

Data collection after the 2010 Maule earthquake in Chile

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Abstract This article presents an overview of the different processes of data recollection and the analysis that took place during and after the emergency caused by the M_w 8.8 2010 Maule earthquake in central-south Chile. The article is not an exhaustive recollection of all of the processes and methodologies used; it rather points out some of the critical processes that took place with special emphasis in the earthquake characterization and building data. Although there are strong similarities in all of the different data recollection processes after the earthquake, the evidence shows that a rather disaggregate approach was used by the different stakeholders. Moreover, no common standards were implemented or used, and the resulting granularity and accuracy of the data was not comparable even for similar structures, which sometimes led to inadequate decisions. More centralized efforts were observed in resolving the emergency situations and getting the country back to normal operation, but the reconstruction process took different independent routes depending on several external factors and attitudes of individuals and communities. Several conclusions are presented that are lessons derived from this experience in dealing with a large amount of earthquake data. The most important being the true and immediate necessity of making all critical earthquake information available to anyone who seeks to study such data for a better understanding of the earthquake and its consequences. By looking at the information

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provided by all these data, we aim to finally improve seismic codes and engineering practice, which are important social goods.

Keywords Post-earthquake data collection · 2010 Chile earthquake · Shear wall building damage · Structural damage · Seismic codes · Resilience

1 Introduction

The M_w 8.8 February 27th, 2010, Chile earthquake, affected more than 12 million people (75 % of the Chilean population) and impacted a large geographic area, including several large urban areas (e.g., Santiago). This earthquake tested the country's building codes, construction practice, disaster preparedness efforts, emergency response actions, and community resilience. It, therefore, offers a unique opportunity to investigate the country's overall response to a large seismic event. In particular, the research described here is motivated by an assessment of our reconnaissance practice and the role that the collected data provide in better understanding the performance of our physical and social stocks in coping with this catastrophic event. A large amount of data (structured and non-structured) was collected during and after the earthquake, and used by stakeholders in a myriad of ways, sometimes conflicting, during the phases of emergency, recovery, and reconstruction (ERR). These stakeholders include ministers, undersecretaries, service directors, non-governmental organizations (NGOs), and technical professionals (i.e., architects and structural engineers). The paper will describe innovative methods for seismic reconnaissance data collection as well as the effectiveness of the data for decision-making by key stakeholders in various stages of the disaster.

The Maule megathrust earthquake struck central Chile (latitudes from 33 to 38) at 6:34:14 UTC, and mobilized a section of the underlying Nazca plate of approximately 540 km by 200 km. The event released a seismic moment of 1.8×10^{22} N m (USGS 2010) and the rupture was bilateral; the hypocenter was located at 35.91°S–72.73°W at depth 35 km. This event was generated by the sudden release of an Andean subduction zone widely known as a mature seismic gap (Lorito et al. 2011; Moreno et al. 2010; Ruegg et al. 2009). In this region, the Nazca and South American continental plates converge at a rate of about 68 mm/year (Ruegg et al. 2009). Although most of the seismic gap appears to have been involved in the slip, there is evidence that part of the gap remains strongly coupled (Lorito et al. 2011). Several studies (e.g., Delouis et al. 2010; Tong et al. 2010; Vigny et al. 2011; Pollitz et al. 2011; Lin et al. 2013) have obtained models of co-seismic slip distributions for the 2010 Maule earthquake using InSAR and GPS data. The maximum slip was located north of the epicenter near the town of Pichilemu (161 km southwest of Santiago), reaching values in the range 15–20 m depending on the data set and model used (Delouis et al. 2010; Lay et al. 2010; Lin et al. 2013; Lorito et al. 2011; Moreno et al. 2010; Pollitz et al. 2011; Tong et al. 2010; Vigny et al. 2011). A secondary patch of large slip is found south of the epicenter near Lebu (536 km southwest from Santiago).

Large surface displacements were measured nearest the shoreline using InSAR and GPS data (Tong et al. 2010; Vigny et al. 2011). The vertical component of the displacement field measured by GPS (Vigny et al. 2011) shows upward surface displacements along the shoreline and downward displacements inland. The horizontal displacements were directed towards the SW and W and are consistent with the direction of plate convergence (Ruegg

et al. 2009). Based on the InSAR data, it is possible to identify two zones of major co-seismic displacement gradient, namely the Arauco Peninsula ($37.15^{\circ} \rightarrow 37.4^{\circ}\text{S}$, $73.42^{\circ} \rightarrow 73.67^{\circ}\text{W}$) and Pichilemu (34.4°S , 72.0°W), south and north from the epicenter (Tong et al. 2010), respectively. Maximum vertical displacements are associated with the southern cluster, where upward deformation measurements reached 1.7 m (Lin et al. 2013; Vigny et al. 2011), and are consistent with field observations (Fariás et al. 2010). Larger horizontal displacements were measured along the coast from Constitución (35.33°S , 72.42°W) to the south (Lin et al. 2013; Vigny et al. 2011) with values that range from 3.3 to 5 m (Delouis et al. 2010; Vigny et al. 2011).

A significant portion of Chile's assets and population, increased due to the accelerated economic development of the country in the last 25 years, were exposed to the strong and long duration shaking of this severe earthquake. The earthquake affected over four million households, 24 % of which were insured; about one-fifth of those insured sustained damage and filed insurance claims. The government estimated the direct and indirect losses due to the earthquake and tsunami in \$30 billion USD, or about 18 % of Chile's GDP; the economic sectors with greatest impact include industrial, fishing, tourism, housing, and education. About 71 % of these losses correspond to property destruction, future GDP losses, and emergency expenses that reached \$1.7 billion USD (Gobierno de Chile 2010). According to OECD, of the G-20 plus some other selected countries, Chile presents the largest percentage of the GDP in damage attributed to catastrophes between 1980 and 2011 (1.13 %), which is equivalent to more than \$2.5 billion USD per year (OECD 2012). The insured losses total an estimated \$8 billion USD, of which, just \$11 million USD were covered by local insurance companies (SVS 2012). However, the early morning timing of the earthquake during the country's summer vacation likely minimized the overall economic and other impacts of the earthquake.

In addition to the impacts of the strong ground shaking, the subsequent tsunami also wreaked havoc along Chile's coastline. As a result of the sea floor deformation, the earthquake generated a tsunami that affected over 500 km of the coastline; the tsunami runup reached 29 m on a coastal steep bluff at Constitución (Fritz et al. 2011). According to the literature, the tsunami killed 124 people (69 in Maule, 33 in Biobío, 18 in Robinson Crusoe Island and Easter Island, and 4 in Mocha Island), nearly a quarter of earthquake-related fatalities. Earthquake knowledge transmitted over generations in coastal Chilean towns, and firsthand experience with historic seismic events (e.g., the great 1960 Valdivia earthquake), made locals evacuate immediately to higher ground. However, many tourists residing in low-lying campgrounds did not know to evacuate; these tsunami victims are attributed to poor risk communication and lack of effective evacuation alerts.

In order to manage the response after the earthquake, the National System for Civil Protection (NSCP) was activated after the earthquake. The National Emergency Office (ONEMI) was the lead in coordinating the national emergency plan. Civil protection is carried out by an integrated system of organizations, services, and institutions that belong to the public and private sectors, including community leaders and volunteers. Figure 1a shows the organizational structure and associated political levels of key disaster stakeholders. The chain of command starts with the President, and runs to the Minister of Interior and Public Security, to the Regional Intendants, to the province Governors, and finally to the communal/municipal Mayors. The Civil Protection Committee (CPC) and an Emergency Management Committee (EMC) are together defined as the Emergency Operation Committee (COE). The COE is replicated at all jurisdictional levels to support decision making by the corresponding political authority leading the CPC. The COE convenes in a predefined location equipped for the emergency, including the

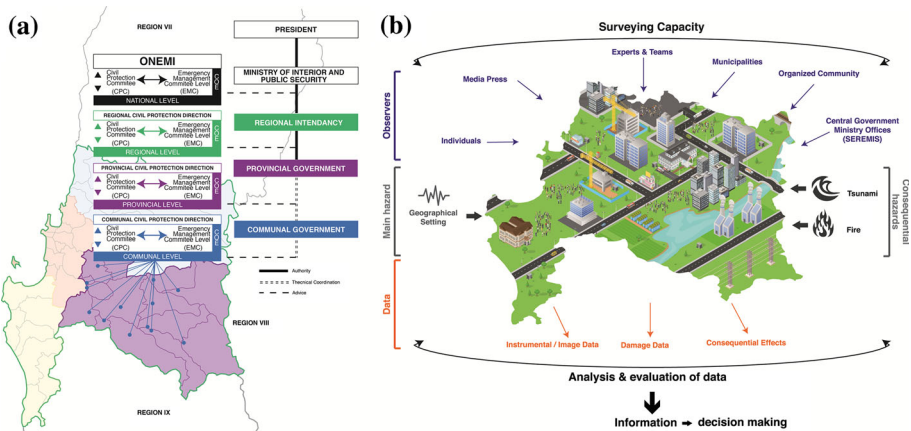


Fig. 1 a Schematic representation of the National Civil Protection System and the types of interactions with ONEMI and the COEs; b conceptual representation of the large scale, natural, *shaking table test* of the country, some agents, type of data generated, and information used in the decision making processes

communication facilities necessary to centralize data collection, the analysis and evaluation of the information required for timely, quick, and accurate decisions, the transfer of relevant information to superior authorities, the technical services in charge of the recovery works, and the press and social media. All three armed forces and the national police are represented in each of these Committees. This integrated system (Fig. 1a) is coordinated by ONEMI, and aims to protect people, their goods, and the environment from a collective risk situation.

2 Data gathering

An earthquake is somewhat equivalent to a large real-scale experiment on a shaking table. Once the event occurs, scientists, engineers, sociologists, press, government, and other individuals start gathering and interpreting data with completely different purposes and levels of knowledge as shown schematically in Fig. 1b. A myriad of different methods were used to survey the extensive area affected by this earthquake, depending on the type of data required and the system observed. Some of these methodologies and procedures will be analyzed in more detail later in this article. Data collected can be organized into: (1) objective instrumental, geological, and geotechnical data needed to characterize the main event and the consequential hazards; (2) data on the response of physical systems (built environment); (3) data on the response of people and communities; and (4) data on the response of services and other complex systems.

A large number of international teams visited Chile immediately after the earthquake to survey the affected region, and to collect perishable earthquake data. Many of them played an important role in surveying and mapping data at different scales after the earthquake and helped cover the vast affected area. The country was very supportive of these international seismic experts. The teams were sponsored by professional associations, universities, and private firms; the team members had expertise in the fields of architecture, civil construction, structural, geotechnical, and hydraulic engineering. Some came to learn

about the ground motion itself and its effects on geotechnical and structural aspects; the collected data also helped identify imminent risks to provide short-term solutions, such as the emergency stabilization of several almost collapsed buildings in the city of Concepcion. Other teams gathered ground motions and building shaking records during aftershocks. The results of these visits have been reported in several journal publications (e.g., Moehle et al. 2012; Fritz et al. 2011), extended reports (e.g., Bray and Frost 2010; Comerio 2013; Tang and Eidinger 2013), and many community outreach activities. In parallel to international reconnaissance efforts, many local independent teams collected data to inform actions of sectorial ministries (e.g., health, education, housing, and public works).

Ground motion and geophysical data is of paramount importance in increasing our knowledge of earthquakes. However, more often than not, instrumental data does not become immediately available. Shown in Table 1 are the main sources of ground motion and geophysical data collected from this event. The main accelerometer strong motion network of the country (RENADIC) was managed by University of Chile. This network collected various previous earthquake records, such as the 1985 Valparaiso M_w 8.0 earthquake, the 2007 Tocopilla M_w 7.8 earthquake, and others. The M_w 8.8 Maule earthquake was recorded by 32 strong motion instruments (FCFM 2012). As opposed to RENADIC records, acceleration records obtained in ten stations by the National Seismologic Service (SSN) from Universidad de Chile were published online shortly after the earthquake. This information was published as raw data without instrumental correction and instrument details required to convert recorded counts into units of acceleration. RENADIC did publish reports with plots of the recorded ground motions showing the locations of the instruments, PGA, the history of recorded accelerations, and their response spectra; the final of these reports was published 8 months after the earthquake (Boroschek

Table 1 Ground motion and geophysical data sources for the 2010 Maule earthquake

Data type	Source	Website
Acceleration records	Servicio Sismologico Nacional (SSN) of Chile	http://www.sismologia.cl/
	RENADIC	http://terremotos.ing.uchile.cl/
Waveform data	IRIS	http://www.iris.edu/wilber3/find_event
GPS	UNAVCO Data Archive	http://facility.unavco.org/data/dai2/app/dai2.html#
	International GNSS Service	http://fgscb.jpl.nasa.gov/
	Argentinian GPS network operated by Instituto Geografico Nacional (IGN) of Argentina	http://www.ign.gob.ar
	Brazilian cGPS network operated by Instituto Brasileiro de Geografia e Estatistica	http://www.ibge.gov.br/
InSAR	Chilo-German observatory of Concepcion operated by BKG-Frankfurt/U-Concepcion/IGM	http://www.tigo.cl
	Tong et al. (2010)	http://supersites.earthobservations.org/chile.php#surface
SAR images	JAXA, ALOS/PALSAR data	http://www.eorc.jaxa.jp/ALOS/en/

et al. 2010). However, the raw data from the 22 ground motions recorded by RENADIC was not made available until 20 months after the earthquake.

Because of the importance of this data, ONEMI signed an agreement with the University of Chile December 2012, which renamed the old SSN as the National Seismological Center (CSN). The mission of this Center is to monitor seismic activity and to rapidly characterize and disseminate seismic information taking place in the country. CSN officially informs ONEMI and SHOA (the Chilean Navy Hydrographic and Oceanographic Service) of the seismic events and their main characteristics. All data provided by a set of nearly 100 broad-band and strong motion instruments will be available to the academic community and interested parties. ONEMI will provide connectivity to the additional 297 strong motion instruments installed by the Ministry of Housing and Urbanism (MINVU), which will be available immediately to interested parties. In the meantime, CSN distributes on-line strong motion records of events with magnitudes larger than M_w 7 (e.g., the 2014, Iquique M_w 8.2 earthquake, and its aftershocks).

A large multidisciplinary research team with scientists and professionals from Chile and the United States, organized by the Geotechnical Extreme Event Reconnaissance Association (GEER), came to Chile to assess geotechnical structures. The team worked closely with other reconnaissance teams, including EERI, USGS, NIST, FEMA, TOSG, PEER, and ASCE. Reconnaissance was performed by fieldwork, and remotely using satellite imagery geo-referenced with GPS and other geospatial tools. A selected number of critical sites were further characterized using advanced tools, such as LiDAR, SASW, and DCPT to provide insights on damage patterns. GEER's first team arrived 1 week after the earthquake for a definition of the scope of the damage in the geotechnical systems, including air and ground reconnaissance efforts at a regional scale. More in-depth studies were conducted by a second team, with emphasis on geological aspects, shoreline studies, ground failure, landslides, subsidence, and damage in buildings due to liquefaction. GEER's last team arrived a month after the earthquake to revisit specific sites and conduct LiDAR, SASW and penetration cone tests in the field. One the challenges faced by all teams was the permits to access sites of interest.

Results of this reconnaissance show that soil liquefaction caused damage in some buildings and several port facilities and often led to significant ground failure and lateral spreading. Ground shaking and ground failure damaged critical lifelines, especially the transportation network, leading to an interruption of the longitudinal connectivity of the country. Most dams, levees, mine tailings, and earth retention systems performed well. Detailed research findings and further discussion on the results of the research are discussed in the extended report the team generated (Bray and Frost 2010).

A few days after the earthquake, the International Tsunami Survey Team (ITST) surveyed more than 800 km of the coast from Quintero to Mehuin, as well as the pacific islands of Santa Maria, Mocha, Juan Fernandez Archipelago, and Easter Island (Fritz et al. 2011). A few members of GEER also conducted a study of the extent of the tsunami inundation and the consequences in Dichato. GEER observations focused on patterns of tsunami related damage, and in cataloguing simple parameters such as minimum flow depth measurements, and the landward limit of tsunami runup (Bray and Frost 2010). Local residents were also interviewed to describe several characteristics of the tsunami waves, such as arrival time, size, type, number, etc. Furthermore, a team formed by national researchers from PUC, Universidad Tecnica Federico Santa Maria, and Universidad de Valparaiso collected tsunami related data in the zone between Constitucion and Ritoque following the UNESCO-COI methodology (COI 1998). This work was performed 2 weeks after the event and during several weeks in periodic visits to cover the affected

zone. Results of this reconnaissance effort were added to those of ITST, and were published afterwards (Fritz et al. 2011). The observations demonstrate large variability of the tsunami characteristics and effects along the Chilean shoreline. It was apparent that the maximum inundation levels were not localized around the epicenter of the earthquake, and that inundation had important variations along the shoreline, which was later explained by the large heterogeneity of the rupture and the complexity of the topo-bathymetric conditions of the shore (Yamazaki and Cheung 2011).

Many informal and private efforts also played an important role in the data gathering during the 2010 Chile earthquake in all phases, including the emergency. One neat example was the case of Martina Maturana, a 12 year old girl in Robinson Crusoe Island that barely felt the earthquake, but knew its magnitude by calling her grandfather in Valparaiso. Martina rang the bell of the town to warn all residents of a possible tsunami, and to alert them to run into the hills (BBC 2010). Less than 10 min after she rang the bell, most of the town was engulfed by the first wave. Martina's initiative, determination, and emergency preparation saved most people living close to the shore of this small town. Despite her effort, 16 people died in the island: some were impacted by the first wave that entered more than 300 meters inland, and others who initially evacuated died with the second wave upon an anticipated return to their homes. Just as the brave example of Martina, many individuals, communities, institutions, and industries played a fundamental and independent role in providing very valuable information to decision makers, professionals, and researchers during the emergency.

3 Data on critical infrastructure, lifelines, and services

The following sections provide a brief overview of the information gathered on specific critical infrastructure, including hospitals, schools, ports, public infrastructure and the road network, communication infrastructure, and electric power networks.

3.1 Hospitals

Of the 130 public hospitals in the regions affected by the earthquake, the Chilean Ministry of Health (MINSAL) reported that 4 hospitals became uninhabitable, 12 had a loss of function greater than 75 %, eight operated only partially after the main shock, and 62 % needed repairs or replacement. Of the beds in public hospitals, 18 % continued to be out of service 1 month after the earthquake. Given this widespread damage of healthcare delivery facilities, a multi-section interview questionnaire was drafted and designed to capture qualitative and quantitative information on the effects of the earthquake on hospital operations and facility responses to those effects. Data were gathered from hospital administrators using a structured interview technique, MINSAL statistics, and hospital annual reports. A multidisciplinary team, including structural engineers, public health scientists, and disaster specialists, visited each hospital. The engineers conducted a damage assessment of the structural and nonstructural components following ATC 20 guidelines (ATC 1989) and evaluated the operational capacity of the hospitals. The public health scientists interviewed the hospital administrators and/or chief medical officers to collect information on the impact to hospital operations and healthcare delivery. Data not readily available at the time of the site visits (e.g., number of annual visits) were collected by

email afterward. The survey tool used in all site visits was tested at the Talca Regional Hospital, and is provided as an Appendix in Mitrani-Reiser et al. (2012).

After feedback from MINSAL personnel, the Province of Biobio in the Biobio Region was chosen as a study area to assess the impact on a regional hospital system. The study area included seven public hospitals, 17 health centers, and no private hospitals. The bed-size of the hospitals ranges from 26 to 433, with a mean bed-size of 109. The largest hospital, in the city of Los Angeles, serves as the regional referral center. The seven studied hospitals of this region include: (1) the Los Angeles hospital, composed of three newer structures that are 4–6 stories tall based on concrete frames with shear walls and masonry infill walls, and two older buildings that are 3-stories tall structured in concrete and brick masonry; (2) the Mulchen Hospital, which is a 2-story concrete-frame building constructed in the shape of an *H*; (3) the Laja Hospital, which has an older 1-story steel-frame main structure and a newer 2-story administrative building that is also a steel frame with masonry infill walls; and (4–7) Yumbel, Nacimiento, Santa Barbara, and Huepil Hospitals, which are all single story concrete-frame buildings built after the Great Chilean Earthquake of 1960. All of the hospital visits were coordinated by MINSAL, included at least one MINSAL employee, and took place between weeks 2 and 3 after the earthquake. The damage observed to structural, nonstructural, and mechanical, electrical, and plumbing systems by the reconnaissance team in the hospitals of the study are described in detail in Kirsch et al. (2010) and Mitrani-Reiser et al. (2012).

The five smallest hospitals did not suffer any structural damage. The second largest hospital had minor visible concrete cracking. The only hospital that suffered structural damage is Victor Rios Ruiz of Los Angeles; the damage in this hospital was limited to the three midrise reinforced-concrete frame and shear-wall buildings constructed after 2000. One building suffered severe racking of its penthouse due to torsion; this building also had buckled steel roof trusses. The two other damaged buildings at Victor Ruiz suffered concrete spalling and exposure of the steel reinforcement of its columns, and light cracking of shear walls. The two older buildings at Victor Ruiz Hospital, circa 1950–1970, all suffered from pipe failures, causing extensive water damage and relocation of patients. Four of the seven hospitals—differing in height, lateral load resisting system, and construction material—reported damage too, collapse of their suspended ceilings, cracking of the plaster over their brick walls, and partition damage. One hospital reported several overturned oxygen tanks that were not anchored properly, a broken maternity incubator caused by the shaking, as well as a fallen wall-mounted television. Additionally, the hospital in Los Angeles suffered damage to all of the elevators and had rooftop equipment jump off shock vibration pads. The most notable nonstructural damage in all the hospitals was the loss of utilities immediately following the earthquake: all hospitals in the region lost municipal electrical power for several days, and although all hospitals had back-up power supplies, 43 % of them reported some difficulty with their systems. Five of the seven hospitals lost their municipal water supplies, although all had backup water supplies. Some hospitals, however, reported problems with their backup water system.

The redundancy observed in power and water systems did not exist in their communication systems. External communications were disrupted for all facilities for several days, creating difficulties in coordinating aid and for requesting outside help. This problem was further exacerbated by the nationally-centralized management of hospitals with limited regional and individual autonomy and control. All hospitals suffered some physical damage, though all but one saw reductions in multiple services for up to a week. Radiology and the laboratory were the most commonly affected areas because of the combination of the loss of municipal electrical power with damage to either the building or their sensitive

equipment. More than a quarter of the hospitals reported impact to their operating rooms, outpatient clinics, kitchen, laundry, and their administration due to earthquake damage. In terms of clinical services, the main regional hospital suffered more than a 50 % reduction in bed count. Regarding non-clinical services, the most frequent interruption was due to the loss of patient medical record organization, due to collapsed and tipped file management systems. The records were not backed up electronically, but took from one day to a week to restore the paper files. Food preparation and laundry services were a problem in two of the seven hospitals. In summary, although none of the surveyed hospitals suffered catastrophic collapse or any directly-related fatalities, there was sufficient damage to significantly impair patient care.

3.2 Public schools

The Ministry of Education (MINEDUC) reported that one-third of the public schools in Chile were affected by the earthquake and tsunami, leaving 1.25 million children out of school at the start of school year (March). Immediately after the earthquake, MINEDUC reached the school managers and asked for a rapid basic assessment to overview the magnitude of the damage in the schools infrastructure. This assessment was performed by the schools' managers supported with a basic form designed by MINEDUC for this purpose. Basically, the form allowed identifying completely collapsed schools and buildings near to imminent collapse.

One week after the earthquake, teams with professionals from the Infrastructure Department of MINEDUC (i.e., architects, civil constructors, and civil engineers) were sent to the affected regions to assess the damage using a technical form designed by MINEDUC. Due to the large amount of schools affected by the earthquake, structural engineers and private consultants were additionally hired in certain regions to complete the inspection of the schools. Overall, MINEDUC inspected 4 thousand schools in the affected regions, and reported approximately 24 % of schools with no damage, 45 % with minor damage, 27 % with moderate damage, 3 % with severe structural damage, and 1 % with high structural damage and needing replacement (MINEDUC 2010). Schools with no damage and minor damage were permitted to start classes on time, while those with moderate and severe damage were partially opened after some of their students were relocated to other public schools. Schools needing seismic retrofits were closed, resulting in the relocation of all their students.

Different funding programs to cover from minor repairs to reconstruction of damaged schools were launched to foster the recovery and accomplish the goal set by the government to MINEDUC of bringing all the affected children back to classes 2 months after the earthquake. The urgency goal placed by the authority came from the fact that besides providing education, these public schools provide critical sustenance to children by feeding them daily with breakfast and lunch. By April 26th, MINEDUC managed to accomplish the goal set by the president. For the 51 schools that needed full reposition of the infrastructure, MINEDUC asked DICTUC, a subsidiary branch of the School of Engineering at PUC, to perform a complete damage assessment (structural and nonstructural) of the schools needing repair, strengthening, or demolition. Eleven teams were formed for the damage assessments; each team was composed of four people including at least one senior structural engineer. Each team inspected four to six schools during the summer months of 2011 (January and February). Baseline information of the schools was collected regarding construction materials, structural layout, and utilities; rapid safety evaluations were also performed to tag the structures (equivalent to ATC-20 process) and to identify the need to

stabilize the structure. Detailed damage assessment consisted on an element-by-element inspection of all structural and nonstructural elements in each building. The results of the inspection were given to each school as a report, including all gathered data, the observed damage, and recommendations of action. Retrofit project designs were delivered on February 2012, which were then executed by MINEDUC. As stated by the new Chilean code NCh433 (INN 2009), the level of structural intervention depended on the observed damage level. Therefore, some schools were retrofitted to their original strength (small damage), while others were repaired to current seismic standards (moderate and severe damage), i.e. higher than the standards used for the original design. Structural systems and damage varied among schools, and interventions were tailored made in each case—data on these interventions are available for research purposes upon request to DICTUC.

3.3 Ports

Several port structures located south of the epicenter were severely damaged. Field research of the damage observed in 14 of these ports was conducted in two phases and is reported in Brunet et al. (2012). The information gathered on the affected ports is summarized in Table 2. The first phase started 1 month after the earthquake, and consisted of gathering field data. It included technical visits to the ports to identify structures that suffered significant structural damage. The visits were useful in assessing the overall structural health of the ports; however, in most cases, visitors were not allowed to get detailed observations of damage. Since failed structural elements were not easily accessible, fishermen boats and other equipment were required to reach the structures.

The second research phase began approximately a year later, in 2011, and focused on gathering structural design information including structural drawings, geotechnical data, research on common failure mechanisms and patterns, and analysis of the possible causes of failure. This aimed to provide empirical recommendations for future port design. The hurdles associated with access to the ports by researchers were overcome by contacting the general manager of each facility via a third party (e.g., the engineering company that designed the port or other associates in the port industry). Several obstacles were also faced during the second research phase, especially concerning the quality of the available design information. To collect the best possible structural data, engineering companies involved in the designs, municipal governments, and, in some cases, governmental offices were contacted. Despite the help of all these institutions, the information collected was less than optimal for research purposes. Structural drawings in some ports were not updated to as-built conditions, and blueprint quality was poor, and in some cases practically useless. It was also very difficult to determine repair costs due to confidentiality issues with the insurance claims; so, several of these obstacles led to efficiency loss and lack of precision in the analyses of the collected data.

3.4 Public infrastructure

The Ministry of Public Works (MOP) approached the data collection process for the reconstruction knowing that 27-F affected more than 500 km in north–south extension, spread over six different regions, and damaged public infrastructure over a large portion of the most populated Chilean territory. Final numbers showed 1701 damaged points, with 748 related to the potable rural water network, 717 to the national road network, 54 to river defenses, and 21 to the rainwater collectors throughout the country (Almonacid 2012). The assessment of public infrastructure was performed by MOP in two stages: the emergency

Table 2 Most frequent problems observed in ports caused by the 27-F earthquake

Port	Type	Cargo type	Structure type	Lateral spreading	Liquefaction	Battered piles damage	Port access damage	Other structural damage	Non structural damage
Lirquen Este	Open	Container	Pile-support. Pier	No	Yes	Yes	No	Yes	Yes
Lirquen Oeste	Open	Container	Pile-support. Pier	No	No	No	No	Yes	No
Penco	Open	Bulk	Pile-support. Pier	No	Yes	Yes	No	Yes	Yes
Talcahuano	Closed	Container	Quay Wall	No	Yes	No	No	Yes	Yes
Asmar	Closed	Navy	Quay Wall	No	No	No	Yes	Yes	Yes
San Vicente	Open	Container	Pile-support. Wharf	Yes	Yes	No	Yes	Yes	No
Enap	Open	Oil	Pile-support. Pier	No	Yes	Yes	Yes	Yes	No
Huachipato	Open	Bulk	Pile-support. Pier	Yes	Yes	Yes	Yes	Yes	Yes
Puchoco	Open	Bulk	Pile-support. Pier	Yes	Yes	No	No	Yes	Yes
Jureles	Open	Bulk	Pile-support. Pier	Yes	Yes	No	Yes	Yes	Yes
Chollin	Open	Bulk	Pile-support. Pier	Yes	Yes	No	No	No	No
Lo Rojas	Open	Fish Cove	Jetty	Yes	Yes	Yes	Yes	Yes	Yes
Coronel Norte	Open	Container	Pile-support. Pier	Yes	Yes	Yes	Yes	No	No
Coronel Sur	Open	Container	Pile-support. Pier	Yes	Yes	No	Yes	No	No

response and the reconstruction. Emergency response focused on recovering connectivity in the country through the road network, thus allowing access and transit of people and external help. For this purpose, three engineers were sent by the National Roads Department to each of the four most affected regions to assess damage of the road network. The inspection took over a week, was conducted at each location without a predefined protocol, and without supplemental structural drawings of the bridges or any other infrastructure. Each group had the authority to close a road and to make the first decisions such as installing special signals or a flagman, limiting the weight of transit, or installing temporary bridge supports in order to recover connectivity in the country.

For the long-term reconstruction, MOP decided to perform a detailed inspection of the damaged infrastructure and generate a global database to facilitate decision-making and follow-up of reconstruction projects. For this purpose, a web platform was created (*SIF platform*). MOP hosted this GIS-based platform on its intranet system to centralize all the information of the damaged infrastructure, owned and managed, over time. Personnel from the regional offices were responsible to perform detailed inspections of damaged infrastructure, and upload the information to the platform, including the GPS coordinates, the identification of the use (road, bridge, retaining wall, potable water rural tank, etc.), description of damage, and its severity. Figure 2 shows an image produced by the *SIF* system, identifying the damaged points in the road network and their evolution in time. After the damage assessment was performed, and despite the fact that information had been collected locally in the regions, the information uploaded to the platform was analyzed in the central MOP office in Santiago. A team composed by the Minister, the National Directors of the different MOP departments, and a group of technicians subsequently decided on the best solution to be implemented at each damaged point. These solutions were then uploaded to *SIF* and communicated to the regional offices for local execution and coordination.

Schematically shown in Fig. 3 is how information flows within the *SIF* platform. The graph identifies the different levels involved in the process of data collection, decision-making, and implementation of solutions. Additionally, *SIF* interacted with the traditional management system of MOP, formed by the financial management platform that identifies the work progress, milestone accomplishments, and payments; and the platform for contract management, which provides contract information, identification of responsibilities, and schedules. One of the main benefits of the platform was the existence of only one

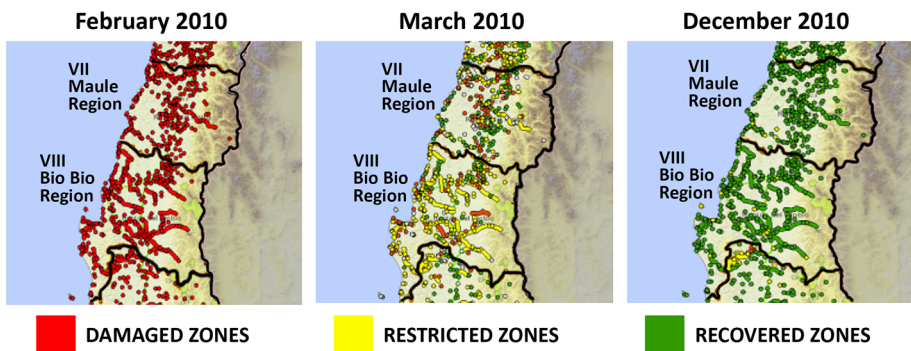


Fig. 2 Sequence of images taken from *SIF* system in February (*left*), March (*center*), and December (*right*) 2010; all of the 717 damaged points in the road network are identified (*Source*: Almonacid 2012)

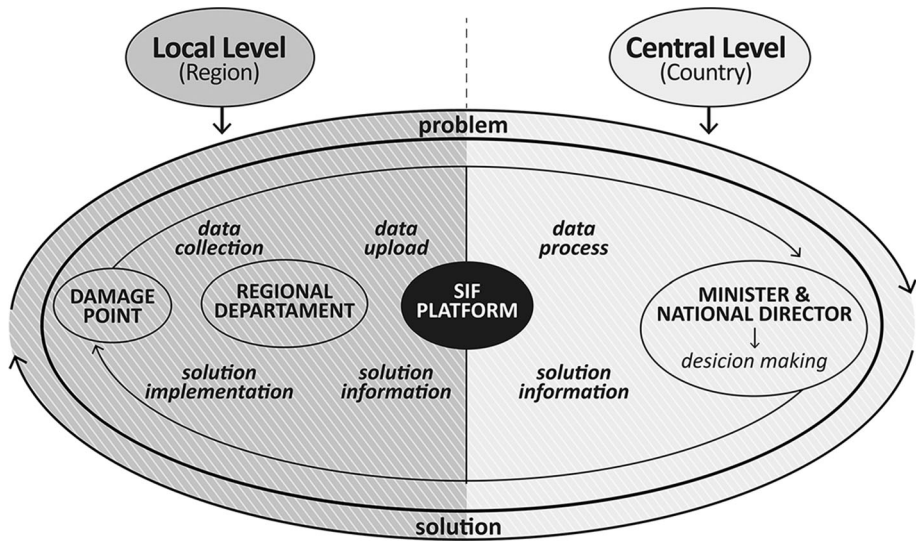


Fig. 3 Information flows for the SIF platform in the decision-making process, communication of the decisions, and execution of the reposition projects

reliable database with all the information related to public infrastructure, allowing rapid decision-making and efficient communication among the different agents involved in the reconstruction process. The system also allowed for better communication with the public, and provided accurate numbers on the advancement in the recovery of the infrastructure. If the time needed to implement a final solution was excessive, a temporary solution was implemented. For example, temporary repair schemes such as *military* modular bridges were used to maintain the flow of vehicles while the final repair schemes of the 14 bridges that collapsed were designed under the new seismic standards.

Despite the work conducted by MOP to tackle the emergency and to face reconstruction of the public infrastructure, no standard protocol was developed to address future disasters such as the 2010 earthquake. After the 2015 Illapel earthquake (M_w 8.3), a similar procedure was followed for the field reconnaissance, but again without a predefined official inspection form.

3.5 Communication and electric power systems

One of the first consequences of the Chile 2010 earthquake was the loss of electric power in a vast area of central Chile, which caused the failure of most of the communication media (radio and television). The communication media that recovered fastest were some of the AM/FM radio stations, which had diesel electric generators, and were able to resume transmissions a couple of minutes after the earthquake ended. Also, due to the flurry of calls from individuals checking in on relatives and friends, the mobile phone network collapsed shortly after the earthquake and the fixed phone network experienced severe congestion. Immediately after the earthquake, the number of mobile phone call attempts raised dramatically, reaching 24 times the value expected in a normal day and three times the value of New Year's Eve (Atton 2011). This demand clearly outruns the capacity of the mobile phone network, which is not designed to support such a heavy demand. As a

consequence, the grade of service went down and very few of those call attempts resulted in actual successful calls.

The failure of power affected the operation of some vital parts of the mobile phone network: base transceiver stations (BTS), base station controllers (BSC), and mobile switching centers (MSC). For instance, of all the BTS that went down after the earthquake, 2 % were damaged by the earthquake itself, while 34 % went down within 20 min of the electric power failure, mainly because the power backup systems (batteries) did not function. The rest (64 %) lasted between 2 and 8 h before failing. There was also an increase of failures on March 14th due to an electric power system failure, which demonstrates the network's fragility (Atton 2011).

The earthquake also highlighted the fragility of the emergency communications system. This emergency network went down due to the following reasons: (1) the emergency communication network was strongly dependent on the public service (fixed and mobile telephone networks), which broke down by lack of power and/or congestion; (2) lack of maintenance of the HF and VHF emergency networks with operation protocols that were outdated; (3) a number of available satellite telephones were unusable because of discharged batteries and lack of knowledge of the phone numbers; and (4) the information available at the emergency center was unreliable and outdated. Some remedial actions have been implemented since then to avoid the recurrence of these problems in future events. Among those are the legal requirement to ensure power supply backup for at least 48 h in 527 critical mobile phone communications components, and of 4 h for the rest; increment three times the SMS capability of the mobile phone system; establish a new emergency communications system, which is independent of the public network; and implement a mobile phone alert communication system using the Cell Broadcasting System (CBS).

The electric power systems suffered damage to its generation, transmission, and distribution systems (Fig. 4). The earthquake affected the area covered by the Chilean Central Interconnected System (SIC), which provides electricity to over 90 % of the Chilean population (Araneda et al. 2010). The earthquake produced a blackout, which took out a significant portion of its power generation: 4522 MW out of a peak demand of 6145 MW. Of those, 693 MW belong to a power plant that had to shut down for major repairs. The seismic event also impacted several parts of the power transmission system, including damage to 12 out of 46 transmission substations, and affecting 1.6 km out of 7280 km of transmission lines. However, the grid was able to operate and power was restored within a few hours after the earthquake. The main consequences of the earthquake were severe damage in the distribution network where repairs took several days and, in some cases,

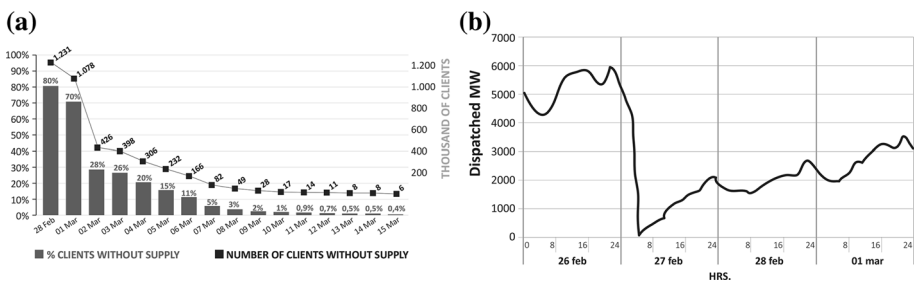


Fig. 4 The evolution of power in Feb-27, 2010: **a** clients without electricity (Source: Donoso 2010); **b** network resilience: megawatts dispatched in the days before and after Feb-27

weeks to complete. Figure 4b shows the evolution of the recovery of power distribution; the main causes of these problems were the direct earthquake or tsunami damage of the distribution network. However, in general, the electric power system responded as expected, with most of the service to clients being restored within 48 h.

4 Building data

As stated earlier, this earthquake affected six regions that account for 75 % of the country's population. Central government statistics estimate damage in 370,051 dwellings (including both independent houses and condominiums), 22 % collapsed, 29 % with major damage, and 49 % with light damage (Gobierno de Chile 2010). From the total dwellings affected, 37 % were adobe construction, 9 % were along the coastline, 19 % correspond to housing complexes built by the government for low-income residents (*social dwellings*), and 35 % correspond to privately built housing complexes. In the case of buildings, 46 reinforced concrete (RC) apartment buildings of 9 stories or more underwent severe damage during the earthquake, which represents 2.8 % of the estimated stock of 1939 RC apartment buildings of 9 stories or more present at the time of the earthquake in the densest cities of the country (Santiago, Viña del Mar, and Concepcion) (Massone et al. 2012). To February 2016, the numbers by MINVU indicate that of a total of 225 thousand subsidies assigned after the earthquake, 2.3 % remain in execution and 0.2 % are yet to be executed during 2016. This finalizes the country's reconstruction phase for housing (MINVU 2016). The following sections provide more specific description of the data collection processes for houses and shear-wall buildings separately since the seismic performance was significantly different.

4.1 Houses

Several organizations participated in damage surveys to houses after the earthquake and provided recommendations of structural safety. Most of the participants were volunteers: engineers from the Chilean Association of Structural Engineers; architects from the *Colegio de Arquitectos*; students and professors from schools of engineering, architecture, and civil construction; firefighters from local fire companies; and engineers from private companies. More of these efforts were not coordinated by any central agency or municipality, and there was no centralized database to facilitate the planning, prioritization, and implementation of these post-earthquake evaluations. This lack of coordination resulted in professionals using different survey instruments to record and assess the same damage, different criteria to define damage levels, and inconsistent objectives and scope for the post-earthquake inspections. The above problems led in some cases to contradictory assessments. MINVU also separated the housing recovery process in two stages, the emergency and reconstruction phase.

4.1.1 Emergency reconstruction

MINVU's first task was to determine the number of affected people and their needs throughout the country—a process that was supported by local COEs activated after the event. The data collection process was completely decentralized. For instance, the Municipal Works Department (DOM) and municipal social workers inspected their

territories to assess the need of people; the Army also collaborated with the authorities at different levels to perform activities related to the cadaster. The dependency on the municipalities meant that the whole process was restricted to the available professional capacities and resources (technical, human, and economic), generating uncertainty on the time span required to complete the national cadaster and to produce an accurate database of variables such as the displaced population. The number of emergency houses needed by each municipality was sent from the municipalities to the regional COEs and the regional ONEMI offices. The decision to give Mayors the responsibility to centralize their citizen needs was an important one, encouraging local government involvement in the national housing recovery plan, and enabling connections amongst citizens and local government officials during the registration process at municipal offices (Comerio 2013). One of the hurdles related to the data collection process was the inability to locate many of the impacted residents who live in rural areas, where geo-referencing could not be used to track them. Alternatively, the data collection was straightforward in regions less affected by the main shock and not directly impacted by the tsunami; in these areas, residents were responsible for self-reporting their damage and emergency construction needs.

Another organization that supported the immediate needs of residents was TECHO, an NGO working to solve low-income housing problems in Chile and Latin-America. After the event, TECHO formed a national reconstruction team to implement emergency social housing solutions, and to move volunteers throughout the country for rapid construction of these temporary shelters. The reconstruction team had a central coordinating office in Santiago and four regional offices in the most affected regions. Each one of these offices had a multidisciplinary staff of 15–20 people, led by a regional director, with the objective of building the number of emergency houses that were necessary for the displaced population. The housing units had 18 m² and were built from prefabricated timber elements. The regional director of each office participated in the regional COE, thus facilitating the communication with central offices.

Both TECHO and the central government had a shared goal of constructing emergency houses, although each organization took a different route to complete the task. Non-experts conducted the inspections for TECHO; they used the municipal cadaster as a reference, and then performed visual inspections to assess the fidelity of the data, identifying either collapsed or evidently uninhabitable houses. After this verification, TECHO created a list of housing with priorities for reconstruction, leading to construction campaigns with volunteers from around the country. TECHO also developed an information system named PILOTES to manage the information and emergency construction process. PILOTES included housing needs, the logistics required for the construction including the campaign organization, and a final registry of the families that received the emergency houses. Data were collected locally, reported to the regional offices of TECHO and uploaded to the PILOTES platform. The central office was in charge of funding, logistics, acquisitions, and organization of the different construction campaigns and volunteer recruitment to satisfy regional demands; local offices managed materials and volunteers. On the other hand, the central government sent the emergency houses to the municipalities, which were responsible for their distribution. This may have led in some case to favoritisms in certain municipalities, by distributing houses using a populist approach and without a fair established process. It is known that some people took advantage of this process and received more than one house.

4.1.2 Long term reconstruction process

The long-term reconstruction process led by MINVU was divided into three scales: (1) *housing*, addressing the work on reconstruction and repair subsidies for the affected people; (2) *neighborhoods*, associated with the work on social camps and villages and addressing the problem of an urban housing deficit in a sustainable way; and (3) *city and territory*, linked to the urban scale and incorporating the qualitative hazard assessment in future urban regulation plans and providing guidance to the reconstruction process in heavily damaged regions (e.g., the small coastal fishermen villages). By law, the DOM is the only entity empowered to sign a decree to declare a house uninhabitable, and hence the DOM of each municipality undertook this process. Several issues arose from this decentralized method of assessing the safety of houses. First, no consistent criteria were used to inspect the houses across municipalities. Second, the technical capabilities of the DOMs are very limited, which could have resulted in various buildings being condemned to demolition instead of possible conventional structural retrofits. Sometimes local DOMs also had financial incentives to declare houses uninhabitable and benefit from external resources to resolve housing deficits prior to the earthquake. In the end, MINVU had an unreliable database to work with, and resulted in MINVU hiring private consultants and structural engineering companies to perform rapid visual inspections of social dwellings. The purpose of these inspections was to rapidly identify the status of damaged buildings and the imminent risk to people; more detailed evaluations were required in some buildings. This process helped MINVU improve the building database. The regions most affected by the earthquake had to wait longer to initiate reconstruction because they experienced also longer emergency response phases. Reliable information was generated only 1.5 months after the earthquake, since many important documents not electronically stored (e.g., blueprints and land ownership legal documents) were lost in the tsunami flooding.

Despite the aforementioned problems, MINVU's single most important decision was to assign *housing demand* subsidies for reconstruction and repair, which focused on keeping families in place (Comerio 2013). Owners who qualified for subsidies had options on how they could use their subsidies, including buying a new house, building a new house on the same or different site, or acquiring units in a new development. However, in cases where a group of houses, or a complete village, was heavily damaged by the earthquake or tsunami, the case was very complex. In some cases, it was difficult to decide whether houses were damaged by the earthquake or were in poor condition before the event. It was also challenging to verify if certain needs of family groups just appeared due to the earthquake. To address these issues, MINVU developed an information system that helped them in the assignment of subsidies to the neighborhood programs, which covered about 4500 families. The core of the system was based on crossing searches in databases and information available in the Ministry of Social Development (MIDEPLAN), the Chilean IRS (Sii), and the Civil Registry Service, instead of using the customary process based only on MIDEPLAN information where each person has a score based on the Social Protection File. The subsidies were assigned by family group, using the information from the Civil Registry to validate if the family groups reported by people were such. The only document the system needed to assign the subsidies was a form from the DOM that credited the family group as a candidate of subsidy because of the current state of their house (destroyed or uninhabitable, and waiting for demolition). MINVU also implemented a follow-up system for the construction of social dwellings. Under this system, the fiscal inspectors uploaded to

an internet platform, real-time information with a smartphone application with photos of the progress in construction. This information could be accessed by the beneficiaries of the subsidies at any time in order to give them information on the construction milestones. Programs like these, which ensure transparency of all the available information, helped decreasing the anxiety of people.

4.2 Shear-wall buildings

4.2.1 Data collection process

The damage observed this time in several shear-wall buildings was somewhat surprising, especially when compared to the impeccable performance of these buildings during the March 3rd, 1985 Chile earthquake. Indeed, in addition to the 16-story Alto Rio building that collapsed in 2010 killing 8 people, at least 46 other reinforced concrete buildings in the cities of Santiago, Viña del Mar, Curico, Talca, Chillan, Concepcion, and surroundings suffered a similar pattern of brittle structural damage in their shear walls. Some of these structures remained in a rather unstable condition after the structure, and had to be quickly stabilized for the aftershocks. The estimate is that these 46 buildings represent about 2 % of the total inventory of shear-wall buildings above 9-stories (Jünemann et al. 2015).

The data collection process of building damage after the earthquake was divided into three different time phases, which roughly coincide with days, weeks, and months/years (Fig. 5). Data for each of the phases had different objectives, was of different nature, and its recollection was conducted by different stakeholders following different methodologies as summarized in Table 3.

The first phase of shear-wall building data collection was conducted immediately after the event and aimed to protect human lives. Mainly requested by communities, owners, real-estate companies, construction companies, professionals, and local governments (Table 3), this stage was intended to inspect as much structures as possible in order to establish their conditions and tag them in one of three categories: (1) habitable with essentially no risk (green); (2) non-habitable but repairable (yellow); or (3) with collapse risk (red). Unlike what happened with houses, the evaluation of tall buildings was led mainly by well-established local engineering firms. Again, there was no central coordination for any campaign of collecting building data, and different groups used different

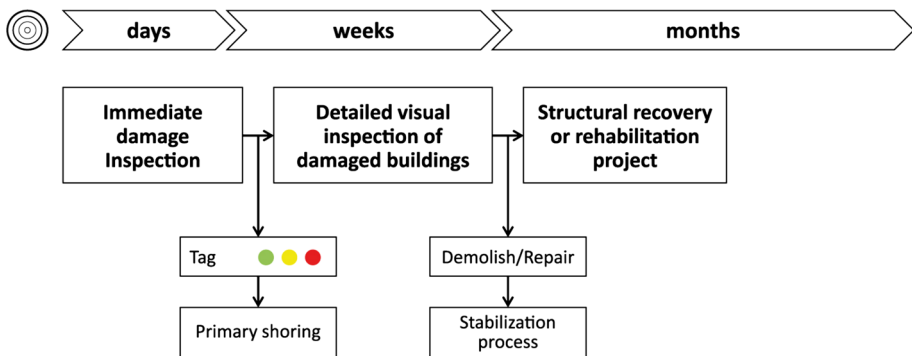


Fig. 5 Schematic view of data collection process

Table 3 Summary of data collection stages

Type	Stakeholder	Objective	What?	Who?	How?
Immediate damage inspection	Community, owners, local governments, constructors	Define basic security conditions of housing units: habitable/non-habitable/risk of collapse	Global building situation, general buildings data, photographs	NGOs, volunteers, students, professionals	Different damage inspection reports, no pre-established plan, on-site decisions
Detailed visual inspection of damaged buildings	Owners, local governments, constructors	Analyze the current status of damaged buildings and decide on repair or demolish	Building damage information, detailed buildings data (drawings, soil mechanics, reports, etc.)	Professionals, academics	Inspection protocols for global damage survey, internal strategies
Structural recovery or rehabilitation project	Owners, central government	Feasibility study for repair or recovery of damaged buildings	Detailed damage information by element and/or lab tests	Professionals, academics	Detailed survey of damaged elements, instrumental measurements

survey instruments or inspection report templates to evaluate the buildings; some of these were very general while others were designed to collect extensive data. The types of data collected varied by survey tool and by inspector. For the most favorable cases, available data included general damage information, general building information such as location, type of structure, use, and a photographic record of the visit together with some of the observations.

Although some specialized groups performed a very adequate rapid visual inspection of the different buildings affected by the earthquake, the lack of knowledge of shear-wall damage, and the absence of a unified and coherent strategy to evaluate the extent of damage led to several adverse situations. First, several structures that presented significant damage were immediately condemned to demolition by communal decrees prior to any proper evaluation or structural analysis. Only aspects such as responsibilities on the demolition, insurance, and cost stopped some unnecessary building demolitions. Second, the mistrust of stakeholders led to the request of several building reports performed by different groups (i.e., municipalities, building communities, the developers, construction companies, engineers, and insurance companies) that presented sometimes biased (and contradicting) views of the state of a structure, resulting in lengthy building evaluations. Moreover, since the demand of these kinds of quick damage reports lasted for several months, many professional engineers were tied up in building assessments and had little time to respond to difficult questions such as the true need for demolition of a damaged structure. Another adverse situation magnified by the lack of uniform building-evaluation

protocols was the rapid repair action that some people took without a sound retrofit project. All this occurred in the first weeks and months even prior to any legal action.

The second stage of building data collection started a couple of weeks after the earthquake and lasted for several months. The process was focused mainly on buildings that were tagged yellow or red during the previous phase. These structures underwent a rigorous evaluation process, but without a unique damage-evaluation protocol. The objective of this data collection stage was to define the real condition of the damaged buildings, the need for additional stabilization, and a final decision on repair versus demolition. For these more complex cases, building developers, construction companies, communities, or local and central governments requested complete assessments by structural engineers. Each structural engineering office developed its own inspection protocol to visit the damaged buildings and collected as much information as possible. Detailed building data (e.g., structural and architectural drawings, soil mechanics reports, and structural design documents) were provided by the building owner; municipalities also have this information but typically not in the latest versions. The in-depth assessments included photographic logs to document building damage, and a final report including the overall damage state of the structure. The main outcome of this report was usually a recommendation to stabilize first, and then repair or demolish the building. Because the observed damage in many buildings affected the vertical load carrying system, vertical stabilization went before any repair. Stabilization served sometimes the purpose of safely demolishing parts of the structure, and to ensure safety of people around the structure.

The third and longer phase of building data collection took place once the emergency and stabilization process was under control, 2–3 months after the event. During this phase, complete projects were developed by engineering offices in order to study the recovery or demolition of the building. These studies were usually requested by building developers, communities, or central government offices in cases where the damaged structure could pose a risk to people. Detailed structural damage data were collected, instrumental measurements, and material laboratory tests were carried out. These studies, which are lengthy and lasted up to 1 year, were carried out for a small group of buildings. During this time span several academic studies advanced in collecting as much perishable data as possible about the response of buildings (Alarcon et al. 2014, 2015; Hube et al. 2014; Jünemann et al. 2015; Westenek et al. 2012, 2013).

4.2.2 Data collection: case studies

This section presents five case studies of data collection processes after the 2010 Chile earthquake. The cases are: (1) the experience of the company DICTUC in implementing a rapid visual inspection protocol; (2) the field campaigns conducted by international researchers; (3) the experience of local structural engineering offices in the inspection of buildings in Santiago; (4) the detailed study of 9 RC buildings in Concepcion requested by the central government; and (5) the creation of a database of damaged buildings.

4.2.2.1 Immediate damage inspection by DICTUC Immediately after the earthquake, building owners, residents, neighborhood associations, real-estate and construction companies, and central and local government institutions needed technical reports about the safety status of buildings structures. As an independent renowned consultant with a specialization in structural forensic studies, DICTUC received several of these requests to assess the damage status of approximately 150 buildings and 15 housing complexes. The

company implemented a methodology to visually inspect the buildings and generate a technical report with conditions for occupancy and safety recommendations in emergency situations. The visual inspections were done by engineers who visited the damaged buildings and carried out the following tasks: (1) fill out a damage inspection form, (2) build a photographic record of the damage, and (3) present the preliminary visual inspection report. The damage inspection form contains detailed information on the structure and its damage level. Structures are identified by name, location, use, number of stories, approximate floor plan dimensions, age, description of the structural system, and building material. Additionally, the form describes the general status of the building and the observed damage in primary and secondary structural and nonstructural components. A global classification of the structure in five damage categories is included: none (0 %, habitable), light (0–10 %, habitable), moderate (10–30 %, restricted use), heavy (30–60 %, inhabitable) and severe (60–100 %, risk of collapse). At the end of the visit, a preliminary visual inspection report was presented to the client. These reports contain a summary of the global damage classification and safety recommendation measures.

4.2.2.2 Damage inspections in Santiago: experience of local offices Santiago was the densest city affected by the earthquake and many building inspections were conducted by local engineering offices that work in the city. Because Chile is a country where large earthquakes occur frequently, a large majority of the structural engineers of the affected buildings are active professionals working on different engineering firms. Consequently, it is a common practice that just after the earthquake professionals from these engineering firms immediately check the structural condition of their own projects. Therefore, most of the engineering firms have developed protocols to inspect their buildings. The inspections typically include photographs, videos, and general information of the buildings and their damage. This practice of inspecting the projects without an external request is very unique and provides high quality information. The process includes first a rapid visual inspection first, and only in the cases with damage, more detailed studies. Detailed studies include an inspection of damaged primary and secondary structural and nonstructural components and their report on structural drawings. With the collected information, a detailed private report was usually developed including suggestions for retrofit.

4.2.2.3 Stabilization process After the second stage of visual inspections of damaged buildings, engineering offices recommended that structures be either repaired or demolished. However, in some cases the buildings were so severely damaged and at collapse risk that it was necessary to stabilize them before taking any other action, prior to getting anyone to work inside these buildings. This was the case for tall buildings in Santiago and Concepcion, where local firms (e.g., SIRVE) developed interesting stabilization techniques that were later adopted by other constructors in their damaged structures. The data collected during stabilization was very unique, since to our knowledge this was the first time that a process like this followed a formal methodology. This allowed transferring the proposed stabilization techniques into other projects. One example is shown for the particular case of a damaged RC building in Santiago (Fig. 6). The emergency stabilization included an important number of struts readily available in the market; however, these elements have low axial capacity and the solution was insufficient to ensure building stability during high-intensity aftershocks. Consequently, a more robust stabilization system was designed that consisted of 10'' Yoder tubes with Parker bolts installed directly below the wall offset and in all basement levels (Fig. 6e). The bolts were required to

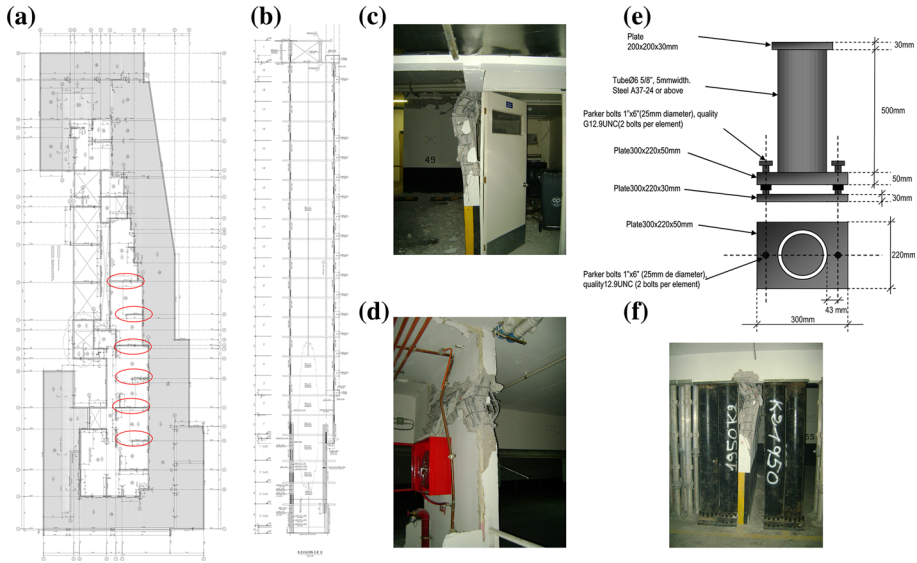


Fig. 6 EM Building: **a** floor-plan and damaged walls; **b** typical wall elevation; **c**, **d** examples of interior damage; **e** Yoder tubes stabilization solution for EM Building: drawing and **f** implementation

partially transfer vertical load into the strut. The Parker bolts were calibrated to control the axial load on each tube and avoid damage to the slab. This procedure was repeated in a large number of severely damaged buildings and ended up being very successful in strong aftershocks after the earthquake.

Once the permanent stabilization system was in place, some buildings needed to be straightened up prior to retrofitting the walls. In lifting the building, a second system was used as shown in Fig. 7a. The system consists of beams that go through the top and bottom of the wall as well as parallel vertical struts with servo-controlled lifting jacks. In the jacking-up process, lifting occurred simultaneously for the entire building plan. Jacks were installed with continued struts running down to the building foundation without transferring vertical load into the slabs (Fig. 7b). At the top, where the strut reacts against the

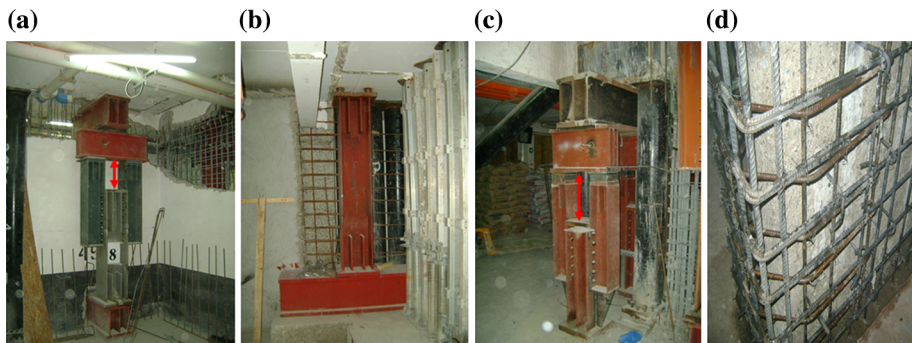


Fig. 7 Lifting process for EM Building: **a–c** struts and beam system; **d** reinforcement of damaged walls

shoulder of the wall, a transfer beam was installed (Fig. 7c). The Yoder struts were maintained throughout the retrofit process for security reasons. Afterwards, the walls were reinforced and detailed according to new standards (Fig. 7d).

An even more complex case was the TO building in Concepcion that collapsed partially during the earthquake. The main objective of this stabilization solution was to open one of the main streets downtown Concepcion, closed after the earthquake, to allow transit of pedestrians and cars. Most walls and columns collapsed along the northeast side of the 12th story of the building (pointer *a* in Fig. 8a), causing the complete collapse of that sector in one story. The same occurred in the southeast side of the 16th story, which descended a complete story as well (*b* in Fig. 8a), and in the south side of the penthouse (20th story, pointer *c* in Fig. 8a). Several slabs were partially or completely detached from the walls and stairwells (Fig. 8b–e).

A special strut and tie system was designed to stabilize the northeast and southeast facades of the buildings, as well as the slabs from stories 12 through 20. Because the stairwell was the only element that remained stable, it was used to tie the slabs and other stabilizing elements. The stabilization methodology consisted of replacing the vertical damaged elements by strong 10" Yoder tubes on the outside of the building, since it was very dangerous to work inside the structure (Fig. 9). The Yoder tubes were bolted to distribution beams (Fig. 9d) using anchoring bolts tightened to a torque that was defined by laboratory tests to obtain an in situ controlled preload close to 80 % of the tube capacity. The Yoder tubes were also anchored to the facade lintels through the connection system shown in Fig. 9e, placed above lintels in the undamaged stories, and below the lintels in the damaged ones. This anchorage system prevents buckling of the tubes, works as vertical support of the Yoder tubes in the undamaged stories, and becomes a lintel support in the damaged stories. Additionally, the Yoder tubes were tied to the stairwell through the cables shown in Fig. 9f to prevent out-of-plane collapse of the façade envelope. The southeast façade elements presented very low shear strength, and hence they were supported by the steel cables shown in Fig. 9g. Finally, once the external stabilization system was in place, some interior supports were also implemented, as shown in Fig. 9h, i.

As shown by these two examples, precise data and information about the true building conditions were critical in saving the risky situations during the stabilization process. This process in damaged buildings requires a thorough analysis of the *as-it-is* condition of the

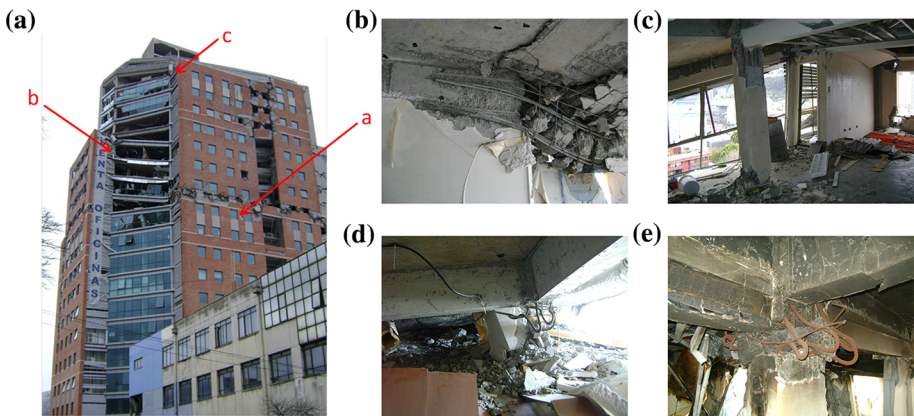


Fig. 8 Observed damage in TO Building: **a** building façade; **b–e** examples of interior damage

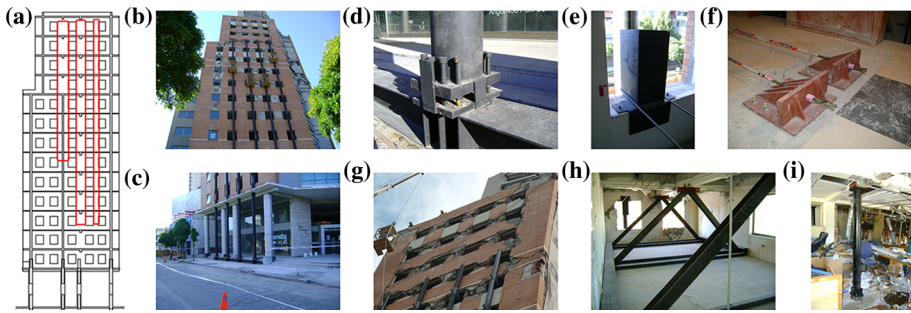


Fig. 9 Vertical stabilization system for TO Building using Yoder tubes: **a** reinforcement diagram, **b–c** stabilization elements from the outside; **d** support beam for Yoder tubes; **e** lintel anchorage for Yoder tubes; and **f** cable anchorage; and **g** reinforcement steel cables; **h**, **i** examples of interior reinforcement elements

building, thus generating valuable information in dealing with damaged buildings, not readily available in the literature.

4.2.2.4 Detailed analysis of RC buildings in Concepcion This work dealt with the thorough inspection of 9 severely damaged RC buildings in Concepcion and was requested by MOP to a local company. The aim of this project was to evaluate the actual structural status of these privately owned buildings, investigate the reasons for the observed damage, and plan their eventual demolition. Information on each building was provided by the owner, including original drawings and information on the original structural design. This project lasted more than 7 months and involved structural modeling, soil mechanics, material testing, individual damage evaluation of elements, and demolition studies.

One of the data collection highlights of this study was the thorough damage survey performed in each building. A detailed element-by-element inspection was carried out and an individual report generated. Damage in each element was analyzed and classified in three categories: (1) light, (2) moderate, or (3) severe damage. General and geometric data were also recorded, such as location of the element, length, thickness, continuity conditions, as well as other observations. Additionally, an estimate of damage extent, approximate residual building strength, and possible causes of damage were also recorded. Photos and drawings were included later in the post-processing stage. The data sheets were coordinated, studied and discussed previously in an iterative design process, and allowed to have coherent information across all damaged elements in different buildings, since the inspection was done in parallel by different groups. Additionally, the inspection was documented by video of every damaged element in the building. Finally, complete damage reports and drawings, finite element structural analyses, material laboratory tests, and soil tests were all combined for each building. Detailed results are found elsewhere (Westenenk 2011; Westenenk et al. 2012, 2013).

4.2.2.5 Damaged building database Motivated by the large amount of field observations, a local campaign was conducted with the objective of creating a robust post-earthquake database with the most complete descriptions and characteristics of buildings damaged during the 2010 earthquake. The focus was placed on reinforced concrete shear-wall buildings taller than 9 stories and located in the densest cities affected by the earthquake: Santiago, Viña del Mar, and Concepcion. Sufficiently complete information was obtained

for 36 of the 46 identified buildings with damage during the earthquake (Jünemann et al. 2015). For each of the buildings a data-sheet was prepared and organized into three groups: (1) general information; (2) damage information, including damage level and availability of damage reports, photos and/or video; and (3) design documents indicating the professionals involved in the building design and construction, and the availability of building documents like soil mechanics, structural drawings, structural models, calculation notes, architectural drawings, and construction documents.

Damage information was collected also from several local and international teams that visited the damaged buildings after the earthquake. The different teams used different forms to gather building data and different methodologies. A thorough damage survey considering every structural element including walls, columns, beams, and slabs was available in some cases. In other, there was only a damage report derived from a visual inspection. In the worst cases, there was only a brief description of damage. However, regardless of the source of information, each building was classified into one damage level considering the habitability conditions after the earthquake: green (habitable); yellow (non-habitable); red (collapsed or at collapse risk). Some building documents in the database were obtained mainly from the DOM of the corresponding municipality, or supplemented by other sources, such as engineering and construction firms. The information collected through this campaign was the base for much research on damaged buildings. Westenek et al. (2012, 2013) presented a detailed description of 8 severely damaged RC buildings in Concepcion, showing that in most cases the severe damage concentrated in lower stories and without a significant spread of the inelastic response. Building orientation, soil quality, plan and height building irregularities, slenderness and plan aspect ratio, high levels of compression stresses, lack of boundary element confinement, and small wall thicknesses appear as critical aspects of the damaged buildings (Westenek et al. 2012, 2013). On the other hand, Jünemann et al. (2015) analyzed the structural characteristics of the database showing that most of them were structures built after year 2000, with normal wall area densities, but presented small wall thickness, high axial load stresses, and significant vertical irregularities. Alarcon et al. (2015) analyzed geometric and design parameters of critical walls of five RC buildings damaged during the earthquake finding that the available methods to assess the displacement capacity of the buildings do not correlate well with the observed behavior. Additionally, an experimental campaign on RC walls was also developed, which included identical wall specimens tested for equal lateral displacement cycles and subject to different axial load ratios. It was shown that high axial trigger a brittle crushing failure immediately after spalling of the concrete cover (Alarcon et al. 2014).

5 Information on social and human impact

Human data collected by several organizations aimed to evaluate mental disorders in the population. MIDEPLAN added a mental health module to the Survey of Socioeconomic Characterization (CASEN), and conducted a survey shortly after the 2010 earthquake (Post-Earthquake CASEN survey). CASEN had been applied on 2009 to the same sample, but did not evaluate mental health outcomes. The 2009 survey evaluated the socioeconomic composition of households, including some variables of the dwellings, goods, education, and income. The survey is applied every 3 years since 1985 and is representative at the country and regional levels. The 2010 application of CASEN aimed to identify post-traumatic symptoms and examined changes in poverty levels as a result of the

earthquake (greater emphasis on dwelling damage). This survey is representative of the country and the sample was collected from 27,000 homes. The data collection focused in the regions more affected by the earthquake, and the survey was applied between May 13th and June 28th, 2010. Data were collected using trained interviewers using face to face interviews, and also with the collaboration of MINSAL. The aim was to evaluate mental health outcomes in individuals exposed to the earthquake, and looking at both risk and protective factors. This was done using phone interviews 2 months after the earthquake over a sample of more than 800 adults.

A depression study was also conducted with workers of the Constitucion Hospital; self-administered questionnaires were completed by 104 workers. Questions asked about demographics, previous trauma, and exposure to the event. Children data was also obtained in the area close to Concepcion by a group of researchers from the University of Concepcion, mainly aimed to evaluate post-traumatic stress disorder among children and adolescents. The work had a sample of 711 children and youth, and data were collected using trained interviewers. An additional dataset that has been used to study mental health outcomes is the data from the social program *Chile Crece Contigo*, which includes a periodic assessment of mothers and their children, which includes some mental health outcomes.

6 Change in seismic codes

Earthquake demand is usually characterized by a design spectrum. The ground motions recorded and the response of Chilean buildings during the March 3rd, 1985 Chile earthquake led to a new version of the seismic code for earthquake resistant design of buildings, the NCh433 of 1996. Such code remained essentially unchanged until the 2010 earthquake with minor changes in 2009 (INN 2009). Because shear wall buildings performed very well during the 1985 Chile earthquake, it was concluded then that the ductility demand in shear wall buildings was small. Consequently, the 1996 seismic code ignored the ACI 318-95 seismic provisions for wall boundary confinement. Recent results have shown that boundary confinement also has limits and ACI confinement detailing may be insufficient by itself to lead to a ductile behavior of the wall (Arteta et al. 2014). No attention is placed in these codes to the Axial Load Ratio (ALR) on walls, which plays a fundamental role on the ductile behavior (Alarcon et al. 2014, 2015; Hube et al. 2014; Jünemann et al. 2015). Boundary element, web confinement, and ALR are important factors that control the ductile behavior of these elements. Moreover, such brittle behavior is inconsistent with the reduction factor assumed in building design. Other factors may have contributed also to the brittle behavior of walls like out-of-plane bending behavior and buckling, a subject currently under study.

Because damage occurred in 46 shear wall buildings approximately during the 2010 earthquake, new decrees were created to improve the Chilean design standards for reinforced concrete structures: NCh433 (INN 2009) and NCh430 (INN 2008). Decree DS 117 (2010) introduced three major changes on the classification of soils: (1) changes in the pseudo-acceleration design spectrum used to calculate design forces; (2) a modification in the soft soil-type definition; and (3) the incorporation of an expression to estimate the design lateral roof displacement in terms of the cracking period of the building, T_{cr} , with $\delta_u = 1.3S_{de}(T_{cr})$ and $S_{de}(T) = \frac{T^2}{4\pi^2} S_{ae}(T)$, where S_{de} and S_{ae} are the pseudo displacement and acceleration design spectra, respectively. Later, decree DS 61 (2011) modified DS 117

and introduced the following changes: (1) preserved the NCh43 original pseudo-acceleration design spectrum, but applied a factor S that depends on the soil type; (2) modified the soil-type defined previously in DS 117, included an additional type of soil between soil types II and III, and added several requirements for the new soil type definition; and (3) maintained the expression to calculate lateral roof displacement δ_u , but defined a new modified displacement spectrum for these effects.

Shown in Fig. 10 is a comparison of the design spectra of several building codes: (1) Chilean code NCh433 modified in 2009; (2) current Chilean code NCh433 modified in 2011 by decree DS 61; (3) Chilean code NCh2745 for base-isolated buildings (INN 2013a); (4) Chilean code NCh2369 for industrial structures (INN 2002); (5) ASCE 7 code (ASCE 2010) for the city of San Francisco, California; and (6) Eurocode 8 (CEN 2004) for zone I in Italy. All spectra are calculated for the best possible soil (type A) and with an importance factor of 1.

Furthermore, decree DS 118 (2010) modified NCh430 by specifying: (1) the use of ACI 318-08 for the design of special reinforced concrete walls; (2) a new classification of structures designed with reduction factor $R = 7$ as *special structural reinforced concrete walls*; (3) a classification of buildings up to 5 stories with R lower than 4 as *ordinary structural reinforced concrete walls*; and (4) a set of new conditions for special structural elements to increase wall ductility—longitudinal reinforcement strain higher than 0.004 when concrete compression strain reaches 0.003, an additional actor 1.4 to apply to the seismic actions when ultimate design shear is calculated, i.e. $V_u = 1.2D + 1.4 \times 1.4E + 1.6L$, transverse reinforcement in splicing zones, a boundary element length in terms of the lateral displacement demand of the building, but without considering $\delta_u/h_w = 1.5\%$ as it is implicit in the ACI 318-08 code:

$$\frac{c_c}{l_w} = \frac{c}{l_w} - \frac{1}{600\delta'_u/h'_w} \tag{1}$$

where c_c is the extension of the confined zone measured from the external edge of the boundary element; l_w is the length of the entire wall, wall segment, or wall pier considered in the direction of the shear force; c is the largest depth of the neutral axis calculated for the factored axial load and nominal strength with the bending moment consistent with the design displacement δ_u ; δ'_u is the design relative displacement between the upper extreme of the wall and the displacement at the section level of the analyzed wall; and h'_w represents the height of the wall measured from the edge of the wall to the analyzed section.

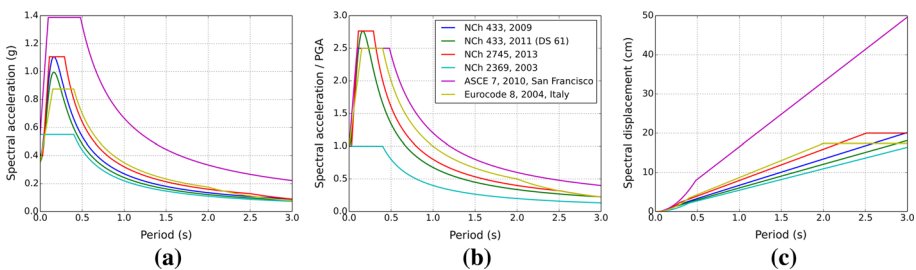


Fig. 10 Design spectra for NCh433 (PGA = 0.36 g), NCh2745 (T = 475 years, PGA = 0.4 g), and NCh2369 (PGA = 0.55) Chilean codes for zone 3 and soil type A ($V_{S30} \geq 900$ m/s); ASCE 7 code for San Francisco and site class A (hard rock, $V_{S30} > 1524$ m/s, T = 475 years, PGA = 0.55); and from the Eurocode 8 (T = 475 years, PGA = 0.35) for zone I in Italy and ground type A ($V_{S30} > 800$ m/s). **a** Spectral acceleration, **b** normalized spectral acceleration, **c** spectral displacement

Later, DS 118 was overridden by DS 60 (2011) and brought new aspects: (1) maintained the reference to ACI 318-08 defined in decree DS 118; (2) maintained the definition of special and ordinary shear wall elements; (3) maintained the provisions defined in decree DS 118 regarding splicing zones and boundary element detailing; and (4) included the following provisions regarding special wall elements: limit the ultimate axial load of the wall to $0.35f_c' A_g$, impose a curvature capacity higher than curvature demand in the critical section of a wall limiting $\varepsilon_c \leq 0.008$, and eliminate the additional 1.4 factor for seismic actions when calculating the design shear. Recent experimental results have shown that this limit in axial load is still too high to have a ductile behavior of a shear wall. Currently, NCh433 is under discussion and it has been proposed that a unique post-earthquake evaluation form be used.

A new version of the code for seismically isolated structures NCh2745 was also generated (INN 2013a), but as opposed to conventional fixed-to-the-base structures, it accounts for the successful performance of these structures during the 2010 earthquake. The main changes in this code are to: (1) increase the R-value of the substructure from 1.0 to 1.5; (2) relax the requirement of *special frame detailing* to an *intermediate frame detailing* for the superstructure; (3) increase the maximum period of applicability of the design spectrum from 3.0 to 3.5 s, resulting in lower design shears; (4) limit the design shear of the superstructure to a maximum value equal to the elastic shear, resulting in lower design shear; (5) limit the design shear of the substructure to a minimum value equal to the shear in the superstructure; and (6) use soil factor $S = 1$ to calculate the minimum shear for every soil type, thus reducing the minimum design shear for poor soils (types C and D), and increasing it for stiff soils and rock (type A).

Moreover, the earthquake led to the discussion of new standards published between 2013 and 2015 on the following subjects: NCh3332 for retrofitting of historic earth buildings (INN 2013b), addressing adobe construction for the first time in Chile; NCh3357 for seismic design of non-structural components and systems (INN 2015a); NCh3359 with requirements for strategic buildings and community service buildings (INN 2015b); NCh3363 for design of buildings in tsunami inundation risk areas (INN 2015c); and NCh3365 with requirements for vertical transportation equipment (INN 2015d).

7 Lessons learned and conclusions

Earthquakes provide a unique opportunity to study the resilience of a country and share this experience with the rest of the world. A direct consequence of the data generated by a severe earthquake and its analysis is the improvement of seismic codes. Some of the lessons learned in this earthquake are presented next.

7.1 Data gathering and information

This real life experiment generated substantial data on the source mechanism and ground motion, the tsunami generated and its consequences, building performance (e.g., structural and nonstructural damage), performance of critical lifelines and infrastructure (e.g., utilities, ports, schools, and hospitals), interruption of basic community services, damage costs and insurance claims, business interruption, human response and psychological impacts (i.e., post-traumatic stress disorders and mental health), and a number of other relevant processes, including lawsuits (e.g., *retrofit* vs. *demolition*). In the case of structures,

evaluation forms are critical in obtaining reliable structural data after an earthquake. This article briefly described in the previous sections, and to the best of our knowledge, the most important evaluation forms used in data collected after the February 27th, 2010, Chile earthquake. The list discussed is surely not exhaustive since many professionals and institutions carried out their own studies that were never disclosed publicly. It is apparent though that the collected data could be classified at different scales of resolution, depending on its intended use. For example, building stabilization and retrofit decisions were based typically on reliable building information, structural drawings, ground motion records when available, and material tests on samples obtained directly from the structure.

Furthermore, relationships between the different forms of data can be established. For instance, it can be concluded that there is significant positive correlation between building data and damage. The most obvious is the strong correlation between building damage and (soft) soil conditions. This motivated the immediate changes in soil classification in the new design decrees. Indeed, the large majority of buildings that were severely damaged during the earthquake were founded on soft or intermediate soils, which in some cases were incorrectly classified by the old code (INN 2009). Another interesting aspect described in more detail elsewhere (Westenenk et al. 2012) is a clear positive correlation between geographic orientation of the principals axes of the building, and the existence of a preferred direction of damage. A formal correlation analysis was also performed using data from 36 damaged buildings aimed to check if the designer could foresee the structures that were prone to damage by simple geometric and response indices. Results show that no obvious trends exists using simple global geometric and response parameters (Jünemann et al. 2015); this could well be a sign that damage was sudden and that our conventional building models are not capable of capturing the essence of the response. Another evidence that was identified by the earthquake was the negative impact caused by the performance of nonstructural components, an aspect usually not included in the design and construction process of buildings; damage in nonstructural components was large and led many people to evacuate their homes. Other interesting data correlations are: (1) the tsunami effects and fault slip distribution; (2) the damage and fault slip distribution; (3) focal distance and height of affected structures; and (4) socio-economic demographic distribution and damage intensity, among several others. By far the most critical operational aspect is the National Civil Protection System, a complex system, in which timely and accurate data is critical.

As stated earlier, many organizations were involved in collecting field data and their needs varied depending upon their goals. Although understandable, stakeholders *nominally responsible* of the structural damage usually tend to respond quickly to get the problem out of the contingency (news, etc.). Many mistakes were made in repairing buildings quickly. Just as an example, a few weeks after the earthquake, there was evidence of shear walls being repaired in Concepcion with no understanding of the cause of damage and how to avoid it next time. On the other hand, one exceptional case was that of a construction company with a severely damaged structure that immediately moved all owners to hotels, while they carefully worked on the damaged structure. Owners could sell to the company their properties in case they did not want to return to the retrofitted structure. Moreover, unless a completely independent, unbiased, and knowledgeable professional does the evaluation, it will be very difficult for all the parties involved in a case of damage to trust the data completely. In summary, it is obvious that a more synergistic and coordinated effort to collect data is required in the country.

For different reasons and despite that technology is quickly evolving to facilitate gathering and sharing of data, there are still several coordination problems in sharing data across public and private organizations. This is a very critical point, and everyone in the

society needs should understand that hiding critical data may have serious consequences and should be considered legally, at the very least, as a negligence and misdemeanor. The consequences are obvious; several damaged buildings were temporarily shored in Concepcion without detailed inspections being reported back to any central entity. Because some of these buildings were near collapse, working on them while ignoring their actual condition was too risky. For this purpose, recorded ground motions were critical, and if not for the San Pedro record disclosed by SSN, all the stabilizations of the buildings would have been essentially a purely theoretical guess. Developing a model capable of representing the actual state of damage of these structures was a critical point in order to check the stability of the intervened structures during aftershocks. For a building close to collapse, a much more refined inelastic analysis of the structure is required. Indeed, several people were in these buildings few days and weeks after the main shock to survey the structure in the interior and to build the shoring system.

A critical case in terms of data sharing occurred with the ground motion records. This is a lesson the country already learned and future acceleration records will be publically open almost immediately after the earthquake to everyone. On the other hand, available satellite data is readily available and can be used in a number of important geophysical studies. In summary, a national policy should be in place to guarantee free universal access to earthquake data at least for research and security needs. It is fair to recognize that in several other cases, people and institutions were very generous in sharing data to collaborate with advancing knowledge.

Failure in the electric power grid led to a number of other consequential failures; 3 days after the earthquake the SIC electric system had recovered 50 % of its capacity. Several factors helped in the quick recovery and resilience of the system; the most important being the human factor. One direct consequence of the electric failure was the communication system, in particular the mobile phone system, aggravated by the rise in the number of calls 24 times above the value expected during a normal day. Remedial actions have been implemented since then to improve resilience, such as the legal requirement to ensure power supply for 48 h or more in 527 critical mobile phone communications components, and 4 h in the rest; triple the SMS capability of the mobile phone system; generate a new emergency communications system independent of the public network; and implement an alert communication system using the CBS.

In general, there is a tremendous disparity between data collection practices in terms of what does it work and what does not. In general, data of damage are difficult to obtain from the responsible person or institution, since it involves their personal or corporate reputation. Almost always, indirect means need to be activated in order to get building drawings, damage reports, and detailed information on damage. Based on the post-earthquake work, it is apparent that keeping an updated as-built copy of the architectural and structural drawings at the municipalities should be mandatory. This would facilitate tremendously the efficiency in evaluating structures at risk as well as for any other emergency situation with the structure.

A critical aspect in collecting data is to have simple and commonly accepted protocols to gather it, store it, and use it. To facilitate the use of earthquake data for research purposes, it is possible to provide confidentiality to the identity of a damaged structure in all publications, and request the explicit consent of the owner for that. Undoubtedly there are several examples of difficulties in sharing data, but in many other cases people understood that earthquake information would be beneficial to them.

Unfortunately, it is not straight forward to evaluate the percentage of earthquake data that may have been lost. The general impression is that for most significant damaged

structures data was almost always collected by someone. Secrecy on dealing with the data has many different causes ranging from commercial aspects to professional reputation. One idea could be that of creating a national law of earthquake data transparency and availability for research purposes.

7.2 Conclusions and suggestions

The principal needs obtained from the data collecting process after the February 27th, 2010 Chile earthquake, are to: (1) develop a standard instrument to guide and record damage during inspections; (2) create a better coordination in reconnaissance efforts; (3) avoid the large disparity in knowledge and technical criteria used by damage evaluators during emergency inspection; (4) declare earthquake data as a free resource to everyone involved in research; (5) develop an open access clearinghouse for earthquake data that enables consolidation and classification of data; and (6) improve preparedness of institutions with clear response protocols and equipment to inspect a large number of structures.

The previous ideas should improve protocols of data collection and dissemination. Some suggestions are to: (1) define a clear scope of the post-earthquake inspection procedure; (2) standardize the procedure in order to consolidate results from different evaluators; (3) validate the data for later research purposes such as improved design codes and construction practices; (4) take advantage of the many calibrated post-earthquake inspection forms available elsewhere in the world; (5) develop a protocol to share data freely among researchers; (6) use new ITs for communication and data collection protocols; and (7) make universities participate in the definition of these protocols, and train a civil work force capable of applying correctly these protocols.

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