M8.3 Coquimbo, Chile Earthquake and Tsunami: Preliminary Reconnaissance Observations

Two teams sponsored by the National Research Center for Integrated Natural Disasters Management, CIGIDEN, and the Department of Structural and Geotechnical Engineering of the Pontificia Universidad Catolica de Chile, traveled to the Coquimbo region to assess damage in the infrastructure due to earthquake and tsunami. From September 23rd through 25th, the first reconnaissance team focused on the performance of the public hospitals and on reinforced concrete buildings in the largest cities of the Region, Coquimbo and La Serena. From October 1st through 2nd, the second team focused on road infrastructure.

Introduction

On Wednesday, September 16th, at 19:54 hour local time, a M_w 8.3 megathrust subduction earthquake struck offshore the coast of the Coquimbo region in Central Chile. The hypocenter was located 28 km west of Canela Baja, 48 km from Illapel, at a depth of 25 km (Fig. 1). Rupture of the interlocking plates was bilateral as in the 2010 earthquake with a larger patch of slip north-west of the epicenter. Eleven minutes after the earthquake, a tsunami warning was issued by the Hydrographic and Oceanographic Service of the Navy (SHOA), and the National Emergency Office (ONEMI) ordered the evacuation of the coastline along the country, mobilizing more than 1 million people. Around 20:30 hour local time, tsunami waves had already arrived to Coquimbo, Atacama and Valparaiso regions. Wave heights recorded offshore by SHOA reached 4.5 m in Coquimbo, 1.9 m in Valparaiso and Pichidangui, 1.66 m in Chañaral, and 1.05 m at Juan Fernández Islands in the Pacific Ocean.

Figure 1: Map of Coquimbo region, the most affected by the earthquake and tsunami. The position of the epicenter is showed in red, Canela Baja in green, and the 9 public hospitals surveyed in yellow. Source: Google Earth.

The last official information released by ONEMI on October 7th showed a death toll of 15people, 2 reports of alleged casualties, 5 injured, 57 sheltered, and 26,773 people affected by the earthquake and tsunami. In addition, 2,281 houses were destroyed, and 2,404 houses were reported to have major structural damage and were declared uninhabitable. ONEMI has dispatched a total of 163 emergency houses to different municipalities in the Coquimbo region to the date.

Severe damage was observed in adobe constructions in interior small cities and rural communities of Coquimbo region, as expected, where we estimated a stock of 18,055 residential structures (9% of the total structures in the region).

The day after the earthquake, 96,705 people (41% of the region) in the Coquimbo region were reported without electrical supply and 9,070 (3.8% of the region) without potable water. The quick response of the authorities allowed for a fast recovery of utilities: people without electricity on September 18th were 32,123 (13.6% of the region), and only 1,183 by September 19th (0.5% of the region). Road plowing and debris removal operations were also expeditious in the most affected locations in the region.

The road network was damaged by slope failures, rockfalls, and raveling of loose materials, which obstructed traffic and left some communities disconnected. The National Roads Department of the Ministry of Public Works (DNV) informed of 24 emergency events in the network, including 3 roads completely cut, 9 with slope failures, 9 with large rockfalls, and 1 partially obstructed road. Additionally, eight bridges suffered damage, six of them on Route 5, which is the most important highway in the country (Fig. 2). The most commonly observed damage was sliding (creeping) of elastomeric bearings, soil abutment damage, and damage in bridge joints. The largest residual displacement of the superstructure (16 cm) was observed in the west span of the Talinay underpass as a result of the rotation of the superstructure (Fig. 3). El Teniente bridge presented a settlement of around 20 cm in the abutment of its southern access (Fig. 3). Restoring connectivity has been the priority for the DNV, including blasting of large rocks that fell in certain portions of the network. 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. No damage was observed in the Amolanas Bridge, the highest road bridge in the country (100 m high), which is equipped with seismic protection, i.e., friction bearings on piers and abutments, and two viscous dampers at each abutment in the longitudinal direction.

Figure 2: Slope failures obstructed traffic in Route 5, Chile's main highway (Photos: Felipe Rivera).

Figure 3: A residual displacement of 16 cm of the superstructure was observed in Talinay underpass, where creeping of the elastomeric bearings was observed (left). Settlement of almost 20 cm was observed in the southern abutment of El Teniente bridge; an emergency asphalt concrete was used to partially restore the use of the bridge (right) (Photos: Matías Hube and Gabriel Candia).

Coastline damage

The tsunami triggered by the earthquake caused severe damage in the city of Coquimbo and coastal town of Tongoy, and flooding in Los Vilos, Pichidangui, and Concon. The tsunami waves in Coquimbo reached 4.5 m and a run-up distance over 500 m from the coastline. As a result, the rock fills along Avenida Costanera and the shoreline of Avenida del Mar were destroyed, large vessels and fishing boats were tossed onto the streets, and the area was left literally with tons of tsunami debris. Although RC buildings and steel frame facilities within the inundation zone performed well, the flooding interrupted lifelines and critical utilities (electricity, potable water, natural gas), forcing residents to move out. Several light-weight facilities 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 passenger terminal had significant damage and was closed. Additional damage included the maintenance garage, administrative offices, settlement of pavements, and flooding of warehouses. Detailed studies are being conducted with divers together with the Port Department of the Ministry of Public Works (DOP), in order to restore the operation of the port. In Coquimbo, a 10 m deep building excavation was flooded by the tsunami; however, the vertical wall supported with soldier piles and anchors showed no signs of damage due to ground shaking.

Figure 4: Generalized damage was produced by the earthquake and tsunami along the coastline in the city of Coquimbo (Photos: Claudio Fernández).

Impact on hospitals

A specific survey on the seismic performance of the nine hospitals located in Coquimbo region was conducted. The main objective was to gather information on the response of these facilities, specifically on their physical damage, reduction or loss of medical services, and change of healthcare demand and patient inflow. This information will be used to better understand and simulate the functionality of hospitals and the healthcare network during future earthquakes. Fortunately, most hospitals in the region were overstocked with medical supplies, fuel for the backup generator, and potable water in the backup tanks when the earthquake occurred, since they were preparing for the Chilean national festivities weekend that started September 18th, when the number of emergency patients usually increases due to the large amount of tourists that visit the region.

In general, hospitals underwent only non-structural damage and loss of contents, affecting the normal functionality of healthcare services. In some of the hospitals, hardcopies of medical files and records did not have digital backup and information was lost (Fig. 5). Despite this, the healthcare network experienced only a minor reduction of its capacity. A notable exception was Coquimbo's hospital, which sustained severe non-structural damage in one of its buildings. Patients and services from the upper floors were relocated internally in the hospital, significantly reducing its overall capacity.

Figure 5: Non-structural damage decreased the capacity of providing healthcare services in the Coquimbo hospital (left). Some of the hardcopies of the medical records, without digital backup, were lost in the region (right) (Photos: Claudio Fernández).

A noteworthy case is the low complexity hospital in the city of Los Vilos, which was completely evacuated since it is located within the tsunami inundation area. All personnel and patients moved to an educational facility located outside the inundation zone, and remained there for nearly 12 hours before returning to the hospital. However, this temporary facility does not have backup electric generators nor water tanks, and does not have the capacityto provide basic care services if the municipal water and electric supply is lost.

Building performance

A visual inspection and preliminary damage assessment was conducted on 20 RC buildings with 8 stories and higher, located along the coastline between El Faro in La Serena and Avenida Costanera in Coquimbo, which represents about20% of these types of buildings along the coastline. Additionally, three structures were inspected at Illapel: the city's hospital (2 stories RC moment frame building), one adobe structure that belongs to the Municipality of Illapel, and a two-story RC housing building.

Surveyed buildings in La Serena did not exhibit damage due to ground shaking and were not significantly affected by the tsunami. In contrast, buildings in the Coquimbo bay had severe non-structural damage due to the direct effect of tsunami waves. The buildings affected by the tsunami and located in the inundation zone (Coquimbo bay and Peñuelas) presented two repetitive patterns: (i) non-structural elements in their first story were completely destroyed by the wave, and (ii) ground settlement around the buildings. In some cases, a series of very narrow vertical and diagonal cracks (*e<0.2mm*) were observed in RC walls and/or RC slabs.

In *La Herradura*, Coquimbo, a 16 story RC building with an irregular C-floor plan and no construction joints underwent structural damage in the slabs at the intersection with walls from the 3rd story and above (Fig. 6). Concrete crushing was observed in the slabs, probably due to the large bending and shear induced in the floor diaphragms aggravated by the horizontal irregularity of the building, and the small slab thickness.

Figure 6: Structural damage in the slabs of a RC building in La Herradura, in the city of Coquimbo (Photos: Claudio Fernández).

The Coquimbo Hospital presented severe damage in non-structural components, ceilings, partition walls, and spalling of the concrete cover in some RC columns. Likewise, buildings in Illapel showed significant damage in structural and non-structural components. In the Illapel's hospital, the concrete spalling in some beam-column joints exposed the rebar (Fig. 7), some very thin horizontal cracks were observed in partition walls, and the ceiling collapsed in many rooms. The adobe structure located in the Municipality and non-confined masonry walls of a 2 stories house were also severely damaged by the ground shaking, and joints between structural and non-structural components were exposed.

Figure 7: Spalling of concrete was observed in structural elements in the hospital of Illapel (Photos: Claudio Fernández).

Aftershock instrumentation

In order to study whether the structures of the region were affected by the earthquake and their dynamic properties changed, an aftershock instrumentation was performed in the oldest tower of San Pablo Hospital of Coquimbo. The building dates from 1976 and consists of 3 towers of 4 stories and a mechanical story. Its structure consists of a RC beam-column frame system arranged on a regular grid in plan, RC non-structural walls located around the perimeter of the floor plan, and concrete partition walls. Each tower is independent from the others, separated by expansion joints.

Given the configuration of the structure, the instrumentation consisted on the installation of 2 tri-axial accelerometers (principal and secondary) on the 4th and 2nd stories of the building. In order to capture the three lateral and torsional components of acceleration for each tower, the principal accelerometer was placed on the approximate coordinate of the geometric center, and the secondary accelerometer on the farthest corner of the building. Three measurements of 30 minutes of signal were completed on each story on September 24th, 8 days after the main shock. During the measurements, 3 aftershocks were recorded, including a Mw 5.5 (16:13:25 UTC, 24 km SW of Ovalle).

Closing remarks

The overall assessment is that the impact caused by this megathrust earthquake in the built infrastructure was less than expected in part as the result of the fresh memory of the recent large earthquake in 2010 and the continuous effort of the country to be better prepared for such extreme events. It was apparent that the lessons learned from the Maule earthquake were implemented in the successful evacuation of more than 1 million people along the coast of the country. The good performance of engineered masonry structures and RC buildings designed after 2010 might be indicative of the progress in seismic and material codes, but further analysis is required to substantiate this point.

A more detailed analysis of the field reconnaissance data collected by CIGIDEN's teams on the earthquake and tsunami impacts in the built and social environment will be soon submitted for publication, and will also be presented in the forthcoming world conference in Earthquake Engineering (Chile, 2017).

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