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UNDERSTANDING EARTHQUAKE RESILIENCE IN CHILE: THE PROS AND CONS OF SAFE BUILDINGS

Felipe RIVERA[1], Tiziana ROSSETTO[2] & John TWIGG[3]

Abstract: *Chile is one of the most seismic yet also one of the most earthquake-resilient countries in the world. This article seeks to understand the process of resilience building in the country and its implications for urban contexts. For this purpose, semi-structured interviews are conducted to 16 Chilean experts from the fields of seismic engineering, urban planning, emergency management and disaster risk reduction (DRR), and representatives from different public and private stakeholders (e.g., academics, practitioners, public servants, local government authorities). Results show that the main approach that the Chilean state has used to provide seismic resilience has been purely rational, by means of safe and high-quality buildings. This has led to earthquake risk being essentially absent from the urban planning regulation. Although this approach has provided good overall results in time, over-reliance in seismic safety of buildings has contributed to a weak national DRR system which failed its most recent test after the 2010 earthquake and tsunami. The increasing complexity and concentration of people and assets in cities, together with the dynamism of knowledge about local seismicity are challenging this rational approach. Thus, a call for a more comprehensive approach for seismic resilience provision arises, which based on the successfully provided safe buildings could also tackle the social and political dimensions of earthquake risk in urban contexts.*

Introduction

Located in the Pacific Rim of Fire, Chile is one of the most exposed countries to natural hazards in the world (Dilley et al., 2005). With 13% of its territory and more than 50% if its population exposed to three or more hazards, Chile is seventh in the world ranking and the leader of the countries in the Organisation for Economic Co-operation and Development (OECD) (Dilley et al., 2005). From all the natural hazards to which Chile is subjected, earthquakes are by far the most important. Although accounting for only 31% of the mortality of disasters between 1990 and 2014, earthquakes are responsible for 75% of the combined economic losses (UNISDR, 2015). Moreover, whereas earthquakes contribute only 36% of the global multi-hazard average annual loss, they represent more than 84% for Chile (UNISDR, 2015).

Chile is regarded as one of the most seismic countries in the world. Since 1900, more than 80 earthquakes with M_S magnitude equal or larger than 7.0 have been registered in the country (CSN, 2019). By frequently facing large earthquakes, the country has been able to develop a capacity to cope with earthquakes in a successful way. Chile is thus recognized today as one of the most earthquake-resilient countries in the world (Stein and Toda, 2013).

Earthquakes are a part of the geophysical context where Chilean cities develop. Chile has been a mostly urban country since mid-20th century and urbanization rate has steadily increased for the last decades to reach almost 90%. Moreover, the country is highly centralized and concentrated in the centre of its territory. More than 40% of the 17.5 million people living in Chile does it in the Metropolitan Region of Santiago, where the city of Santiago—the capital—lies. Besides, 78% of the population lives within around only a quarter of the more than 4,000 km of the country's length (INE, 2018). Indeed, more than half of the population is concentrated in three large metropolitan areas, Santiago, Valparaíso, and Concepción.

In this context, it becomes highly relevant to understand the process of resilience building and its implications for urban contexts. This article presents the first part of a research looking to characterize how the state of Chile has addressed the challenge of building seismic resilience in

[1] PhD student, EPICentre and USAR, University College London, London, UK, ucesriv@ucl.ac.uk
[2] Professor, EPICentre and USAR, University College London, London, UK
[3] Honorary Professor, EPICentre and USAR, University College London, London, UK

time, and the unexpected drawbacks it may have with regards to achieving an effective integrated multi-hazard Disaster Risk Reduction (DRR) national capacity.

Methods: semi-structured interviews

Qualitative research is used to understand the perspective that local experts have about how Chile has built its seismic resilience, and the challenges to continue improving. Sixteen semi-structured interviews are conducted for this purpose. The use of qualitative research methods is preferred because of their capacity to pay further attention to the social context where research is conducted (Phillips, 2014). Note that, unlike quantitative methods, qualitative research does not aim to generalize the findings coming from the studied subjects. Instead, qualitative interviews are a tool to access to information otherwise unavailable, and not necessarily identify or characterize those who hold them (McCracken, 1988).

The population of interest are local experts in the subject of seismic risk and resilience. The inclusion criteria are that participants have a professional degree or formal training and renowned academic and/or professional experience working in at least one of the fields of earthquake engineering, construction, structural design and building codes development, urban planning, real estate development, urban resilience, DRR, and public administration at national, regional, or local levels. The final interviewee list is limited to 16 people representing different stakeholders and groups of interest (Table 1).

Interviewee	Academia	Industry	ONEMI	Metropolitan gov.	Local gov.
Architect/ Urban planner	3	1	1		2
Civil/ structural engineer	3	3			
Lawyer				1	
Public administrator				1	
DRR expert					1

Table 1. The 16 interviewees classified per their background or expertise field (rows) and sector where they work at the moment of the contact for the interview (columns).

Two of the 16 experts are female and 14 are male. All but one interviewee are Chilean, although the one who is not has lived and worked in Chile for more than 20 years. All of them have local knowledge on project development, legal framework, policy, and/or research in their expertise subject. Six of the interviewees are full-time academics who have also participated in consultancy. One of them has served a period as officer at the Ministry of Housing and Urbanism (MINVU). Four interviewees have developed their careers as practitioners, two of them—an architect and an engineer—closely related to academia. The remaining six have developed their careers mainly in the public sector; three of them in municipalities, one in a ministry and later at the National Emergency Office (ONEMI), and the other two in different positions in local and national governments.

Interviews take place in Santiago between March and April 2018. Participants sign an informed consent before the interview begins, and data is collected with semi-structured, long qualitative interviews (McCracken, 1988). Interviews are conducted in Spanish with the aid of a topic guide and mainly cover the case for Santiago, but most of the results can be generalized to the country. The main subjects discussed in the interviews are: (i) the drivers for development and urban growth, (ii) the concept of risk-informed decision-making, and (iii) the tensions between different levels of administration regarding planning and DRR. The interviews last between 42 and 108 minutes, with an average of 67 minutes.

Post-processing of the interviews is done with thematic analysis, which allows to identify and analyse the main patterns of meaning in a dataset (Joffe, 2012). For the analysis, the recordings of the interviews are divided into 30 seconds slots where the main ideas discussed by the interviewees are identified. A keyword is assigned to each of these ideas to create a topics map of the interview. The interview maps are analysed to identify the most frequent topics. Then, the common topics are grouped to form the key themes arising from the set of interviews.

Results

The topics identified in the data can be grouped into three main themes. The first addresses the approach that Chile has taken as a country to cope with its earthquakes and some reasons for its success. The second unveils some negative unintended consequences this approach has generated for developing a holistic DRR capacity. The third is related to some of the institutional and governance barriers for improving seismic resilience and DRR in the country.

Tackling seismic risk via safe buildings

Experts agree that the main DRR tool Chile uses to address its seismic condition is safe, high-quality construction:

> *In the case of earthquakes, Chile has played [its cards], more tan by generating conditions for zoning and planning, in having a format of perfecting the quality of construction. And therefore, that obligates to have a very rigid system of approval [of construction projects], right? Which is very criticized, obviously, by private [companies]. But truth is, that it is a state of the art. It is like this; we have been like this for many years* [2].[4]

Developing seismic safety is a cumulative process. It started after the 1928 Talca earthquake, when the first seismic regulation was published. Since then, codes have changed and improved after every major catastrophic event (de la Llera et al., 2018). For example, the reconstruction after the Chillan earthquake of 1939 privileged functional architectural designs and reinforced concrete as building material at the expense of restrictions for using (seismically vulnerable) vernacular construction based on adobe (Gil, n.d.). As the quote above reveals, the Chilean state has dealt with the *technical* problem of earthquakes and earthquake risk from a *rational*, *technological* approach by improving the quality of buildings and construction practice independently from urban planning.

The cycle for improving building design and construction starts with a large earthquake producing widespread damage and the eventual destruction of the most vulnerable building typologies in the affected area. Quickly, experts are deployed throughout the country to assess and study the performance of buildings and infrastructure. Finally, lessons learned are discussed and shared, new research is triggered, codes are updated and improved, and eventually new codes are generated (see the case of the 2010 earthquake in e.g., de la Llera et al., 2017). The country is now better prepared to face the next event:

> *After every earthquake, important changes in regulations have been produced in terms of design and construction, which have really been applied, and that therefore have produced important changes between one state, the event, and when the next event arrives. When the next event arrives, the state of the city is different. Now, not because what existed before had been modified. […] The vulnerability of those structures does not change, but everything that grows afterwards, grows in a state of much higher quality, or much less vulnerability. Therefore, risk, I believe risk goes diminishing in terms, as I said, of damage. Because what happens in practice—it sounds, sorry, a bit ugly, but it is—those more vulnerable structures are running out. Because we have earthquakes so close [to each other], they are literally running out. Besides the replacement with new constructions* [9].

Because of this cycle, earthquake specialists are confident that each event contributes to improve knowledge and practice, and hence resilience. With a historically effective system in place, little concern about the structural performance of engineered buildings is observed from the data. Because the technical problem of safe buildings is perceived as solved, experts' apprehensions lie beyond. Non-structural elements and contents, the concentration of people and assets, and

[4] Numbers in brackets after the quotes identify each expert in an anonymized way.

the increasing complexity, fragility, and interconnection of physical systems are identified as the current challenges around earthquakes.

The perils of safe buildings

After acknowledging the virtues of the system around building safety, experts open-up to some of its drawbacks. One of them is related to the over-confidence in building performance:

> *[Regulation] is based in fear. When I said that constructions in Santiago were limited to 9 storeys until the year [19]60 approximately, it was because of the fear of doing something that had never been done before. But as the ties are released and it is started to see that things work, fear starts to diminish. […] Seismic safety of constructions in Chile had a* peak *of quality in the decade of [19]40. […] And why this boom? Because […] the earthquake of Chillan, year [19]39, provoked fear, panic that the number of victims and material damage observed in Chillan and the surroundings would repeat. […] when we start realizing that the thing is going fine, we start having less scruples. […] as the Chillan earthquake was very positive in terms of generating edifications with high standards of security […], little by little this was being abandoned. […] When, after the earthquake of [19]85, it was showed that Chile was a country of an extraordinary seismic safety, […] people felt backed-up on what they were doing, and the braids got loose, and we started building structures every time more riskier, from my point of view. The requirements were lowered […], things that were not allowed before started to be allowed, and the earthquake of 2010, which was successful but not as much as that of [19]85 […] revealed that one thing is the safety of the structure as such, and that other is the habitability of the structure after the earthquake. […] And the evidence was the observed damage, as a result of which the codes were modified* [7].

Codes are calibrated with experience. After the M_W 8.8 Chilean earthquake of 2010, the engineering community was surprised. A fragile failure was observed in the lower storeys of reinforced concrete shear wall buildings. This was contrary to that observed after the last large earthquake striking central Chile in 1985. Research shows that some of the reasons for this damage pattern are rooted in structural design decisions such as small wall thickness and vertical irregularities (Jünemann et al., 2016). As the quote above states, changes after the good results observed in 1985 led to less conservative designs that were tested 25 years later and did not perform well. These decisions were somehow reverted with the corresponding update of the codes after the 2010 event (de la Llera et al., 2017).

Similarly, there is a conflicting view about earthquake damage between experts and the communities. While buildings are designed to prevent collapse at the expense of some residual damage, especially in large earthquakes, people's standards have increased in time up to the point where almost no damage is considered acceptable regardless of the magnitude of the earthquake. Building codes state already high minimum requirements for design. However, no-damage is beyond them. Interviews show that although there are technologies allowing a better seismic performance of infrastructure (e.g., base isolation, seismic damping), both privates and the public sector are in general not willing to pay extra for this.[5] Historical good performance and the "lack of seismic trauma" [8] are identified by experts as barriers hindering generalized investment in further seismic safety for residential, educational, commercial, and public buildings.

As hinted earlier, a second problem is that earthquakes are essentially absent from urban planning. In the words of a renowned architect and urban planner:

[5] Perhaps the most noteworthy exception is in the healthcare sector. After the 2010 earthquake and based on the great performance a couple of private clinics with base isolation had, the Ministry of Health made this technology mandatory for all public hospitals built afterwards.

Sadly, urban planning of Santiago has not incorporated seismic risk as a critical variable in planning […]. Truth is, […] the natural risks and particularly the seismic risk does not appear with the importance it should appear. Although already there exist zonings that typify soils according to the seismic risk, this is not yet included in the Metropolitan Regulatory Plan, and even less in the local regulatory plans [3].

Two arguments can help understand this situation. First, note that the disciplines related to earthquakes (e.g., seismology, engineering) have a longer tradition than urban planning in Chile. Then, if earthquakes have been technically tackled via safe buildings in a successful way, planning could rely on this problem to be solved elsewhere. Or in other terms, to *compensate* lack of planning for earthquakes with good design and strict enforcement of codes. Second, consider that earthquakes are almost omnipresent in Chile. Essentially, the whole country is subject to earthquake shaking from large events produced nearby or very far. Therefore, unlike with other natural hazards, seismicity is understood as a national condition and not a local one. For example, in the case volcanism, despite being a hazard present throughout the territory, its consequences are much more constrained to the surroundings of the hazard's source and hardly affect large cities, reducing national awareness and political importance to the problem. Since it is not possible or practical to constrain earthquakes within a geographical or administrative region, it seems convenient to address them through design and building codes, which have a national scale, instead of local zoning or planning instruments. This also makes sense considering the weakness of local governments, specially from a technical perspective.

Recent findings about the Chilean seismicity are challenging this approach. The San Ramón Fault (SRF) runs across Santiago for ~30 km and it has been estimated that it could produce crustal earthquakes as large as magnitude M_W 7.5 (Vargas et al., 2014). Evidence of activity in the SRF dates only since 2004 and lots of efforts are being put to characterize the fault and its seismicity recently. Unlike the well-known large subduction earthquakes causing national-scale consequences, a potential earthquake in the SRF is clearly an urban phenomenon that particularly threatens at least the eight *comunas*[6] siting on the fault, but also the rest of the city. This process is putting pressure to the traditional way Chile has managed earthquakes. With codes developed and improved only considering subduction earthquakes, a concern about the real capacity of Chilean buildings to properly respond to crustal earthquakes arises (Estay et al., 2016). Planning experts agree that this is an opportunity to improve the methods used today to produce local planning instruments, explicitly incorporating risk information and using planning tools such as zoning to contribute to earthquake resilience.

The challenges for earthquake DRR

Earthquakes are one of the most damaging natural hazards in Chile. Thus, it results natural that the country has historically allocated most of its DRR efforts towards earthquakes. However, as discussed previously, earthquakes have been addressed mostly from a technological perspective. Although this has proven a successful approach, it is apparent that over-reliance in this dimension of risk has neglected other complementary actions such as disaster preparedness and emergency management. This was evidenced by the effects of the 2010 Maule earthquake disaster: the country's infrastructure performed extremely well for an event of this magnitude, but the scale of the disaster found ONEMI, the country's national DRR institution, "woefully underequipped, understaffed, and unprepared" (Sehnbruch, 2017, p.5). As a result, the most devastating consequences of the earthquake were not associated to the collapse of buildings and infrastructure, but to weaknesses in DRR capacities for managing tsunami warning and evacuation, the urban emergency, and the reconstruction at a local scale, among others.

Chile has always been reactive. While this is traditionally seen as a downside—as opposed to being proactive—, the interviews show that, in this context, reactiveness is good when considering that opportunities for improvement have been capitalized after every major event (see de la Llera et al., 2018). The most mentioned example is the update of building codes. However, the same has not been observed for other DRR dimensions. Noteworthy, the law that will modernize ONEMI and transform it into the National Service of Risk and Emergency Management rests in the parliament since 2011 and has now seen a third presidential period without being approved. ONEMI has notably changed and improved the way it operates since 2010. However,

[6] A *comuna* is the smallest administrative level in Chile. It corresponds to a local territory governed by a Municipality.

the dormant bill shows a lack of political will and priorities for DRR. This is very relevant when compared to the upgrade of building codes—a technical decision agreed mostly between experts—, which after the 2010 disaster saw one modification in less than 9 months and a second one in less than 2 years:

> *In general, I would say that [DRR] it is not a very relevant [perspective for the public administration]. Political authorities do not dedicate much time to this type of subjects, especially at the preventive level. At the reactive level, all. When it is a mess, everybody is* full time*, 24/7. But the question is how much time you dedicate to it in times of no-crisis, and I believe it is little. […] But there is no institutionality. The regional director of ONEMI in the Metropolitan Region must be one of the public servants that has the largest responsibility in the state, and one of the worst paid. […] There is a gap between the experience, the evidence, the discourse […], and the institutionality we have. There have passed four years [the 2014-2018 presidential period], and eight since the last earthquake, and no, we still have the same. And in between, we have legislated 35,000 stuff. […] How is this not the number one [topic] in the [legislation] agenda?* Beats me [10].

When asked to identify the most relevant stakeholders involved in the process of providing updated seismic standards, experts rapidly converge into a short list. Whilst the state is represented by the MINVU and the National Institute of Normalization (INN), private actors include structural engineering academics, practitioners, and their associations (e.g., *ACHISINA* and *AICE*). Moreover, experts highlight the close collaboration between these public and private (technical) stakeholders in this matter as key to success. On the one side, public stakeholders coordinate and host the discussion as neutral entities ensuring common good. Experts contribute their knowledge and expertise to the discussion, generating the technical document (the code). Once the new standard is agreed upon, public institutions again take the lead in its publication and, most importantly, in making it mandatory though the law. Then, the industry becomes responsible to comply, while both public and private actors enforce, inspect, and supervise this process.

On the contrary, when asked about who should oversee the preparedness of Chilean cities for future earthquakes, experts disagree. This is perhaps linked to the conception each expert has about risks and DRR, their knowledge of the state's institutions, and how to fit them together. For some, natural risks are a matter of urban security related to multiple sectors of the public administration. Political power is required to oversee and coordinate them, and hence the main role should be played via the line of the Ministry of Interior, similar to the current situation.[7] For others, risks should be managed from a technical perspective through urban regulation, and hence MINVU should play a more important role. Two interviewees instead propose DRR as a transversal value, like human rights, and therefore a perspective to be considered when making any decision—including investment and policy making—across the public and private sectors. Note that experts within the same discipline or with similar backgrounds disagree on this matter. Regardless of the approach, it is clear that today's institutional framework is not adequate for addressing the complex problem of DRR in a country largely exposed to many natural hazards.

A group of experts identify the fragmentation of the public administration as one of the main hurdles for an effective DRR system. Traditionally, the country has addressed its problems with a sectorial logic. As discussed, this has worked fine for the building-related issues of earthquakes. However, complex concepts such as *resilient cities* are difficult to grasp within this logic because they require interdisciplinary expertise, political leadership, and modern governance. Likely, the difficulty of identifying a unique actor or institution to oversee earthquake preparedness of Chilean cities is the acknowledgment that holistic DRR should tackle the whole spectrum of natural and anthropic hazards. Therefore, it is not reasonable to choose one only for the earthquake case. The closest to policies addressing the city perspective appears to be coming from the National Council for Urban Development (CNDU). The work of the Council is promising for the future in terms of positioning urban subjects in the policy agenda. However, in the meantime and as a complement, there are many simpler actions that local governments could take to improve preparedness and overall resilience. The simplest may be communication and coordination. Local authorities recognize the lack of inter-sectorial coordination within municipalities in the interviews.

[7] ONEMI lies within the Ministry of the Interior and Public Safety.

For example, despite the awareness about the impacts that large housing projects could have in the DRR actions within a *comuna*, the granting of construction permits is assessed as per they compliance with urban regulation and not in consultation with the emergency management unit of the municipality, sometimes a door away in the same building.

Conclusions

Chile's approach to deal with earthquake risk from a technical perspective via safe buildings has reported overall successful results. Moreover, the way building codes are rapidly upgraded after each damaging event shows the system's capacity for self-learning and improvement. However, whereas lessons learned from the greatest disaster in the last decade have allowed Chile to improve its DRR institutions and capacities, new knowledge about Chilean seismicity is challenging the approach the country has traditionally taken to tackle seismic risk in urban contexts. For example, the threat of a major urban disaster in Santiago due to activity in the San Ramón Fault is bringing more attention to the need of coping with earthquake risk not only thought safe buildings, but also by means of other urban planning and DRR tools.

The main contribution of this article is to unveil and understand some of the limitations of the Chilean earthquake resilience system beyond its technical component. The portion of seismic risk that can be tackled through high-quality buildings is limited. Therefore, further attention and priority needs to be put on urban and political discussions about planning, zoning, governance, and institutional framework among others. Falling short in these dimensions of seismic risk resilience may put Chile in a fragile condition for coping with its favorite natural hazard in the near future.

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References

CSN (2019). Grandes terremotos en Chile. Available at: http://www.csn.uchile.cl/sismologia/grandes-terremotos-en-chile/ (Accessed 26/03/2019)

de la Llera JC, Rivera F, Gil M and Schwarzhaupt U (2018). Mitigating Risk through R&D+Innovation: Chile's National Strategy for Natural Disaster Resilience, *Proceedings of the 16th European Conference on Earthquake Engineering*. Thessaloniki

de la Llera JC, Rivera F, Mitrani-Reiser J, Jünemann R, Fortuño C, Ríos M, Hube M, Santa María H and Cienfuegos R (2017). Data collection after the 2010 Maule earthquake in Chile. *Bulletin of Earthquake Engineering*, 15: 555–588

Dilley M, Chen RS, Deichmann U, Lerner-Lam AL, Arnold M, Agwe J, Buys P, Kjevstad O, Lyon B, and Yetman G (2005). Natural disaster hotspots: A global risk analysis, Report No. 34423, *The World Bank*

Estay NP, Yáñez G, Carretier S, Lira E and Maringue J (2016). Seismic hazard in low slip rate crustal faults, estimating the characteristic event and the most hazardous zone: study case San Ramón Fault, in southern Andes. *Natural Hazards and Earth Systems Science*, 16: 2511–2528

Gil M (n.d). Catastrophe and State Building: the Earthquake of Chillán in 1939. *Unpublished*

INE (2018). XIX censo nacional de población y vivienda [XIX national census of population and housing]. *Instituto Nacional de Estadísticas*.

Joffe H (2012). Thematic Analysis, in: Harper D and Thompson AR (eds.), *Qualitative Research Methods in Mental Health and Psychotherapy: An Introduction for Students and Practitioners*. Chichester: Wiley-Blackwell

Jünemann R, de la Llera JC, Hube MA, Vásquez JA and Chacón MF (2016). Study of the damage of reinforced concrete shear walls during the 2010 Chile earthquake. *Earthquake Engineering and Structural Dynamics*, 45: 1621–1641

McCracken G (1988). *The Long Interview, Qualitative Research Methods*. SAGE Publications, Inc.

Phillips BD (2014). *Qualitative Disaster Research*. New York: Oxford University Press

Sehnbruch K (2017). The Impact of the Chilean Earthquake of 2010: Challenging the Capabilities of the Neoliberal State. Latin American Perspectives, 44: 4–9

Stein RS and Toda S (2013). Megacity Megaquakes—Two Near Misses. *Science* 341: 850–852.

UNISDR (2015). Country risk profile: Chile. Available at: https://www.preventionweb.net/english/hyogo/gar/2015/en/home/data.php?iso=CHL (Accessed 11/07/2018)

Vargas G, Klinger Y, Rockwell TK, Forman SL, Rebolledo S, Baize S, Lacassin R and Armijo R (2014). Probing large intraplate earthquakes at the west flank of the Andes. *Geology*, 42: 1083–1086