The Need For Age Dependant Vulnerability Models For Unreinforced Masonry Structures

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Abstract

Historically, unreinforced masonry (URM) structures have performed poorly in earthquakes, sustaining greater damage than other typical construction types.

Geoscience Australia's Risk Research Group (RRG) has developed a sophisticated computational tool for estimating structural damage caused by earthquakes, the Earthquake Risk Model (EQRM). Currently, the model presumes that older URM structures sustain identical levels of damage to new URM structures given the same structural response. Much of the research into previous earthquakes suggests otherwise, indicating that older URM structures sustain higher levels of damage.

The premise of this paper is to investigate the impact of altering damage threshold parameters for older URM structures, making them more vulnerable to ground shaking, and illustrating the importance of modelling them independently of their newer counterparts. Furthermore, it introduces some key areas of future research including validation of the EQRM model and further refining the modelling of URM structures. This type of refinement is of particular significance when modelling regions such as Perth where more than 87% of the building stock is URM.

Introduction

On the 28th December 1989 an earthquake registering 5.6 on the Richter scale claimed the lives of 13 people and caused approximately AUD $1.2 billion (2002 dollars) to the City of Newcastle (Dhu and Jones, 2002). This extensive damage can, in part, be attributed to the relatively high percentage of older and more vulnerable unreinforced masonry (URM) structures in populated areas of Newcastle.

Geoscience Australia's Earthquake Risk Model (EQRM) estimates losses from the Newcastle event quite accurately, only slightly overestimating the damage when compared with insurance data (Edwards *et al*, 2004). Nevertheless, the model does not accurately describe the spatial distribution of the loss. To a certain extent, this is thought to be due to EQRM modelling older masonry structures (defined in this study as built prior to 1960) in the same manner as newer masonry structures (built post 1960).

Historical events suggest that older URM structures are more vulnerable than newer URM structures under shaking conditions. It is therefore the purpose of this study is to adjust the fragility curves of the old URM structures within EQRM to illustrate the associated increase in damage (particularly in suburbs that have a high relative percentage of older URM structures), compare the results with available insurance data and emphasise the importance of having age-dependant fragility curves.

Unreinforced Masonry Structures

Unreinforced masonry buildings, particularly older ones, have historically performed poorly in earthquakes. The Newcastle earthquake of 1989 is a pertinent example of this and research by the University of Newcastle's Department of Civil Engineering and Surveying revealed that older URM structures experienced the greatest amounts of damage during this event (Page, 1992). The major causes being weak mortar joints, inadequate connection between the two leaves of double brick construction, poor masonry construction techniques and extensive renovations to properties in the area.

Lime mortar joints are common in this type of construction and prior to the earthquake it was known that they were in a state of deterioration (Page, 1992). As a result the joints were soft and eroded, providing little resistance to the shaking induced by the event. In addition, the workmanship and quality control process of older URM construction were worse than current practices. In some instances, wall ties were found to have been bent down and not engaged and in other cases the ties were non existent (Melchers, 1990). Even when ties were engaged it was found that many were poorly anchored and highly corroded, and provided little support for the walls against lateral loading (Page, 1992).

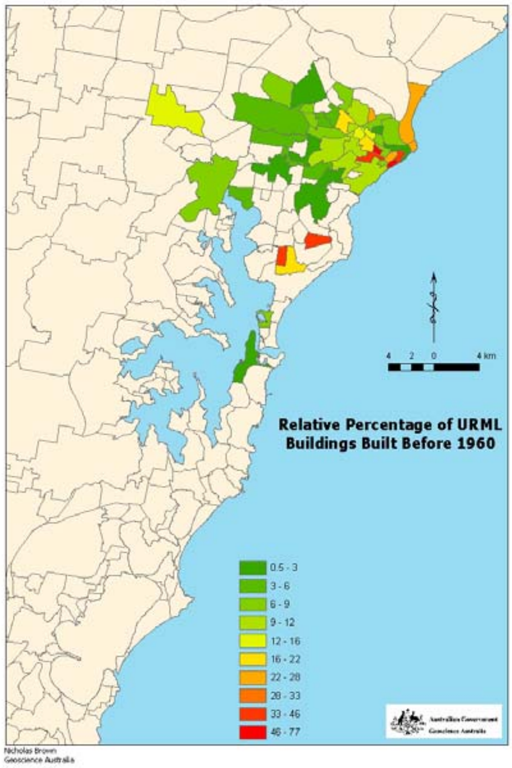
Another catalyst of damage, particularly in the Newcastle CBD, was the number of unsafe renovations to URM terrace houses. It appears to have been common practice to remove load bearing walls which inevitability decreased the resistance and increased the amount of damage suffered as a result of the earthquake (Melchers, 1990).

The Newcastle earthquake demonstrated that the collective impact of flaws in older URM construction can be devastating. Newer URM construction should have fewer flaws and hence perform better in an earthquake. However, newer URM structures performed poorly during the Newcastle earthquake when compared with other contemporary structure types. Consequently, it is essential that earthquake damage models are able to accurately model the performance of URM construction.

Findings from the Newcastle Report

The *Earthquake Risk in Newcastle and Lake Macquarie Report* of 2002 investigated the risks presented by earthquakes to the Newcastle and Lake Macquarie communities (Dhu and Jones, 2002). This report revealed that when compared with NRMA data, the EQRM predicted losses of a similar magnitude, with the major discrepancy being in the Newcastle CBD. It is the contention of this investigation that this discrepancy is partially due to the high relative percentage of older URM structures in the Newcastle CBD.

Following the 1989 Newcastle event, survey teams from Geoscience Australia travelled to Newcastle and collected data from 6339 structures including their location, age, construction type, etc. By summing the number of old (pre 1960) URM structures and dividing by the total number of structures within the suburb, we have been able to display the spatial distribution of older URM structures as a percentage of the total number of structures in each suburb (Figure 1). It is important to note that this is the **relative** percentage of older URM structures in each suburb, therefore, negating the problems caused by the uneven number of houses observed in each suburb.



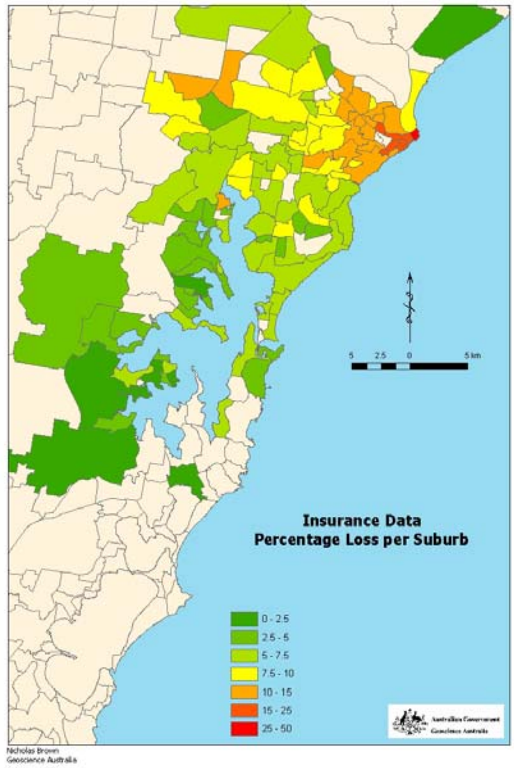


Figure 1: Relative Percentage of old URM structures aggregated by suburb.
Figure 2: Relative Insurance Losses of each suburb (data provided by NRMA).

In order to substantiate the hypothesis that older URM structures sustain greater damage, Figure 2 displays actual losses incurred within each suburb. These percentages are calculated by dividing the total amount claimed by NRMA policy holders in a suburb by the total sum insured of the policy holders who claimed. The correlation between the two figures is obvious, with those suburbs having a higher percentage of older URM structures incurring higher levels of damage as a result of the earthquake. Nevertheless, these results are only preliminary given that the insurance loss information only pertains to NRMA policy holders that claim and does not allow for underinsurance, which was widespread at the time (ICA, 2002).

Independent Fragility Curves for Old URM Structures

If we accept the hypothesis that older URM structures sustain greater amounts of damage than newer URM structures, then it is also fair to assume they should have independent fragility curves. That is, older URM structures should be modelled as more vulnerable than newer URM structures. This was one of the recommendations made by Dhu and Jones (2002) who suggested further refinement of the building parameters (part of the risk component of EQRM) may be required given the large discrepancy between the actual damage and the modelled damage in the Newcastle CBD (where there is a high proportion of older URM) (Dhu and Jones, 2002).

EQRM models damage based on the HAZUS methodology (FEMA, 1999) using the capacity spectrum method which calculates the peak building displacement and acceleration for each earthquake – building pair. From this, the fragility curves define the cumulative probability of a particular building being in or exceeding a given damage state (Robinson and

Fulford, 2005). Fragility curves are defined for the following damage states: Slight, Moderate, Extensive and Complete, and for three types of damage: Structural, Non-Structural (Drift Sensitive) and Non-Structural (Acceleration Sensitive) (for more information refer to FEMA, 1999, Table 5.2).

For the purposes of the Newcastle study and more recently a GA study on Natural Hazard Risk in Perth (Sinadinovski *et al*, 2005), all URM structures had the same damage threshold parameters (refer to Table A.2 of Robinson and Fulford, 2005). The present study creates more vulnerable structures (older URM) by reducing damage state thresholds (as shown in Figure 3).

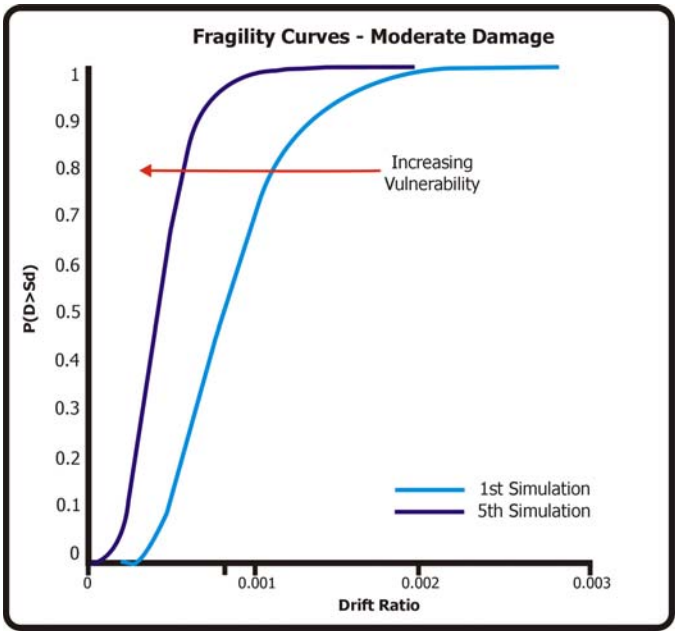


Figure 3: Modifying the damage state threshold parameters can increase the vulnerability of a modelled structure.

Results of the Independent Fragility Curves

In the Newcastle report, Geoscience Australia segregated the URM building stock into URML (low rise) and URMM (medium rise). For the purposes of this study, only URML structures have had their damage thresholds modified because the majority of URMM structures were assumed not to be residential housing. This distinction is used to be consistent with the NRMA insurance data which only includes residential claims.

Fragility curves are partially defined by median damage state thresholds (as drift ratios) for Slight, Moderate, Extensive and Complete structural damage. A series of new damage state thresholds were input into the EQRM software, each causing the older URML structures to be more vulnerable to damage then the previous. For example, the original drift ratios for URM structures were 0.0005, 0.0008, 0.0012 and 0.002 for Slight, Moderate, Extensive and Complete damage respectively. These values were used in the first of five simulations in which only the drift ratios were changed to make older URML structures more vulnerable to ground shaking. The drift ratios were then altered to 0.00045, 0.0007, 0.0011 and 0.0018 for the second simulation. Five simulations were completed in total, with the drift ratios used in the 5th being 0.0003, 0.0004, 0.0008, and 0.0012.

The most effective way to assess the impact of the various drift ratios is to identify those suburbs which have the highest relative percentage of older URML structures (Figure 4) and then compare the percentage damage of these suburbs between the first and fifth iterations (Figures 5 and 6 respectively), where the damage is expressed as a percentage of the full replacement cost of the structure(s). The results for the suburbs identified in Figures 4 – 6 demonstrate a general increase in percentage damage when comparing the first iteration to the fifth (Table 1). In particular, examine Hamilton East (5), The Hill (6), Hamilton South (7) and Bar Beach (9) which have the highest relative percentages of older URML. Not surprisingly, they are among the suburbs which have the greatest increase in modelled damage.

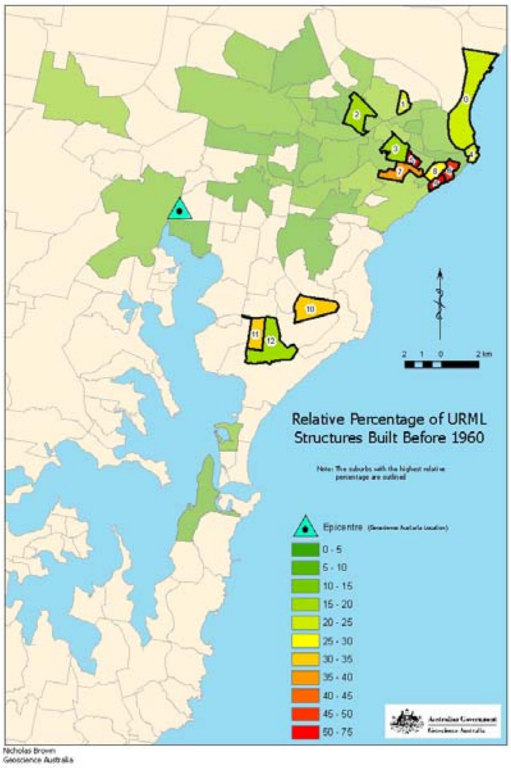
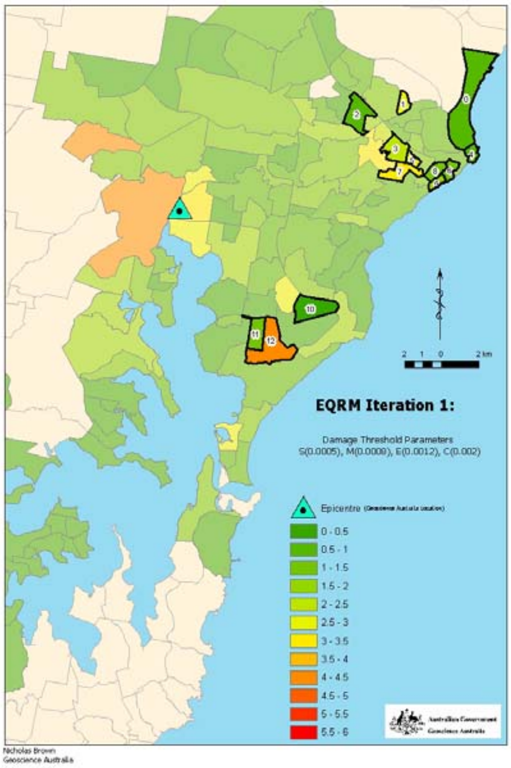
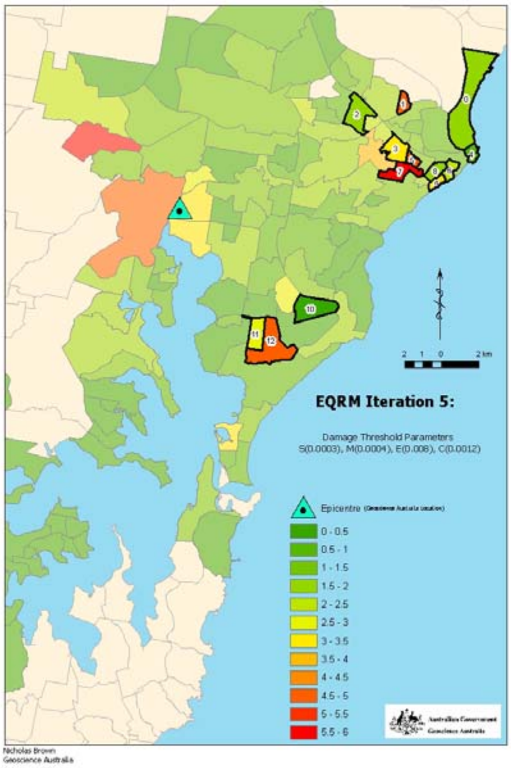


Figure 4: Those suburbs with the highest relative percentage of older URM structures have been highlighted.





Figures 5 and 6: The first and final iterations of EQRM after having altered the damage threshold parameters.

			Percentage Damage		
Suburb	Feature ID	No. Structures	1st Iteration	5th Iteration	% Change
Stockton	0	196	0.90	1.55	0.65
Mayfield East	1	67	2.73	4.60	1.87
Waratah	2	151	0.98	1.51	0.53
Hamilton	3	172	2.27	3.37	1.10
Newcastle East	4	36	0.74	0.98	0.24
Hamilton East	5	46	2.88	4.81	1.93
The Hill	6	35	1.20	2.27	1.07
Hamilton South	7	151	3.32	5.76	2.44
Cooks Hill	8	110	1.20	1.79	0.59
Bar Beach	9	30	1.66	3.39	1.73
Bennetts Green	10	3	0.65	0.73	0.08
Floraville	11	3	1.50	2.52	1.02
Belmont North	12	5	4.24	4.91	0.67

Table 1: Identifies the increase in percentage damage between the first and fifth iterations in suburbs with a high relative percentage of older URML structures.

The correlation between older URM structures and increased in damage is not perfect. For example, consider Newcastle East (4) and Bennetts Green (10) where there is no significant increase in damage between the iterations. In the case of Bennetts Green (10), only three structures were surveyed by the Geoscience Australia team in that suburb, and of those three, only one was an older URM according our the definition used in this study. Because that structure was not significantly damaged, the overall percentage did not increase a great deal. As for Newcastle East (4), it is likely that the distance from the epicentre limited the damage caused. Note that site effects have been modelled as described in the previously referenced Newcastle report (Dhu and Jones, 2002).

Conclusions and Further Work

History shows that older URM structures sustain more damage due to groundshaking than other types of Australian construction and the results of the preliminary work in this study illustrate the need for older and newer masonry to be modelled independently. Nevertheless, there is still a great deal of work to be done. In the near future, the Geoscience Australia is planning on further examination of the structural components in the EQRM application, and potentially defining another URM category, that of older URM structures in an aggressive marine environment.

The detailed validation of the EQRM application requires more work as there are still significant concerns about the accuracy of the estimated insured value of all properties in a suburb. Nonetheless, we do have access to insurance data that describes the relative damage that occurred in each suburb, including a breakdown of how much damage was sustained by each construction type. From this, we have been able to infer that older URM structures sustain relatively large amounts of damage and therefore, it is essential to have independent damage state thresholds for this class of structure.

Acknowledgements

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