemu, Constitucion, Concepcion, Curanipe, Curico, Dichato, Lebu, and Talca.

14.7 National Policies and Plans for Post-Earthquake Recovery

Soon after taking office on March 11, President Pinera created a special reconstruction team to advise on the rebuilding effort and also began reviewing the national budget to make adjusts in2010 to help finance reconstruction (Burgoine 2010).

Based on observations in mid-March, the national government's initial priorities in recovery have been to help disaster-impacted populations with basic food, water, and shelter needs; repair and reconstruct the main highways and bridges; inspect buildings; and remove debris.

Interviews with impacted residents verified that most were receiving basic assistance of food, water, and shelter, but there were a few exceptions where these services had been delayed or were insufficient. Most residents interviewed did not expect to receive government assistance for rebuilding their damaged homes or businesses.

On March 29, the GoC announced plans for a national housing reconstruction plan called "Chile United to Build Better" (Van der Horst 2010). The plan will cost approximately $2.5 billion and will provide housing subsidies to assist nearly 196,000 families affected by the February earthquake and tsunami. Housing subsidies will be provided between April 2010 and April 2012 and will target the most vulnerable and middle-income families. Additional details of the subsidies, conditions for funding, are needed.

Based on initial investigations, however, hazard mitigation does not appear to be an integral part of national, regional, or local planning or disaster management policies. There do not appear to be any guidelines to require mitigation as part of post-disaster assistance, such as the local and state hazard mitigation planning requirements of the U.S. Disaster Mitigation Act, or post-disaster assistance requirements of the U.S. Stafford Act.

But, it is early in the recovery and government agencies, at all levels, are only beginning to plan for the rebuilding. Given Chile's fairly robust framework of building standards and planning regulations, there are many potentially valuable lessons to be learned (at the national, regional, and local levels) on how risk reduction and other improvements are considered and addressed in rebuilding from the February 27 earthquake.

14.8 References

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