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Earthquake Risk and Mitigation Assessment in Tasmania: State-wide Assessment of Risk, Resilience and Mitigation

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Abstract

We performed an earthquake risk assessment of the state of Tasmania through a collaboration between the Tasmania Department of State Growth and Geoscience Australia (GA) with geotechnical and geological support from Mineral Resources Tasmania (MRT). We developed local surface earthquake hazard maps for Tasmania, focusing on the twenty largest communities, based on the 2018 National Seismic Hazard Assessment and seismic site conditions map for Australia augmented by geotechnical information provided by MRT. For the building exposure database, the National Exposure Information System was augmented with an engineering survey of Hobart central business district (CBD) undertaken by GA. We used GA's current vulnerability functions including a range of models for high-risk unreinforced masonry buildings (URM). With a focus on the Hobart CBD, retrofit measures were applied to the URM building types in order to quantify the effectiveness of mitigation. This study provided a synoptic state-wide view that enabled the identification of communities of high risk and low resilience by combining the damage related risk with the Australian Disaster Resilience Index. In addition, three earthquake scenario events centred on Hobart were modelled along with the impact reduction achieved through a virtual retrofit of old URM buildings in the Hobart CBD.

Keywords: earthquake risk; resilience, Tasmania, mitigation, masonry

1 Introduction

Earthquake hazard in Australia is low compared to some neighbouring countries such as New Zealand and Indonesia. The latter are located adjacent to plate boundaries, unlike Australia which is within the Australian tectonic plate. Based on the 2018 National Seismic Hazard Assessment (NSHA18; Allen *et al.*, 2018), the peak ground acceleration (PGA) with a 10% probability of exceedance in 50-years at Hobart and Launceston are estimated to be 0.011 g, which is lower than those at capital cities on the mainland (e.g., 0.021g at Sydney). Notwithstanding this, Tasmania has a long history of earthquake occurrence since European settlement. The most notable earthquakes in this history are a sequence of earthquakes that occurred between 1883 and 1892 beneath the Tasman Sea, with the largest one being M_L 6.9 (Michael-Leiba, 1989). Whilst the recent instrumental period has recorded few significant earthquakes within the state of Tasmania, the pre-instrumental period provides an history of felt earthquakes within the state (e.g., McCue, 2013; 2015) Furthermore, as with other capital cities on the mainland, there exist a significant number of unreinforced masonry (URM) structures with poorly restrained facades in the Hobart and Launceston central business districts (CBD), which pose a significant earthquake risk to Tasmanian communities.

The Earthquake Risk and Mitigation Assessment in Tasmania (ERMAT) project was formulated to assess the current earthquake risk in Tasmanian communities and the opportunities to mitigate it in the high pedestrian exposure precinct of the Hobart CBD. This project was a collaboration between the Tasmanian Department of State Growth and Geoscience Australia (GA), with technical support from Mineral Resources Tasmania (MRT).

For the risk assessment, we followed the risk assessment framework that combines the three key elements: hazard, exposure, and vulnerability. In this paper, development of each of the key elements for the assessment are described and the results of the modelling are presented. Assessed damage related risk was combined with the Australian Disaster Resilience Index (ADRI) to identify communities of high risk and low resilience. In addition, three earthquake scenario events centred on Hobart were modelled along with the impact reduction achieved through a virtual retrofit of old URM buildings in the Hobart CBD.

2 Local surface hazard maps

GA produced an updated National Seismic Hazard Assessment with contributors from the wider Australian seismology community in 2018. In the NSHA18, the horizontal PGA and the spectral accelerations are calculated on Standards Australia's AS1170.4 (Standards Australia, 2018) Soil Class Be (approximated at V_{S30}=760 m/s). In order to model the surface hazard, we used the site condition data extracted from the Australian Seismic Site Conditions Map (ASSCM; McPherson, 2017). The site condition data for the city of Hobart were refined following the review of MRT. In addition, two ground-motion models used for the NSHA18 were adjusted to incorporate site effects. The amplification model by Seyhan and Stewart (2014) was implemented for both the Allen (2012) and Somerville *et al*. (2009) ground motion models in the OpenQuake-engine version 3.13 (Pagani *et al*., 2014) to compute ground motion for a given site class. The local surface probabilistic seismic hazard maps for the twenty largest communities in Tasmania were developed. The probabilistic seismic hazard maps of the mean PGA with a 10% probability of exceedance in 50-years for the greater Hobart region are presented in Figure 1 for the bedrock and surface hazard, respectively. Increased hazard values along the banks of the Derwent River, sites near Sullivans Cove and near the Hobart CBD are observed due to firm to soft soils.

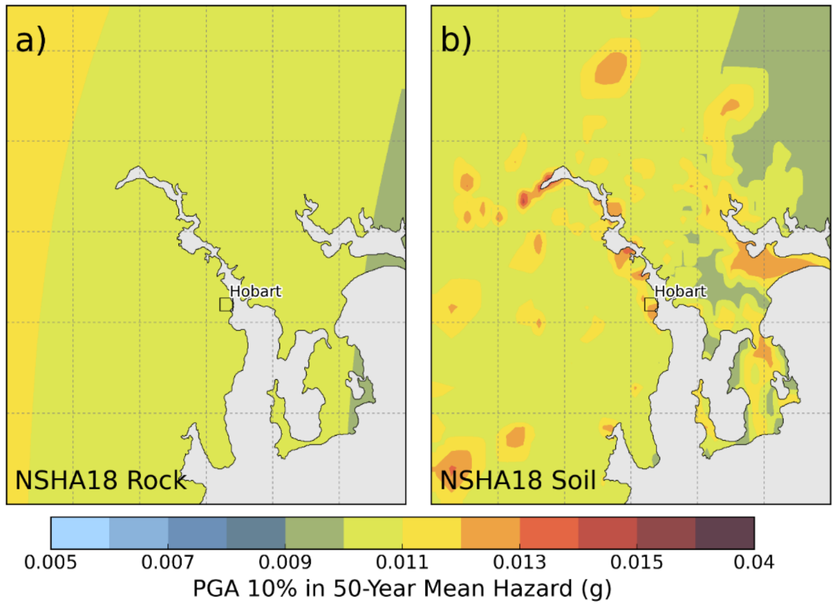

Figure 1. Comparison of the (a) bedrock (V_{S30} = 760 m/s) and (b) surface hazard for the greater Hobart region. Maps show the mean PGA with a 10% probability of exceedance in 50-years.

3 Building exposure information and vulnerability models

3.1 Building exposure information

Building level exposure information was developed by combining three different sets of data: 1) data extracted from GA's National Exposure Information System (NEXIS), 2) Hobart CBD survey data, and 3) Hobart desktop survey data.

Building level exposure information for the entire State of Tasmania was largely extracted from GA's NEXIS. NEXIS is a software application developed to collate, model and manage the exposure information required to assess multi-hazard impacts. The output of NEXIS is a point spatial feature layer representing locations for residential, commercial and industrial buildings with associated exposure information attributed at the building level. NEXIS utilises data from a range of national, state, local and commercial sources. Where building-specific information exists it is utilised, and the remainder of the information is attributed to each building using rules, heuristic assumptions and best available statistical information for all exposure attributes. The residential building information developed and maintained by the Tasmanian government is particularly complete and integrated into NEXIS.

Hobart CBD building survey data was undertaken by GA from October to December 2018 to collect detailed building level information for the Australian Reinsurance Pool Corporation (ARPC) with a counter-terrorism application. The total number of surveyed buildings was 502. The range of building attributes captured in the survey includes those that can be used for natural hazard impact and risk modelling.

NEXIS building data in the Hobart study region was improved for a number of building usage types that potentially could have high human exposure and/or post-earthquake functional requirements. Specifically, these were emergency services buildings, hospitals, and schools. MRT provided a list of the addresses of buildings or facilities of interest. Each building or campus of buildings was desktop surveyed to capture the attributes required by NEXIS. In total, specific information on 702 individual buildings was obtained for integration into the building exposure database used for the project.

The surveyed data for the CBD buildings and community buildings was integrated into the NEXIS derived exposure database to produce a single exposure file. Unreinforced masonry buildings were further classified to enable the assignment of available vulnerability curves for URM.

3.2 Vulnerability models

Vulnerability models relating the mean loss ratio (repair cost normalised by replacement cost) to peak ground acceleration (PGA) were required for each building type in the exposure database. Fragility functions were used to determine damage states of buildings subjected to ground shaking.

We used GA's current vulnerability curves for non URM buildings. We adopted vulnerability models specifically developed for the selected types of URM buildings. Vulnerability curves for 1 or 2 storey URM buildings were sourced from Wehner *et al*. (2020), and those for 3 to 5 storey commercial URM, Church and Town hall buildings were taken from a current project undertaken by Shire of York, WA and Adelaide University and GA (Vaculik *et al*., 2022). For a virtual retrofit of URM buildings, vulnerability curves for retrofitted URM buildings were taken directly from Wehner *et al.* (2020) assuming full retrofit, i.e. retrofit of all chimneys, parapets, gable walls and exterior walls tied to floor and roof diaphragms.

4 Risk assessment

For each event simulated in the risk assessment the PGA was estimated at the location of each building and the measure subsequently used as an input for the vulnerability associated with the building. Consequences such as physical damage, monetary loss, and human casualty were computed using the corresponding vulnerability models. Consequences at building level were then aggregated either by a group of buildings of interest or for each geographical boundary of interest.

Average Annualised Loss (AAL) is the common measure of long-term financial risk associated with long-term exposure to a hazard environment. The AAL of the whole state was estimated to be 2.7 M AUD, and the AAL ratio was estimated to be 0.011‰, which is larger than the estimated value (less than 0.01) by GEM (Country Risk Profiles – Australia, 2019) but smaller than estimated by Daniell *et al.* (2015), which is between 0.02 to 0.04‰ for the state. The AAL ratio of the major Tasmanian cities ranged from 0.004 to 0.017‰ with the largest being for Smithton, and the smallest being for Midway Point, respectively. They are approximately one or two orders of magnitude smaller than those for Perth (0.098‰) (Edwards *et al*., 2021) and York (0.22‰) (Ryu *et al*., 2019). The AAL ratio by ABS Statistical Area Level 1 (SA1) for Hobart is shown in Figure 2, where SA1s with relatively larger AAL ratio can be identified.

In addition to the AAL, a loss exceedance curve was developed through an event-based probabilistic calculation using the NSHA18 input seismic source and ground motion models (Allen *et al*., 2018). The computed loss exceedance curve for the whole state is presented in Figure 3.

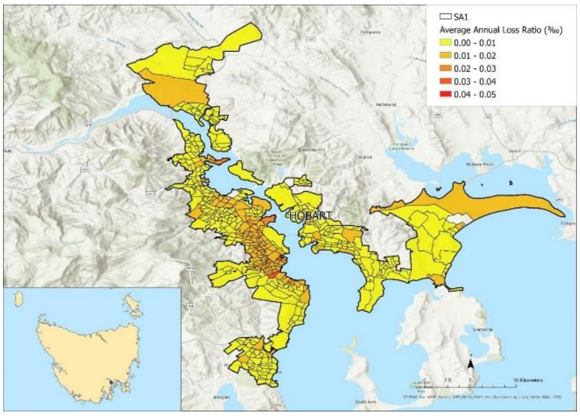

Figure 2.Map of AAL ratio by SA1 for Hobart

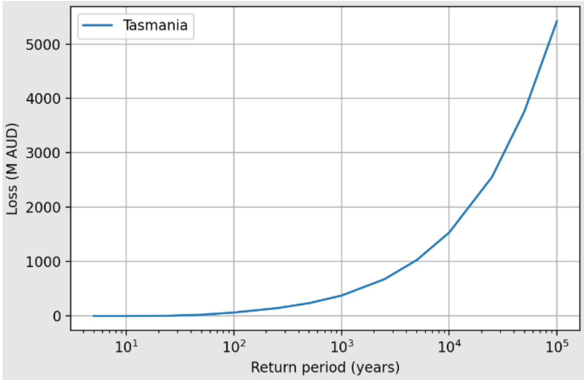

Figure 3. Loss exceedance curve for the state of Tasmania

The Australian Disaster Resilience Index (ADRI) is a recently developed top-down assessment of the resilience of communities to natural hazards at a national scale (Parsons *et al*. 2021). To integrate with ADRI, we divided SA1s into three categories based on the AAL ratio: Low (smaller than 1st quartile), Medium (between the 1st quartile and 3rd quartile), and High (larger than 3rd quartile). The maps of holistic risk combining AAL and ADRI categories by SA1 for the twenty largest communities were developed. The combination of AAL and ADRI categories for Hobart is presented in Figure 4, which provides a more holistic picture of risk to communities and helped to identify communities of high risk and low resilience.

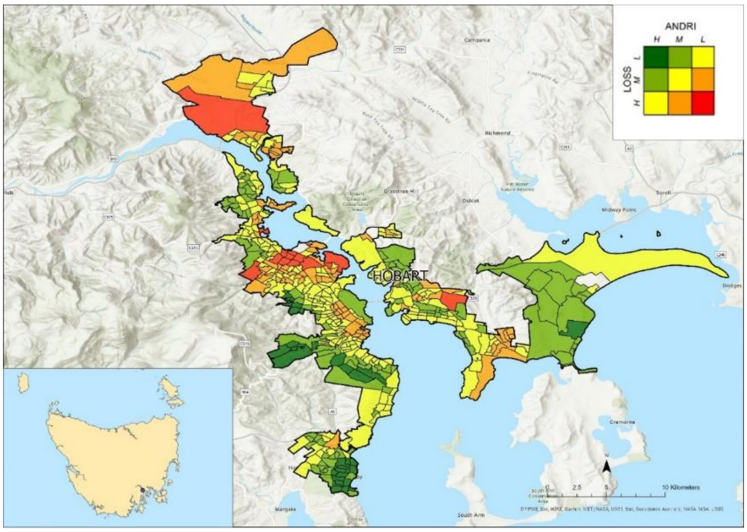

Figure 4. Map of holistic risk based on the combination of AAL and ADRI by SA1 for Hobart.

5 Scenario impact assessment

5.1 Scenario events

Three earthquake scenarios in the Hobart region were selected. The first is a large and distant event that ruptures the Lake Edgar fault scarp (McCue *et al*., 2003; Clark *et al*., 2011), which is approximately 90 km west of Hobart. The second and third are local events near to the Hobart urban area and are more typical of the earthquake events that are driving the bedrock hazard in Hobart. These events are selected based on deaggregation analysis from the NSHA18 (Stephenson *et al*., 2020) and available through GA's Earthquake Scenario Selector Tool. The macroseismic intensity fields for the events are shown in Figure 5. The basic source information and return period based on the NSHA18 for the selected events are set out in Table 1.

Table 1 Selected scenario events

Scenario Event	Magnitude (Mw)	Depth (km)	Distance from Hobart (km)	PGA (g) at Hobart CBD	MMI at Hobart CBD	Return period based on NSHA18 (years)
1	7.04	11.8	90.6	0.046	4.5	3912
2	4.90	10.0	16.5	0.040	4.3	3030
3	4.90	10.0	12.5	0.055	4.8	5020

a) b) c)

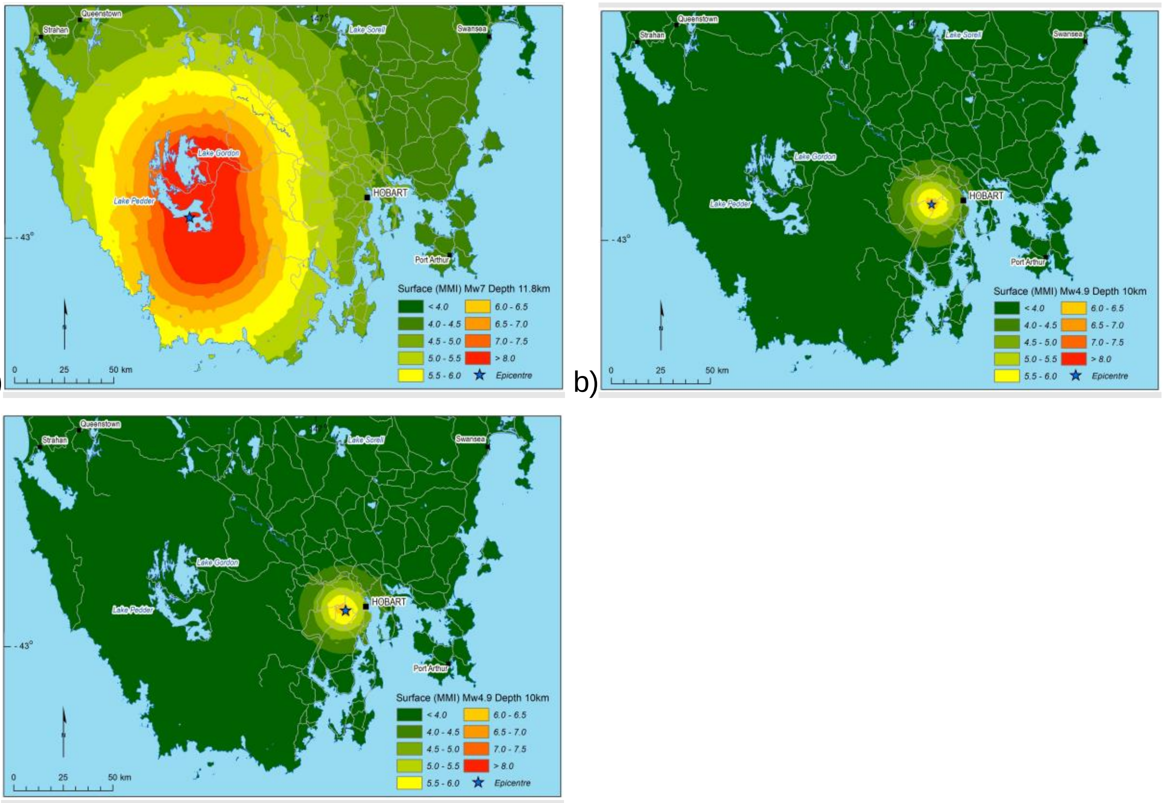

Figure 5. Simulated ground motion field at surface presented in terms of Modified Mercalli Intensity (MMI). a) scenario event #1, b) scenario event #2, and c) scenario event #3.

The consequences of the scenario events were calculated for three metrics: 1) monetary loss from necessary repair of physical damage to buildings and contents; 2) number of damaged buildings; and 3) number of casualties within buildings.

The loss ratio by SA1 from the scenarios are shown in Figure 6. Overall loss ratios from the selected events were estimated to be less than 0.05% in the greater Hobart CBD. The monetary loss from physical damage damage to buildings and contents for seected localities are set out in Table 2. It was noted that the Lake Edgar fault event was large enough to cause damage in all three tabulated communities as well as other Tasmanian communities. The number of damaged buildings in Hobart from the scenario events are set out in Table 3. The number of causalities within buildings from the scenario events was estimated as negligible.

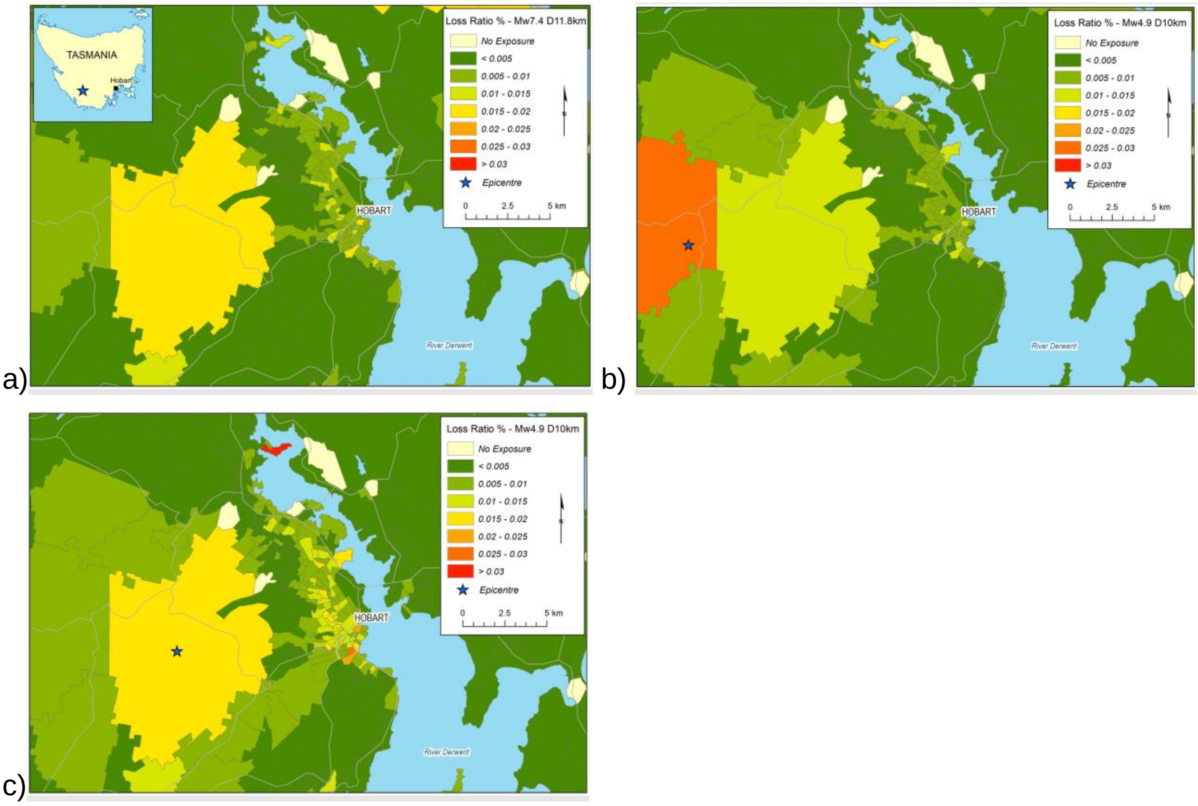

Figure 6. Loss ratio by SA1 from the scenarios. a) scenario event #1, b) scenario event #2, and c) scenario event #3.

Table 2. Summary of direct monetary loss (M AUD) and loss ratio (in parentheses) by locality from the scenario event.

Scenario Event	Hobart	Launceston	Burnie - Somerset
1	331 (0.46%)	76 (0.24%)	25 (0.17%)
2	271 (0.38%)	5 (0.02%)	0 (0.0%)
3	385 (0.54%)	5 (0.02%)	0 (0.0%)

Table 3. Estimated number of damaged buildings in Hobart from the scenario event.

Scenario Event	Slight	Moderate	Extensive	Complete	Total
1	1727	27	0	3	1757
2	1415	15	0	2	1432
3	2464	63	0	4	2532

5.2 Hobart CBD mitigation case study

A total of 35 buildings located in two SA1 in the Hobart CBD were virtually retrofitted, which translates into a little over one building being retrofitted every year over 30 years. This will result in close to 20% of the high risk URM building stock being addressed after 30 years. The total AAL of all buildings in the two SA1s was reduced from 0.0185‰ to 0.0166‰, which corresponds to 10% reduction from the mitigation. We also assessed consequences from the scenario events after the mitigation, which resulted in 15-16% reduction in the monetary loss due to building damage, and 9-10% reduction in the number of damaged buildings, respectively.

6 Summary and Discussion

We performed an earthquake risk assessment of the state of Tasmania through the collaboration. Key outcomes from the assessment include: 1) local surface earthquake hazard maps for the twenty largest communities, 2) building exposure database by augmenting NEXIS data with the two types of survey data, 3) long-term earthquake risk combined with community resilience for identification of communities of high risk and low resilience, and 4) three earthquake scenario events centred on Hobart and their impact on the communities. This is the first Australian state-wide earthquake surface hazard and risk assessment undertaken by Geoscience Australia.

This study found that earthquake risk to Tasmanian communities as measured by damage is low in general and of the same order of magnitude of a broader probabilistic risk assessment for Tasmania undertaken by the Global Earthquake Model Foundation. It was found to be significantly lower than other Australian communities studied by Geoscience Australia such as Perth and York in WA. The study did identify Tasmanian regions with high risk and low resilience where mitigation measures could be undertaken to reduce consequences from future events. Although outdoor casualties were not explicitly modelled, there still exists a high risk of debris falling from URM buildings in pedestrian precincts as happened in the recent Woods Point Earthquake (2021) (Vaculik *et al.*, 2021). The findings were found to be consistent with the Tasmanian State Natural Disaster Risk Assessment which identified earthquake hazard as a low likelihood high consequence hazard.

The project outcomes have highlighted the value of nuancing damage related risk by local scale coping and recovery capacity. The financial risk ranged by a factor greater than four from the lowest risk community of Midway Point to the one with the highest in Tasmania, Smithton. However, the ranking between was found to change within this range when resilience as quantitated by ADRI was incorporated. In prioritising risk reduction and resilience building initiatives across the state, the revised ranking could be a valuable reference. The outcomes were shared with local stakeholders at workshops convened in Hobart and Launceston along with resources for addressing high risk masonry buildings. The Tasmanian government indicated that preventing falling masonry in high pedestrian exposure precincts would be a focus for targeted retrofit into the future, rather than more general damage avoidance.

7 Acknowledgements

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