Australian Earthquake Engineering Society
2022 National Conference, 24-25 November 2022
Mount Macedon, Victoria, Australia

Tailored Earthquake Risk Mitigation Information for Decision Makers

Mark Edwards[1], Martin Wehner[1], Jerry Vaculik[2] and Michael Griffith[2]

1. Geoscience Australia, 101 Jerrabomberra Ave, Symonston ACT 2609

2. University of Adelaide, North Terrace, Adelaide, SA 5005

Abstract

In Australia there is a lack of retrospective building regulation to address earthquake prone buildings within communities. The commitment of funds to retrofit high risk buildings either by property owners or by government requires decisions to commit constrained resources for this purpose. Engineers are able to communicate the physical solutions to address these buildings but may be less able to articulate the risk reduction proposition to property owners who may reside or operate a business in the building. Further, emergency managers and government policy makers may not understand the broader issues and benefits of targeted intervention.

This paper focusses on unreinforced masonry and describes a program of work that has translated earthquake hazard and engineering vulnerability into a range of communication products. Learnings from the application of masonry mitigation research in two case study communities are presented along with their translation into a range of communication products tailored to a range of decision makers and users. The range of benefits considered are broader than damage avoidance, extending to emergency management logistics, economic activity and avoiding losing heritage value in communities. It also describes forward initiatives to integrate earthquake retrofit into broader resilience building interventions that address other natural hazard deficiencies.

Keywords: earthquake, risk, masonry, mitigation, retrofit, decisions, benefits

1 Introduction

While earthquake hazard in Australia is low compared to some neighbouring countries such as New Zealand and Indonesia, the nature of our seismicity can result in large earthquakes. When these occur close to communities, the consequences can be very significant, as borne out by historical events. This is particularly the case where older unreinforced masonry (URM) buildings are exposed as this building type is arguably the most vulnerable in the Australian built environment. They may also be considered to be valuable by communities and jurisdictions as they form part of the Australian heritage.

The vulnerability of URM can be significantly reduced through targeted retrofit and over the past five years two collaborative projects in Western Australia have extended and applied research undertaken under the recent Bushfire and Natural Hazards CRC to better understand the effectiveness of these measures across a broad range of impact metrics. The research has resulted in a body of work that can inform decision makers in making investment in earthquake risk reduction and that can assist building professionals in implementing it.

In this paper the benefits of retrofit to a range of stakeholders is discussed. The outcomes of case studies in York and Melbourne are explored and how these have translated across to a consideration of the heritage value and the taking of a broader resilience-based approach. Finally, a suite of tailored communication products is described that are aimed at informing a range of stakeholders in either investing in mitigation, or in providing funding to make these initiatives more affordable through grant schemes.

2 Benefits of Retrofit

The benefits of retrofit can be measured by the avoided consequences that are achieved through the retrofit measures undertaken. These benefits are broad and are realised by a range of stakeholders. For a residential homeowner these can include:

- Avoided building damage loss.
- Avoided damage to contents achieved by reduced building damage.
- Avoided temporary accommodation costs that would otherwise result from having a home unfit for habitation for a period.

These reduced costs are typically realised by an insurer where the homeowner has effectively transferred the earthquake risk to them through the purchase of home and contents insurance, with earthquake being a standard cover in Australia. However, the temporary accommodation cover by insurers may be time limited and exceeded in major events, thereby representing an added cost to homeowners.

Other avoided homeowner losses through retrofit are broader than the direct financial losses. These can include:

- Reduced clean-up costs for the property itself.
- The intangible value, that can be measured by a “willingness to pay”, for not having one’s household disrupted through damage, including temporary relocation.
- If the home is an investment property or is used for a home business, other avoided losses through retrofit can include:
  - Reduced loss of rental or lease income.
  - Reduction of business turnover losses through reduced disruption time.
  - Avoided temporary relocation and accommodation costs to resume business activity in temporary premises.

More broadly, benefits of reduced residential impacts are realised by government and other agencies:

- Reduced emergency management response costs.
- Reduced community clean-up costs.
- Reduced community recovery costs associated with measures undertaken by local government and key government agencies.
- Reduced medical care costs for the injured.
- Reduced long term mental health costs of those traumatised by the damage caused by an intense earthquake.
- Avoided lost contributions to society that otherwise deceased individuals would have made as measured by the Value of Statistical Life.
- Reduced staffing challenges for key agencies where staff are not available due to the need to provide primary care to family.

The above retrofit benefits are not comprehensive and are not all realised by a single stakeholder. However, they do highlight the broader benefits of resilience building retrofit and may be used to justify the funding of incentive schemes to cost share retrofit initiatives.

3 York Mitigation Case Study

The recently completed study of earthquake retrofit of vulnerable buildings in York, WA, illustrated the broader realisation of community and government benefits (Wehner et al., 2020). These benefits were explored through the consideration of the change in consequences predicted for each of three scenario earthquake events that were relocations of historical WA events. The scenario events are described in Table 1.

Table 1 Scenario earthquake events adopted for York study utilising historical events that were relocated as to epicentral distance to York to match target bedrock hazard likelihoods.

Scenario Event	Average Recurrence Interval [years]	Historical Event Relocated	Magnitude(M_W)	Depth [km]	New Epicentre (Long., Lat.)	Distance From York [km]	Target PGA in York [g]
1	500	Calingiri *(10th March 1970)*	5.0	15	*116.650, -31.755*	18.8	0.059
2	1,000	Lake Muir *(16th Sept 2018)*	5.3	2	*116.934, -31.820*	17.5	0.102
3	2,500	Meckering *(14th Oct 1968)*	6.6	10	*117.057, -31.906*	27.4	0.199

Based on the scenario events, the losses realised after 30 years of URM retrofit that would retrofit a total of 90 buildings were assessed over a range of metrics. These are summarised in *Table 2* and show typically a 23 to 24% reduction across the range of ground shaking severities and realised by a range of stakeholders. Significantly, no single stakeholder realises all the benefits considered.

Table 2 Scenario damage losses expected for York for each of the three scenario earthquakes. The forecast reduced losses at the end point of a high uptake rate retrofit scheme are also presented.

Scenario Loss Measure	Earthquake Scenario Event Losses [$m]					
	Scenario Event 1 500 year ARI		Scenario Event 1 1,000 year ARI		Scenario Event 1 2,500 year ARI	
	Un-retrofitted	30 years retrofitting	Un-retrofitted	30 years retrofitting	Un-retrofitted	30 years retrofitting
Building Damage	7.69	6.20	15.25	12.61	43.95	36.09
Contents Loss	3.75	2.70	7.57	5.67	21.48	16.28
Proprietor Income Loss	0.15	0.04	0.49	0.13	1.76	0.73
Wage Loss	0.26	0.09	0.84	0.27	3.44	1.59

Rental Income Loss	0.03	0.02	0.1	0.09	0.71	0.67
Lease Income Loss	0.10	0.03	0.35	0.10	1.38	0.65
Total	11.98	9.08	24.6	18.87	72.7	56.0
% age reduction	24		23		23	

Damage-related losses were found to increase more rapidly than ground shaking severity as rarer earthquakes are considered. The work also illustrated that the benefits realised locally were significant and a similar proportion for all earthquakes. Assessment of changes in health care costs and the value of human life showed broader benefits to jurisdictions. The research also showed that earthquake retrofit in York, a region of higher Australian seismic hazard, is not justified on economic grounds and that insurance premium discounts, if made available, would be modest.

4 Melbourne Case Study

As a related research project, a parallel case study to the York work was a case study undertaken on the greater Melbourne central business district (Melbourne, Docklands and Southbank). This research is presented separately (Ryu et al., 2021) but has key messages for emergency management. The study region had 1,543 buildings of which 687 were unreinforced masonry (45%) and 470 were estimated to be heritage listed. In the study 25% were virtually retrofitted over a 30-year period and the consequences of a major earthquake simulated before and after the retrofit program was undertaken. Initially the URM buildings were randomly selected and then, for comparison, those in high pedestrian exposure precincts were chosen as a priority. While the economic loss reductions were very similar for both approaches, the change in human casualties was very different. Randomly selected retrofit reduced the expected deaths by almost 100 people, or 18% of the retrofitted total. However, the targeting of buildings in high exposure precincts almost doubled this to 34%. Urban search and rescue (USAR) logistics, though not modelled, would correspondingly reduce as a consequence of reduced damage and reduced human exposure to falling masonry.

Firstly, it was noted that almost all the serious injuries and deaths were in the street, as result of falling masonry. This could highlight a priority need to at least tie back masonry elements. Secondly, the outcomes are supportive of the New Zealand strategy of prioritising the retrofit of high risk buildings where the consequences to human life in high pedestrian precincts are high.

5 Community Value of Heritage Building

One further measure of benefit is the avoided potential loss of buildings of heritage value to a community due to irreparable damage. While this lost value is generally considered intangible, recent research (Rogers et al., 2021) undertaken by the University of Western Australia (UWA) has assigned an indicative community value to these older buildings through a measure of household “willingness to pay” to avoid lost heritage and a loss of the “sense of place” they provide. The new semi-intangible value that can be placed on avoided heritage loss has been found to be as significant as other “market” related avoided losses. As reported, in the York study three scenario earthquakes were modelled and the two rarer events did cause heritage building damage that was categorised as extensive or complete (irreparable). The UWA research assessed that overall 85% of households in the community are willing to pay $195 to avoid the loss of a heritage building through damage that would typically lead to demolition rather than repair. York Shire has approximately 2,000 households and 85% could be assumed to be willing to pay. This would translate to 1,700 households. If the number of additional willing households outside of the Shire (including Perth) was approximately five times this, the total value placed on an avoided heritage building loss would become $1.99m per building. This additional avoided loss for a retrofit of York is summarised in Table 3 which includes an aggregation of values previously presented in Table 2.

Table 3 Scenario heritage damage and losses for the three York study scenarios corresponded with the current building stock and a high retrofit uptake rate. Included are heritage values.

Scenario Loss Measure	Earthquake Scenario Event Losses [$m]					
	Scenario Event 1 500 year ARI		Scenario Event 1 1,000 year ARI		Scenario Event 1 2,500 year ARI	
	Un-retrofitted	30 years retrofitting	Un-retrofitted	30 years retrofitting	Un-retrofitted	30 years retrofitting
Extremely Damaged	0	0	1	0	10	6
Completely Damaged	0	0	0	0	3	2
Total Market Losses	12	9.1	24.6	18.9	72.7	56.0
Heritage Loss	0	0	1.99	0	25.9	15.9
% age reduction	24		29		27	

Community heritage value of older URM buildings was found to be a significant factor in measuring the benefit of pre-emptive conservation focussed retrofit.

6 Severe Tropical Cyclone Seroja and Resilience Focussed Retrofit

TC Seroja passed over south-west WA in April 2021 and caused significant wind-induced damage to buildings of both modern and older vintage. Despite the damage caused, the wind speeds of the cyclone were estimated to have been below the modern design wind speeds stipulated in the National Construction Code. A detailed description of the cyclone and its effects can be found in the Cyclone Testing Station Technical Report No. 66 (Boughton et al., 2021).

Damage was observed to many older unreinforced masonry buildings throughout the affected region. The damage observed in this class of building typically affected the roofs of the buildings although occasionally extended to other parts of the buildings. The extent and type of damage varied by individual buildings, but failures were observed to every part of the roof structure and cladding. Examples of wind related damage caused by the cyclone are presented in Figure 1.

Figure 1 Wind damage caused by Severe Tropical Cyclone Seroja which passed over south-west WA in April 2021 (courtesy DPLH)

Earthquake retrofit does improve building resilience to severe wind. However, the outcomes of TC Seroja illustrated that URM buildings have other deficiencies that could be addressed as part of a multi-hazard retrofit intervention.

7 Tailored Communication Products for Decision Makers

The commitment of funds to retrofit high risk buildings either by property owners or by government requires decisions to allocate constrained resources for this purpose. In supporting these, engineers are able to communicate the physical solutions to address these buildings but may be less able to articulate the risk reduction proposition to property owners who may reside in or operate a business from the building. Further, emergency managers and government policy makers may not understand the broader issues and benefits of targeted intervention. The collective research described has been translated into a series of information products to enable a range of stakeholders to make decisions regarding retrofit investment and the provision of incentives to motivate this behaviour. While there are several valuable resources on the physical retrofit of older URM, these new resources are targeted to decision makers who have a partitioned vestment of interests in community assets, the design professionals that will develop solutions with their clients, and the construction industry which will implement it. Each is described below and pictured in Figure 2.

Resisting the shake – Resources for owners of older masonry buildings

This resource document has been prepared to assist individual property owners to make personal investment decisions regarding earthquake retrofit of their buildings. It is written for members of the public who may have no technical nor science background. The seismicity in Australia is generally not well-understood and the potential for earthquake damage not fully appreciated. For this reason, both are explained along with the implications for highly vulnerability older URM. It highlights the consequences that can be avoided in the context of a residence or business premise that are much broader than avoided losses related to damage. The focus on the broader benefits is significant, as avoided direct damage costs would not justify such a retrofit investment alone, nor would the owner necessarily see insurance premium reductions. Finally, it describes the types of retrofit measures, how to seek professional services and where state government grants could be sought to cost-share the project.

Earthquake retrofitting for resilient communities – Lessons for government and emergency management

This resource document has been prepared for local government, state government policy and emergency management officers. It aims to give staff in these organisations information to assist with the formulation and provision of strategies to promote earthquake retrofit of high risk masonry buildings within local government areas and the jurisdiction. It is written for those with a non-technical nor science background but has greater detail than the public document. The seismicity in Australia is generally not understood and the potential for earthquake damage not fully appreciated. For this reason both are explained along with the implications for highly vulnerability older URM. It describes the key findings of the research undertaken with a focus on York in terms of understanding vulnerability of various older masonry building types, methods for reducing this vulnerability for retrofit and the effectiveness of these when applied. In particular, quantified benefits that can be realised by a range of stakeholders are presented. The reduction in economic losses and emergency management logistics is described using three scenario events in York and a scenario event centred on Melbourne. In particular, it highlights the broader benefits to government achieved through retrofit. Finally the implementation of a multi-hazard approach to retrofitting older URM as a resilience lifting approach is illustrated with the conservation works undertaken on the York Residency Museum.

Earthquake retrofit for older masonry buildings – Resources for design and construction

This resource document has been prepared for the building design profession and the construction industry working on URM. It aims to assist heritage architects and structural engineers to discuss retrofit option with clients and to highlight the benefits of undertaking this work. It is anticipated that most clients will have limited appreciation for the seismicity in Australia and the potential for earthquake damage. For this reason, both are explained along with the implications for highly vulnerable URM. It is written for those with a specialist background and provides considerable information in the form of generic retrofit details for key vulnerabilities. Significantly, it also provides guidance to structural engineers on how to assess current building resilience to earthquakes and the effectiveness of retrofit measures. Finally, it promotes a multi-hazard approach to retrofit interventions, thereby lifting the entire building’s resilience. The York Residency Museum conservation project is described as an exemplar of this approach.

Figure 2 Earthquake retrofit communication products for (a) property owners, (b) government and emergency management, and for (c) design professionals and building industry.

Prompted by the damaging outcomes of TC Seroja, stakeholders in WA requested an equivalent product for design professionals and the construction industry for wind retrofit of URM. In response, a fourth information product was developed that makes reference to the earthquake retrofit measures and identified additional measures required to address other severe wind deficiencies in this building type. The product is described below and pictured in Figure 3.

Wind retrofit for older masonry buildings – Resources for design and construction

This resource document is focused on severe wind and has been prepared for the building design profession and the construction industry working on URM. It aims to assist heritage architects and structural engineers to discuss retrofit option with clients and to highlight the benefits of undertaking this work. It provides an overview of severe wind hazard in Western Australia and describes the typical damage older URM buildings sustain due to severe storm. It is written for those with a specialist background and provides considerable information in the form of generic retrofit details for key vulnerabilities. Importantly, it cross references the parallel industry guidance document “Earthquake retrofit for older masonry buildings – Resources for design and construction” and the earthquake focussed retrofits that are beneficial in increasing severe wind resilience. The learnings from Tropical Cyclone Seroja are highlighted and the York Residency Museum conservation project is described as an exemplar of this approach.

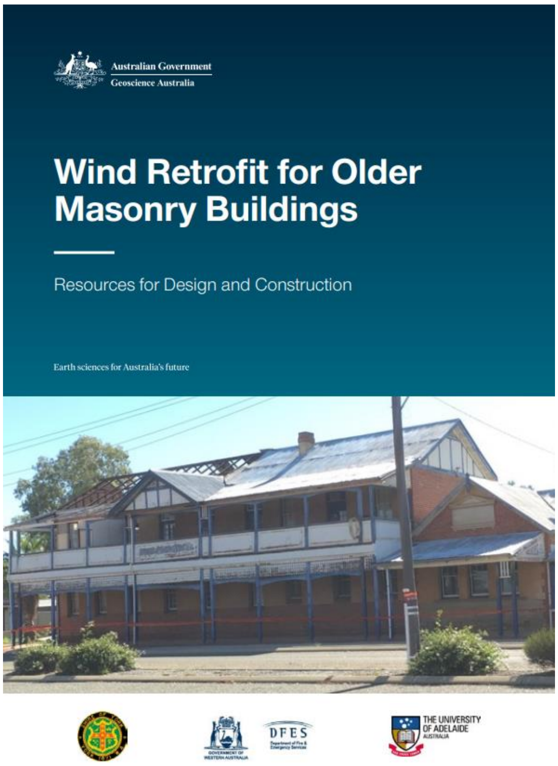

Figure 3 Severe wind retrofit communication product for design professionals and building industry.

8 Summary and Discussion

The risk posed by URM to Australian communities is significant. The commitment of funds to retrofit high risk buildings, either by property owners or by government, requires decisions to commit constrained resources for this purpose. Benefits realised by retrofit investment and other contributions may vary depending upon the stakeholder. Recent research has developed a body of information that enables the respective cost-effectiveness of risk reduction measures, along with the reduction of post event logistics, to be viewed through a range of lenses. This paper has described how this work has been brought together into a range of tailored communication products that can inform decision making. It further has advanced broader resilience-based approaches to retrofit whereby deficiencies to more than a single hazard are addressed as part of a single intervention. The objective is to motivate and inform action to progressively lift the resilience of Australian communities.

9 References

Boughton, G.N., Falck, D., Parackal, K., Henderson, D., and Bodhinayake, G., (2021). Tropical Cyclone Seroja – Damage to buildings in the mid-west coastal region of WA, 2021. James Cook University, Cyclone Testing Station. Technical Report No. 66. https://www.jcu.edu.au/cyclone-testing-station/education/publications

Rogers, A.A., Rollins, C., Florec, V. 2021. Willingness to pay to avoid the non-market impacts of earthquakes in York, Western Australia. Bushfire and Natural Hazards CRC

Ryu, H., Wehner, M., Vaculik, J., Juskevics, J., Edwards, M., Griffith, M., Mohanty, I., Butt, S., Corby, N, Allen, T., and Hewison, R., (2021). Cost-Effective Mitigation Strategy

Development for Building Related Earthquake Risk: Melbourne Case Study, Bushfire and Natural Hazards CRC, Melbourne, Australia

Wehner, M., Ryu, H., Griffith, M., Edwards, M., Corby, N., Mohanty, I., Vaculik, J., and Allen, T., (2020). Earthquake Mitigation of WA Regional Towns: York Case Study Final Report, Bushfire and Natural Hazards CRC, Melbourne, Australia

This paper is published with the permission of the CEO, Geoscience Australia Ecat: 147428