
Exposure of critical infrastructure networks to seismic and co-seismic hazards

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ABSTRACT

Nationally consistent natural hazard models have been developed for seismic and co-seismic hazards as part of efforts to understand how they vary across the country. A range of complimentary research programmes have produced these models, with this paper covering ground shaking, liquefaction, landslides and tsunami hazard. Focussing on critical infrastructure networks, exposure of these networks as a function of return period are discussed using simple thresholds to represent the potential onset of damage or disruption. The spatial distribution of these hazards across the country are presented, highlighting which hazards are important at different return periods and locations that are potentially exposed to multiple hazards. This research can help identify and prioritize exposed areas that future site-specific work could focus on to support resilience-building initiatives.

1 INTRODUCTION

Critical infrastructure networks across New Zealand are exposed to seismic and co-seismic hazards, with the intensity of these hazards varying as a function of location and the return period of interest. These interconnected networks extend across the country, through regions where natural hazard models and assessments may be based on different approaches. This variability may mean that decision making related to natural hazard resilience investments may not be consistent. Balanced and consistent decision-making would require natural hazard models that are based on a consistent methodology and underpinning datasets.

Recently completed research programmes have been able to develop nationally consistent seismic and co-seismic hazard datasets for a range of return period events. While significant progress has been made in understanding and modelling these hazards independently, less effort has been made to integrate the outputs of these individual hazard models. This paper presents the results from an approach to combine nationally

consistent natural hazard datasets and assess the exposure and potential high-level impacts of multiple hazards at a national scale. Focussing on seismic and co-seismic hazards and two critical infrastructure networks, the aggregated exposure statistics across the country are presented alongside the spatial extent of natural hazards for various return periods. Single and aggregated representations of the hazards are presented and discussed.

2 METHODOLOGY

The processing and analysis of the natural hazard datasets involved:

- Collection and modification (where required) of each dataset.
- Aligning the datasets to consistent spatial resolution.
- Setting of natural hazard thresholds to provide a simple representation of the onset of potential damage or disruption.
- Simplified linking of natural hazard data to critical infrastructure network locations
- Development of aggregated and spatial representations of single and multiple natural hazards.

These steps are discussed in more detail in the following sections.

2.1 Hazard Models

Nationally consistent natural hazard models for ground shaking (GS), liquefaction manifestation (LQ), co-seismic landslides (LS_{GS}) and tsunami inundation (TI) were used in this study. To enable comparisons and combinations across these models, consistent return periods of 50, 100, 200, 500 and 1000 years were used.

Ground shaking hazard was represented using peak ground acceleration (PGA) from the National Seismic Hazard Model (NSHM) (Gerstenberger et al. 2023) and time averaged shear wave velocity over the top 30 m of the ground profile (V_{S30}) from Foster et al. (2019). For each return period, the PGA from the NSHM was extracted for a range of V_{S30} values, with varying levels of PGA across the country. The V_{S30} model was developed at a 100 x 100 m grid resolution across the country, setting the maximum resolution for the GS dataset. PGA values were assigned to each grid cell based on the V_{S30} in the cell and the PGA from the NSHM (whose outputs were provided at a lower resolution) to develop the GS hazard dataset

Liquefaction manifestation was represented using the geospatial liquefaction model developed by Lin et al. (2021) and landslide triggering was represented using the geospatial model developed by Lin and Wotherspoon (2023). Both models use a ground shaking input based on peak ground velocity (PGV). An approach similar to the GS hazard was used to combine the NSHM and V_{S30} models and develop a 100 x 100 m grid for spectral acceleration at a period of 0.5 seconds, which was then converted to PGV using the approach of Bommer and Alarcon (2006).

Tsunami inundation was represented using the geospatial inundation method developed by Kimpton et al. (2024) and the tsunami wave amplitudes at the coast from Power et al. (2021). This was developed for a 10 x 10 m grid resolution along the coastline.

2.2 Hazard Model Alignment and Thresholds

Each natural hazard dataset was developed at different resolutions nationally, with this resolution controlled by the input characteristics of each model. The coarsest resolution datasets (GS, LQ, LS_{GS}) based on a 100 x 100 m grid were all aligned to each other, so no further modifications were needed. The TI, at a higher resolution, was aligned to the 100 x 100 m grid by assigning the maximum hazard intensity from the 10 x

10 m grid within each 100 x 100 m cell. This updated combined dataset representing the hazard intensity at a 100 x 100 m grid across the entire country.

Each hazard dataset represented the variation in hazard intensity across the country for each different return period, from some maximum value down to a value close to 0. Instead of including very small values of the hazard intensities that may not be consequential, a simplified representation of potential damage or disruption based on threshold values was used to convert the hazard datasets to a binary representation of YES: potential for damage or disruption or NO: no potential for damage or disruption. This simplified the presentation of data and the comparison across each hazard. For the purposes of the study, the thresholds used were:

- GS: greater than 0.2g.
- LQ: binary manifestation threshold defined Lin et al. (2021).
- LSGs: binary manifestation threshold defined Lin and Wotherspoon (2023).
- TI: greater than 5 cm depth.

These thresholds could be varied (and have been in other associated research) to explore the sensitivity of the outcomes of the analysis to these thresholds. Vulnerability or fragility model representative of New Zealand construction practices would be needed to add more resolution into this assessment; however this is out of scope for this work.

2.3 Critical Infrastructure Networks and Exposure

This study focused on the State Highway and Transpower critical infrastructure networks across the country (these networks are shown in Figure 2). A simplified approach was used to link these networks to the hazard datasets described in the previous sections. For State Highways, each 100 x 100 m that was intersected by a road was included in a filtered dataset that represented the hazards associated with the State Highway. A similar approach was used for the Transpower network, with the datasets filtered based on whether a transmission structure was present or not. This simplified approach likely overestimates the exposure for some of the hazards, given the spatial resolution for each dataset, however for the purposes of this national-level assessment this was deemed appropriate.

3 RESULTS

Figure 1 summarises the percentage of the grid cells with critical infrastructure that have natural hazards exceeding the threshold values, with these values presented as a function of the return period for each hazard. Ground shaking has the highest percentages across all return periods for both the State Highway and the Transpower networks. Given the lower density of the State Highway and Transpower network in the lower seismic zones (Northland and Auckland), the percentage levels exceed 50% for return periods of 200 years and higher. The overall trend is similar between the two networks, suggesting a similar distribution of the network assets relative to GS hazard.

A higher percentage of the State Highway network is exposed to liquefaction manifestation across all return periods, reflecting the position along coasts and sedimentary basin areas. This coastal position is also why a higher percentage of the State Highways are exposed to tsunami inundation. At lower return periods, the percentages of the State Highway and Transpower networks exposed to landsliding are similar, and as the return period increases, a greater percentage of the Transpower network is exposed to this hazard. This is likely due to a higher proportion of the Transpower network being located along more mountainous areas that have higher seismic hazard. The rate of increase of the percentage exposed for these three hazards is much slower than that for GS. LQ and LSGs manifest at lower return periods, meaning that higher shaking

results in less additional manifestation. TI has the flattest curve, suggesting that most of the roads and transmission structures on the coasts that could be exposed to this hazard are exposed at lower return periods.

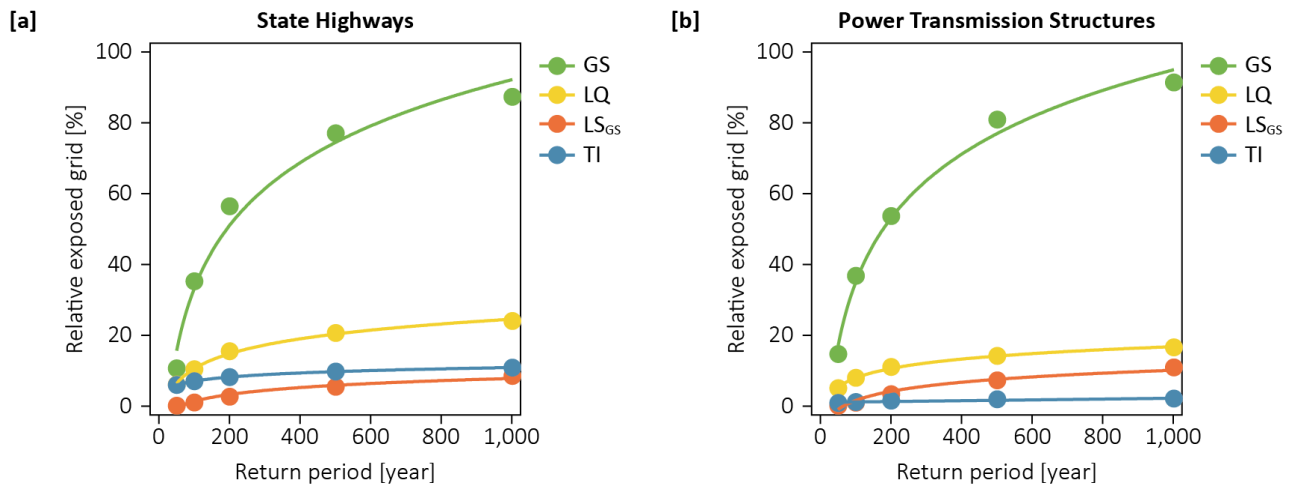


Figure 1: Percentage of the grid cells with [a] State Highways and [b] power transmission structures exposed to ground shaking (GS), liquefaction manifestation (LQ), co-seismic landslides (LS_{GS}), tsunami inundation (TI) that exceed their thresholds across different return periods.

Figure 2 provides a spatial representation of the hazards across the country for return periods of 50, 500 and 1000 years. As TI is only present along the coastline, this is not presented as it is harder to see at this resolution. The location of the State Highway and Transpower networks are shown in each sub-figure. Cells where GS exceed their threshold are shown in green, with the area of the country exposed showing a large jump from a 50 to 500-year return period. At a 1000-year return period only a small part of both networks in Northland and Auckland do not reach the threshold. In some locations the level of ground shaking leads to liquefaction or landslides exceeding their threshold, with this clearly visible along the mountainous areas that follow the plate boundaries. In most cases these cells also have GS that exceeds its threshold. Given the variable nature of New Zealand's topography it can be difficult to pick out all of the details of the exposure at this scale, with larger areas of liquefaction exposure in some of the roads that run through valley areas between more mountainous terrain.

Figure 3 presents potential combinations of hazards that could exist across these networks and how these combinations vary with return period. As mentioned above, most of the locations that exceed the LQ and LS_{GS} thresholds also exceed the GS threshold. Given the extent of this overlap this data is not presented in Figure 3 for clarity. In these locations the combined effects of these hazards would likely lead to more severe effects, with landsliding likely to result in a more significant increase in these effects. Outside of these combinations, the combination of liquefaction and tsunami is the most prevalent. This affects the State Highway network more than the Transpower network, again because of the relatively small number of transmission structures in the coastal zone.

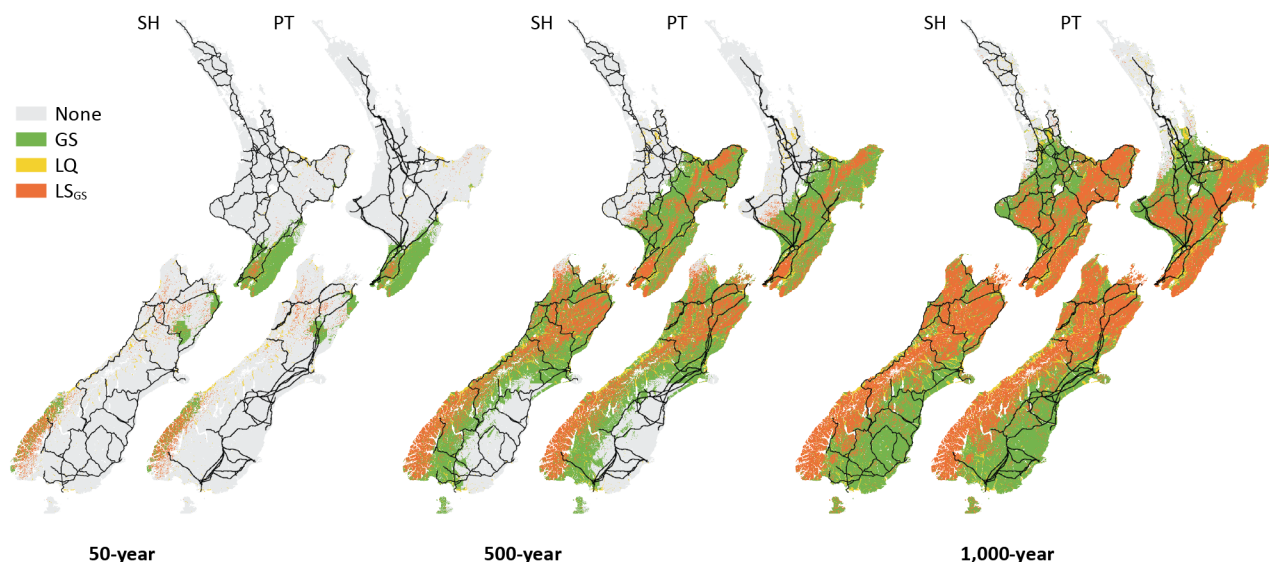


Figure 2: Grid cells where ground shaking (GS), liquefaction manifestation (LQ) and co-seismic landslides (LSGS) exceed their thresholds across different return periods overlaid with State Highways (SH) and power transmission structures (PT).

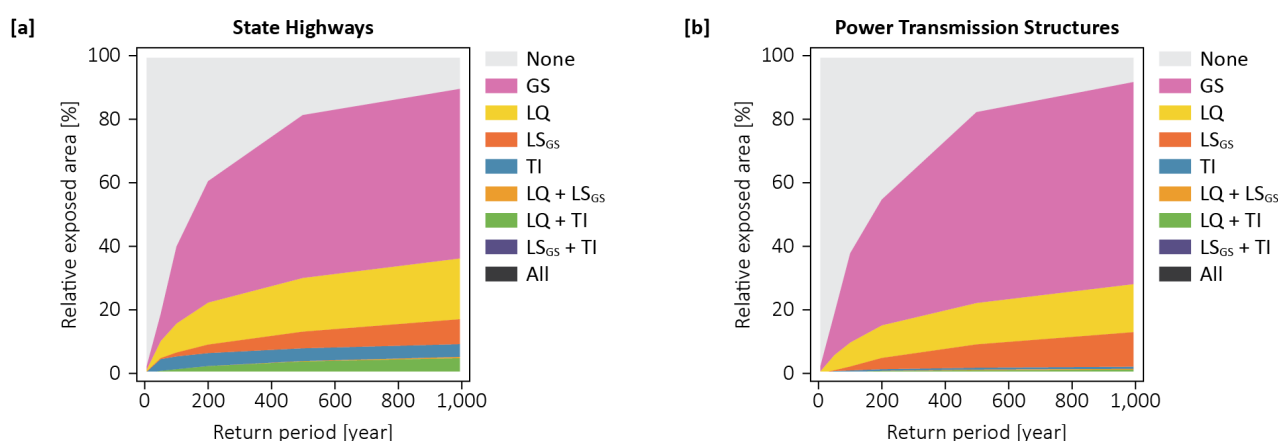


Figure 3: Percentage of the grid cells with [a] State Highways and [b] power transmission structures exposed to different combinations of hazards across different return periods

4 SUMMARY AND NEXT STEPS

This paper has presented an assessment of the exposure of critical infrastructure networks in New Zealand based on nationally consistent natural hazard datasets. Focussing on seismic and co-seismic hazards, the aggregated and spatial trends across these networks as a function of return period have been highlighted. Ground shaking is the dominant hazard exposing these networks, with liquefaction and landslide adding to the severity of the hazard where these can manifest. Tsunami inundation affects a smaller proportion of these networks, with more significant exposure to the State Highway network along coastal areas. Future research will move from exposure to risk by making use of improved representations of the vulnerability of critical infrastructure elements. Given that these networks are exposed to other natural hazards, a more complete assessment should include hazards such as flooding and rainfall-induced landslides. This sits alongside improved representations of the dynamic and connected nature of these networks, with scenario-based assessments providing a deeper view of the impact of different natural hazards scenarios on network function.

5 REFERENCES

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