Seismic Assessment of Unreinforced Masonry Buildings in a Heritage-Listed Township

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Abstract

This paper describes the preliminary results from the building survey work by the project team to document and classify the full inventory of unreinforced masonry (URM) buildings in the heritage listed township of York in West Australia. This Bushfire and Natural Hazards CRC project evolved out of the concerns of one of its end users, the WA Department of Fire and Emergency Services, because of the predominance of URM (brick and stone) buildings in the township. York is located only 36 km away from Meckering which has experienced several moderate size earthquakes in the past 50 years, and URM construction is known to be particularly vulnerable to earthquake ground shaking. The presence of many iconic heritage buildings, the importance of these buildings to York's tourist economy and the local earthquake hazard make York an excellent subject for examining the effectiveness of seismic retrofit to this class of Australian buildings. This paper also highlights the most likely seismic vulnerabilities identified for the URM building inventory and foreshadows possible structural interventions that could be employed to improve the seismic resilience of York township.

Keywords: Heritage construction, unreinforced masonry, seismic response

INTRODUCTION

The earthquake research cluster working under the umbrella of the Bushfire and Natural Hazards Cooperative Research Centre (BNH CRC) involves staff from Geoscience Australia, Swinburne University of Technology and the Universities of Melbourne and Adelaide. The earthquake research cluster has focussed on what are perceived to be the most seismically vulnerable forms of construction – unreinforced brick and/or stone masonry (URM) and low ductility reinforced concrete (LDRC) buildings. The cluster is working towards an improved assessment methodology that can give reliable estimates of cost and benefit for a range of earthquake magnitude and seismic strengthening scenarios. The ultimate aim is to develop a "Cost-effective mitigation strategy for building related earthquake risk" which can inform decision makers on the mitigation of the risk posed by the most vulnerable forms of Australian buildings. Towards that end, the earthquake project team is working with two of our 'End Users'—Western Australia's Department of Fire and Emergency Services (DFES) and the York Shire Council—to use York as a case study for a regional township to assist us developing a practical and robust assessment methodology.

This paper will highlight, in the first instance, the generic building typologies identified during the course of the building survey work followed by examples of the most common building damage patterns observed in URM buildings in previous earthquakes. Here we will use examples of damage seen in URM buildings in Christchurch as well as seismic retrofit solutions that were successful during the September 2010 earthquake.

SURVEYS UNDERTAKEN AS PART OF THE PROJECT

Surveys were undertaken to capture the three types of exposure information—buildings, business, and population—as the remainder of this paper will discuss in greater detail:

- **Buildings:** For the purposes of the project the detailed exposure information is required at the resolution of individual buildings. A feature of Australian URM buildings, mostly built prior to WW2, is a variety of architectural forms. Architectural features such as chimneys, parapets, storey heights and construction materials all affect a building's vulnerability to earthquake and hence its repair cost in the event of earthquake damage. Further, the presence and form of such features will influence the type and necessity of earthquake upgrade works appropriate for an individual building.

- **Businesses:** Knowledge of the nature of businesses in York is also required so that estimates of earthquake impact on them, including direct loss due to damaged premises, loss of custom and loss of staff, could be made.

- **Population:** Additionally, some knowledge of the distribution of the exposed human population with time is desired so that estimates of injuries from earthquake events could be made.

Buildings Survey

The capture and collation of building exposure information for the buildings in York presented the largest task for the project. Two levels of information were required:

1. Collection of a range of attributes for all buildings in York, and
2. Collection of more detailed information for the URM buildings in York.

To achieve this aim, a two stage building survey was designed. Firstly, a coarse survey of all York buildings using GA's Rapid Inventory Collection System (RICS) (Geoscience Australia, 2011) with subsequent interrogation of the captured images, aerial imagery and internet resources using GA's in-house Field Data Analysis Tool (FiDAT) software (Geoscience Australia, 2013) was completed. This survey captured 38 attributes for each building (Corby et al, 2018).

The main information captured by the survey included:

- Classification of building type as either 'house' (typically residential), 'hall' (buildings with open internal space, e.g. churches), 'industrial/warehouse', or 'other' (capturing most normal buildings such as pubs, hotels and retail);
- Classification as either residential, commercial or industrial;
- Building usage;
- Building plan dimensions, number of storeys and storey heights;
- Roof shape;
- Presence/detail on chimneys;
- Presence/detail on awnings and verandas;
- Presence/detail on parapets;
- Presence/detail on existing retrofit;
- Masonry wall material and bond pattern;
- Separation with respect to adjacent buildings; and
- Presence of neighbour falling hazards.

Secondly, a follow-up door-to-door foot survey was undertaken to capture those exposure attributes for non-residential URM buildings that could not be determined during the RICS survey.

The RICS survey captured building attributes for 1463 buildings in York. Of the surveyed buildings, 307 buildings were identified as URM buildings of interest to the project which are shown in Figure 1.

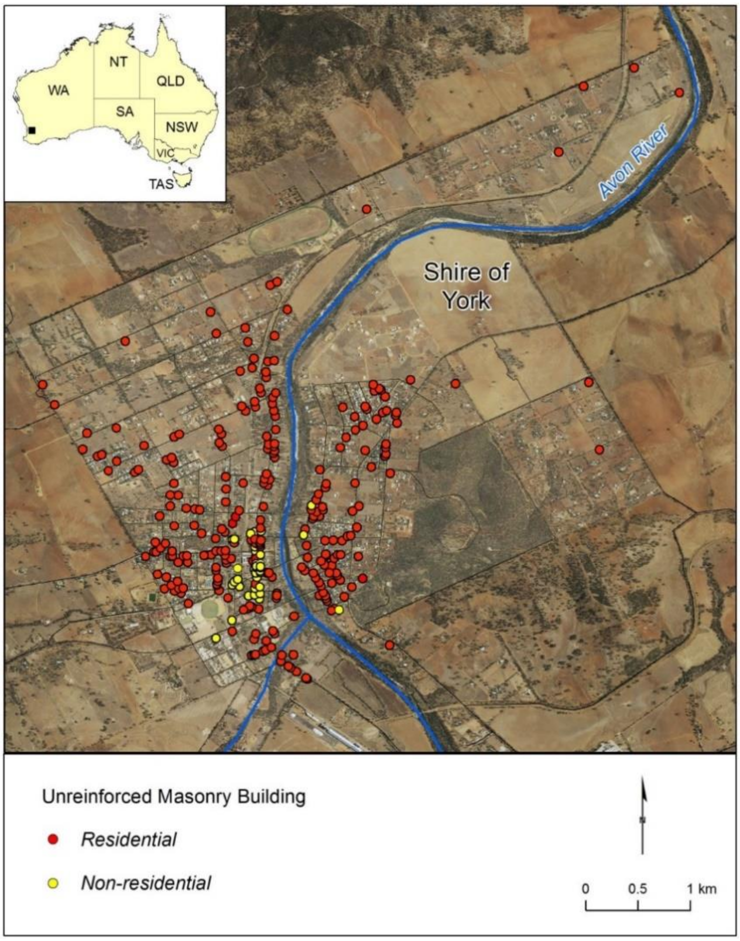

Figure 1: York URM buildings identified by survey.

Business Survey

Face-to-face interviews were conducted with York businesses to gather information on business type, structure, age, trading times, business size based on number of employees, value of assets and liabilities, business income and expenditure.

Population Survey

In a streetscape dominated by low-rise URM buildings, during an earthquake many casualties may potentially arise from people in the street being impacted by falling masonry (Brower, 2017). In order to have some understanding of the distribution of people in Avon Terrace (the main street of York), time-of-day photographs of the main streetscape were taken at mid-morning, midday and evening times during the course of one normal business day. Counting of cars and pedestrians in each photograph enables the population in the street to be estimated.

Generalised findings of the buildings survey will now be discussed. Note that the outcomes of the business and population surveys is beyond the scope of this paper; however, further detail in relation to these aspects of the project are provided in Edwards (2018).

GENERIC BUILDING TYPOLOGIES

On the 9th of August a workshop was held in York with local government, heritage, insurance industry and DFES representatives to discuss the survey results and decide on the most appropriate generic building typologies for the project team to use in its development of assessment methodology and seismic strengthening options. The discussion converged on five typology classifications, as identified through the buildings survey: 1 storey isolated, 1 storey row, 2 storey isolated, 2 storey row, and 2 storey corner buildings. With the exception of several unique buildings such as churches, The Mill and the Town Hall, almost all of York's URM buildings fall into one of these classes. Examples of these typologies are shown in Table 1. In column 3 of this table, the elements in the buildings that are identified to be seismically vulnerable are also identified.

Table 1: Generic building typologies for York, WA URM buildings (photos courtesy of Geoscience Australia).

Type	Example photo	Typical vulnerabilities
House – 1 storey isolated building		Chimney; out-of-plane (OOP) failure gable walls
Pub – 2 storey corner building		Parapets; chimneys; outward OOP failure of external leaf of cavity wall; collapse of these elements through awning and balcony
Single storey commercial – 1 storey row building		Parapet, possible failure through awning

Two storey commercial – row building		Parapet; OOP failure of upper storey wall
Two storey institutional – isolated building		Chimneys; OOP failure of upper storey wall
Two storey Bank – isolated building		Parapets; chimneys; OOP wall failure

TYPICAL SEISMIC VULNERABILITIES AND EXAMPLES OF SUCCESSFUL RETROFIT

Chimneys: According to the survey, 141 URM buildings have one chimney, 117 have 2 chimneys, 45 have 3 chimneys, 16 have 4 chimneys, 3 have 5 chimneys, one has 6 and two have 7 chimneys. That is a large number of chimneys, however, the good news is that only 60 of them are 'slender' chimneys. The bad news is that chimneys with a height-to-thickness ratio of 3 or more may be liable to failure for earthquake ground motions with peak ground accelerations as low as 0.1g. The rest are relatively short in height and so less vulnerable to failure than the taller slender chimneys. Figure 2 shows an example of a successful chimney retrofit that survived the M_W7.1 September 2010 earthquake in Christchurch.

Figure 2: Successful chimney retrofit survived the M_W7.1 September 2010 earthquake.

Gable end walls: There were not many gable walls observed in commercial premises on the main street of York, Avon Terrace, but many pitched roof houses have gable walls. If not well tied back to the roof structure, they can be highly vulnerable to outwards bending failures. See Figure 3 for photos of secured and unsecured gable walls in Christchurch.

(a) Gable wall ties to roof structure (b) Unsecured gable wall failure

Figure 3: Gable end walls after M_W7.1 September 2010 earthquake.

Parapets: Many commercial buildings on Avon Terrace have parapets. Some have existing retrofit in the form of cable ties connected back to the roof structure, but in most instances the ties are connected to the parapet only at a single point (refer Figure 4). Experience around Christchurch, and Newcastle, has shown that this manner of connection will be unsuccessful due to punching shear failure in the masonry around the connection point. More frequent, closely spaced ties are required to reduce the force imposed on the connection and keep it within the capacity of the masonry (see Figure 5).

(a) Parapet front view (b) Rear view, note point connection for parapet restraint

Figure 4: Collins Building, Avon Terrace, York.

(a) Parapet with ties at ~1.5m spacing (b) Parapet with no ties back to roof

Figure 5: Parapets after M_W7.1 September 2010 earthquake.

Walls: The external walls in URM buildings are particularly vulnerable to out-of-plane bending failure. Where brick cavity walls are in use, the external leaf of masonry can easily fall outwards if wall ties are absent or badly corroded as is common in coastal locations. This failure mode can be prevented by the use of wall ties that anchor the wall to the floor diaphragm at each level of the building and the roof diaphragm at the top as shown by Figure 6(a) where a heritage listed 2-storey URM building withstood all the earthquakes in Christchurch with no obvious damage. The building in Figure 6(b) had no wall ties and once the parapet commenced to fall outwards from the top the rest of the front wall went along with it, falling through the awning and crushing the taxi which was parked in front of the building.

(a) Building with wall ties to floor/roof (b) Building without wall ties

Figure 6: URM walls after M_W7.1 September 2010 earthquake.

CONCLUDING REMARKS

This paper has provided an overview of the URM buildings in the township of York, WA in terms of their typologies, main seismic vulnerabilities, and possible retrofit actions to improve their seismic resilience. This work is being undertaken as part of a project under the umbrella of the Bushfire and Natural Hazards CRC, and further detail in relation to its role in the wider context of the project is discussed in Edwards (2018).

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