RECONNAISSANCE OBSERVATIONS BY CIGIDEN AFTER THE 2015 ILLAPEL, CHILE EARTHQUAKE AND TSUNAMI

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Abstract

This paper describes the reconnaissance work conducted by researchers from the National Research Center for Integrated Natural Disaster Management (CIGIDEN) between September 23rd and October 2nd in the area affected by the M_w 8.3 Illapel megathrust earthquake, which struck offshore the coast of the Coquimbo Region in central Chile on September 16th, 2015. A first team focused on the seismic performance and effects of the tsunami on public hospitals and on reinforced concrete (RC) buildings. A second team focused on the road network infrastructure. Field work included: (i) a survey on the physical and functional damages of the public hospitals in the Region; (ii) a visual inspection and preliminary damage assessment of 20 RC buildings in the largest cities of the region and an aftershock instrumentation of the Coquimbo hospital; and (iii) the inspection of bridges, pedestrian bridges, and rockfall along overstepped cut slopes of the road network. The overall limited impact of this megathrust earthquake may be explained in part by the long-term efforts made by the country to prepare for such events. Learnings from the 2010 Maule earthquake were evidenced in the successful evacuation along the coast of the country, and the overall good performance of engineered masonry structures, and of RC buildings designed after 2010.

Keywords: post-earthquake reconnaissance; Illapel earthquake; critical infrastructure; healthcare network; road network

1. Introduction

The central coast of Chile was violently struck at 22:54:32 UTC on September 16th 2015 by a M_w 8.3 subduction earthquake with hypocenter (31.57º S, 71.67º W) located roughly 48 km west of the town of Illapel in the Coquimbo Region. This earthquake ruptured a section of ca. 280 km of the Nazca–South American plate interface [1]. Preliminary analysis shows that the focal mechanism was thrust slip with a nodal plane defined by strike, dip, and rake angles of 5º, 22º, and 106º, respectively [2]. The compromised segment was dormant since the full rupture occurred in 1943 [3] that generated a M_w 7.9 earthquake. Since then, this segment has been identified as a region of high plate locking with an estimated coupling coefficient between 31-69% [4], implying that a significant fraction of the average plate convergence rate (~74 mm/yr) converts into accumulated strain over the years.

Interference of SAR images (InSAR) obtained closely before and after the main shock by satellite Sentinel-1A allows mapping of the coseismic displacement field, which reveals a maximum ground deformation of 1.4 m at latitude close to 31ºS as shown in Fig.1a. As explained elsewhere [5], typical seismic inversion of surface displacements measured from InSAR and GPS data yielded the slip distribution model presented in Fig.1b, which shows a single path of slip of nearly 200 km long, with maximum and mean slip of 7.2 m and 1.6 m, respectively, and a corresponding seismic moment of 3.60×10^{21} N·m, equivalent to a moment magnitude M_w 8.3 [5]. The main event was followed by several aftershocks, including a M_w 6.4 (22:59:15 UTC) and a M_w 7.0 (23:18:41 UTC) during the first hours [6], and more than 1,400 aftershocks in the first 30 days after the main shock [7].

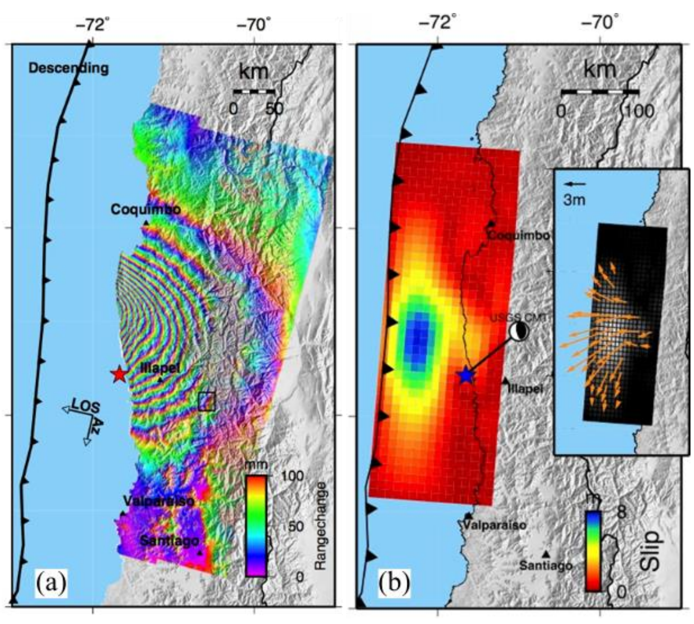

Fig. 1 – (a) Descending Sentinel 1A interferograms for the Illapel earthquake; and (b) slip distribution model obtained from inversion of InSAR+GPS data

Eight minutes after the earthquake, the Chilean Navy Hydrographic and Oceanographic Service (SHOA) issued a tsunami warning. Eleven minutes after the main shock, the National Emergency Office (ONEMI) ordered the preventive evacuation of all the coastal regions of the country, mobilizing more than 660,000 people throughout 13 regions [7]. The tsunami triggered by the earthquake arrived quickly to the coast flooding several small fishermen's coves and causing severe damage in the cities of Coquimbo (capital of the Coquimbo Region), Tongoy, Los Vilos, and Concon. Measured tsunami run-up reached 4-6 m near Coquimbo, and a peak run-up ~11 m in a small bay in south of Los Vilos [8]. In Coquimbo, the tsunami waves reached an inland distance over 500 m from the coastline resulting on severe erosion on the rock fills along the shoreline, tossing large vessels and fishing boats onto the streets, and leaving the area with tons of tsunami debris. In the rural zone of Illapel, industrial residues and pollutants flowed over 10 km downstream from a mining plant as a result of the failure of two walls on a tailing dam. Overall, the earthquake left a death toll of 15 people (8 of them attributed to the tsunami), 14 people injured, 1 missing, and 428 sheltered; direct costs of the emergency response was approximately $44 million USD [7].

As it should be expected, several adobe and non-engineered clay-brick masonry structures were damaged and collapsed. The stock of residential adobe structures in the Coquimbo Region is estimated in 18,055 (9% of the total structures in the Region), and that of unreinforced clay-brick masonry structures in 5,560 units [9]. These typologies are mainly present at inland small towns and rural communities, but also in the Historical District of larger settlements such as Illapel and La Serena. The official damage information of residential structures reported 2,303 completely destroyed houses, 2,743 with severe damage, and 7,301 with minor damage (all but 11 cases reported in the Coquimbo Region) [7]. Although RC buildings and steel frame structures within the inundation zone performed well in the Coquimbo Region, the tsunami flooding interrupted basic utilities (e.g., electricity, gas, and potable water), forcing residents to move out. The day after the earthquake, 135,000 people lacked electricity supply (18% of the Region population) and more than 9 thousand had no potable water supply (1% of the Region population) [10].

To better understand the response of the Chilean built environment to strong earthquakes, the National Research Center for Integrated Natural Disasters Management (CIGIDEN) deployed two reconnaissance teams in the Coquimbo Region following the earthquake. The teams were integrated by researchers and graduate students from CIGIDEN, Pontificia Universidad Catolica de Chile (PUC), and Universidad del Desarrollo, and members from the Geotechnical Engineering Extreme Event Reconnaissance (GEER) Association. The first team focused on the recollection of perishable data and the performance of the public hospitals network of the Region as well as the response of RC buildings in the coastal cities of Coquimbo and La Serena. The second team concentrated on the tsunami effects along the coast, and the ground motion effects on the road network. Fig.2 shows the Coquimbo Region and the position of the epicenter of the earthquake [1] together with the surveyed hospitals and roads.

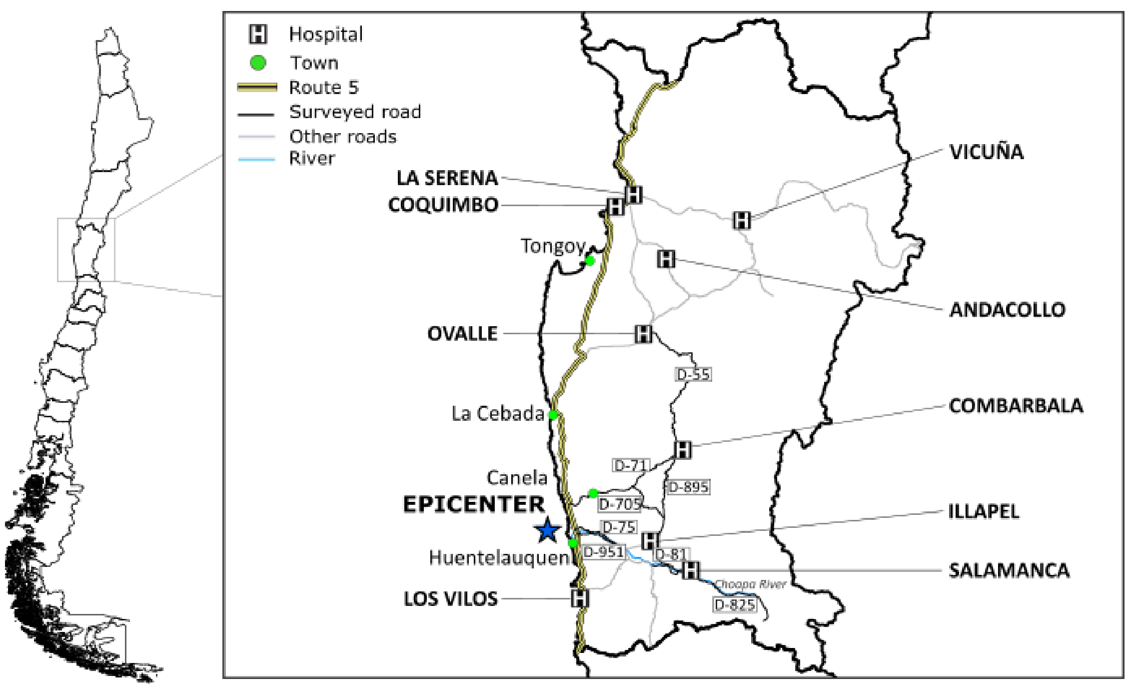

Fig. 2 – Map of the Coquimbo Region in Chile showing the position of the epicenter of the 2015 Illapel earthquake [1]. The main highway of the country, Route 5, is highlighted in yellow. The cities with surveyed public hospitals are showed in capital letters. The assessed roads are identified in black

Each of the following sections describes in more detail specific aspects of the assessed infrastructure, identifying first the visited areas of the Coquimbo Region and the methodology used in gathering field observations. Then, we present a summary of the collected data and an analysis of the conditions observed in the field. Section 2 deals with the performance of the public hospitals network of the Coquimbo Region addressing both their physical and functional damage. Reinforced concrete (RC) buildings performance is assessed in Section 3, first by means of the damage inspection conducted in the coastline between Coquimbo and La Serena—the largest cities of the Region—and then with the results of an aftershock instrumentation conducted at the Coquimbo's hospital. Section 4 presents the assessment of the port in Coquimbo, the road network including roads and bridges, and other geotechnical observations. This article presents some general conclusions of the overall effect of the earthquake a few lessons learned from this earthquake.

2. Performance of public hospitals

The first reconnaissance team surveyed 7 out of the 9 hospitals of the Coquimbo Region. During this visit the team also conducted a personal interview with the Director of the Coquimbo Regional Healthcare Service. The in-site survey included the hospitals of Andacollo, Combarbala, Illapel, La Serena, Los Vilos, Ovalle, and Coquimbo. The hospitals of Salamanca and Vicuña (Fig.2) were later surveyed by phone. The applied survey was the Health Facility Impact Survey developed at The Johns Hopkins University, which has been used previously to assess the physical and functional damages and overall seismic performance of hospitals in Chile after the 2010 Maule earthquake [11], in New Zealand after the 2011 Christchurch earthquake [12], and in Nepal after the 2015 Gorkha earthquake. The analysis of survey results [13] have been used to better understand and simulate the functional response of the healthcare network during strong earthquakes.

After the earthquake, most hospitals conducted a full or partial evacuation in less than an hour. The Coquimbo hospital, however, needed 6 hours to evacuate 12 patients from the intensive care and intermediate treatment units (ICU/ITU) and 12 patients from the psychiatric unit to another undamaged zone of the facility. A noteworthy case is the low complexity hospital in the city of Los Vilos, located within the tsunami inundation zone. All personnel and patients were evacuated to an educational facility in higher grounds (i.e., 30 m.a.s.l.), and returned to the hospital nearly after 12 hours. This temporary facility, however, did not have backup electric generators or water tanks, so no basic healthcare services could have been provided should the supply of municipal water and electricity had been lost in the emergency.

From the survey, it was observed that all public hospitals of the Coquimbo Region, but the one in Vicuña (Fig. 2), experienced slight structural damage including diagonal cracks in some RC and masonry walls and spalling of concrete cover in a limited number of elements (Fig.3a and b), while non-structural damage was observed in all facilities. Falling of contents was the most common form of non-structural damage, together with damage in glazing and in partition walls (Fig.3c). The inpatient ward was the most affected service in all facilities, and was often closed or relocated due to damaged glazing. The largest number of physical areas affected in services was reported in Combarbala and Salamanca. In the Coquimbo hospital, hardcopies of several medical records were lost after the collapse of shelves; most of these records were not digitally backed up (Fig.3d). Due to its importance within the healthcare network, a military field hospital was installed at the hospital in Coquimbo during 5 months to partially restore its ability to address emergencies and regular medical appointments. With regards to the electrical supply, the backup generators required over 30 minutes to start in Salamanca. In the Combarbala and La Serena hospitals, the generators supplied electricity only for critical units, thus reducing the capacity of the facility and its functionality.

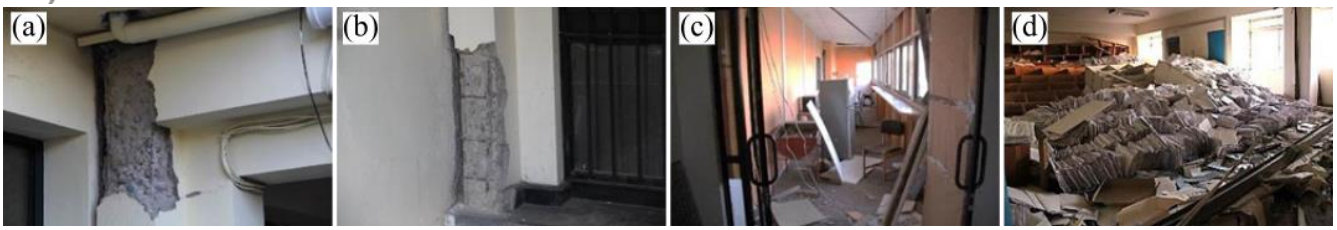

Fig. 3 – (a, b) Concrete spalling at Illapel hospital; (c) non-structural damage at Coquimbo hospital; and (d) shelves collapse with medical records at Coquimbo hospital

Overall, the emergency response of the hospital network was adequate despite the generalized loss of functionality as a result of non-structural damage and loss of contents. Due to the forthcoming Chilean holidays starting on September 18th and the large amount of tourists in the Region, the hospitals were overstocked with medical supplies, fuel for the backup power generators, and water in the backup water tanks to absorb an increased patient inflow. This allowed the hospital network to cope with the emergency properly.

3. Performance of RC buildings

3.1. Damage inspection

A visual inspection and preliminary damage assessment was conducted on 20 RC buildings 8 stories and taller, located on an approximately 15 km strip along the coastline between El Faro in La Serena and Avenida Costanera in Coquimbo (Fig.4a). Additionally, five RC buildings were inspected in the La Herradura sector (Fig.4a). The damage inspection was carried out by groups of three to four professionals following the "Visual Inspection Protocol" developed by DICTUC, a subsidiary firm of the School of Engineering at PUC, after the 2010 Maule earthquake.

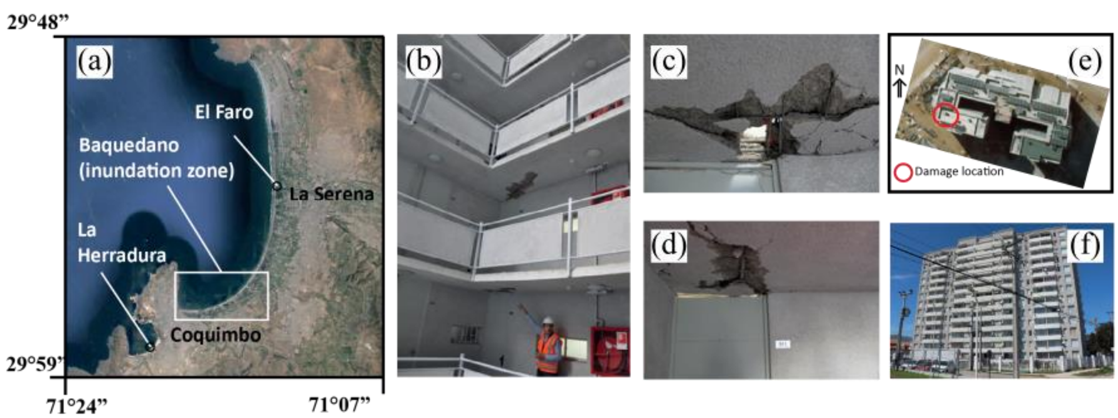

Fig. 4 – (a) Geographic location of surveyed sectors; (b) structural damage in a building in La Herradura; (c) and (d) detail of structural damage in RC slabs in building in La Herradura; (e) floor plan configuration and damage location; and (f) view of the north façade of the building

In general, no significant damage was observed in the surveyed coastline buildings; only small cracks in concrete cover and a low degree of ground settlement was observed in some cases. A single medium-rise RC building located in La Herradura (Fig.4b through f) presented severe structural damage, characterized by significant concrete crushing in the slabs at their intersection with shear walls in stories 3 and above (Fig. 4b, c and d). The building presented a C-shaped floor plan configuration (Fig. 4e) and had a single diaphragm with no construction joints. Severe damage was observed in the south west corner of the building (Fig. 4e), while minor damage was found in the north west corner. The observed damage was probably the result of large bending and shear forces induced in the floor diaphragms, aggravated by the horizontal irregularity of the building, the small slab thickness, and the absence of lintels. Probably, this building considered a rigid diaphragm model and the actual stresses during the earthquake exceeded those estimated by the flexural slab action during the design process.

Approximately ten RC buildings with 8 or more stories were inundated by the tsunami. In all cases, non-structural elements in the first story were completely swept off by the sea waves as seen in Fig.5a and 5b. On the other hand, no evidence of structural damage was observed as a result of ground shaking or hydrodynamic forces; only a series of very narrow vertical and diagonal cracks (e<0.2 mm) were observed in some RC walls and slabs. Unlike these buildings, two RC buildings next to the coastline had been designed using the recommendations for constructions within tsunami flood risk areas developed after the 2010 Maule earthquake and tsunami [14]. These buildings were characterized by a high-rise first story used for common areas and storage, electrical and emergency equipment located above the first story, and a layout that allows water flow (Fig.5c). Furthermore, the common areas of the buildings were insured against tsunami inundations. With these considerations, these buildings performed better than anticipated, and the economic impact for the residents was minimized.

Fig. 5 – (a) Run-up marks left on the walls; (b) non-structural elements washed away in first story housing units; and (c) non-structural damage in first story common areas

3.2 Aftershock instrumentation

Part of the reconnaissance team performed an instrumentation campaign at the Coquimbo hospital with the objective to measure the dynamic properties of the structure and estimate the effects of the earthquake, particularly on building vibration periods. Ambient vibrations and aftershock instrumentations were deployed in the hospital, finding a period elongation relative to a previous measurement. The hospital is composed by three independent 5-story towers, each of them based on a RC beam-column frame system (60x60 cm) arranged on a regular square grid of 6.6 m in plan, combined with RC non-structural walls located around the perimeter of the floor plan, and concrete partition walls (Fig. 6b).

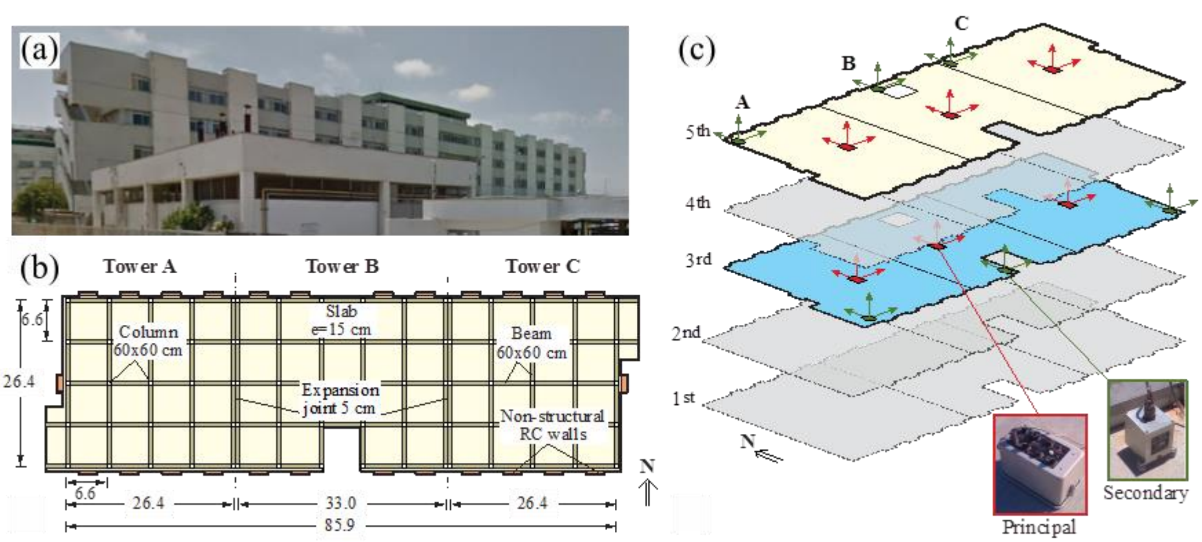

Fig. 6 – (a) General view of the Hospital, (b) structural plan view of 5th floor (units in meters), and (c) sensor layout in building and sensors used

For the instrumentation campaign, two tri-axial accelerometers (principal and secondary, Fig.6c) were installed at six different locations of the building (3rd and 5th stories of towers A, B, and C). For each location, the principal accelerometer was placed at the approximate coordinate of the geometric center, and the secondary accelerometer on the farthest accessible place of floor plan in each tower (Fig. 6c), in order to capture the three lateral and torsional components of acceleration of each tower. Measurements of 30 minutes signal were completed at each location on September 24th, 8 days after the main shock. During the measurements, 3 aftershocks were recorded, including a M_w 5.5 (16:13:25 UTC, 24 km SW of Ovalle), which was captured at the 5th story of Tower B.

The recorded accelerations were base-line corrected and filtered to remove spurious noise. Power Spectral Density (PSD) spectra were computed for lateral N-S, E-W, vertical (Z), and torsional (Θ) components. To identify the predominant direction and comparable measurements between directions, a normalized PSD was used [15]. Figures 7a and 7b show the normalized PSD of Tower B at stories 5 and 3, respectively, where the first 4 modes are clearly identified. It is observed that the 5th and 3rd stories have similar fundamental periods and the modal direction coincide for the first 3 modes, which is also observed for towers A and C. Indeed, the maximum difference between 5th and 3rd story periods is 4.2%. Close values in lateral and torsional modes (modal tuning) and lateral-torsional coupling are also observed. Additionally, the 3rd story spectra in Tower B (Fig.7b) shows non-negligible PSD near 4 Hz, which is also observed for measurements in towers A and C. This effect may be due to ambient vibrations such as human operations, elevators, highways (Route 5), and railway line close to the building, which pulses are stronger in lower stories.

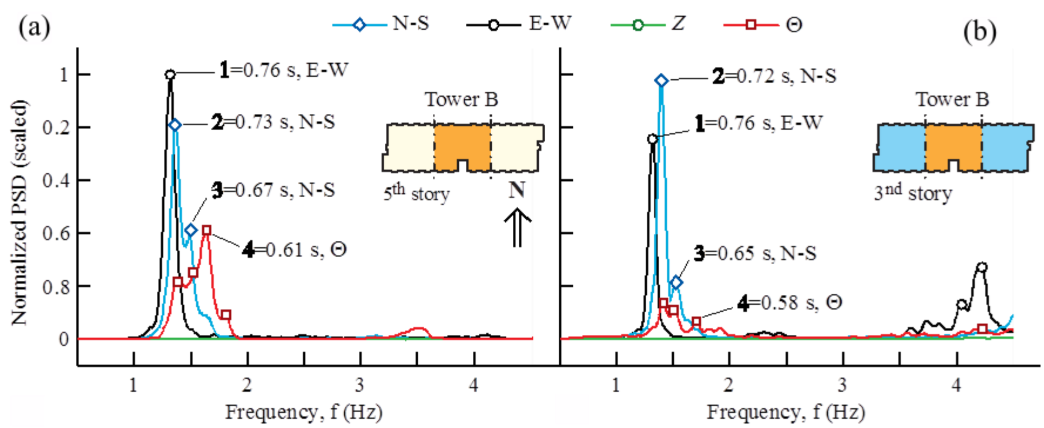

Fig. 7 – Normalized Power Spectral Density (PSD) of recorded ambient vibrations measured by sensors at (a) 5th story; and (b) at 3rd story of tower B, in N-S, E-W, Z and Θ-directions

Table 1 shows the first 4 modes (period and direction) for the measurements at the 5th story of each tower, compared with a similar measurement performed in 1997 [16] after the Punitaqui earthquake (October 14th 1997, M_w 7.1). At that time, ambient vibrations at the 5th story of each tower were measured to estimate the first 4 vibration modes. The building suffered severe structural and non-structural damage during the 1997 earthquake, especially shear failure and concrete spalling in perimeter columns at the 2nd story, which was not observed during the 2015 earthquake [16].

Table 1 shows that the fundamental period is very similar for the three towers during the 1997 and 2015 measurements. In all three towers, the first period in 1997 measurements was 0.69 s with a mode shape in the longitudinal E-W direction, which elongates to 0.76 s during the 2015 measurements along the same direction (i.e., a fundamental period 10% longer). The second mode was between 0.61 s to 0.67 s in 1997 measurements with a mode shape in the transverse N-S direction and coupled between lateral and torsional directions, especially in Tower B. This mode elongates to a value between 0.70 s to 0.73 s during the 2015 for the same direction. The first 4 periods measured in 2015 are between 5% and 22% longer than the 1997 measurements. Even so, the predominant direction in 1997 and 2015 measurements coincide for the first 3 modes. The reasons for the period elongation may be caused by several factors: (i) structural changes of the building after the 1997 earthquake; (ii) damage in the structure (cracks and concrete spalling in columns by bending-compression forces in upper stories) and non-structural elements, including collapse of concrete and drywall panels in almost all stories in 2015; and (iii) considerable increase of live load masses due to accumulation of numerous hardcopies of medical reports (more than 500,000) (Fig.3d).

Table 1 – Periods measured instrumentally (T) at the 5th story and directions for the first 4 modes of the Coquimbo hospital

Mode	Tower A			Tower B			Tower C		
	T_{1997}[a]	T_{2015}[b]	T_{2015} / T_{1997}	T_{1997}	T_{2015}	T_{2015}/ T_{1997}	T_{1997}	T_{2015}	T_{2015}/ T_{1997}
1	0.69 EW	0.76 EW	1.10	0.69 EW	0.76 EW	1.09	0.69 NS-EW	0.76 EW	1.10
2	0.61 NS-Θ	0.70 NS	1.15	0.67 NS-Θ	0.73 NS-Θ	1.09	0.67 NS	0.70 NS	1.05
3	0.54 ?	0.66 NS	1.22	0.61 NS-Θ	0.67 NS-Θ	1.10	0.61 NS-Θ	0.65 NS	1.07
4	0.50 Θ	0.60 EW	1.19	0.54 NS-Θ	0.61 Θ-NS	1.13	0.54 Θ-EW	0.61 EW	1.14

[a] Ambient and aftershock after the Punitaqui 1997 earthquake (October 14th 1997) [16]

[b] Ambient and aftershock after the Illapel 2015 earthquake (September 24th 2015)

4. Performance of port, road network, bridges and other geotechnical effects

4.1 Port of Coquimbo

In Coquimbo, several light-weight structures and non-structural components were swept away by the waves, shutting down production in the port and commerce along the coastline. The Coquimbo port was also evacuated after the earthquake, but no damage was observed at the wharf. The copper concentrate stockpile garage performed well after the earthquake, but a stockpile tent presented significant damage. Moreover, the port's passenger terminal had significant damage and was closed. Additional damage was observed in the maintenance garage and on administrative offices, together with the flooding of warehouses and settlement of pavements. Detailed studies were conducted with the support of the Port Department of the Ministry of Public Works (DOP), including new bathymetry and topography after the earthquake, and submarine inspection studies. The port returned to its operation one month after the earthquake.

4.2 Road network

The National Roads Directorate of the Ministry of Public Works (DNV) reported 24 roads with disruptions in the Coquimbo Region. From these, 3 roads became inoperative due to large rockfall on adjacent cut slopes, 18 roads presented minor to moderate rockfall, and 3 presented lane closure or temporary closures of the complete road [17]. A cluster of rockfall and mass-wasting was observed near the epicenter along Route 5 along interior roads D-55, D-71, D-75, D-81, D-85, and D-951, which cross hilly terrain (Fig.2). These failures affected primarily steep cut-slopes through highly jointed weather igneous rocks and sedimentary rocks.

The secondary and tertiary road networks also evidenced several problems that interrupted the connectivity of the Coquimbo Region. Road D-75, connecting the cities of Huentelaquen and Illapel through the north rim of Choapa River, was affected by a massive rockfall in km 11 generating permanent closure of the road (Fig.8a). Road D-75 presents a double treated surfacing and low-volume traffic, constituting an alternative route connecting Route 5 with the city of Illapel. Two weeks after the earthquake, the road remained closed in this point. The road is located in the river canyon, presenting steep cut-slopes with slope angles greater than 30° starting from km 9. The slopes are made of weakly cemented rocks, sedimentary rocks and soils, with native vegetation present in the natural soil on the top of the slope. Minor rock falls were also observed starting from km 9 (Fig.8b), causing partial blockage of the road after the main shock. The material was plowed off and traffic was restored until km 11. The pavement in this area suffered permanent local surface deformations similar to punch-outs caused by rock-fall (Fig.8c).

The north access to Illapel from Route 5 was also assessed. This includes road D-71 connecting Route 5 with Combarbala and passing through the town of Canela, road D-895, and road D-705 (Fig.2). The three roads present asphalt pavements typically demanded by moderate traffic, with presence of trucks, buses, and light vehicles. The main failure observed in these roads was moderate to minor landslides that were plowed by the time the field evaluation was performed, with the exception of road D-71. This road was permanently plowed in three points, where partial closures were observed and only one lane was operating. Road D-81 connecting the cities of Illapel and Salamanca through the north bank of the Choapa River was also assessed (Fig.2). By the time of the evaluation, minor landslides were already plowed given the importance of this road as it connects the large copper mine Los Pelambres with the coast. An alternative route through the north bank of the river is road D-825, which is an unpaved low-volume traffic road. The road presented major rockfall, where rocks of considerable size obstructed the road (Fig.8d). At the time of the reconnaissance, the road was already cleared, requiring the detonation of major rocks and plowing of oversized material to the road side and down the hill to the river.

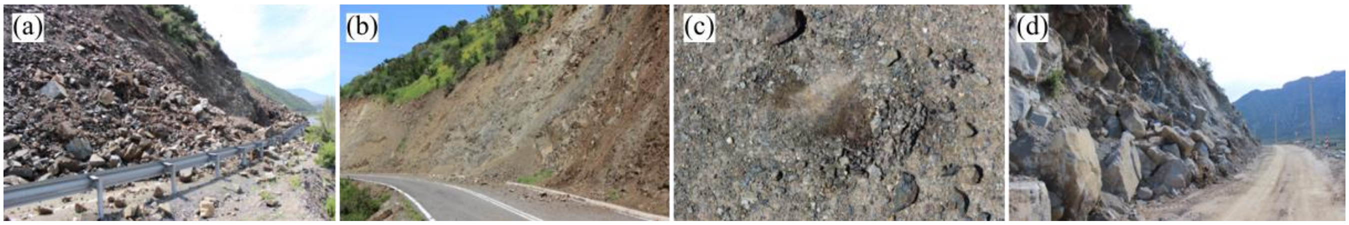

Fig. 8 – (a) Massive rockfall on km 11 of road D-75; (b) raveling on steep cut slops of road D-75; (c) punch-outs on road D-75; and (d) plowed rockfall on road D-825

4.3 Bridges

Eight bridges suffered damage without losing its functionality. Six of these bridges were on Route 5 (Fig.2), and one of them corresponded to a pedestrian bridge. The other 2 bridges were located in secondary roads. The observed damage was displacement and/or rotation of the superstructure due to sliding of elastomeric bearings, settlement of the bridge approach, and damage in bridge joints of the superstructure due to impact with the abutments. The largest residual displacement of the superstructure (16 cm) was observed in the west span of the Talinay underpass (km 346) as a result of the rotation of the superstructure (Fig.9b). Apparently, the hold downs or "seismic bars" used to connect the deck slab with the abutment and bent cap did not prevent lateral displacement of the superstructure. This sliding behavior increases energy dissipation and limits the shear forces transferred to the piers and abutments.

Similar rotations of the superstructures have been observed in previous earthquakes [18], but mostly in skew bridges. Settlement of the bridge approach was observed in El Teniente bridge (Route 5, km 334), which presented a settlement of about 20 cm in the embankment of its southern access (Fig.9c). A similar performance was observed in the Illapel II Bridge, located in Illapel. The two abutments settled 10 cm, and the abutment slopes suffered minor raveling [19]. No damage was observed at the Amolanas bridge (Route 5, Km 309), the highest highway bridge in the country (100.6 m the tallest pier). This bridge is a 273 m continuous steel box girder connected to three piers and end abutments, and is equipped with two viscous dampers at each abutment in the longitudinal direction. Evidence of liquefaction was observed in the river bed of La Cebada Bridge (Route 5, km 339) located 66 km north of the epicenter. However, no settlement was observed in the bridge approach. Besides the aforementioned problems, the pavements suffered additional distresses such as cracks and potholes due to the impact of the rocks and gravel that fell into the roads.

Fig. 9 – (a) Talinay underpass; (b) creeping and 16 cm residual displacement of the elastomeric bearings on the superstructure of Talinay underpass; and (c) temporary asphalt ramp on the south access of Teniente Bridge

4.4 Geotechnical effects

In general, earth retaining structures in non-liquefiable media performed very well, this includes gravity walls, mechanically stabilized walls, basements structures, and anchored soldier piles supporting deep excavations. Adjacent to Coquimbo's port and within the inundation zone, a 30 m section of a gravity retaining wall overturned as a result of ground shaking, tidal wave forces, and possibly liquefaction at the wall footing. The backfill material was made of loose sand and rock fragments.

Liquefaction in the region was not extensive; it was limited to a few locations with high water elevation and loose sand deposits. In many cases, the evidence of liquefaction was washed away by the tsunami waves. For instance, the structures adjacent to El Faro in La Serena (Fig.4a) settled differentially, and based on shear wave velocity profiles this site should have liquefied, but the tsunami scour and erosion could also have contributed to increase the settlements. For more details about the observed liquefaction and field testing of shear wave velocity profiles, the reader is referred to [19] and the GEER Association report [20].

5. Lessons learned and closing remarks

This article summarizes the field observations conducted by two teams from CIGIDEN that visited the Coquimbo Region after the 2015 Illapel earthquake to assess the performance of the infrastructure and gather perishable data. Surveying efforts were focused on RC buildings and critical infrastructure such as roads, bridges, and the healthcare network. Overall, RC buildings performed well with no signs of shear wall failures—as those observed after the 2010 Maule earthquake—and slight structural damage was observed as a result of the ground shaking. The tsunami, however, caused large disruption of services and losses, thus forcing a significant amount of people to relocate.

The impact of the earthquake on the hospital network was significant, damaging the most important facility of the network, namely the Coquimbo hospital. The most critical areas were heavily affected by non-structural damage, which decreased the capacity of the hospital to properly respond to the emergency in the Region. Lack of emergency planning and preventive actions of the hospital network were evidenced at the Los Vilos hospital. The complete hospital had to be evacuated because its located is in the inundation zone. The earthquake also caused loss of connectivity between major cities and rural areas. The road network lacks redundancy and blockage of small roads due to landslides and rockfalls lead to connectivity loss for primary healthcare and other critical services. Connectivity was quickly recovered by plowing operations done by the DNV. Notwithstanding the large social positive effect of this immediate actions aimed to recover the functionality of the infrastructure, authorities should also acknowledge that scientific reconnaissance campaigns are needed to learn from these severe events and advance knowledge to improve future societal response and resilience.

The overall low impact of such a megathrust earthquake, together with a similar situation during the M_w 8.2 Pisagua earthquake in 2014, shows that the country is better prepared for these large events. This is in part the result of a continuous effort made by the country at different levels to better prepare for such extreme events, but also to the recent experience of the large M_w 8.8 Maule earthquake in 2010. One example of these learnings is the successful evacuation along the coastline of the country that resulted in a very low number of casualties.

Another example is RC buildings designed after 2010 with the new seismic design code provisions and the tsunami preventive recommendations. It is important to recognize that events such as the Illapel earthquake challenge not only the performance of the built environment, but also the installed capacities to monitor the phenomenon and its consequences, the channels of information to the population, and the local and national organizational capacity to cope with the emergency, response, and recovery phases during and after the event. The continuous exposure of the country to such extreme events represents an opportunity to improve scientific learning following these "natural experiments", thus contributing to the major goal of improving resilience of communities in Chile and elsewhere.

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