

# MASONRY RESEARCH IN AUSTRALIA SINCE NEWCASTLE - 10 YEARS AND WHAT HAVE WE LEARNED ?

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## **ABSTRACT:**

The 1989 Newcastle earthquake raised awareness in Australia of the risk posed to unreinforced masonry (URM) buildings by earthquakes and prompted a flurry of research activity in this area. This paper presents an overview of the research conducted in Australia since 1989 on the topic of the seismic behaviour of URM buildings. The paper highlights the questions that have answered, those still outstanding, and the practical outcomes that have made their way into practice through codes and their like as a result of this collective research effort.

## 1. INTRODUCTION

In December 1989 Newcastle experienced a magnitude  $M = 5.6$  earthquake. That unexpected seismic event caused over \$1 billion damage and, for the first time in Australia, 13 deaths due to earthquake. Intensive post-disaster investigations consistently highlighted the fact that [10]:

- most of the damage was associated with URM construction on soft soil sites;
- many of the damaged URM buildings were badly deteriorated, poorly constructed or designed; and
- many of the failure modes observed in Newcastle could have been prevented with simple improvements to detailing practice.

From this starting point, there has been a significant amount of research into the seismic resistance of URM construction. In the remainder of this paper, we will attempt to briefly summarise the results of this research in Australia over the past 10 years with particular attention being paid to the work carried out by the co-authors at the Universities of Adelaide and Melbourne.

## 2. OVERVIEW OF MASONRY RESEARCH IN AUSTRALIA

### *General Seismic Behaviour*

Following the 1989 earthquake, there was a real need to be able to explain why URM buildings fared so well and others fared so poorly. In order to understand the damage pattern, fourteen URM buildings in Adelaide were analysed as part of a large case study into the seismic resistance of typical URM buildings [5]. This project aimed to (1) establish the accuracy of the period formulae in AS1170.4 for URM buildings; (2) determine the dynamic in-plane stiffness of unreinforced brick wall panels; and (3) evaluate the current earthquake design requirements in AS1170.4 for URM buildings. The project consisted of three phases. In the first phase, ambient vibration field tests were conducted on 14 URM buildings in Adelaide to verify the suitability of the period formulae in AS1170.4. In the second phase, earthquake simulator testing of URM wall panels was conducted to study the in-plane dynamic behaviour of clay brick masonry walls. From these tests, the effective dynamic stiffness of clay brick walls was calculated. In the final phase, the detailing and earthquake force requirements of AS1170.4 were evaluated against the results of detailed 3D dynamic analyses of eleven of the Adelaide buildings studied in phase one of this project. The study resulted in 2 major findings.

- (1) Current design methods overestimate the stiffness of brick walls by a factor of as much as 10. Furthermore, the value for Young's modulus needed to correctly predict the fundamental period of the buildings was found to be about 1000 MPa, much less than normally expected for good quality URM (ie, about 5000 MPa). Similar results were found from tests conducted at Melbourne University [7] and in Sydney at UTS [3]. Of course, these estimates of seismic demands led to the need to verify the "seismic capacity" of URM walls and connections.
- (2) The minimum earthquake connection force requirements in AS1170.4 are significantly smaller than required, implying that URM buildings must rely on friction to withstand earthquake loading. Roughly half the buildings did not comply with the current seismic design requirements and so are theoretically at risk. The

seismic demands for connections in URM buildings were calculated for each building in this study. It was noted that in the absence of mechanical fasteners to "tie" the walls of buildings to the floor and roof systems, friction would be required to transmit the seismic forces generated by the earthquake. For most buildings in this study, a "capacity" friction coefficient of 0.3 was all that was required.

#### Masonry connections

Many walls failed during the Newcastle earthquake due to the wall ties which were either insufficient in number, missing completely, or had been severely degraded over time. Furthermore, the new Australian earthquake loading code AS 1170.4 required that all parts of buildings be positively "tied" together. Hence, research was required to better understand the seismic forces placed on wall ties and to quantify the seismic "capacity" of typical friction joints in URM buildings. Experimental and analytical work at Newcastle has greatly improved our understanding of wall tie behaviour under earthquake loading in both brick veneer and brick cavity construction [4]. With regard to wall-to-floor connections, initial static tests at Newcastle University [12] were performed to establish reliable friction coefficients for damp proof course (dpc) and slip joints in typical brick masonry construction. These results were subsequently confirmed with quasi-static cyclic tests at Newcastle and dynamic shake table tests at Adelaide University [2] and are consistent with results of quasi-static tests conducted at the University of South Adelaide [13]. These results indicated that typical dpc joints, through friction, are capable of transferring shear force greater than 30% of the corresponding normal force at the dpc joint.

#### Out-of-plane wall behaviour

Another common failure mode in Newcastle was out-of-plane bending failure of walls. Research on this topic has been carried out by a number of investigators. For example, an improved method for calculating the flexural strength of brick masonry has been incorporated in the new version of AS 3700. This method is based on virtual work principles and relies on realistic estimates of the moment capacity of brick masonry along vertical and diagonal cracks. Expressions for these values are largely empirical and are given in AS 3700. There is still a need to improve our understanding of the influence of vertical compressive stress on the moment capacity of URM walls along vertical and diagonal crack lines.

Much work has also been conducted to establish, through dynamic testing at Adelaide and Melbourne Universities, the flexural strength of brick walls. The shaking table tests results indicate that the walls have a surprising amount of residual capacity beyond the "first crack" loading. An analytical model was originally developed by Melbourne researchers [8] to describe the dynamic behaviour of URM parapet walls. This model has been further developed to accurately predict the time-history response of URM walls simply supported at top and bottom [1] subject to arbitrary dynamic loading, including earthquake ground motion.

The analytical results further indicate that it is displacements which are critical for establishing seismic capacity of URM walls. Indeed, these results have been used to evaluate the acceleration-based, the velocity-based and the displacement-based analysis procedures. Acceleration-based force design criteria appear to overestimate the likely

seismic demand placed on a URM wall. The findings suggest that a displacement-based approach for design of brick walls in bending may be more accurate and less conservative than current force-based design procedures. However, only 1-way (vertical) bending tests have been conducted so far. A substantial amount of effort is required to extend the results to the much more representative case of biaxial bending.

#### In-plane wall behaviour

Researchers have also worked to fine-tune their models of the in-plane behaviour of brick masonry walls. Zhuge [14] has used the results of experimental work at Sydney [3] and Adelaide [6] to validate finite element models for this problem. Klopp at Adelaide used standard finite elements with a Young's modulus of 1065 MPa to analyse the buildings in his case study. Experimental and analytical work is currently underway at Newcastle to study the in-plane behaviour of masonry panels subjected to dynamic cyclic biaxial loading [11]. The results of these tests will provide researchers with much needed data for validation of improved analytical models.

### **3. WHAT DO WE KNOW NOW THAT WE DIDN'T IN 1989**

Many of the questions arising out of the Newcastle earthquake were associated with why some buildings survived and why other (apparently similar) buildings failed. So, what have we learned?

- We now have a much better idea of how to model URM buildings for earthquake analysis and design. There remains some discrepancy in the literature as to what are realistic values for Young's modulus and masonry stiffness. Continuing work in this area is expected to further clarify these questions.
- What we did not fully appreciate before the Newcastle earthquake was how widespread the wall tie related problems were. To industry's credit, they quickly developed a variety of "rust-resistant" alternatives. Furthermore, we now have a much better appreciation of the force distribution between wall ties in both veneer and cavity forms of construction. More rational specifications of wall tie spacings are now possible because of this.
- Based on many case studies, we now have a quantitative understanding of the seismic demand for most of the key structural components and connections in the seismic load-path for URM buildings. This information will enable engineers to better design for earthquake effects.
- We now have an improved (static) method for out-of-plane strength of URM based on virtual work principles. While the method still relies on largely empirical data for the moment capacity of brickwork along vertical and diagonal crack lines, it is much more accurate than previous linear elastic based methods.
- Furthermore, we now have a better understanding of the physical process governing the out-of-plane collapse resistance of URM walls. The displacement of the wall support in space appears to control the response behaviour of the wall, which provides an explanation to the severe damages of URM buildings on soft soil sites.
- Finally, and perhaps most importantly, there is a raised awareness amongst engineers, architects and builders of the need for seismic resistance in all buildings.

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