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IMPACT OF SEISMIC RISK ON THE FINANCIAL RESERVES REQUIRED FOR AN INSURED PORTFOLIO

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Abstract

Chile has been regularly affected by destructive earthquakes. Some of these earthquakes have resulted in great economic losses, in addition to the loss of human life and social disruption. The insurance industry has participated as an important player in the financial recovery of losses incurred by its policyholders. It is then consequent that from the 1985 Chile earthquake, the insurance companies operating in Chile have seen their exposed portfolios regularly increasing. The 2010 Maule earthquake caused USD 30 billion of estimated losses in the country; USD 7.5 billion came from claims paid by the insurers. The insurance industry in Chile traditionally sets the financial reserves according to static formulas based in part by past experience and procures reinsurance coverage for their portfolios, analyzing computational results obtained by risk-based software models using available technologies developed in foreign countries and by foreign experts and "adapted" to Chile. The Association of Insurers of Chile has begun the development of its own model to calculate the probable maximum losses of portfolios insured in Chile, which is presented herein with preliminary results obtained by the model as applied to an actual insured portfolio exposed to the 2010 Maule earthquake.

Keywords: Financial assessment of earthquake risk; Earthquake catastrophic risk; Probable Maximum Loss; Chile.

1. Introduction

1.1 Background

After the 27 February 2010 Maule earthquake, the Chilean insurance industry covered losses estimated close to 30% of the total incurred in the country. These losses were the result of the physical and financial damage due to the devastating earthquake and tsunami effects on the country's total insured portfolio exposed on that date. Once the emergency subsided, the industry, represented by the Association of Chilean Insurers (*Asociación de Aseguradores de Chile A.G.*, AACH), considered the following: (a) Chile's intense and frequent seismicity; (b) the industry penetration to date in the seismic risk insurance market; and (c) the availability of modern and realistic tools to evaluate financial risk exposed to effects of seismic events. Thus, the AACH, in consultation with the industry's regulating governmental entity, Superintendence of Securities and Insurance (*Superintendencia de Valores y Seguros*, SVS), commissioned a team of specialists with the tasks to determine the theoretical basis to quantify the financial risks of exposed insured portfolios and to develop a tool to facilitate the evaluation of these risks, given Chile's particular seismic characteristics.

The tool developed has the scientific databases and algorithms, including algorithms defining the financial insurance structure, packed in a computer program, which in the future would allow users (in the industry and the SVS) to model and evaluate the financial risks and calculate catastrophic reserves, due to the actual characteristics of risk in Chile derived from seismic events. This multidisciplinary project was divided in several tasks, each one representing the different risk components: seismic, seismo-geological, tsunami, and infrastructure vulnerability risks. By acquiring this scientifically-based risk model AACh's main objectives were:

- To provide the industry with a tool to analyze and manage insured portfolios and associated risks under realistic assumptions, based on parameters and data measured in and calculated for Chile's characteristics.

- To provide the industry with a tool to analyze and negotiate coverage with reinsurers.
- To seek SVS acceptance of the tool as mandatory for calculating catastrophic reserves.
- Managing this model in-time will bring a virtuous cycle toward better and new information on insured portfolios that the industry has yet to collect: directly from portfolios and from the effects of catastrophic events on portfolios.

Thus, the project will bring a significant contribution to the Chilean insurance industry. In addition, the AACH aims that the scientific outcome be shared with the government and public at large, bringing a contribution to the community.

1.2 Current Risk Evaluation

The insurance industry in Chile traditionally sets the catastrophic reserves according to static formulas based on past experience and what it is mandated by the SVS. The formulas are functions of the probable maximum loss (PML). The PML is assigned a value 10% for buildings and contents risks, otherwise 15% for all other risks [1]. These values came from the industry experience with the 1985 San Antonio earthquake, a magnitude M=8.0 event affecting Chile's central region. Before that event, the PML was assigned a value three times higher. Considering this regulation of risk, each insurance company analyzes the results obtained by risk-based software models available in the market, to finalize the design of its portfolio financial structure. These software models are built around technologies developed in foreign countries by foreign experts, and then "adapted" to Chile. Insurance companies in Chile buy coverage from reinsurers who make use of several of these packages. The structure of the insured portfolio, including reinsurance, comes after a comparative analysis of results obtained from all these packages.

On the other hand, it is well-known that Chilean infrastructure behaves rather well under moderate to severe earthquakes, as compared to infrastructure in other parts of the World. It is the result of improvements in the design codes that have been modernized and implemented since the early 1940s. Even before, the continuous occurrence of moderate to severe destructive earthquakes [2] has forced Chilean architects and engineers to continuously improve traditional design and construction methods to include techniques counteracting the effects of earthquake forces on the infrastructure. Nonetheless, Chilean engineers are fully aware that it is not financially possible to design and construct buildings capable of resisting the largest earthquake that can strike anywhere in the country. The actual Chilean code expresses this in the following fashion [3]: "This code… is oriented to achieve that structures:… even though may exhibit damage, prevent collapse during exceptionally severe intensity earthquakes." This can be interpreted as: structures are to be designed such that after the most severe earthquake they should end up standing to let their occupants walk out alive, even if the structure is completely destroyed functionally.

Chile is an earthquake-prone country that requires special care in the prevention of disasters caused by the effects of destructive earthquakes. Insurance operates as an effective and important tool to meet these objectives. The current evaluation of risk for insurance purposes is not based on risk, nor is it based on an evaluation of the damage potential on well engineered and flawlessly built infrastructure. So far, this method has been good enough, and proved to be adequate, providing financial strength to the industry, as a whole, to cope with the claims occurred in all major earthquakes. An evaluation based on risk, particularly for individual insurance company portfolios, would improve the current situation, and its applications over the years will increase the reliability of the model based on actual damage data measured after a destructive event occurs. The implementation of the risk characteristics affecting the infrastructure in Chile should eventually help better assess, and in many cases reduce, the risk valuation when compared with those obtained by "adapted" technologies. Also, it will help each company make a better risk allocation of its portfolio insured.

2. Evaluating Risk in Chile

Continental Chile has been, and is, conditioned by a convergence of tectonic plates, the most important being the subduction of the Nazca plate under the South American plate between Arica, from the north, and the triple junction close to the Taitao Peninsula, to the south. This subduction process has generated, and is capable of generating, seismic events of great magnitude, which in turn cause tsunamis with great damage potential along Chile's coastline, and even at distant sites like on the coasts of California, Hawaii, and Japan, amongst others [4-5]. Two recent events standout: (1) the 1960 Valdivia earthquake, M=9.5, which generated the most important tsunami on Chile's coasts during the XX Century, in terms of damage and wave heights; and (2) the 2010 Maule earthquake, M=8.8, which generated the most recent tsunami and one of the most destructive that have occurred in Chile.

The last major earthquake, M=8.8, and tsunami occurred on 27 February 2010, affecting an extensive area of well over 800 km in length and causing damage as far as the Province of San Juan in Argentina. The earthquake and tsunami resulted in 577 casualties, left approximately 800,000 people homeless, and affected 75% of Chile's total population. The published economic losses stemming from this event were estimated to be between USD 24.5 and 30.0 billion. The insurance industry covered close to USD 7.5 billion of insured losses; that is, between 25 and 31% of the total estimated losses, an amount much higher than the 7% covered after the last earthquake affecting Chile's central region in 1985. Since 2010, the Chilean insurance industry paid 30 to 35% of total losses, after two major earthquakes that have occurred in Chile (2014 Iquique, M=8.1; and 2015 Illapel, M=8.4). Thus, ¼ to ⅓ of all losses caused by major catastrophic earthquakes in Chile are paid out of insurance contracts. The main reason these contracts do not account for a bigger share is that public infrastructure (highways, hospitals, schools, public offices) are not insured. Treasury in Chile does not buy insurance; the government has been reluctant to do so and it prefers to raise taxes or take reconstruction money out of the nation´s budget. Some government agencies do buy partial insurance for equipment (Civil Aeronautics General Directory), or even infrastructure (Copper Corporation), but it is the exception.

2.1 Seismic risk

A seismic risk database has been built based on a probabilistic seismic hazard analysis, PSHA [6]. The PSHA was carried out using widely accepted state-of-the-art technologies [7], applied by the US Geological Survey (USGS) over a regular six-year cycle of improvements, expansion, and updates (1996, 2002, 2008, and 2014) [8], resulting in hazard maps that provide the latest integrated data for future ground motions, solidly based in science, with a long history of analysis, revision and discussion in the engineering and scientific communities. To build this database, all the seismic sources affecting Chile were considered: subduction, shallow, intermediate, deep, and outer-rise seismicity, and the main Quaternary faults located within the country or in close proximity to its borders (in Argentina, Bolivia, and Peru). The seismicity was obtained from a collection of more than 58,000 records assembled into a homogeneous and complete catalog of unique and independent seismic events affecting Chile. These records of events, M≥4.5, were obtained from the University of Chile's National Seismological Center, augmented with data from the USGS' National Earthquake Information Center, the United Kingdom's based International Seismological Centre, and historical regionally and locally assembled catalogs. From the analysis, it was observed that most of the risk occurs due to subduction sources on sites close to the coast (see Fig. 1) and due to intermediate depth intraplate sources on sites inland. There are small zones affected by shallow and Quaternary faults, the most notable in Mejillones and Punta Arenas (Fig. 2).

Fig. 3 shows Chile's onshore probabilistic hazard associated with the peak ground acceleration, for two levels of exceedance, 10% and 2% in 50 years (or 475 and 2,475 years of return period, respectively). Hazard maps were also prepared for sites in Continental and Insular Chile for thirteen different spectral periods covering the spectrum of vibration periods where the significant structural interaction occurs, and where the damage occurs. The results were verified using field data recorded during several earthquakes, including three recent events: (1) 2005 Tarapacá, M=7.9; (2) 2010 Maule, M=8.8; and (3) 2014 Iquique, M=8.2.

2.2 Seismo-geologic risk

The geology of Continental Chile has been, and is, conditioned by the underlying tectonics. This characterizes the geologic units mainly composed of igneous rocks over sedimentary and metamorphic rocks. The superficial geologic units constitute the foundation material over which urban settlements and infrastructure are built in

Chile. When affected by the seismic waves, this material interacts with the infrastructure determining the intensity of the seismic events and, eventually, the seismic response and the potential damage risk to said infrastructure. A microzonation was carried out for Chile [9], on a national-scale, using known and available geologic and topographic information. In addition, a microzonation of Viña del Mar was carried out on a local scale. The known geology of Chile was obtained from maps maintained by the Chilean National Service for Geology and Mining (*Servicio Nacional de Geología y Minería*, SERNAGEOMIN) [10], and revised in regions where the seismic behavior has been studied in more detail such as Viña del Mar, Valparaíso, Santiago, Curicó, Talca, and Concepción. The topographic information was obtained from the elevation World model published by NASA (Shuttle Radar Topography Mission, SRTM) [11]. Starting from this information, the seismic shear wave propagation velocity within the top 30 m, VS30, was estimated using available methods [12-13], to finally obtain a microzonation map representing the seismo-geologic risk in Chile (Fig. 4). A microzonation map does not replace the actual knowledge of the geologic and geotechnical site conditions, even on a refined scale, but provides valuable information when the site conditions are unknown, which is the case for all current insured portfolios.

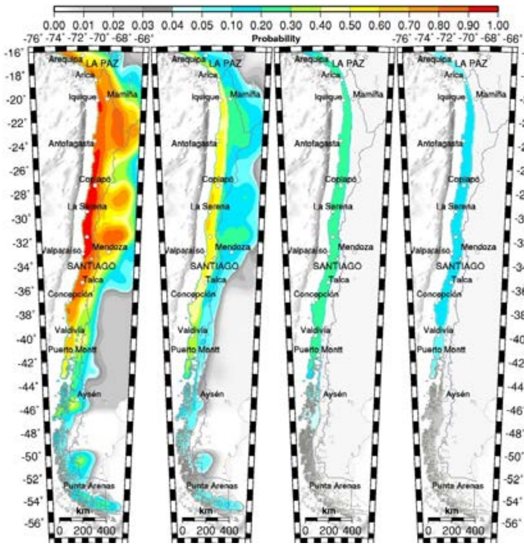

Figure 1 – Probability of occurrence of moderate to large earthquakes within 50 km of each location in any random 30-year period. Panels left to right, earthquakes: M≥6.0, M≥7.0, M≥8.0, and M≥9.0.

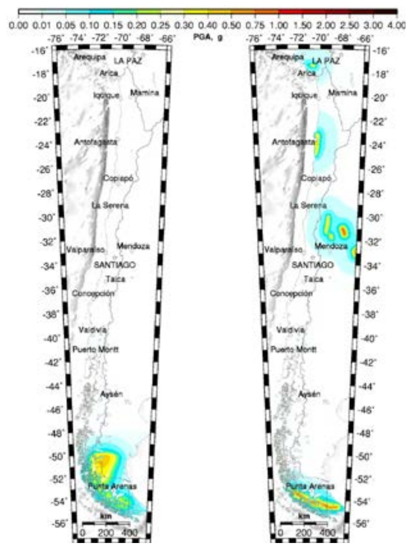

Figure 2 – Probabilistic peak ground acceleration maps for Continental Chile with a 2% probability of exceedance in 50 years (2,475-year return period) on rock. Left panel corresponds to Southern Chile fault sources with M=5.0-8.0 (known Quaternary fault sources are omitted on this map). Right panel corresponds to Quaternary fault sources.

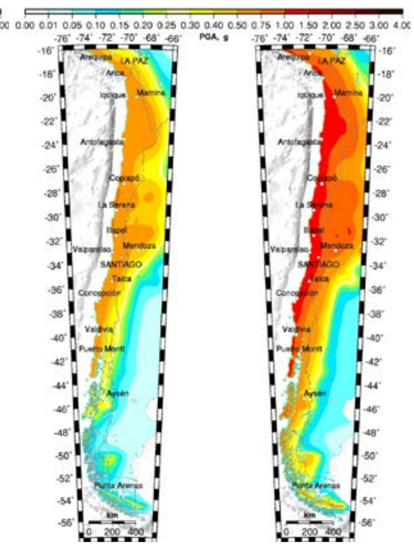

Figure 3 – Probabilistic peak ground acceleration maps for Continental Chile from all sources at 10% (left panel) and 2% (right panel) probability of exceedance in 50 years on rock (respectively 475 and 2,475 years of return period).

2.3 Tsunami risk

For the model, eleven major coastal cities were studied [14]: Arica, Iquique, Mejillones, Antofagasta, La Serena, Coquimbo, Quintero, Viña del Mar, Valparaíso, San Antonio, and Talcahuano. These cities were studied because are characterized by: (a) high urban density next to the coastline; (b) residential, industrial, and governmental exposure to potential destructive tsunamis; and (c) negligible to non-existent infrastructure protection to the destructive effects of tsunamis. In addition to these cities, the entire Chilean coastline, from north to south, is subject to the effects of tsunami-genic seismic events. Thus, if the tsunami-genic event is of great magnitude, a large region of the Chilean coastline will be affected, impacting large urban areas as well as small towns. For the insurance industry, developing a tsunami risk model is a major challenge. At the time this project started, risk models available in the market included tsunami risk as an aggregate percentage of the seismic results. Up until the time this paper is written, some available models include tsunami risk by making approximations to the calculations of losses due to tsunamis.

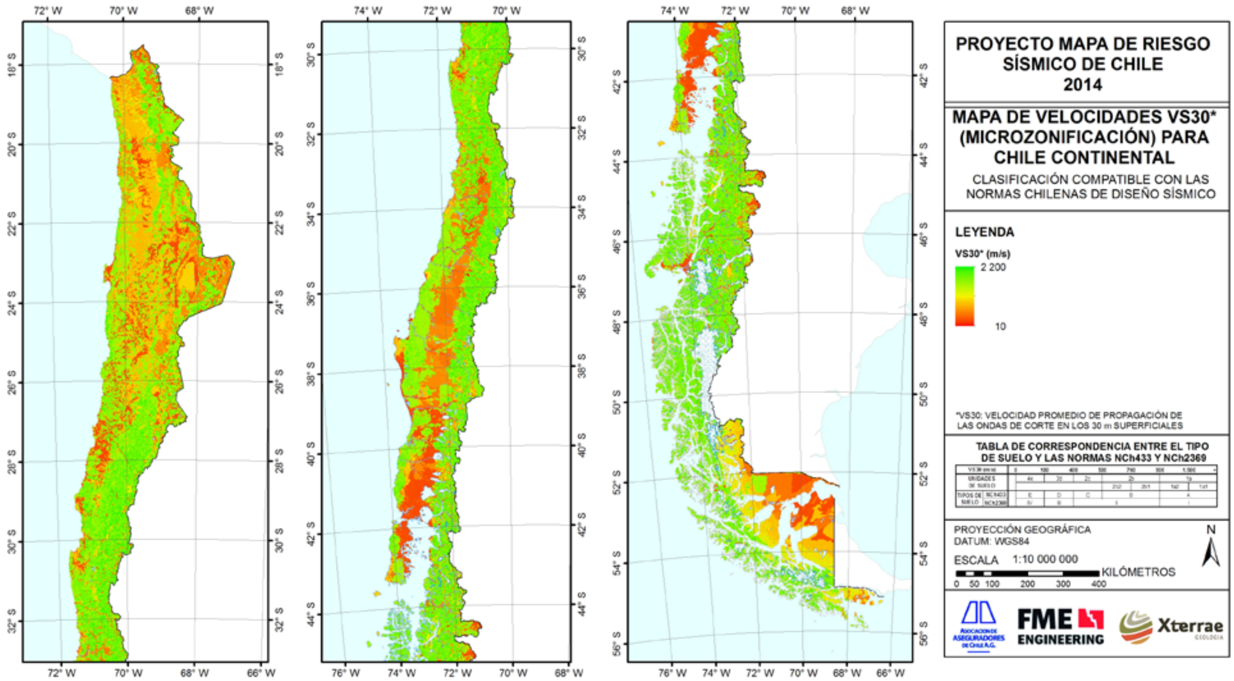

Figure 4 – Final VS30 map for Continental Chile.

Five tsunamis generated by an equal number of earthquakes were numerically modeled with resolutions of the order of 10 m. The tsunamis modeled corresponded to the maximum probable earthquake in the region (150- to 250-year return period), rather than the maximum credible earthquake, such as the 1960 Valdivia earthquake. The models and the methodologies used correspond to the state-of-the-art of tsunami simulation techniques. Maximum water heights and maximum velocity flow magnitudes were obtained in the inundated zones. The models were built with the most up-to-date bathymetric information obtained from the nautical charts published by the Chilean Navy Hydrographic and Oceanographic Service (*Servicio Hidrográfico y Oceanográfico de la Armada*, SHOA), from the database maintained by the International Oceanographic Organization and UNESCO's Intergovernmental Oceanographic Commission (General Bathymetric Chart of the Oceans, GEBCO) [15], and from locally-sourced project-specific bathymetric data records. The topographic information was obtained from the SRTM model [11], from Inundations Charts Due to Tsunami published by SHOA, and from locally-sourced, project-specific topographic data records. The information on urban distribution of buildings and streets was obtained from Shoreline Maritime Plans published by SHOA, complemented and updated with digitized information from Google Earth satellite images. The models were verified with field data obtained after the 2010 Maule earthquake.

As example, on Fig. 5 the maximum inundation depth in Viña del Mar is shown for a tsunami generated by an M=9.0 earthquake offshore Viña del Mar at a depth of 32.9 km; a detail is shown on Fig. 6. On the coastline, 10-m depths are observed. The maximum water penetration occurs on the Marga Marga Creek course reaching over 3 km inland. The Reñaca Creek course also allows an incursion above the average, reaching over 1 km horizontally. It is observed an inundation depth over 8 m around the Casino and between 4 and 6 m around the Municipality. Center areas exhibit a significant inundation.

2.4 Structural vulnerability risk

There is not available information on the vulnerability of Chilean infrastructure due to seismic or tsunami risk. While fragility functions are being developed for Chilean infrastructure the model has been implemented with HAZUS [16] and ATC [17-18] typical curves; some of these curves have been adapted for Chilean infrastructure.

Figure 5 – Inundation depth: Viña del Mar.

Figure 6 – Inundation detail: Viña del Mar urban center.

3. Portfolio analysis

3.1 Probabilistic portfolio analysis

The databases developed for the different risk factors were integrated [19] in to a single model to compute the portfolio total PML for earthquake risk, including the losses due to building damage, contents damage, and business interruption. The financial loss of each of these components is obtained by computing the mean damage ratio as a function of the seismic event intensity at the site of valuation multiplied by the amount insured. The intensity is measured in terms of the Modified Mercalli Intensity, the spectral displacement, or the spectral acceleration, as the functional relationship is defined. The mean damage ratio is the sum of the damage state of each member of the portfolio at the site considered due to the earthquake scenario given. The area covered by the portfolio is discretized by a grid of 0.1° longitude by 0.1° latitude cells. On each of these cells the probabilistic seismic hazard is evaluated for the return period analyzed in terms of the earthquake intensity required. Thus, one scenario earthquake is defined by the maximum considered earthquake at each cell and its effects on the rest of the cells. The total amount of cells, and therefore scenarios, depends on the geographic area covered by the portfolio. A typical well-diversified portfolio would be discretized by over 25,000 cells; thus, the portfolio is subjected to over 25,000 earthquake scenarios.

The model can treat each portfolio member (structure) separately considering the seismic and geology hazards given at the geo-location of said structure, or collect all the structures by (HAZUS or ATC) type at the center of the cell where they fall. In the current situation, due to the lack of accurate geo-location for each member of the portfolio, the structures are collected at the centroid of each of Chile's communes (or municipal districts).

3.2 Deterministic portfolio analysis

The PML for a single scenario can be computed by evaluating the total sum of the loss of each portfolio member due to a uniquely defined event (magnitude, location, depth, source mechanism, rupture displacement angles). The seismic intensity is in this case obtained directly from the attenuation functions corresponding to the scenario event. Again, the structures can be collected at the center of the cells or at the centroids of the communes.

4. Results

Preliminary results obtained with the model developed have been compared with those obtained from three other risk-based software packages available in the market, and currently used by the Chilean insurance industry to analyze their portfolios. These comparisons are carried out on the model not yet calibrated with the data obtained after any of the earthquakes for which insurance data exist. Furthermore, the fragility functions used are

HAZUS, not calibrated either; some of these functions have been adapted, using experience, to the Chilean infrastructure.

4.1 Results from the 2010 Maule earthquake

4.1.1 Mixed portfolio. A real 46,255-member portfolio exposed to the 2010 Maule earthquake with a total USD 87,319 billion of insurance value, distributed along Chile's length (Fig. 7), was analyzed. This portfolio is mixed (industrial, commercial, and residential structures) and includes building structure, content, and business interruption insurance components. In general, this portfolio is relatively well diversified geographically according to the population and industrial distribution existing in Chile. However, the portfolio tends to be concentrated in Central Chile, the region most affected by strong earthquakes. Due to the lack of a well characterized portfolio, the structural typology was approximated to HAZUS types using local expert engineering judgment. The structures were located at the centroid of the communes. The resulting PMLs, measured with respect to the portfolio regional amount exposed, obtained with the model presented are compared with the known paid out amounts covering the losses (Table 1). This comparison is extended to the results obtained with three other software packages. The HAZUS typology was developed for US building structural types; Chilean structures tend to be, by code, more resilient, and therefore, this is a conservative approximation that will lead to higher PMLs. In the case of a severe earthquake, as the location of the structures approach the epicenter, where the damage is expected to be greater, the HAZUS approximation will tend to converge to the actual damage observed. This effect can be observed in Table 1, where PMLs calculated with the model presented is very close to the actual losses paid out in the areas most affected, Chile's Regions 6, 7, and 8. There is another software model which is even identical. It must be noted that the software packages used were updated after the 2010 Maule earthquake and the analysis was carried after this update.

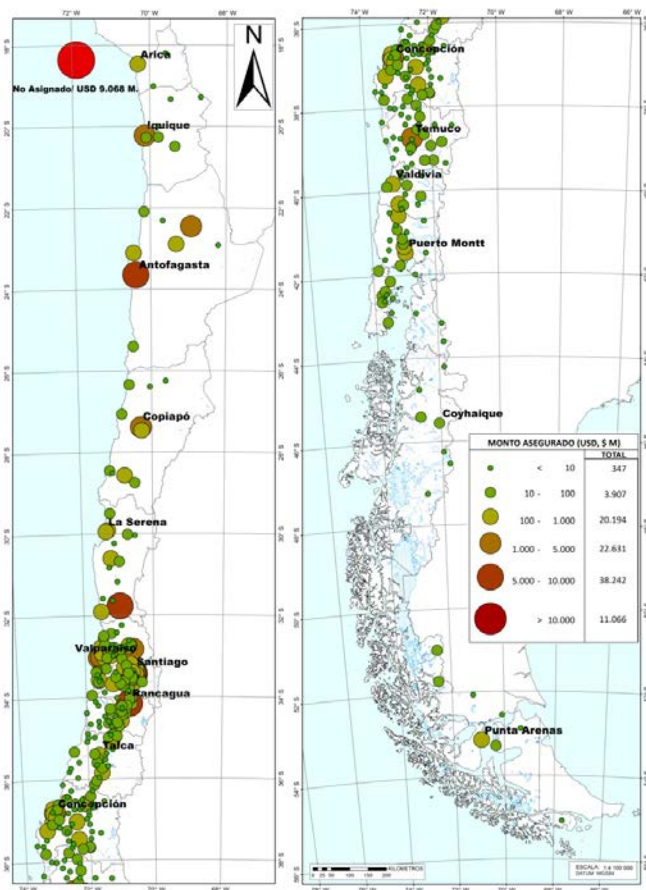

Figure 7 – Mixed portfolio exposed to the 2010 Maule earthquake.

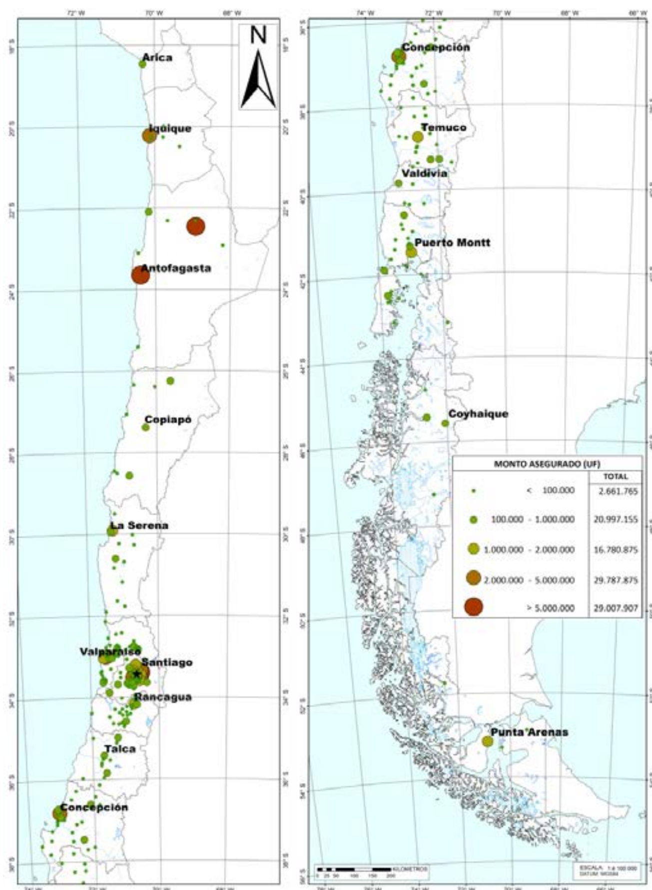

Figure 8 – Mortgage portfolio exposed to the 2010 Maule earthquake.

Table 1 – PML comparison for mixed and mortgage actual portfolios exposed to the 2010 Maule earthquake. PML measured with respect to the regions/zones indicated.

PORTFOLIO	REGION/ZONE	PAID OUT	MODEL 0.0	MODEL 1.1	MODEL 2.1	MODEL 3.1	MODEL 1.2	MODEL 2.2	MODEL 3.2
MIXED	6, 7 & 8 REGIONS	8.52%	9.93%	—	—	—	11.00%	8.53%	4.22%
	ALL REGIONS	2.68%	5.18%	—	—	—	2.87%	3.75%	5.41%
MORTGAGE	CRESTA ZONE 3	2.27%	3.12%	2.94%	3.09%	3.15%	3.43%	3.58%	11.22%
	ALL ZONES	NA	2.76%	NA	NA	NA	3.56%	3.78%	7.12%

NOTES:
MODEL 0.0: Model presented herein.
MODEL 1.1, 2.1, 3.1: Software package 1 (three different models); User 1.
MODEL 1.2, 2.2, 3.2: Software package I (i=1,2,3); User 2.

4.1.2 Mortgage portfolio. A real 51,891-member portfolio exposed to the 2010 Maule earthquake with a total CLF 98,664 million of insurance value, distributed along Chile's length (Fig. 8), was analyzed. This portfolio corresponds to mortgaged building structures (mostly residential and commercial). For the most part, this portfolio is geographically concentrated in Chile's most populated areas. Due to the lack of a well characterized portfolio, the structural typology was approximated using HAZUS types for concrete structures. The structures were located at the centroid of the communes. The resulting PMLs, measured with respect to the portfolio zonal amount exposed, obtained with the model presented are compared with the known paid out values covering the losses (Table 1). The paid out values are only available for Chile's Santiago Metropolitan Region (Region 13 or CRESTA Zone 3), see Table 1. This comparison is extended to the results obtained with the three other software packages used before. These analyses were carried out by two different users; one user knew the actual results. The Metropolitan Region was not the most affected by this earthquake, thus the results should be conservative, resulting in higher PMLs, as it can be observed. The differences between the actual and the calculated PMLs fluctuate between 29.5 and 394%. The PML difference for the model presented is 37.4%.

4.2 Results from seven return periods

4.2.1 Mixed portfolio. The same real mixed portfolio analyzed under the 2010 Maule earthquake was analyzed for several return periods from 50 to 2,500 years, with the same assumptions. The resulting PMLs, measured with respect to the portfolio total amount exposed, obtained with the model presented are compared with the three other software packages used before (Fig. 9). The PML values calculated with the present model are higher than those obtained with the other models, and close to model 1. There is dispersion on the PML values among the various models; this dispersion increases as the return period increases.

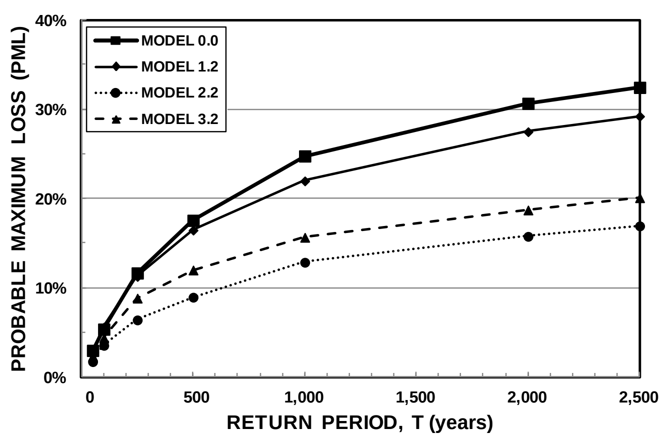

Figure 9 – Mixed portfolio exposed to seismic events on a 50- to 2,500-year return period horizon (for model descriptions see note in Table 1).

4.2.2 Mortgage portfolio. The same real mortgage portfolio analyzed under the 2010 Maule earthquake was analyzed for several return periods from 50 to 2,500 years, with the same assumptions. The resulting PMLs, measured with respect to the portfolio total amount exposed, obtained with the model presented are compared with the three other software packages used before (Fig. 10a). The PML values calculated with the present model are higher than those obtained with the other models, and it almost coincides with model 3. This comparison can also be made for the portfolio located in the Metropolitan Region (Fig.10b). For this section of the portfolio, the PML values calculated are higher than those obtained with the other models, and close to model 3. There is also dispersion among the models that increases with the return period. For illustration purposes a disaggregation of the PML for the different regions of Chile is shown on Fig. 11 for a 250-year return period. The most affected region is the Metropolitan Region where 56% of the portfolio is located.

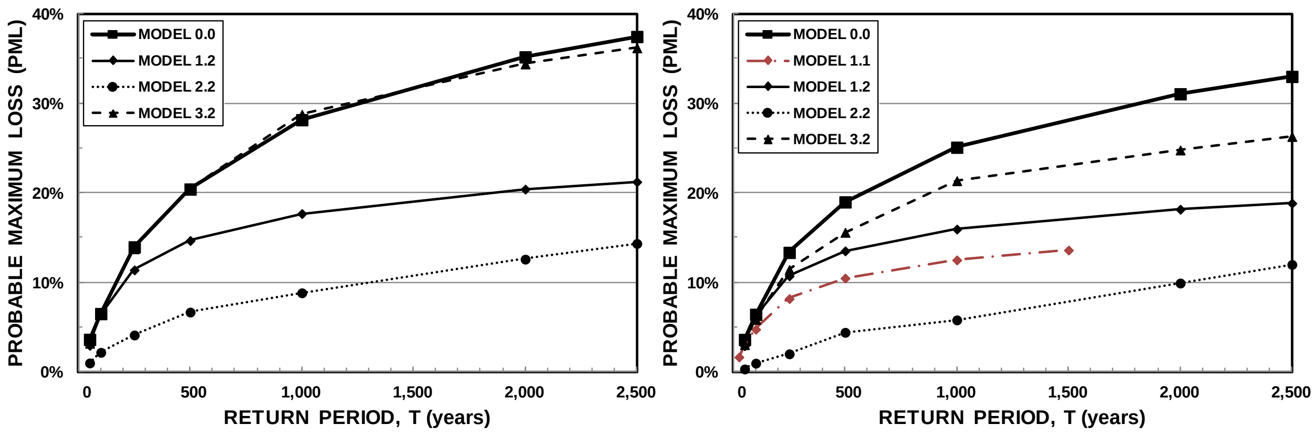

Figure 10 – Mortgage portfolio exposed to seismic events on a 50- to 2,500-year return period horizon (for model descriptions see note in Table 1). (a) Full exposed portfolio. (b) Portfolio exposed in Santiago Metropolitan Region.

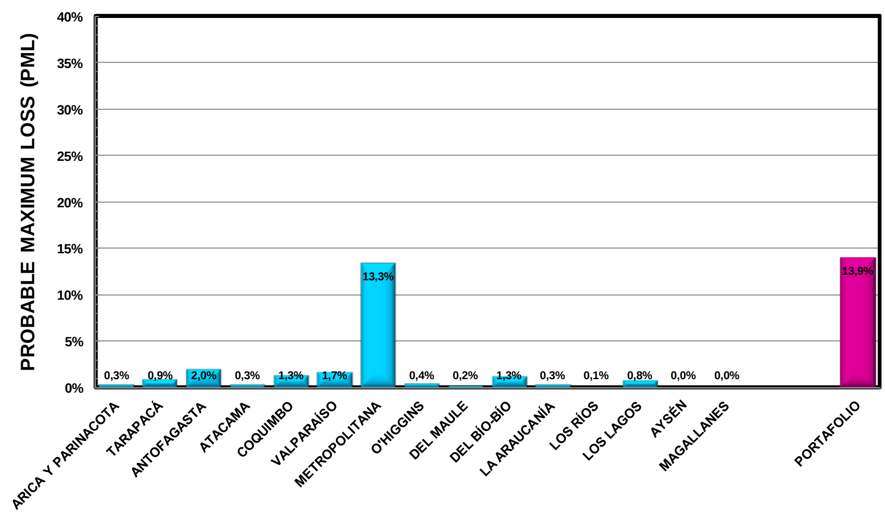

Figure 11 – Mortgage portfolio exposed to seismic events on a 250-year return period horizon Disaggregation of the PML over the regions of Chile.

5. Conclusions

The model presented has been developed from basic science. The structural vulnerability risks represented by the structural fragility curves used are HAZUS, judged to yield conservative results. The model has not been calibrated by using the financial losses incurred due to the damage caused by the last earthquakes, from which insurance companies may have data available. Nonetheless, the results obtained for two large and different actual portfolios covering Chile's territory were satisfactorily compared with real results available and with results obtained with well calibrated software available in the market. The seismo-geologic risk database is being revised to more accurately represent the geology for the industry's geo-referenced portfolio system. Furthermore, fragility functions for structural types designed under Chilean codes need to be developed.

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