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National Seismic Risk Assessment for Residential Buildings in Australia using NSHA23

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Abstract

The overall earthquake bedrock hazard across Australia is low compared to the hazard of countries located at tectonic plate boundaries. This hazard is, however, variable and some regions of the country have hazard that would be considered moderate. Coupling this variability with the variability of overlying regolith and that of the building stock, the risk associated with earthquake damage has greater spatial variability that is not well understood. Reported in this paper is a consistent national-scale seismic risk assessment for residential houses in Australia that has used the latest seismic hazard model developed through the National Seismic Hazard Assessment 2023 (NSHA23). For the exposure information used, building attributes were extracted from the National Exposure Information System (NEXIS) developed and maintained by Geoscience Australia (GA). All the residential buildings were grouped into four primary types for which vulnerability was assessed using empirical damage data from past Australian earthquakes. In turn, the vulnerability models were nuanced to consider the high lateral load resistance of houses in cyclonic regions of Australia. The average annualised loss (AAL) ratio was computed using the OpenQuake-engine implemented at the National Computational Infrastructure (NCI). The computed AAL ratio was later aggregated to Australian Bureau of Statistics (ABS) Statical Area One (SA1). The AAL ratio for the whole of Australia was estimated to be 0.00646 (%). Northern Territory was the highest ranked jurisdiction by AAL ratio, followed by Western Australia. In this paper, details of the inputs and outcomes of the assessment are presented. These are discussed in terms of the changes in hazard understanding in transitioning from NSHA18 to NSHA23 and in terms of the change of vulnerability models across the country.

Keywords: earthquake, hazard, risk, residential, houses, vulnerability

1 Introduction

Earthquake hazard in Australia is low by global standards as the peak ground accelerations (PGA) with a 10% probability of exceedance in 50-years at capital cities are estimated to be less than 0.1g based on the 2023 National Seismic Hazard Assessment (NSHA 23; Allen et al., 2023). This hazard is, however, variable and some regions of the country have hazard that would be considered moderate (e.g. Yilgarn, WA). Coupling this variability with the variability of overlying regolith and that of the building stock, the risk associated with earthquake damage has greater spatial variability that is not well understood.

On average 100 earthquakes of magnitude 3 or more are recorded in Australia each year. Earthquake hazard has been considered in various natural hazard risk assessment undertaken by local and state governments (e.g. Western Australia State Emergency Management Committee, 2017). The recent damaging Mansfield earthquake (M_L 5.9) occurred in 2021 and caused $105 M AUD loss in total. This event was classified as a Significant Event by the Insurance Council (Insurance Council of Australia, 2022).

Geoscience Australia has completed several regional-scale earthquake risk assessments to understand community earthquake risk (e.g. Ryu et al., 2023). However, they are limited in providing a comprehensive profile of earthquake risk for the whole country, because 1) spatial extent and resolution varied across the studies, 2) different building types and hence different set of vulnerability models were used, and 3) different hazard models were used. Therefore, given the recent update of the earthquake hazard model for Australia through the NSHA23, a national-scale seismic risk assessment was undertaken. The exposure data was limited to residential houses as the quality of building related information has been better captured for residential buildings than non-residential ones, and residential buildings comprise the majority of Australian building stock.

In this paper, we describe how we modelled hazard, exposure and vulnerability, which are the three elements for the risk assessment. The average annualised loss (AAL) ratio was computed as a risk metric using the OpenQuake-engine implemented at the National Computational Infrastructure (NCI). The outcomes of the risk assessment are presented and discussed.

2 NSHA 23

Geoscience Australia, together with contributions from the wider Australian seismology community, has completed NSHA23. Figure 1 shows a hazard map indicating the mean PGA (in g) for 10% probability of exceedance in 50-years on AS1170.4 (Standard Australia, 2018) Site Class B_e (equivalent to V_{S30} = 760 m/s). This incorporated 15 independent seismic source models and eight ground-motion models with different weights for seven tectonic region types. The NSHA23 has built upon the 2018 National Seismic Hazard Assessment (NSHA18) through several key updates and revisions to model components, including: 1) updating and extending the earthquake catalogue (Allen et al., in press); 2) updating the fault-source model (Clark, 2023; Allen et al., 2024); 3) the augmentation of the Australian Ground-Motion Database (Ghasemi and Allen, 2021, 2023) with new and legacy data for ground-motion model (GMM) evaluation and weighting; and 4) review and revision of the seismic-source and ground-motion characterisations model logic trees through expert elicitation.

The ratio of the NSHA23 relative to the NSHA18 for the mean PGA with a 10% probability of exceedance in 50 years suggests an almost uniform increase in the seismic hazard in the NSHA23 relative to the NSHA18 on a spatial scale, but generally with ratios near 1.0. Most of the relatively modest changes are a result of changes to the ground-motion characterisation model (GMCM; Allen et al., 2023). The largest changes in hazard understanding occur in northern Australia due to the use of the new Allen (2022) GMM developed for earthquakes occurring in the Banda Sea that affect sites in northern Western Australia and the Northern Territory. In order to compute the ground motion at the surface, we used the site condition data extracted from the Australian Seismic Site Conditions Map (ASSCM; McPherson, 2017).

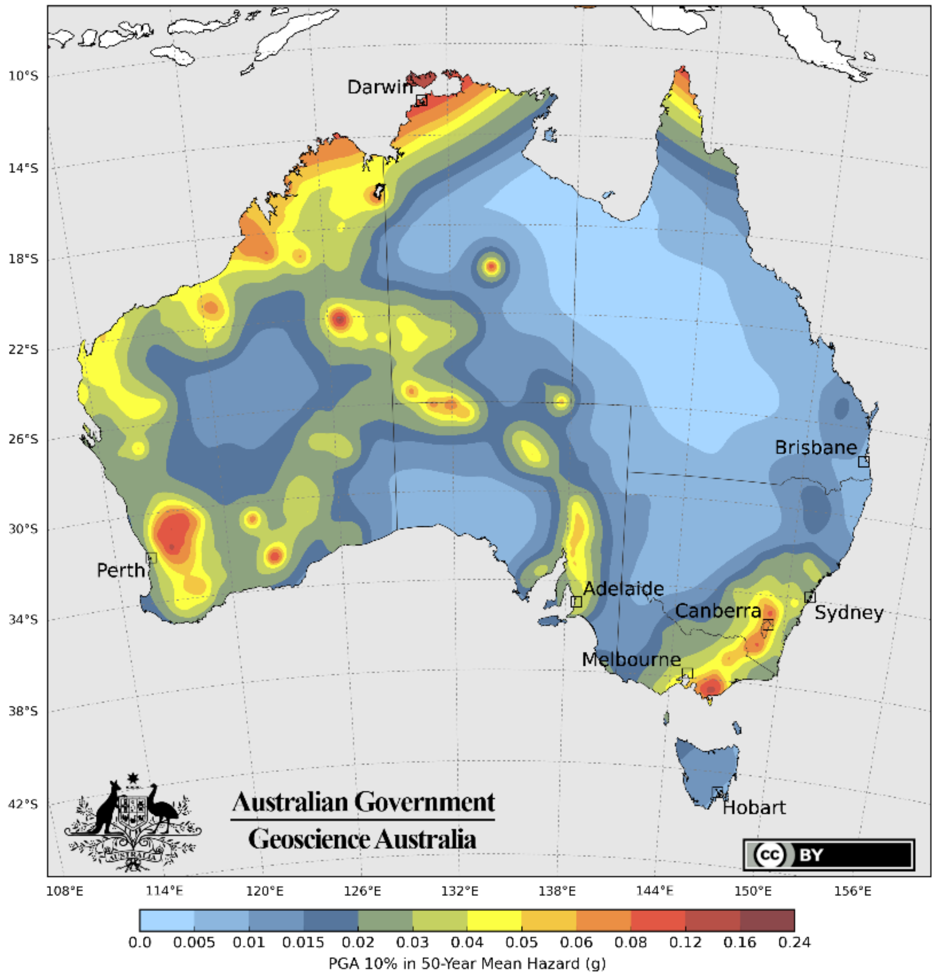

Figure 1. Bedrock hazard as assessed by NSHA23 having a 10 percent chance of exceedance in 50 years. The elevated hazard in northern Australia is evident.

3 Residential building stock

We used Geoscience Australia’s National Exposure Information System (NEXIS) to obtain residential building data. A total number of almost 9 million residential houses was compiled. NEXIS utilises and integrates data from a range of national, state, local, and commercial sources to derive a nationally consistent definition of buildings in the community, as described in Edwards et al. (2021). The information for the states of Tasmania, Victoria, South Australia and Western Australia is more specific at property level through the integration of Valuer Generals Office data from each state. The exposure data used for this study comprised the building level attributes as set out in Table 1. The WIND_REGION attribute was added to assign a vulnerability model depending on the wind region according to AS/NZS 1170.2 (Standard Australia and Standard New Zealand, 2021), which aligns with the revised vulnerability model conditioning based on the wind region. Figure 2 shows the proportion of each building type by state and territory. The dominant building type of ACT, SA, and WA is found to be un-reinforced masonry (URM) built after 1945, while timber buildings built after 1945 make the majority for other states and territories. A further subdivision of timber buildings by wind region, as presented in Figure 3, shows that Queensland (QLD) and the Northern Territory (NT) have a significant number of timber buildings located in Wind Region B and C, respectively.

Table 1. Residential building data attributes

Attribute	Description
LID	Unique site identifier
LONGITUDE	Longitude of the building location
LATITUDE	Latitude of the building location
SA1_CODE	ABS Statistical Area 1 (2021)
YEAR_BUILT	Range of the build year
WALL_TYPE	Wall material type
ROOF_TYPE	Roof material type
SITE_CLASS	Site class from ASSCM (McPherson, 2017)
WIND_REGION	Wind region according to AS/NZS 1170.2 (2021)

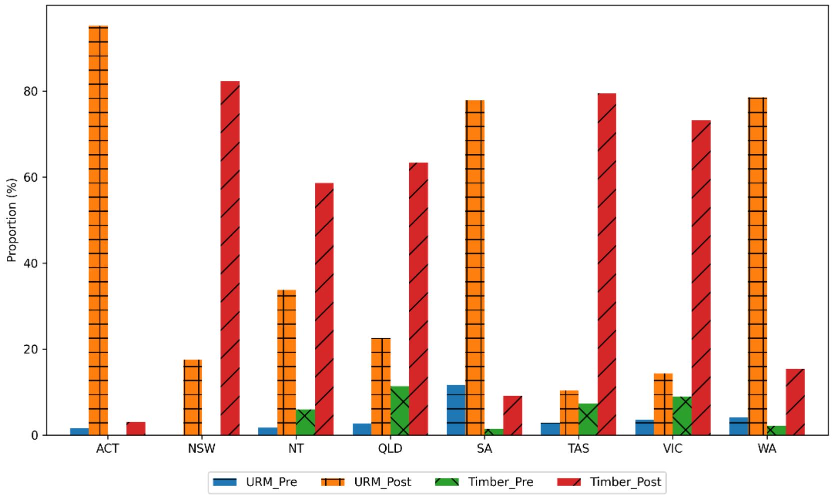

Figure 2. Building type proportion by state and territory

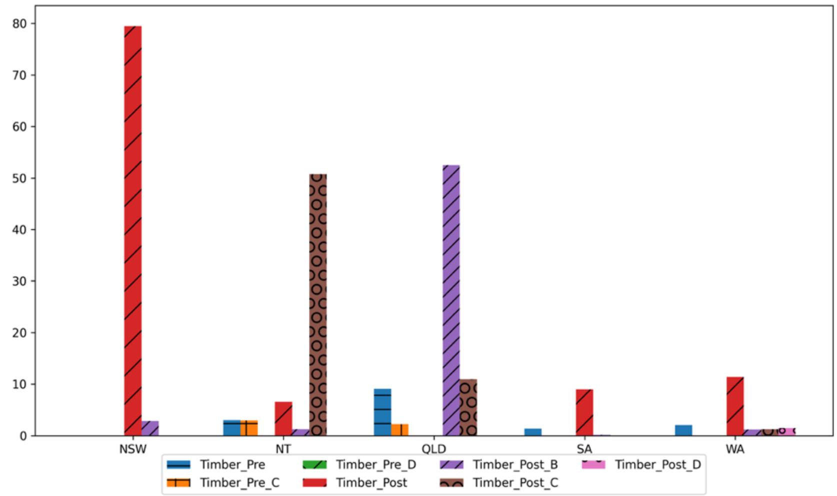

Figure 3. Subdivision of timber building type proportion by state and territory

4 Vulnerability models for Australian residential buildings

Geoscience Australia has developed vulnerability models for Australian residential buildings (Ryu et al., 2013) and applied them for several earthquake risk assessments (e.g. Ryu et al., 2023). The models were developed for two major building types (un-reinforced masonry and light timber frame) with a differentiation of older building being constructed prior to 1945 and newer ones being constructed after 1945. They are partly empirically derived from building damage data from two damaging earthquakes: M_L 5.6 Newcastle (1989) and M_L 5.0 Kalgoorlie (2010).

For the buildings located in regions such as coastal north-Queensland where cyclonic wind loading is more dominant than earthquake, additional curves were derived by assessing the lateral wind resistance at which load resisting elements in the houses would show distress. This was used a measure of the seismic resistance for the same degree of response. In total, four additional models were developed (Wehner, 2024), which are vulnerability models for timber frame buildings in Wind Region B, C, and D, respectively, as set out in Table 2. Note that vulnerability models for the timber frame buildings constructed prior to 1945 in Wind Region C and D are the same. The vulnerability models used in this study are presented in Figure 4.

Table 2. Vulnerability models by building type and wind region

Building Type	Wind Region	Age Bracket	
		Pre-1945	Post-1945
URM	A	URM_Pre	URM_Post
	B	URM_Pre	URM_Post
	C	URM_Pre	URM_Post
	D	URM_Pre	URM_Post
Light timber frame	A	Timber_Pre	Timber_Post
	B	Timber_Pre	Timber_Post_B
	C	Timber_Pre_C	Timber_Post_C
	D	Timber_Pre_D	Timber_Post_D

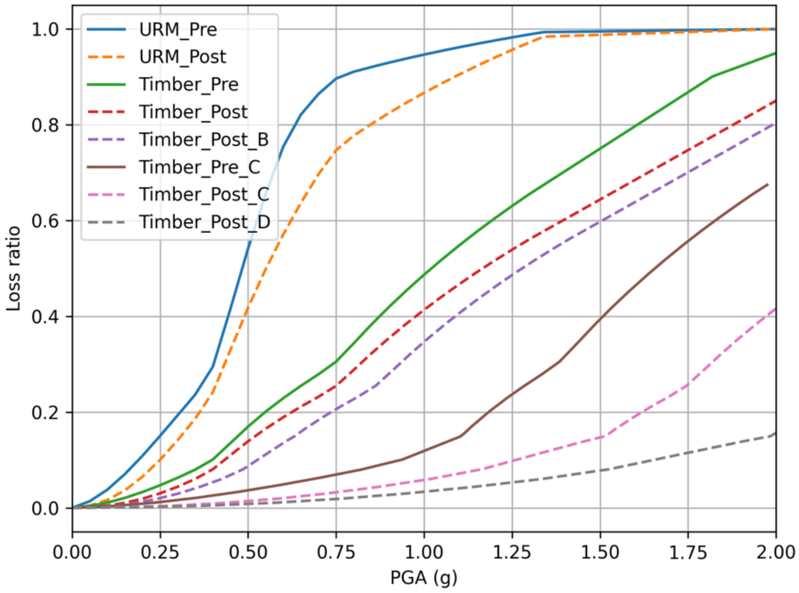

Figure 4. Vulnerability models for residential buildings

5 Risk calculation

The risk calculation was done using the OpenQuake-engine (Version 3.19.0; Pagani et al. 2014) with the input of the hazard model developed for NSHA23, the exposure data, and the revised vulnerability models for the residential buildings. Average annualised loss (AAL) ratio for different geographical boundaries of interest was computed using the classical PSHA-based risk calculator of the OpenQuake-engine.

The AAL ratio for the whole of Australia was estimated to be 0.00646 (%). The AAL ratio by state and territory is summarised in Table 3 and compared with the AAL ratio range by state and territory reported in seismic risk profile for Australia by Global Earthquake Model (GEM) (Silva et al., 2023). The comparison between the two studies suggested that this study predicted higher risk than the GEM risk profile, especially for the Northern Territory, which is more than five times higher. While the earthquake hazard exposure of the housing in Darwin is high, the risk results for the Northern Territory are unexpectedly high. The difference between the two studies was a direct outcome of the difference of the inputs into what was a common methodology. On the aspect of hazard, the GEM's risk profile was based on NSHA 18, which estimates lower than the NSHA23 and is consistent with lower observed estimates of the risk.

The distribution of SA1 level AAL ratio by state and territory is shown in Figure 5. Note that the AAL ratio was computed assuming equal weight across the buildings. Figure 6 shows the spatial distribution of AAL ratio by SA1 for the cities of Melbourne and Adelaide.

Each SA1 was ranked by AAL ratio, and the number of SA1s by state and territory from the highest 100 AAL ratio were counted. It was found that 79 SA1s were in the Northern Territory, 10 were in Queensland and Western Australia, and one in Victoria. Note that New South Wales, South Australia, Tasmania, Australian Capital Territory did not feature in the top 100 AAL ratios.

Table 3. AAL ratio by State and Territory

State/Territory	AAL ratio (%)	AAL ratio (%) by GEM	Capital city (SA4)	AAL ratio (%)
NSW	0.00335	0.0006 to 0.0011	Sydney	0.00366
VIC	0.00854	0.001 to 0.006	Melbourne	0.00927
QLD	0.00215	0.0006 to 0.0011	Brisbane	0.00102
SA	0.01224	0.009 to 0.012	Adelaide	0.01598
WA	0.01343	0.001 to 0.006	Perth	0.01015
TAS	0.00142	0.0006 to 0.0011	Hobart	0.00116
NT	0.03992	0.006 to 0.007	Darwin	0.06563
ACT	0.01324	0.007 to 0.009	Canberra	0.01324

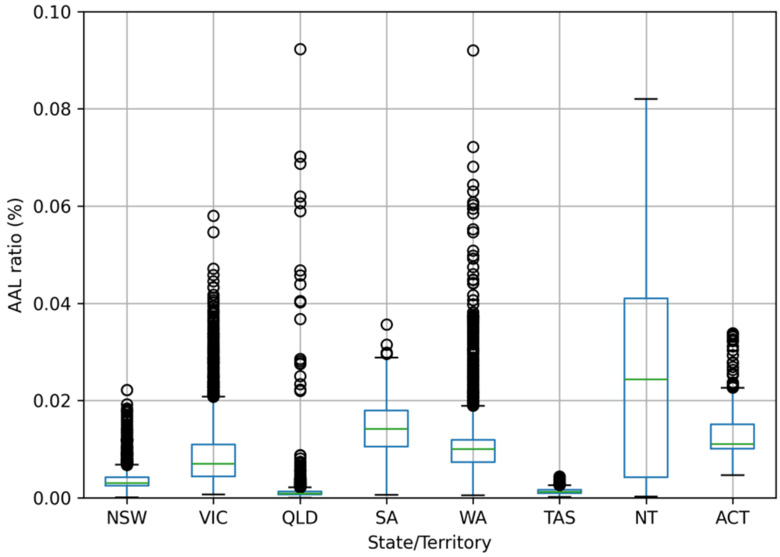

Figure 5. AAL ratio at SA1 level by state and territory. Note that the upper limit of y-axis was set to exclude extreme outliers.

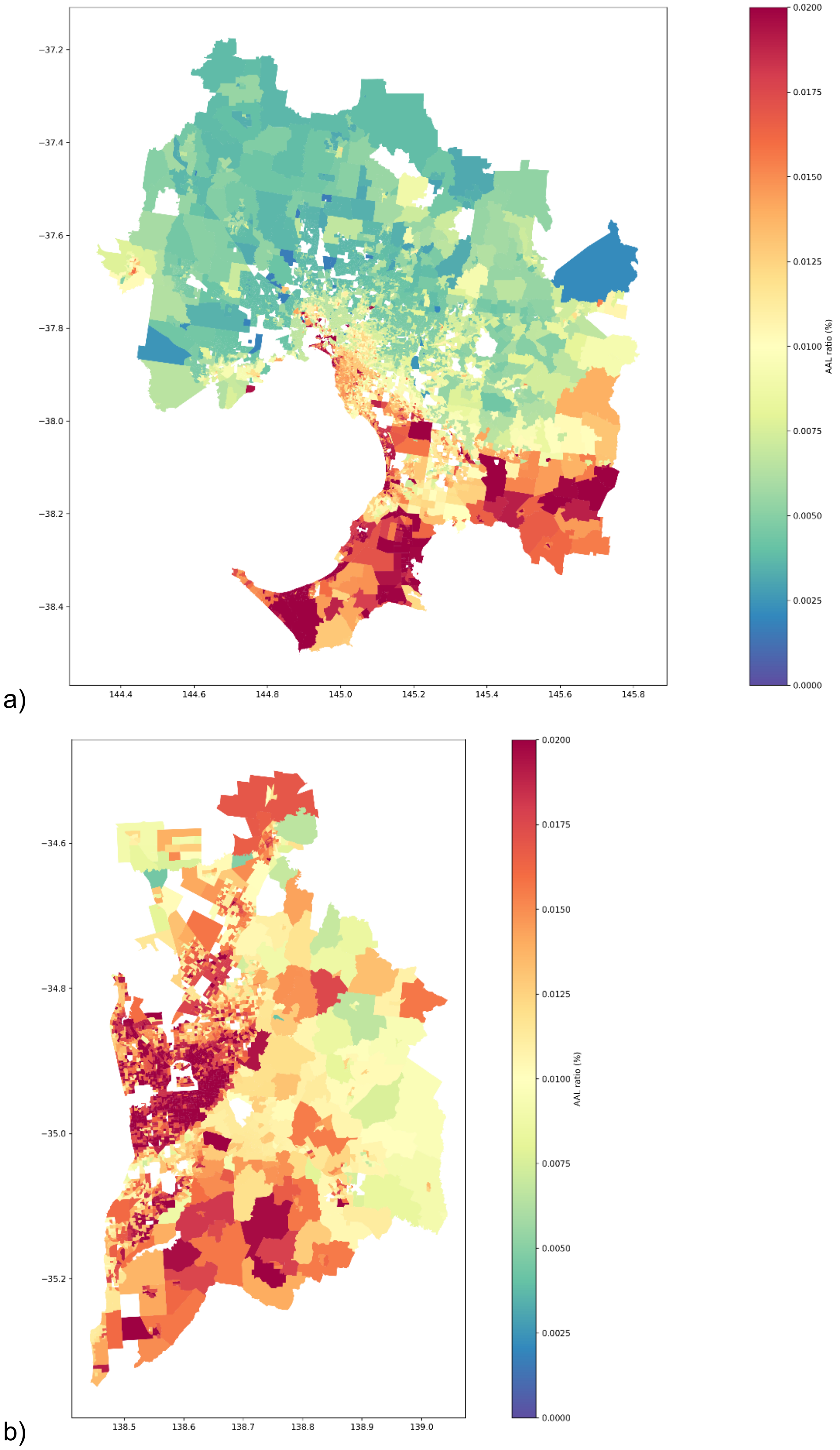

Figure 6. Spatial distribution of AAL ratio by SA1 a) for Melbourne, and b) for Adelaide

6 Summary

We performed an earthquake risk assessment for Australian housing using the latest seismic hazard model from the NSHA23, residential building exposure data extracted from the NEXIS, and revised vulnerability models nuanced for wind region. The assessed national earthquake risk of the residential house building stock provides an initial consistent view of relative risk. While it is limited by the available building stock and vulnerability information, the aggregated SA1 average risk enables some comparison across communities and the country with the varying earthquake hazard and building stock. These measures could subsequently be compared to equivalent assessments for severe wind and riverine flooding. The outcomes are not intended for mitigation assessments as has been done in details for the Heritage town of York, WA (Ryu et al., 2019), Hobart CBD (Ryu et al., 2022) and more recently for seven communities across the Wheatbelt East of Perth (Ryu et al., 2023).

The outcome is the first public domain national earthquake assessment by Australian researchers and the results were found to be of similar magnitude to those obtained by GEM as part of its global earthquake risk assessment. The outcomes of this initial risk assessment suggests that the overall Australian risk is low by global standards, but there are regions of higher risk where mitigation measures may be appropriate to reduce consequences from future events. Present research is being undertaken to better understand the results and to inform future refinements.

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