Preliminary observations from the Chile-NZ research collaboration on the seismic design of hospitals

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ABSTRACT

This paper presents preliminary observations from a collaborative research initiative between New Zealand and Chile, aimed at improving seismic design practices for hospitals. In July 2024, a Chilean delegation visited Wellington, Christchurch, and Auckland, engaging with New Zealand engineers, policymakers, and researchers through workshops, technical site visits, and discussions. Both countries share a long history of devastating earthquakes, with notable parallels between Chile's 2010 Maule earthquake and New Zealand's 2011 Canterbury earthquakes. These events caused significant damage to critical infrastructure, including hospitals, and prompted major changes to building codes. Over a decade later, this study provides a timely opportunity to assess the effectiveness of these changes, offering valuable insights for the continued improvement of seismic design practices.

The visit confirmed broad similarities in seismic design philosophy but also revealed significant differences in the details and implementation. For instance, Chilean base-isolated hospitals have much lower activation threshold which improves functionality during frequent earthquakes whereas New Zealand prioritises protection against extreme events with higher activation levels. New Zealand has much larger isolator design displacements than Chile. Chile has formal requirements for fire protection for lead rubber base isolators, and instrumentation and monitoring requirements which are absent in New Zealand.

This exchange comes at a critical time, as both nations prepare to update seismic standards and invest in healthcare infrastructure. A reciprocal visit to Chile in 2025 will allow the New Zealand delegation to

observe Chilean practices first-hand, further strengthening the collaboration. The initiative will culminate in a comprehensive publication featuring a numerical comparative study of hospital design practices to guide future improvements in designing for seismic resilience.

1 INTRODUCTION

Hospitals play an important role in post-earthquake response and recovery. They must withstand not only seismic events but also remain functional immediately afterward to provide uninterrupted medical care. Importance Level 4 (IL4) Acute Services require continuous operation of life support systems and rapid restoration of core emergency functions within hours. Other inpatient facilities, while also needing to remain safe and operational, may have different performance expectations, with partial functionality restored within minutes to hours and full functionality over a longer recovery period. Any damage that disrupts their operations can have significant consequences, and for this reason, healthcare facilities are typically designed to a higher seismic standard, particularly in countries with a history of major earthquakes.

New Zealand and Chile are situated on the Pacific Ring of Fire, known for its high seismic activity. Two particularly significant recent events are the 2010 Maule earthquake in Chile (M_w 8.8) and the 2011 Christchurch earthquake in New Zealand (M_w 6.2). These events caused extensive damage, including damage and outages to healthcare infrastructure. This led to major revisions in building codes and design practices. Now, about 15 years after these events, it presents a unique opportunity to review the policy and engineering practice changes in each country and assess their effectiveness when there had been recent earthquake events.

Chile has undergone an extensive hospital construction programme, delivering 25 new hospitals in the past five years. This recent large-scale implementation of modern seismic design strategies offers a valuable case study for New Zealand, which is undertaking a significant refresh of its healthcare infrastructure. This knowledge exchange is particularly valuable as hospital design expertise is highly specialised and often embedded with proprietary engineering practices.

This paper presents findings from a Royal Society of New Zealand (RSNZ) funded collaboration, which facilitated workshops, technical presentations, and in-person site visits to compare seismic hospital design practices in New Zealand and Chile. The exchange focused on three key areas:

i. Use of base isolation in health care facilities – Design strategies, interaction with structural systems, detailing complexities, isolator selection, and monitoring techniques.

ii. Non-structural elements (NSEs) – Regulations, construction provisions, quality assurance processes, and recent innovations.

iii. Structural health monitoring (SHM) – The use of real-time building data to inform evacuation decisions, technologies and specifications, policy frameworks and access to past event data.

This paper summarises the field observations, lessons learned and engineering discussions from the July 2024 in-person workshops and site visits in New Zealand. It also outlines the implications for future research, hospital seismic design practice, and details of future engagement, including a reciprocal visit to Chile.

2 SEISMIC SETTING FOR CHILE AND NZ

New Zealand lies at the Pacific and Australian Plate boundary, while Chile lies parallel to the Peru-Chile Trench, where the Nazca Plate subducts beneath the South American Plate. The fault boundary interaction generates megathrust and crustal fault earthquakes for both countries. Figure 1 highlights the key plate boundaries in New Zealand and Chile.

A distinctive tectonic feature in New Zealand is the dual subduction system; the Pacific Plate subducts under the Australian Plate in the Hikurangi subduction zone off the east coast of the North Island, while the opposite occurs southwest of the South Island where the Australian Plate subducts under the Pacific Plate. The Alpine Fault, which runs along the western edge of the southern Alps in the South Island marks the transition zone where the plates slide pass and towards each other forming the elongated mountain range. The slip rate of the Alpine Fault is approximately 42 mm/yr (Grapes & Holdgate, 2014). The largest recorded earthquake in New Zealand is the 1855 M8.2 Wairarapa earthquake.

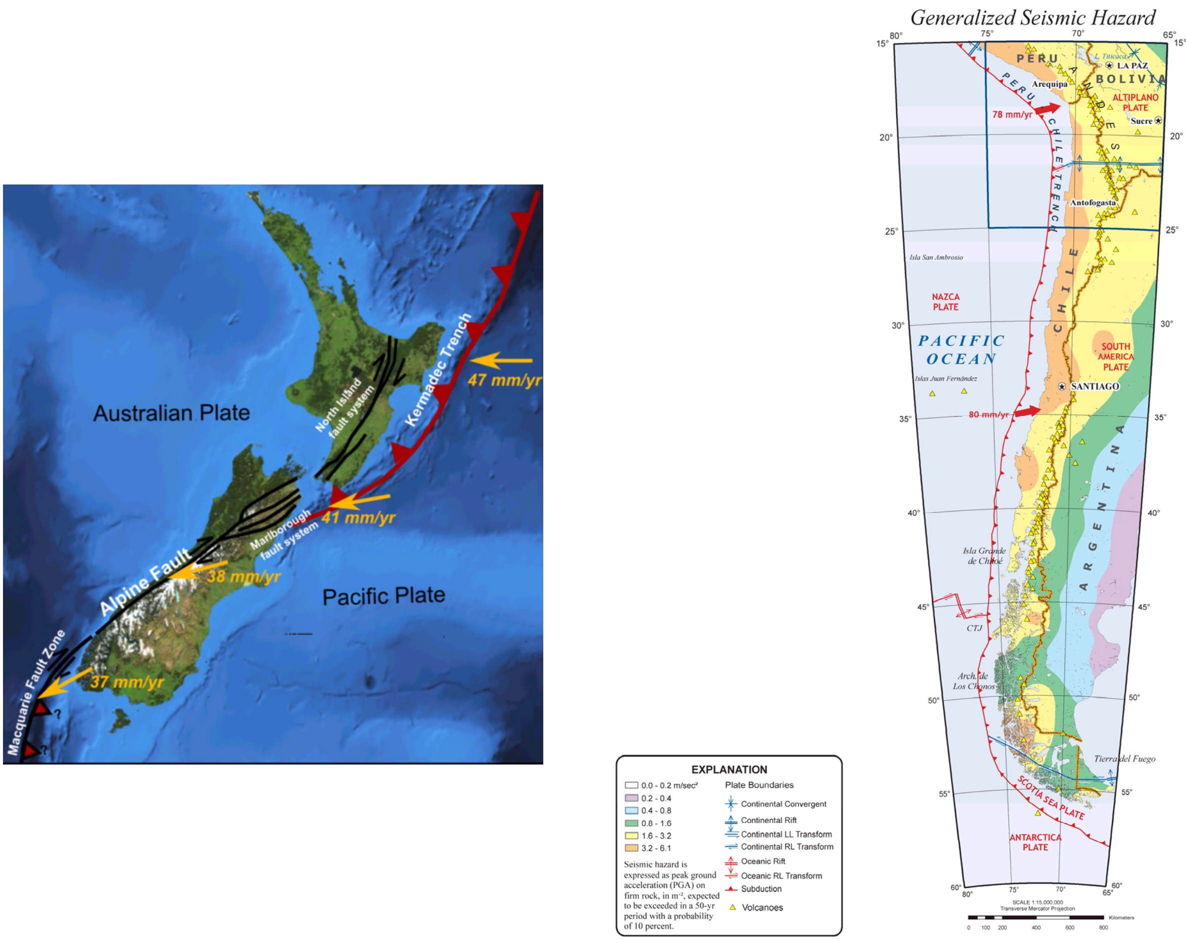

Figure 1: Key fault lines in NZ and Chile (Source: Mikenorton, 2010 and USGS, 2005)

Chile is a very long and narrow country spread between 18°S and 56°S, spanning a 3,000 km subduction zone with a high subduction velocity of around 60-80 mm/yr (Hayes et al., 2015). This rapid convergence makes it capable of producing some of the largest earthquakes in recorded history, including the 1960 Valdivia earthquake (M_w 9.5). Due to the offshore nature of the South American subduction zone, Chile's earthquakes are frequently associated with Tsunami hazards.

Chile is commonly divided into four major zones with distinct tectonic and seismic characteristics. They are,

1. North Chilean subduction zone (18°S - 24°S) – this region is part of the wider central Andes subduction system. Notable events in this zone include 1877 Iquique (M_w 8.8), 1922 Vallenar Earthquake (M_w 8.7), 1995 Antofagasta (M_w 8.0) and 2014 Iquique (M_w 8.2) earthquakes.
2. Central Chilean subduction zone (24°S – 37°S) - This region is characterised by high plate coupling and destructive megathrust earthquakes. It has historically produced highly destructive events that impact Chile's densely populated areas, including Santiago and Valparaíso. Notable events in this

zone include 1906 Valparaiso (M_w 8.2), 1928 Talca (7.6), 1939 Chillán (M_s 8.3), 1943 Illapel (M_w 8.1), 1985 Valparaíso (M_w 8.0), and 2010 Maule (M_w 8.8) Earthquakes.

3. Southern Chile subduction zone (37°S – 46°S) - This region has less frequent earthquakes than the north, yet it is still capable of some of the strongest megathrust events. Notable events include 1939 Chillán (M_s 8.3), 2016 Chiloé Earthquake (M_w 7.6), and 1960 Valdivia Earthquake (M_w 9.5) – the largest earthquake ever recorded, rupturing nearly 1,000 km of the subduction zone with a maximum slip of up to 40 meters (Plafker & Savage, 1970).

4. South American – Antarctic ridge (46°S – 52°S) – Unlike the other zones, this is a divergent plate boundary, where the South American and Antarctic Plates spread apart at 20 – 24 mm/yr. Seismic activity here is mechanically different, producing deep ocean earthquakes with minimal impact on populated areas (South American–Antarctic Ridge, 2025)

Figure 2 below presents a timeline of M7+ earthquakes in NZ and Chile between 1900 and 2025.

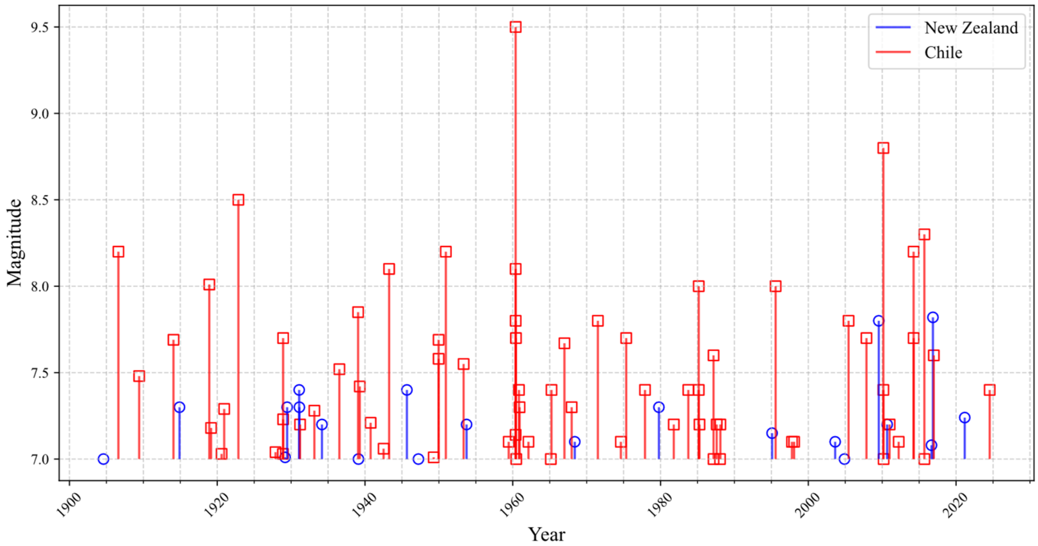

Figure 2: Magnitude 7+ earthquakes in NZ and Chile between 1900 and 2025 (Source: USGS and GeoNet)

2.1 Seismic Standards History in New Zealand and Chile

Seismic design standards in New Zealand and Chile have developed in parallel, and both countries often make significant updates in response to major earthquakes. Both countries have usually adopted similar concepts within similar timeframes. Early provisions, such as N.Z.S.S[1].95:1935 and OGCU[2]-1936, introduced basic seismic coefficients for lateral forces (0.08-0.15g, and 0.1g respectively). By the 1960s and 1970s, both countries incorporated period-dependent force coefficients (NZS 1900:1965, NCh.433Of65 working document) accounting for structural dynamics and began accounting for soil effects (NZS 4203:1976, NCh.433Of72). The 1980s and 1990s saw the adoption of response spectrum analysis in NZS 4203:1984 and the inclusion of topographic amplification in the design through specific studies in NCh.433Of93. After the 2010 Maule and 2011 Christchurch earthquakes, both countries revised hazard assessments and response spectra (NZS 1170.5:2016, NCh.433Of93) to recalibrate for latest data and building performance. It can be concluded that the current seismic loading standards in both countries essentially follow the same philosophy, differing only in its implementation, which is outlined in the next section.

[1] New Zealand Standard Specification

[2] Ordenanza General de Construcciones y Urbanización (General Ordinance of Construction and Urbanization)

Figure 3 presents a timeline showing the key seismic loading code developments for both countries along with major earthquake events.

Another relevant comparison is the historical development of material design codes, such as concrete design standards. Specifically, NZS 3101 for New Zealand and NCh430 for Chile. Detailed reviews of their development and revisions are available in MacRae et al. (2011) and Hamburger et al. (2012), respectively.

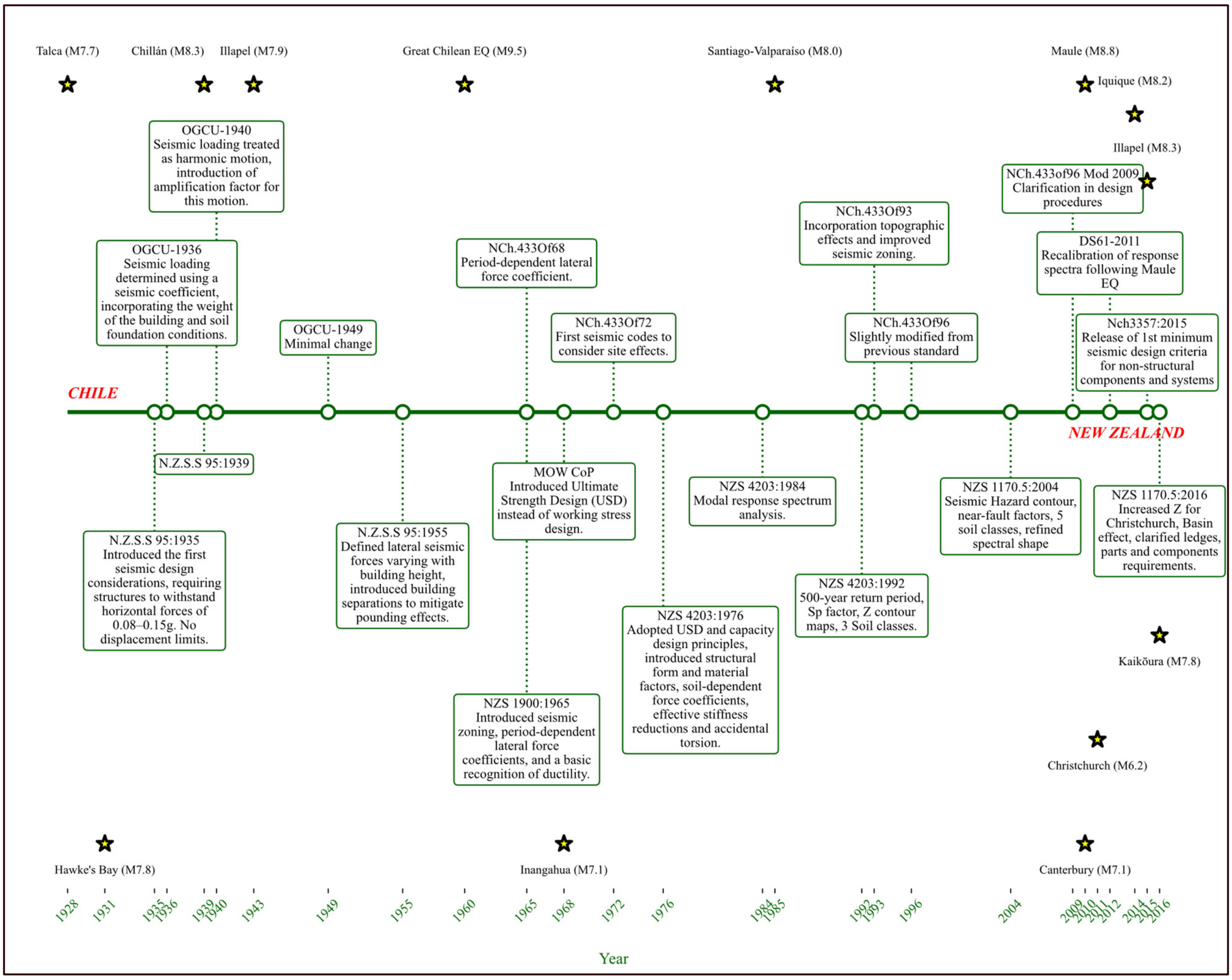

Figure 3: Evolution of seismic design regulations and major earthquakes in Chile and New Zealand

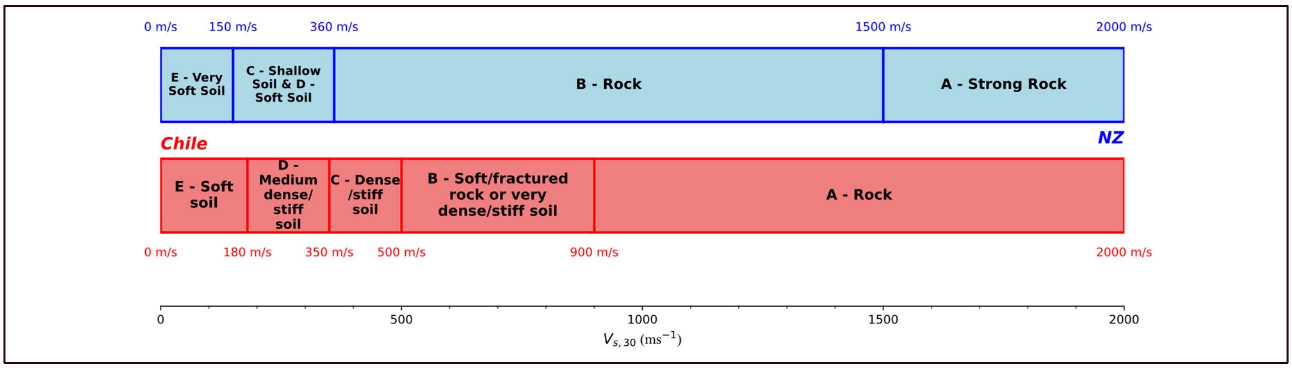

Figure 4: Site subsoil classification for NZS 1170.5 and NCh.433Of96. For NZ, Class D corresponds to a deep soft soil site (typical of V_{s30} < 200m/s, or site period >0.6s)

2.2 Comparison of NZ vs Chile design spectra

This section compares the seismic design loading in Chile and New Zealand. The comparison is based on the elastic site acceleration and displacement spectra for a normal occupancy building located in each country's highest seismic hazard zones. This corresponds to a site in Wellington ($Z = 0.4$) in New Zealand, and on the coast in Chile (Zone 3, e.g. Valparaiso). The spectra will be evaluated across all soil classes following each country's current design standard.

This study adopts shear wave velocity over the top 30 m ($V_{s,30}$) as the benchmark for soil class classification. While this is not yet formalised in New Zealand, it has been proposed in the latest draft revision of NZS 1170. Figure 4 provides an overview of Chile and New Zealand soil class classification criteria.

2.2.1 New Zealand approach (NZS 1170.5:2016)

According to NZS1170.5:2016, the lateral elastic site base shear (V) for a structure is calculated based on Equations 1 and 2 below:

$$V = C(T) \cdot S_p / k_\mu \cdot W \quad (1)$$

$$C(T) = C_h(T) \cdot Z \cdot R \cdot N(T,D) \quad (2)$$

Where

- $C(T)$ = elastic site hazard spectrum for horizontal loading;
- $C_h(T)$ = spectral shape factor based on structural period and soil type;
- S_P = structural performance factor, $S_p = 1$ for elastic;
- k_μ = ductility scaling factor, $k_\mu = 1$ for elastic;
- W = seismic weight;
- Z = hazard factor based on location, Z =0.4 for this study;
- R = return period factor with ZR_u <0.7, $R = 1$ for this study;
- $N(T,D)$ = near fault factor, $N(T,D) = 1$ for this study.

Figure 5 presents the NZ elastic acceleration and displacement design spectra for the example building.

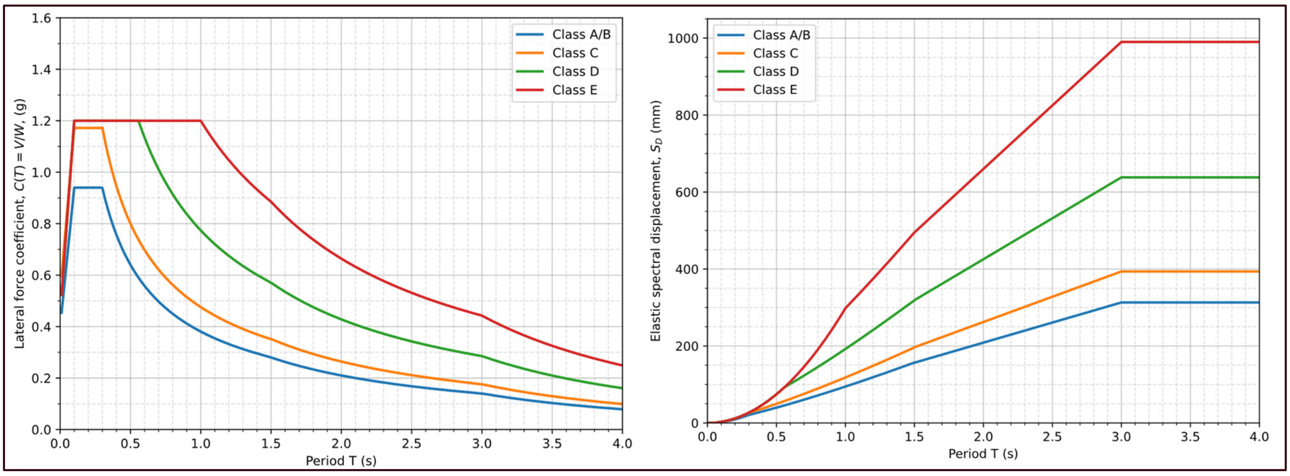

Figure 5: (Left) Elastic site acceleration spectrum and (Right) Elastic site displacement spectrum based on NZS1170.5:2016. ($S_p = k_m = R = N(T,D) = 1$, and Z =0.4). Note for hospitals, R_u=1.8→ZR_u=0.7.

For importance Level 4 (IL4) hospitals (not presented in this paper), ULS is defined as a 2% exceedance probability in 500 years (or a 2,475-year return period). This leads to $R_u = 1.8$, resulting $ZR_u = 0.7$ and effectively amplifies the demand shown in Figure 5 by 1.75 times. In NZ, the most authoritative guidance for seismic isolation is the NZSEE draft guidelines for seismic isolation systems (NZSEE, 2019). These guidelines introduce modifications to the spectral shape for periods greater than 3s and slightly reducing demand to account for the damping of the isolation system.

2.2.2 Chilean approach (NCh.433Of96)

NCh433.Of96Mod2009 and Supreme Decree DS61/2011 specify the site spectral acceleration (S_a) and spectral displacements (S_{de}) as follows:

$$S_a = \frac{S A_o \alpha}{\left(R^*/I\right)} \quad (3)$$

$$S_{de} = \frac{T_n^2}{4\pi^2} \alpha A_o C_d^* \quad (4)$$

$$\alpha = \frac{1 + 4.5\left(\frac{T_n}{T_o}\right)^p}{1 + \left(\frac{T_n}{T_o}\right)^3} \quad (5)$$

Where

- S_a = Pseudo-acceleration design spectrum;
- S_{de} = elastic displacement design spectrum;
- S = Soil type factor (ranges from 0.9 for rock to 1.3 for soft soil);
- A_o = Seismic zone maximum effective acceleration (A_o = 0.4g (Seismic Zone 3) for this study);
- α = Period dependent amplification factor;
- R^* = Reduction factor for structural system/ductility (R^* =1 for elastic)
- I = Building importance factor, I =1 for normal occupancy and 1.2 for hospitals;
- T_o, p = Soil parameters from Table 6.3 in DS61/2011;
- C_d^* = Piecewise spectral displacement function from Table 6.5 in DS61/2011.

Note that soil classification in the standard changed from I, II, III, IV to A to E in the DS61/2011. Roughly the following mapping applies, I = A, II = B, III = C, III/IV = D, and IV = E. Figure 5 presents the Chilean elastic acceleration and displacement design spectra for the example building.

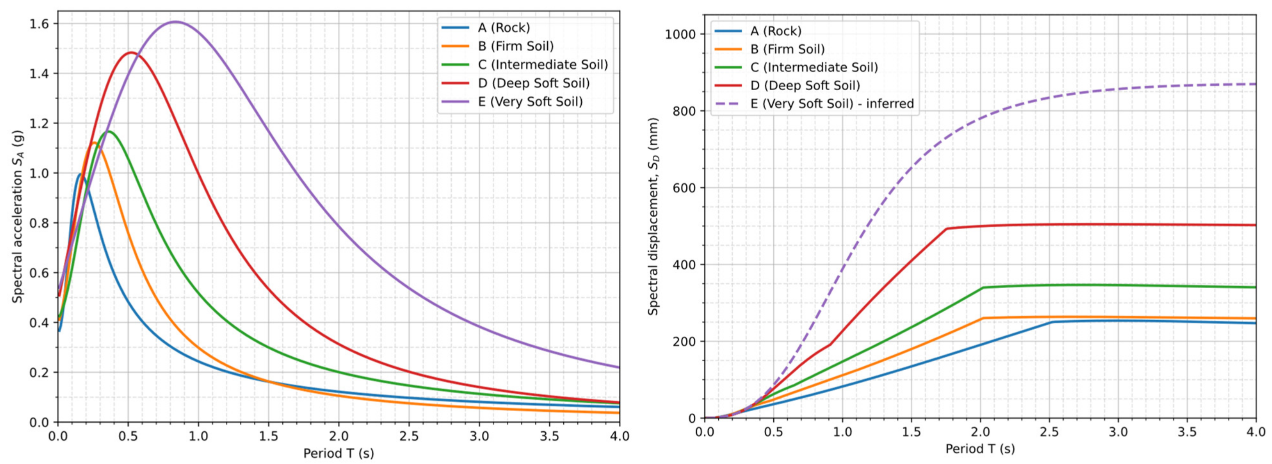

Figure 6: (Left) Chilean elastic site acceleration spectrum and (Right) Chilean site displacement spectrum based on NCh433Of96. (R^*=1, I= 1, and A_o=0.4 – Zone 3). $S_{de\ (Class\ E)}$ is inferred as it is normally subjected to a special study.

The displacement spectra in NCh433, in the long period ranges, are derived based on an envelop of recored historic ground motion in Chile. NCh2745:2013 represents Chile's current design standards for base-isolated structures, which has a slightly different approach to developing the response spectra. But overall, as it can be seen the approach are very similar to that in New Zealand.

2.2.3 Comparing the seismic demand

The preceding graphs provide an initial comparison of elastic seismic demand between Chile and New Zealand. However, direct conclusions are not straightforward due to differences in seismic hazard levels. Notably, this comparison evaluates the highest seismic zones in both countries, where Chile's Seismic Zone 3 likely experiences higher seismicity than New Zealand's highest hazard region. While this does not invalidate the comparison, it highlights that we are examining the upper-bound design forces in each country rather than comparing seismic demand under identical hazard conditions.

A key observation is the difference in spectral shape between the two countries. Chilean acceleration spectrum exhibits a peak, meaning buildings within a narrow range of structural periods experience higher design accelerations, but these values drop off quickly as the period increases. In contrast, New Zealand's spectrum has a plateau at lower periods, mitigating the peak and levels off at longer periods more gradually.

A more meaningful comparison can be made by focusing on Class D soils, which represent similar ground conditions in both countries. It may also be helpful to compare Santiago (Seismic Zone 2, A_o = 0.3g) in Chile against Wellington (Z = 0.4) in New Zealand where the seismic hazard levels are more comparable, in addition to comparing the highest seismic hazard in both countries. This allows us to isolate differences in design methodology and risk appetite rather than differences driven purely by hazard intensity. Figure 7 presents the elastic design acceleration and displacement spectra for this refined comparison.

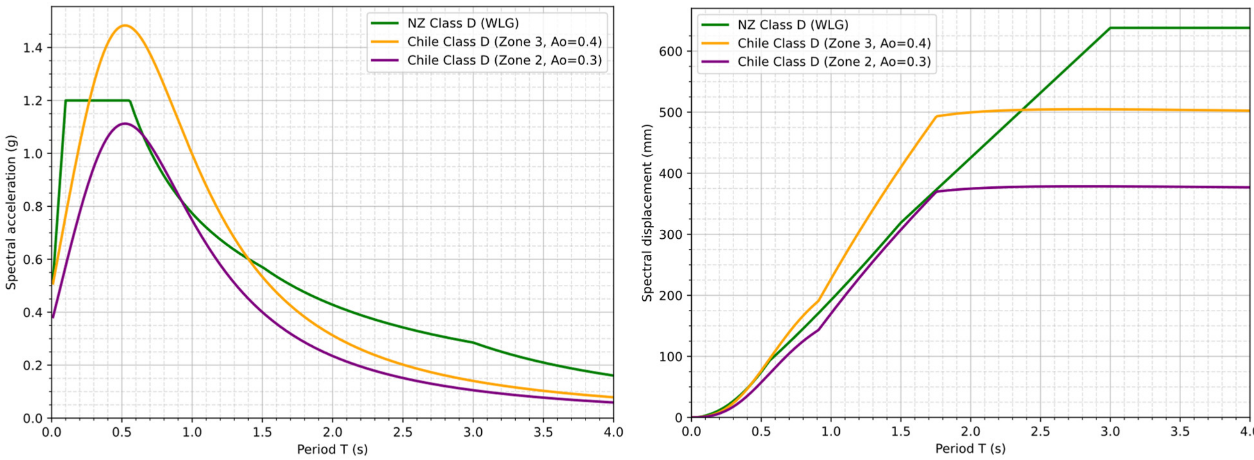

Figure 7: Comparing seismic demands for the same soil condition (class D) (Left) Elastic spectral acceleration and (Right) Elastic spectral displacements

These graphs show that while Chile's highest seismic zone imposes greater design demands than New Zealand's highest zone for structures with periods below 1.5s; at similar seismic hazard (between Wellington and Santiago), New Zealand consistently prescribes higher seismic design requirements across most periods.

New Zealand's plateau-shaped spectrum results in higher acceleration demands for very short-period structures ($T_1 < 0.3$s). The same occurs for very long period structures ($T_1 > 3$s) where NZ has significantly higher acceleration and displacement demand.

However, to fully appreciate these differences, one must also consider ductility provisions, as different approaches to inelastic behaviour influence the effective design forces. In New Zealand, concrete buildings are assigned ductility factors, μ = 1 to 6, with limited-ductile concrete moment-resisting frames (MRFs) restricted to $\mu = 3$ (NZS3101:2006). In Chile, concrete buildings with $T_1 > 1.5$s are typically designed with a reduction factor (R^*) between 3 and 4, while short-period structures in lower seismic zones may adopt R^* values as high as 5.5. (Boroschek et al., 2014). Other design requirements also affect the final results and will be the subject of next phase of this study.

Overall, the seismic demands and methods in evaluating them in both countries are fundamentally similar.

3 FIELD VISIT OVERVIEW & AGENDA

From 28 July to 3 August 2024, a four-person Chilean delegation visited New Zealand as part of a collaborative effort to exchange knowledge on seismic resilience in healthcare infrastructure. The delegation included senior professional engineers in hospital design and construction, representatives from the Chilean Ministry of Health, and engineering academics contributing to national seismic design standards. Their visit provided an opportunity to directly engage with New Zealand engineers, policymakers, and researchers while observing real-world applications of seismic design in hospitals.

The visit began with a full-day workshop in Christchurch, attended by 29 delegates from major engineering firms such as Beca, WSP, Aurecon, Holmes, and Silvester Clark, as well as members of Health NZ's Engineering Advisory Group and academics from the Universities of Auckland, Canterbury, and Waikato. Discussions focused on seismic design philosophies, detailing practices, and the challenges of implementing seismic resilience in healthcare facilities. The workshop presentations and recordings are publicly available on the project website (https://eqsafehospitals.org).

Figure 8: A selection of sample photos taken in New Zealand during the Chilean delegation visit

Following the workshop, the delegation visited the Waipapa building at Christchurch Hospital, which is currently under construction. The visit was led by the structural engineers and designers involved in the project, providing valuable insight into the performance of base isolation systems and the seismic design of non-structural elements (NSEs). Subsequently in Wellington, the delegation met with WSP engineers for technical presentations on NZ hospital design experience, followed by a visit to Hutt Hospital to inspect its base isolation system and ongoing seismic upgrades.

The visit concluded in Auckland, where a hybrid workshop was held to consolidate preliminary observations and compare findings. The delegation then visited Aurecon's Auckland office for a presentation on the Auckland City Hospital upgrade, followed by a site visit to observe seismic strengthening strategies in practice.

4 KEY OBSERVATIONS FROM THE SITE VISIT

The delegation visit highlighted common seismic design objectives and similarities in design procedures on a macro level between New Zealand and Chile. However, different seismicity profiles and design cultures, regulation frameworks and construction practices have led to notable differences in the details. The observed differences are grouped into three key themes below.

4.1 Base isolation system design

Chilean hospitals predominantly employ lead rubber-bearing isolators, with limited adoption of friction pendulum sliders. In contrast, new hospital projects in NZ have favoured friction pendulum systems. One interesting difference is that Chilean designers can assume 2.5% inherent damping in addition to hysteretic damping, a practice that differs from New Zealand's approach.

Chilean engineers were surprised by the large design displacements of base-isolated hospitals in New Zealand, often exceeding 1 metre. The Chilean team noted in past earthquakes worldwide, observed displacements have typically ranged from 300 mm to 350 mm at most. In New Zealand, base isolation systems normally activate at 7.5% to 15% of base acceleration, whereas Chilean hospitals generally activate at 2% to 6%. The 2% limit aligns with minimum activation forces slightly exceeding wind demands. This difference is possibly primarily driven by Chile's higher seismicity, where M6 earthquakes occur approximately every six weeks. Furthermore, as Chile's displacement demand is lower, lead cores are not mandatory to control the total maximum displacement and thus also having the effect of reducing the isolation activation force. Lower activation thresholds ensure base isolation engages even during moderate earthquakes, providing benefits for frequent shaking also rather than just the rare, severe events.

New Zealand's higher activation thresholds reflect a design philosophy prioritising protection against infrequent but severe events, and it may lead to higher acceleration being transmitted to the superstructure during frequent events. The Chilean practice emphasises both: i) continued functionality during frequent and moderate shaking, and ii) controlled damage during exceptionally severe earthquake. This difference affects occupant comfort and design accelerations for NSEs, with Chilean hospitals potentially experiencing smoother operational conditions during regular seismic events. Chile's frequent M6+ earthquakes offer a unique opportunity to study hospital and isolation system operational experience and calibrate design parameters against actual performance.

4.2 Base isolation practicalities

In New Zealand, there are no specific fire protection requirements for elastomeric bearings, beyond general Building Code provisions. In contrast, Chilean hospitals mandate extensive fire protection for isolators, requiring both passive (e.g. fire-resistant blankets) and active systems (e.g. three sprinklers per isolator). This level of fire protection significantly increases costs, with fireproofing expenses for isolators sometimes matching the cost of the isolators themselves.

Chilean hospital design standard practice is to require beams above and below isolators to facilitate replacement and mitigate P-Delta effects during column failure. The lower beam is not a common feature in New Zealand designs. Additionally, Chilean hospital design regulations specify the seismic gap size around based-isolated hospitals based on probability of impact rather than solely ensuring the gap exceeds the total displacement. The gap is sized to limit the probability of impact to less than 5% for design-level earthquakes (10% probability of exceedance in 50 years) and less than 10% for maximum-considered earthquakes (10% probability of exceedance in 100 years).

Chilean regulations enforce isolator inspections every 5 years (or post-M6 events), detailed replacement protocols, and minimum access dimensions for maintenance. NZ recommends annual inspections and 10-year detailed assessments and post-earthquake inspections after moderate or greater shaking.

New Zealand currently lacks formal requirements for in-situ monitoring of base isolators. In contrast, Chilean hospitals mandate ongoing instrumentation to track isolation system performance. At a minimum, scratch plates are required for displacement tracking, while hospitals must also install seismic sensors to measure ground motion, substructure movement, isolation layer displacement, and superstructure response. Introducing a more systematic approach to in-situ monitoring in New Zealand (a scratch plate at a minimum) could enhance long-term performance evaluation and improve the calibration of isolation systems based on observed data.

4.3 Non-Structural Elements

Chilean hospitals commonly use cast-in-place concrete floors with flat soffits, simplifying NSE bracing and partition wall installation, particularly for fire protection compliance. In contrast, New Zealand relies more on proprietary flooring systems, which can present challenges for securing NSEs and services. New Zealand can also benefit from Chile's standardisation approach to hospital design, including standardised structural grids and standardised floor-to-floor heights. This level of design uniformity facilitates easier integration of NSE bracing strategies.

Despite differences in implementation, both countries face similar challenges, for instance:

- Lack of functional certification: Operational test reports for NSEs are often inadequate, as supplier documentation rarely aligns with site-specific installations or tested acceleration levels required for seismic design compliance.
- Contractor-driven substitutions: NSE designs during the project's design phase often serve as reference only, with contractors frequently substituting alternative equipment during construction.

5 CONCLUSION AND NEXT STEPS

This study provides a basic comparative analysis of seismic hospital design practices in New Zealand and Chile, recording some key observations from a Chilean delegation visit to New Zealand. The field visit provided valuable insights into design methodologies, base isolation practices, and non-structural element design, revealing opportunities for cross-learning. The findings from this collaboration underscore the value of international knowledge exchange in refining best practices. The upcoming reciprocal visit to Chile in 2025 will allow New Zealand engineers to observe Chilean hospital design strategies first-hand. Future studies will build upon these preliminary observations by conducting detailed numerical comparisons and field monitoring analyses to inform ongoing improvements in hospital seismic design standards.

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