Lessons from the 2010 Chile earthquake for performance based design and code development

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Extended Abstract

The 27 February 2010 M_w 8.8 Maule in Chile produced MM VII intensity or higher and PGA = 0.3g or higher on a 100 km wide by 600 km long corridor, as well as a tsunami. About eight million people live in this corridor. The central government, and a large percentage of the domestic and export industries are located within. The direct cost of damage may exceed US $25 billion, or about 16% of GDP.

The earthquake occurred over a known seismic gap, where several prior studies had concluded the most likely near future occurrence of an earthquake of the characteristics observed. These studies prompted the deployment of strong motion and other geophysical instruments in and around the most densely populated cities.

Several strong motion records were obtained by the University of Chile during this earthquake. Many of the records show important characteristics of this subduction earthquake: it was an extremely long strong shaking (close to one minute), that include several cycles of high accelerations (some records show more than 10 cycles of motions with amplitude greater than 0.10 g), substantiated amplitude and strong modulation of amplitude due to asperities on the ruptures processes. The long strong duration and the detrimental effect of a permanent displacement motion toward the coast caused by the overall continental plate motion, considerably affected the structural responses.

Notwithstanding the large area affected by strong shaking and the population living in it, only 521 people died, and officially a third of them due to the tsunami. The number of severely damaged tall buildings has been estimated at around 50 out of 2,000 buildings. A large proportion of the structural damage in tall buildings concentrated in buildings 10 or less years old supported on intermediate or soft soils. Three modern buildings collapsed and 8 people died in one of them. About 250,000 dwellings experienced significant damage or collapsed. Most of the damage in dwellings concentrated on non-engineered adobe and unreinforced masonry construction. Most of the hospitals in the area of strong shaking suffered severe damage, some of them are already demolished and new temporary infrastructure had to be build.

There are several codes and official documents that establish the seismic demands and specify or reference material codes for structural design and detailing in Chile, for instance: for residential, commercial and office buildings (NCh433), for industrial facilities and equipment (NCh2369), for base isolated structures (NCh2745), for highways (Highway Design Manual), for electrical systems and components (ETGI or IEEE). All these documents present different seismic demands (different design spectra) and analysis procedures. The seismic demands established in Chilean codes are not based on rigorous probabilistic seismic hazard assessments. In general the response spectra included in the codes consider design factors that completely modify its amplitude and shape.

Taking into account the total building stock exposure and its damage, and the total population exposure and its losses, this earthquake showed that the local engineering practices are effective at prevent-

ing loss of life. However, the disproportionate concentration of structural damage in newly built buildings, the collapsed of three buildings, and widespread damage to nonstructural elements prompted the government to revise current design practices, in part because current societal expectations are different from expected performance tacitly or explicitly stated in the local design codes.

The industrial sector suffered large economic losses not only due to direct losses but also due to the long recovery time. Near 70% of the insurance payments were related to operational losses. There is no intension for the moment to modify the industrial seismic design code. Nevertheless some sectors like mining are taken strong steps aiming at reducing downtime. The mining sector did not suffered considerable damage due to its location away from the epicenter, nevertheless, they have decided to modify their design criteria to include clauses requiring performance checks, rather than strength or displacement values as design verification parameters. The design code will require the designer of civil, mechanical and electrical components to establish, for different earthquake hazard levels, the type and location of expected damage, the possibility of repairing the damage during operation or at scheduled maintenance term, the downtime, and cost of the required repairs.

The 27 February 2010 earthquake prompted the government to revise current design standards in Chile. As a result a tasks groups were formed to: (i) modify the response spectral shape, especially for long period structures; (ii) redefine the soil seismic classification parameters; (iii) abolish the national concrete code and make legal reference the ACI-318 2008 (with especial requirements for bearing wall buildings); (iv) develop a new nonstructural component design code; (v) modify the national design requirements for mining industry to include loss of investment and production procedures, (vi) develop a national code for tsunami design, (vii) establish minimum requirements for engineering calculation for critical infrastructure projects; and (viii) establish procedures for the recovery of historical buildings, among others.

As a first response to this situation, the engineering community decided to fix a known problem with the building design spectra. The spectral curves were modified amplifying the amplitudes of the spectral displacements for periods larger than approximately 0.75 seconds. The increase for stiff type soil was strong reaching for example a plateau of 50 cm at periods of 1.75 seconds, comparing with 26 cm established in the seismic design building code (NCh433). Many soils were reclassified changing from stiff soils to intermediate soils by including new limits and procedures for soil sampling. This modified the seismic demands for most of the buildings that were founded on sand.

For building structures with reinforced concrete bearing walls, several restrictions were applied to limit the possibility of the observed brittle failures (bar fracture after bucking and concrete crushing in non-rectangular walls). The new restrictions include minimum concrete section dimensions, based on story height and rebar size, new detailing to avoid rebar bucking, based on supported bar diameter and stirrups spacing and overall wall displacement demands. Additional restrictions were applied to avoid shear failure and procedures to model walls with complex sections.

Despite the existence of minimum design requirements for nonstructural components, these were typically not applied, excepting for exterior curtain walls. Following the earthquake, a new seismic design code was adopted, based on the ASCE 7 2010 standard. This code will be legally enforced and shall put the responsibility on the designer and the installers of these components.