Earthquake Management Logistics for York, WA, Pre and Post Mitigation

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Abstract

Rare Australian earthquake events can cause extensive damage and present significant logistical challenges for emergency management agencies and local governments. Evidence of this can be seen from recent earthquake events that include the 2010 Kalgoorlie earthquake and the 1989 Newcastle earthquake of 30 years ago. Emergency managers do not experience damaging earthquakes on the same regular basis as storms, floods, and bushfires and therefore don't always fully understand the consequences they may face. Scenario modelling can provide insights to inform response and recovery by emergency management and recovery agencies as well as demonstrate how these impacts can be moderated by the retrofit of the most vulnerable building types.

The Shire of York is partnering with the WA Department of Fire and Emergency Services (DFES), the University of Adelaide and Geoscience Australia in a collaborative project that explores the current earthquake risk in the heritage town of York, Western Australia, and how the risk could be moderated through targeted retrofit. The project forms part of the Bushfire and Natural Hazards Cooperative Research Centre project "Cost-effective Mitigation Strategy Development for Building Related Earthquake Risk". This paper describes the approach taken and the predicted consequences modelled for a range of credible earthquake scenarios. Significantly, based on the recommendations from a stakeholder workshop in York on the 9th August 2018, it is also assessing how these consequences would be moderated in future decades through two rates of retrofit uptake in the town. This work is informing emergency management planning by DFES and the Shire of York. It is also illustrating the benefits of targeted community level retrofit to address the risk posed by the community building types most vulnerable to earthquakes.

1. INTRODUCTION

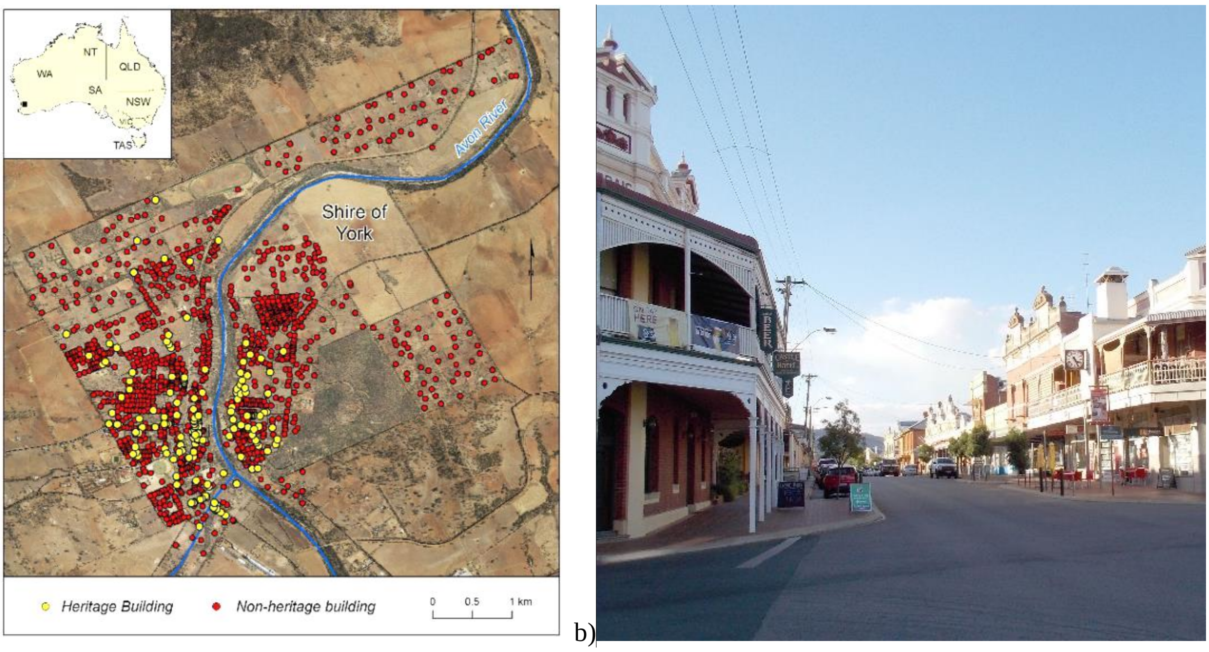
Earthquake hazard was only fully recognised for Australian building design in the early 1990s following the Newcastle Earthquake of 1989. This has resulted in a significant legacy of buildings that are inherently more vulnerable to this hazard. Consequently, many Australian buildings are quite vulnerable to low-to-moderate earthquake ground shaking. Knowledge of the most effective retrofit measures for older masonry buildings will enable and promote the strengthening of buildings resulting in more resilient communities. Key measures of the effectiveness of retrofit are estimations of how these strategies, if implemented, moderate the consequences both in damage loss and in other emergency management logistics if used.

Under a project undertaken as part of the Bushfire and Natural Hazards Cooperative Research Centre (BNHCRC), a case study has been undertaken in the Western Australian town of York located in the Wheatbelt inland from Perth. In an Australian context, York is located in an area of elevated seismic hazard relative to the rest of the continent and experienced significant damage from the 1968 Meckering earthquake. It is Western Australia's oldest inland town and has a significant number of one and two storey unreinforced masonry (URM) buildings dating from before the First World War. Much of this building stock is heritage listed, plays a significant role in the town's economy and is of great interest to both the local Shire and the Heritage Council of WA.

In this BNHCRC project, the mitigation measures developed for six building types have been virtually applied to the town at two rates of implementation. The corresponding changes to the risk of damage and the emergency management logistics have then been compared to the baseline risk of the present town at 10, 20 and 30 years into the future. This paper presents the findings and the effectiveness of community level retrofit is discussed.

2. YORK BUILDING STOCK AND CATEGORISATION

Figure 1a shows an aerial view of buildings in York and indicates that there are a large number of heritage-listed buildings distributed across the community. However, there is a concentration of the buildings along the main street of Avon Terrace as shown in Figure 1b. To understand the number, type and distribution of buildings in York, an exposure survey was conducted (Corby *et al.*, 2018). From that survey a selection of six generic URM building types was made (Vaculik *et al.*, 2018). The building stock characterisation, the assessment of retrofit strategies for each to reduce vulnerability, and the vulnerability of these retrofitted and unretrofitted are described in a companion paper (Edwards *et al.*, 2019a). Some building statistics are set out in Table 1. Note that the majority of heritage-listed buildings are old URM buildings, while the other buildings consist of a mix of timber framed buildings, steel framed light industrial buildings, old URM buildings and modern URM buildings.



a) b)

Figure 1 (a) Map of buildings in York with heritage-listed structures indicated; (b) View of the main business street, Avon Terrace, York.

Table 1 Number of buildings and total replacement cost for heritage-listed and other buildings in York.

	Heritage-listed Buildings	**Other Buildings**	**Total**
Number of Buildings	158	1259	1417
Total Replacement Cost (M AUD)	174	690	864

3. MITIGATION AND IMPLEMENTATION STRATEGIES

The mitigation strategies developed under the BNHCRC project are typically less than what is needed to achieve a building that is fully compliant with modern building codes. The measures, as described in Edwards *et al.* (2019a), are directed at the key vulnerabilities evidenced in damaging Australian earthquakes. The strategies include tying back chimneys, parapets and gables along with making positive connections between exterior walls to roof and suspended first floor diaphragms. The effectiveness of a range of these measures applied to a single storey URM building in reducing the likelihood of physical damage and associated repair cost is presented Figure 2a and 2b respectively.

The rate of uptake of retrofit has a clear bearing on the overall progressive change to the vulnerability and risk of a community like York. The modelled rate needs to realistically reflect the ability of both State and local government to incentivise this behaviour and the willingness of building owners to invest in this way. Insurance can have a role by recognising risk reduction achieved through these measures and reflecting this in premiums. At a workshop convened in York on the 9th August 2018 practical limits to uptake rates were discussed and two uptake rates, or retrofit schemes, were selected for study. Retrofit Scheme I involved an uptake rate that was a modest single heritage building per year in the town and a single non-heritage building every second year. Retrofit Scheme II considered an uptake rate double that for Retrofit Scheme I. The higher uptake rate was considered to be a realistic outcome that could be expected with strong incentivisation. These rates were assumed uniform and are summarised in Table 2.

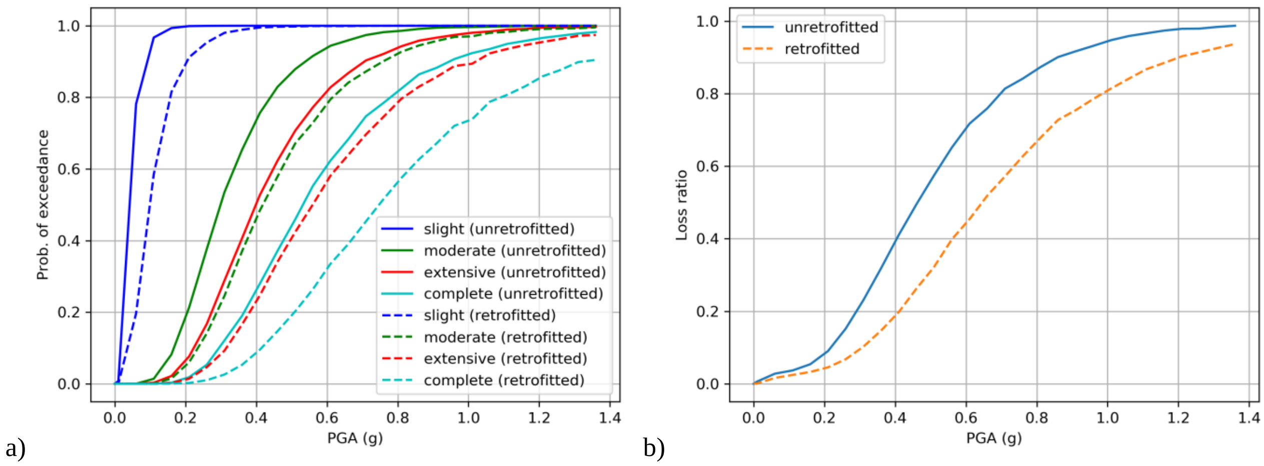


Figure 2 Comparison of curves before and after retrofit for a single storey URM residential building: a) fragility curves; b) vulnerability curves. The vertical shift in the curves downwards corresponds with the reduction in physical damage likelihood and the associated reduction in repair cost through retrofit.

Table 2 Two retrofit schemes considered for York in this research.

Retrofit Regime	Building Category	Aggregated Number of Buildings to Be Retrofitted		
		Over 10 years	Over 20 years	Over 30 years
Retrofit Scheme I	Heritage-listed	10	20	30
	Other	5	10	15
Retrofit Scheme II	Heritage-listed	20	40	60
	Other	10	20	30

4. EARTHQUAKE HAZARD AND SCENARIO EVENTS

Recently, a new national scale assessment of the earthquake hazard for AS1170.4:2018 Soil Class B_e has been completed by Geoscience Australia (Allen *et. al.*, 2018). The probabilistic seismic hazard assessment (PSHA) included many refinements to the earlier assessment by Leonard *et al.* (2013) and entailed broad expert elicitation (Griffin *et al*, 2018). It is considered by the authors to represent the best current understanding of probabilistic earthquake hazard for Australia and has been used in this research. It is referred to as NSHA18 and the hazard level it estimates for York is lower than that specified in the earthquake loading standard for building design, AS1170.4 (Standards Australia 2018). Notwithstanding this, the estimated hazard is higher than for any major city in Australia including the national capital, Canberra. The seismic hazard for Soil Class B_e in York is compared to that for Canberra in Figure 3.

Based on the recommendations of the 9th August 2018 stakeholder workshop, three ground motion rarities were selected for the scenario events. The magnitude and depth of the scenario events corresponded with the historical events presented in the Table 3 as these earthquakes have credibility with the local community. The Meckering earthquake of October 1968 caused significant damage to York with one hotel subsequently demolished as a result of the earthquake damage it sustained. The epicentre of each scenario was adjusted such that the simulated mean ground motion at the city centre matched to the peak ground acceleration (PGA) value at the selected rarity from NSHA18. The ground motion fields were simulated using the OpenQuake-engine (Version 3.6; Pagani *et al.*, 2014). A single ground motion field for each of the scenario events was generated by taking a weighted average of the simulated mean ground motions through adopting the same logic tree of ground motion models used in NSHA18.

Table 3 Selected scenario events.

Scenario Event	Return Period (years)	Historical Events	Magnitude (M_w)	Depth (km)	Epicentre (Long, Lat)	Distance from York (km)	PGA (g)
1	500	Calingiri (10th March 1970)	5.03	15	116.650, -31.755	18.8	0.059
2	1,000	Lake Muir (16th Sep 2018)	5.30	2	116.934, -31.820	17.5	0.102
3	2,500	Meckering (14th Oct 1968)	6.58	10	117.057, -31.906	27.4	0.199

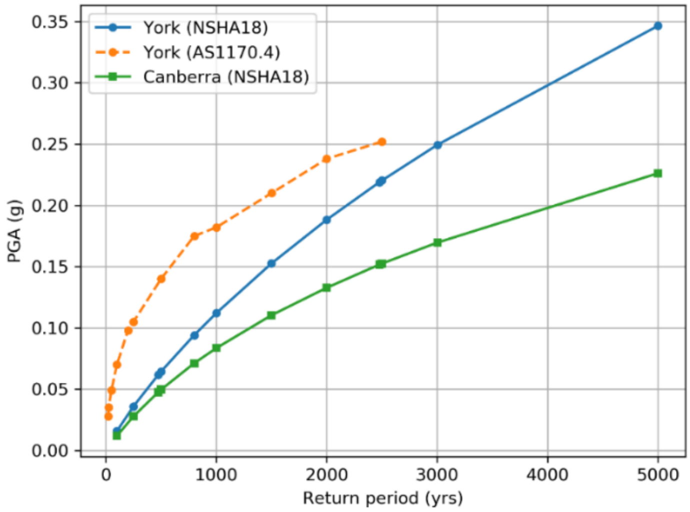


Figure 3 Peak ground accelerations (PGA) at bedrock for a series of return periods for York and Canberra from NSHA18 (Allen *et al.*, 2018) compared to the values for York specified in AS1170.4 (Standards Australia, 2018).

Surface soils can greatly influence the severity of ground shaking. Figure 4a shows the site soil classification across the study area by McPherson (2017) which is linked to the time-averaged shear-wave velocity in the upper 30 metres (V_{S30}). Figure 4a clearly shows the influence of the alluvial sediments deposited by the Avon River that runs through the middle of York. The concentration of heritage structures along Avon Terrace are located on softer soils, described as site class D in Figure 4a, that amplify ground shaking. The simulated bedrock hazard was found to be very uniform across York but greater variability resulted from the incorporation of the surface soil effects as shown in Figure 4b. These ground motions correspond with mean ground motion field at the surface for the Scenario Event 3 which has a 2500-year return period.

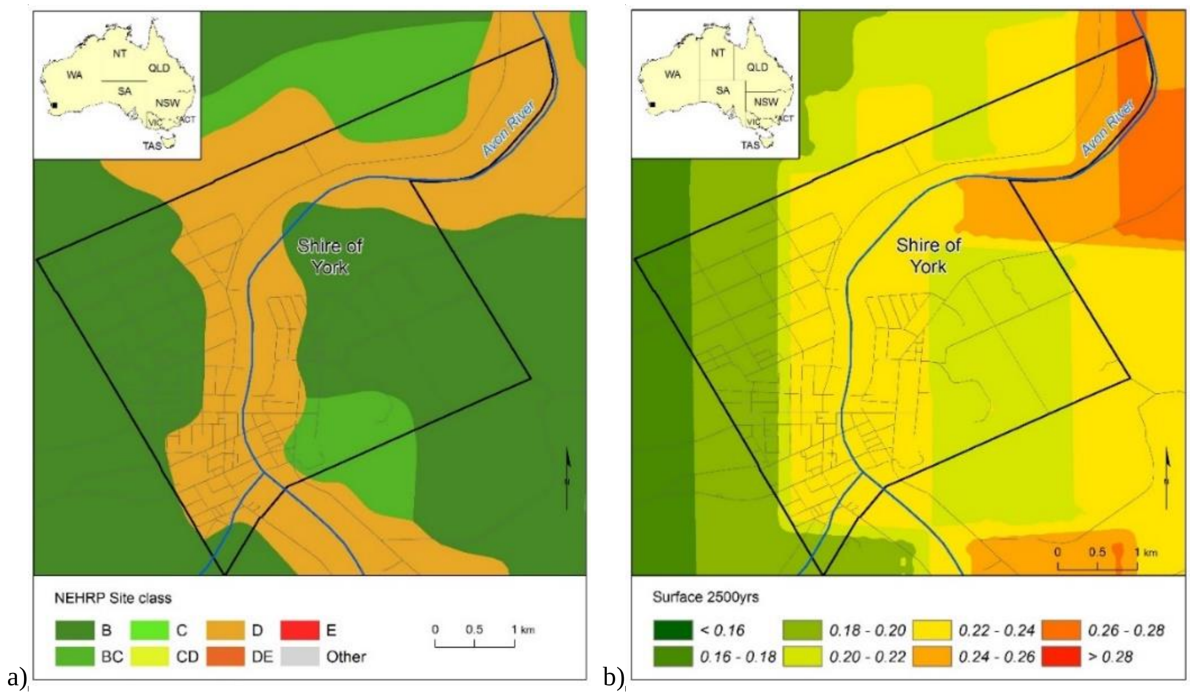


Figure 4 (a) Site soil classification across York and; (b) simulated ground motion field at the surface in terms of PGA for Scenario Event 3.

5. EARTHQUAKE SCENARIO IMPACTS AND RISK

The impacts on the town of York from the selected scenario events were estimated for three metrics: 1) monetary loss from necessary repair of physical damage (expressed as a loss ratio); 2) number of damaged buildings; and 3) number of casualties. The loss ratio was calculated as the ratio of total repair cost to the total replacement cost of the buildings. Due to the limitation of space, only the results of the Scenario Event 3 are presented here. Results for other scenarios can be found in the project report (Wehner *et al.*, 2019).

Table 4 sets out the estimated loss ratios for the scenarios and how these would be moderated over 30 years with the two Retrofit Schemes. The reduction in loss ratio is larger for heritage-listed buildings than the overall population of community buildings due to the larger proportion of buildings retrofitted and the typically greater vulnerability of these older URM buildings. For Event 3 the heritage building stock is predicted to have a 35% reduction in damage repair cost after 30 years under Retrofit Scheme II. Table 5 sets out the estimated number of damaged buildings from scenario Event 3. The reduction in damage repair is less evident in the number of buildings in each damage class. Table 6 summarises casualty estimates for the four injury severity levels considered, which are defined in the HAZUS methodology (NIBS 2003) where the injury severity level 4 corresponds to fatality. The population used in the casualty modelling reflects the comparatively low day-to-day population and not the situation when the town is crowded when hosting large events.

Table 4 Estimated loss ratios (%) for the Scenario Event 3.

Building Group	**Unretrofitted**	**Retrofit Scheme I**			**Retrofit Scheme II**		
		10 years later	**20 years later**	**30 years later**	**10 years later**	**20 years later**	**30 years later**
All	5.09	4.91	4.65	4.44	4.86	4.44	4.18
Heritage-listed	9.61	8.93	7.80	6.81	8.77	7.43	6.20

Table 5 Estimated number of damaged buildings for the Scenario Event 3: a) all buildings, b) heritage-listed buildings.

a)

Damage State	**Unretrofitted**	**Retrofit Scheme I**			**Retrofit Scheme II**		
		10 years later	**20 years later**	**30 years later**	**10 years later**	**20 years later**	**30 years later**
Slight	776	777	778	779	778	782	785
Moderate	153	151	149	148	150	145	142
Extensive	20	19	18	17	18	17	15
Complete	6	6	6	6	6	5	5
Total	*955*	*953*	*951*	*950*	*952*	*949*	*947*

b)

Damage State	**Unretrofitted**	**Retrofit Scheme I**			**Retrofit Scheme II**		
		10 years later	**20 years later**	**30 years later**	**10 years later**	**20 years later**	**30 years later**
Slight	104	105	106	107	106	108	111
Moderate	31	30	29	28	29	26	24
Extensive	10	9	8	7	8	8	6
Complete	3	3	3	2	3	2	2
Total	*148*	*147*	*146*	*144*	*146*	*144*	*143*

Table 6 Estimated casualties for the Scenario Event 3.

Injury Severity Level	Unretrofitted	Retrofit Scheme I			Retrofit Scheme II		
		10 years later	20 years later	30 years later	10 years later	20 years later	30 years later
1	4	4	4	4	4	4	3
2	2	2	2	2	2	2	1
3	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0

Average annualised loss (AAL) was also calculated to estimate potential risk reductions for the two retrofit uptake rates with the results presented in Table 7. The AAL for all the buildings in York was estimated to be 0.022% which is more than double the value 0.0098% recently assessed for the Perth metropolitan area based on NSHA18 (Edwards *et al.*, 2019b). For the heritage building subset the AAL was estimated to be more than four times greater than for the Perth metropolitan area. As with the scenario results, risk reduction by retrofit was clearly observed for the heritage-listed buildings, which had the greater rate of retrofit. By 30 years for Retrofit Scheme II the long term loss associated with earthquake hazard was modelled to be reduced by more than 30%.

Table 7 AAL (%) for all buildings and heritage-listed buildings.

Building Group	Unretrofitted	Retrofit Scheme I			Retrofit Scheme II		
		10 years later	20 years later	30 years later	10 years later	20 years later	30 years later
All	0.0222	0.0216	0.0206	0.0198	0.0212	0.0196	0.0185
Heritage-listed	0.0422	0.0403	0.0368	0.0332	0.0390	0.0343	0.0292

The loss exceedance curve was developed through an event-based probabilistic calculation, using the NSHA18 input seismic source and ground motion models, to assess the likelihood of the scenario losses. The scenarios in Table 3 were selected to match a likelihood of ground shaking intensity at a single site, which is the centre of York sitting on Soil Class B_e. By plotting the scenario losses on the loss exceedance curve as presented in Figure 5, the rarity of the losses can be estimated. Through this analysis, the likelihoods of losses derived from the scenarios were found to be significantly greater than the likelihoods of a single scenario event. For instance, the probabilistic return period for losses equivalent to those incurred from Scenario Event 3 was estimated to be approximately half of the scenario-based approach. This is due, in part, to the incorporation of aleatory ground motion uncertainty in the event-based probabilistic calculation, whereas the scenario-based approach did not include this uncertainty. It is also influenced by the spatial distribution of surface soils and building stock across York. Figure 6 shows loss exceedance curves for the two groups of buildings considered. The change of the curve by the retrofit is more evident for the heritage-listed building subset.

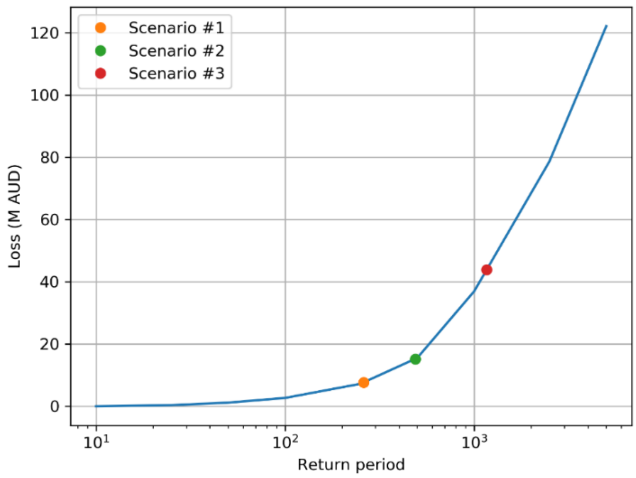
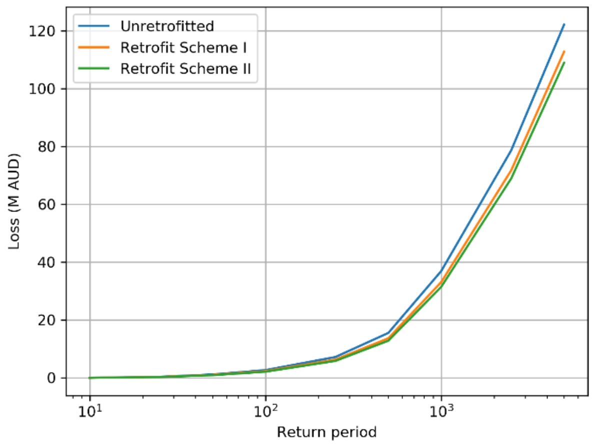
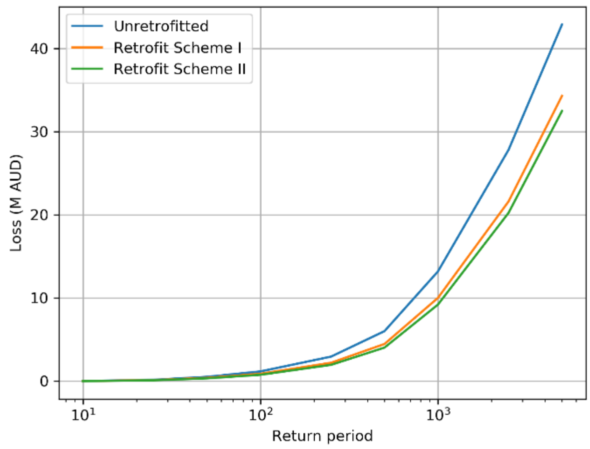


Figure 5 Loss exceedance curve with aggregate loss from the scenario events plotted.



a)



b)

Figure 6 Loss exceedance curves for the two retrofit schemes compared with the current state: a) all buildings; b) heritage-listed buildings.

6. DISCUSSION

The town of York is located in a region of elevated earthquake hazard and adjacent to the region of the Yilgarn that has the highest hazard in Australia. While the understanding of the level of earthquake hazard has improved and been moderated with the release of NSHA18, the financial risk posed by earthquake hazard is still significant for York. It is more than double the overall Perth Metro risk and for heritage buildings it is four times greater.

The risk translates into logistics for emergency management, the Shire and other government agencies with a role in community recovery after disasters. Retrofit programs targeted at the most vulnerable community buildings have a significant impact on this risk which is expressed in this research as avoided damage. Experience from some New Zealand cities has shown that such programs are a journey over decades to effect changes, given the number of existing buildings requiring strengthening. These programs are particularly important for structures that will persist in communities due to their heritage value. A significant proportion of buildings in York are heritage listed old URM buildings.

As shown by this research, progress can be made both in avoided damage and moderation of emergency management logistics with campaigns targeted on highly vulnerable concentrations of high value heritage structures in pedestrian precincts. There are challenges with taking this forward due to private ownership of buildings and the inability of insurance to significantly offset the investment cost.

7. SUMMARY

York has a legacy of heritage URM structures that are of great value to the community and the State. The Shire economy is supported by the tourism that the heritage precinct of the town attracts. To preserve these buildings and to moderate emergency management logistics, mitigation through retrofit is needed. This journey of mitigation takes time, but significant progress can be made where efforts are focussed on high-risk buildings in high human exposure pedestrian precincts.

The building types in York are typical of those found in other Australian towns and cities, particularly regional communities. Future work in assessing earthquake risk and mitigation options is expected to benefit such communities. Recently a new project commenced that will study the actual implementation of retrofit. The project, through a three-year local and state government initiative funded through the Australian Government Natural Disaster Resilience Program, will develop information on earthquake retrofit to inform mitigation in other WA communities and nationally.

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REFERENCES

Allen, T. I., Griffin, J., Leonard, M., Clark, D. and Ghasemi, H. (2018) The 2018 National Seismic Hazard Assessment for Australia: model overview. Record 2018/27. Geoscience Australia, Canberra. http://dx.doi.org/10.11636/Record.2018.027.

Corby, N., Edwards, M., Lavers, A., Mohanty, I., Nadimpalli, K., Ryu, H., Vaculik, J. and Wehner, M., (2018) Earthquake Mitigation of WA Regional Towns York Case Study: Community Exposure Capture June 2018 Progress Report. Report to the BNHCRC.

Edwards, M., Wehner, M., Ryu, H., Griffith, M., and Vaculik, J. (2019a) Modelling the vulnerability of old URM buildings and the benefit of retrofit. Australian Earthquake Engineering Society Conference, 2019 (in publication).

Edwards M., Rahman M., Wehner M., Ryu H., Allen T., Clark D., Silva V., Gray S., Corby, N.; Vassiliou M., MacCarthy S., and Bake R. (2019b) Earthquake Impact and Risk for Pert and Supporting Infrastructure Project : Final Report, GA Record (in publication).

Griffin, J., Gerstenberger, M., Allen, T., Clark, D., Cummins, P., Cuthbertson, R., Dimas, V.-A., Gibson, G., Ghasemi, H., Hoult, R., Lam, N., Leonard, M., Mote, T., Quigley, M., Somerville, P., Sinadinovski, C., Stirling, M., and Venkatesan, S. (2018) Expert elicitation of model parameters for the 2018 National Seismic Hazard Assessment: Summary of workshop, methodology and outcomes, Geoscience Australia Record 2018/28, Canberra, 74 pp, doi: 10.11636/Record.2018.028.

Leonard, M., D. Burbidge, and M. Edwards (2013) Atlas of seismic hazard maps of Australia: seismic hazard maps, hazard curves and hazard spectra, Geoscience Australia Record 2013/41, pp 39.

McPherson, A. A. (2017) A revised seismic site conditions map for Australia. Record 2017/12. Geoscience Australia, Canberra. http://dx.doi.org/10.11636/Record.2017.012

National Institute of Building Sciences (NIBS) (2003) HAZUS-MH Technical Manual, Federal Emergency Management Agency, Washington, D.C., USA.

Pagani, M., D. Monelli, G. Weatherill, L. Danciu, H. Crowley, V. Silva, P. Henshaw, R. Butler, M. Nastasi, L. Panzeri, M. Simionato, and D. Vigano (2014) OpenQuake Engine: An open hazard (and risk) software for the Global Earthquake Model, Seism. Res. Lett. 85, 692–702, doi: 10.1785/0220130087.

Standards Australia (2018) Structural design actions Part 4: Earthquake actions in Australia.

Vaculik, J., Griffith, M., Wehner, M. and Edwards, M (2018) Seismic assessment of unreinforced masonry buildings in a heritage-listed township. Australian Earthquake Engineering Society Conference, 2018.

Wehner, M., Ryu H., Griffiths M., Edwards M., Corby N., Mohanty I., Vaculik J. (2019) Earthquake Mitigation of WA Regional Towns: York Case Study: Final Report, BNHCRC report (in publication).