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AIRCURRENTS: ASSESSING THE SEISMIC VULNERABILITY OF AUSTRALIA'S BUILDING STOCK

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EDITOR'S NOTE: *In this article, AIR research engineer Dr. Arash Nasseri describes several recent enhancements to the vulnerability component of the AIR Earthquake Model for Australia, which will yield more accurate loss estimates and an improved understanding of regional variation in building vulnerability in Australia.*

INTRODUCTION

Located far from the edges of the Indo-Australian plate, the Australian continent would seem well-insulated from the tectonic interactions that give rise to earthquakes. However, historical and paleoseismological data show that damaging earthquakes have occurred in Australia in spite of its distance from plate boundaries. Even earthquakes of moderate magnitude are capable of causing extensive property damage and loss of life in Australia, depending on when and where they strike.

The magnitude 5.6 earthquake that struck Newcastle on December 28, 1989, highlights the vulnerability of Australian cities and towns to earthquake ground shaking. The Newcastle event caused an estimated AUD 4 billion dollars of damage (approximately USD 3 billion) 13 deaths, and 160 injuries (Geoscience Australia 2004). Many of the buildings damaged by the earthquake were unreinforced masonry (URM) structures composed of two layers of bricks, a construction type called cavity double brick masonry (see Figure 1) (Stehle et al. 2005).

Local vulnerability studies in Australia have shown that cavity double brick masonry structures are common in many cities. As is true of URM buildings generally, cavity double brick masonry is known to be highly vulnerable to earthquake ground shaking; indeed it is among the most vulnerable within the general URM class. Therefore, to reliably estimate losses caused by seismic activity, earthquake models for Australia should explicitly account for cavity double brick masonry construction.

Other common construction types in Australia include timber frame homes with masonry or wood veneer. In commercial construction, typical building types are steel or concrete frame structures. The newly updated AIR Earthquake Model for Australia supports 47 unique construction classes, and each is different in its seismic vulnerability.

THE ARTICLE: Discusses how new features of the AIR Earthquake Model for Australia improve loss estimates.

HIGHLIGHTS: The updated AIR Earthquake Model for Australia explicitly accounts for cavity double brick masonry, a construction type that was heavily damaged during the 1989 Newcastle earthquake but is still a large component of the Australian building stock. The updated model also accounts for the evolution of Australia's building codes and construction practices and their impact on the vulnerability of Australia's building stock.

Figure 1. A double brick masonry wall damaged by the Newcastle earthquake (Source: City of Newcastle)

Complicating matters, the vulnerability of these construction types has changed over time, as damaging earthquakes in Australia—such as the 1968 Meckering and the 1989 Newcastle events—and other natural disasters have prompted the adoption and modification of seismic design codes. Therefore, to be robust, earthquake models must account for how the evolution of building codes and construction practices has impacted the vulnerability of a diverse building stock. The AIR Earthquake Model for Australia meets this requirement.

A CLOSER LOOK AT CAVITY DOUBLE BRICK MASONRY

Cavity double brick masonry (CDBM) walls are made of two layers of bricks that are separated by a gap of about 50 millimeters. These two brick layers are attached to each other at intervals by metal ties. While the inner brick layer supports the building's roof, the external brick layer is not load-bearing. A diagram of a typical CDBM wall is shown in Figure 2.

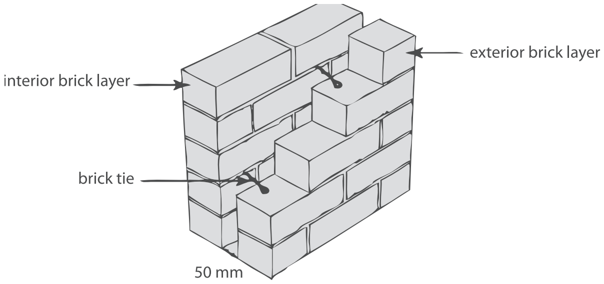

Figure 2. Cutaway view of a cavity double brick masonry wall shows the internal and external brick layers and the metal ties that attach the two. (Source: AIR)

CDBM comprises fully 30% of the residential building stock and nearly 19% of agricultural structures in Australia. It is a popular choice for single-family homes because these buildings are typically warmer in the winter and cooler in the summer than a comparable wood frame or brick veneer building, thanks to the insulating layer of air between the layers of brick. In addition, CDBM walls do not require external cladding or paint and confer excellent insect, fire, and wind resistance (Clay Brick and Paver Manual 3 1996).

However, CDBM walls, like other varieties of unreinforced masonry, are stiff and strong, but inflexible. This means that the inner layer of a CDBM wall fulfills its role of holding up the roof, as long as the primary load it experiences is directed downward. Like all masonry walls, CDBM is strong in compression but much weaker in tension. In an earthquake, seismic waves travel through the ground and propagate through buildings, causing them to vibrate and flex. Because flexure involves tension as well as compression, CDBM walls cannot accommodate powerful earthquake waves without breaking, putting the entire structure in jeopardy.

In fact, AIR engineers have determined that CDBM walls are significantly more vulnerable to earthquake ground shaking than other types of unreinforced masonry. Because the outer wall is not load bearing and is not strongly connected to the inner wall or to the floor, it is more likely to break. However, once the outer wall breaks, the inner, load-bearing wall is also likely to break. Single-wall URM is not subject to this domino effect and can therefore stand up better to ground shaking than CDBM.

Exacerbating the likelihood of damage to CDBM is when the metal ties connecting the two walls rust and break, magnifying the difference in relative motion between the two walls. In fact, much of the damage to CDBM buildings caused by the 1989 Newcastle earthquake has been traced to failure of the iron or galvanized steel ties between their adjacent brick layers, which had been corroded over time. Not surprisingly, starting in 1990, Australian building codes began to require that only stainless steel ties can be used in CDBM walls.

Figure 3 shows the relative vulnerability of CDBM and other URM construction implemented in the AIR Earthquake Model for Australia. Clearly, explicitly differentiating between these two construction types yields more reliable loss estimates.

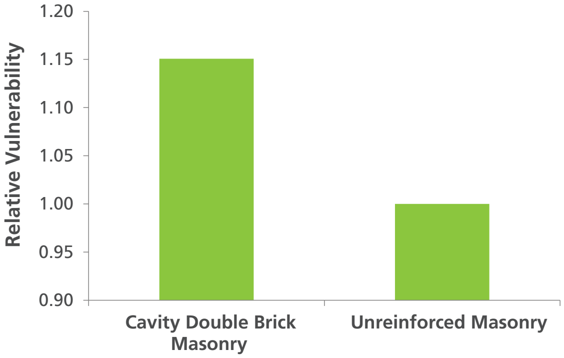

Figure 3. Australia's CDBM construction is considerably more vulnerable than other types of URM. (Source: AIR)

ASSESSING SEISMIC VULNERABILITY IN AUSTRALIA

As noted previously, the recently updated AIR Earthquake Model for Australia supports 47 unique construction classes, and further divides buildings of each class by height (low-rise, mid-rise, and high-rise)—and by the year they were built. As aptly illustrated by the 1990 requirement that metal ties in CDBM walls be of stainless steel going forward, the vulnerability of Australia's building stock has changed over time. By capturing building age, the model captures the impact of changing construction standards and building codes.

In the AIR model, buildings are classified by their seismic resistance as prescribed by seismic design codes. Although there exists a variety of metrics for determining seismic resistance (or building vulnerability), AIR uses design base shear as the primary variable (see Table 1). (Other design provisions, such as ductility, detailing, and construction quality, are also considered). The base shear coefficients shown in Table 1 represent the shear force (or lateral load) that the buildings are designed to resist, normalized by their weight. For example, buildings assigned to the "high code" class are those that should resist lateral loads of between 15% and 22% of their weight.

Table 1. Definition of AIR's building vulnerability classes

Vulnerability Class	*Vulnerability Class Description*	*Relevant Base Shear Coefficient**
Pre-Code	Buildings are designed with no seismic considerations, such as non-engineered buildings	< 0.035
Low Code	Buildings are designed with minimum seismic considerations	0.035 – 0.09
moderate code	Buildings are designed with moderate seismic considerations	0.09 – 0.15
High Code	Buildings are designed with stringent seismic considerations	0.15 – 0.22
Special Code	Buildings are designed with very stringent seismic considerations	> 0.22

*These values are determined for a typical mid-rise engineered building (ordinary reinforced concrete frame)

How the distribution of Australia's building inventory across these vulnerability classes has changed over time was the focus of an extensive research effort at AIR. To capture this evolution, four age bands ("Year Built") are supported in the model: Pre–1980, 1980–1994, 1995–2008, and 2009–present. These bands reflect the timing of the revision and adoption not only of seismic building codes, but also of other relevant building code updates. For example, AIR separates pre-1980 and post-1980 structures on the basis of their compliance with Australia's first seismic design code (implemented in 1979), and also on the basis of their implicit seismic resistance. Few regions of Australia were required to follow the 1979 seismic design code, and even fewer actually implemented it. However, in 1979, strict wind resistance guidelines were also mandated throughout Australia, in response to the devastation Cyclone Tracy inflicted on the city of Darwin on Christmas Day in 1974. Because resistance to strong winds also confers resistance to ground shaking, all homes built in Australia after 1980 can withstand earthquakes better than older structures.

Post-1980 structures are divided into three age bands, each of which reflects further updates to seismic building codes. Specifically, in 1993, new methods for determining soil amplification of seismic waves and a new base shear formula were incorporated into Australia's seismic design code in response to the highly damaging 1989 Newcastle earthquake. In addition, after 1993, Australian seismic design codes were produced using fully probabilistic seismic hazard maps, an improvement over the coarse seismic zonation that had been used previously. These changes are reflected in AIR's 1995–2008 age band.[1]

Then, in 2008, improved formulas to determine base shear inflicted on buildings by earthquakes, as well as better soil-site data and sub-soil classifications, were added to the seismic building code. These updates are reflected in the 2009–present age band.

It is important to recognize, however, that these updates to seismic design codes apply only to new structures. In Australia, retrofitting older buildings to meet current earthquake-resistance standards is not required. This, along with lags in code enforcement, produces a complex picture of the vulnerability of Australia's building stock, as is quickly apparent from Figure 4, which provides a visual depiction of the spatial and temporal variation in vulnerability implemented in the AIR model.

In the area just east of Perth, for example, buildings in all vulnerability classes are represented. Buildings here constructed before 1980 are pre-code and thus very vulnerable to earthquake ground shaking (Figure 4A), while buildings erected between 1980 and 1994 (corresponding to the vulnerability classification "low code") are somewhat more resistant to earthquakes because they had to comply with wind loading standards set in response to Cyclone Tracy and the seismic design provisions of 1979 (Figure 4B). In the same region, buildings constructed between 1995 and 2008 were required to comply with more stringent provisions resulting from the Newcastle earthquake (Figure 4C). Finally, post-2008, new buildings east of Perth are highly resistant to earthquakes ("special code"; see Figure 4D), because these structures must take into account the improvements in site factors and base shear estimates.

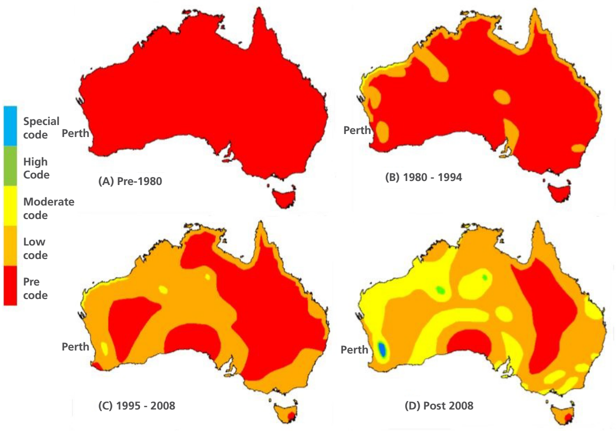

Figure 4. Spatial and temporal variation in vulnerability implemented in the AIR Earthquake Model for New Zealand. (Source: AIR)

CLOSING THOUGHTS

Despite its moderate magnitude (M5.6), the 1989 Newcastle earthquake ranks as one of Australia's costliest natural disasters. With the high insurance penetration in Australia today, AIR estimates a repeat of this event would cost insurers more than AUD 6.24 billion. A larger magnitude earthquake in the seismically active zone near Perth could result in much larger losses.

It is essential for companies operating in this market to have the tools necessary to make an appropriate assessment of the country's earthquake risk and to develop the risk management strategies that will effectively mitigate the impact of the next catastrophe. By providing an incomparable level of detail, enabling superior risk differentiation based on factors including seismic zonation, soil type, construction, occupancy, year built and height, the AIR Earthquake Model for Australia stands ready to help.

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[1] IT IS ASSUMED THAT THERE IS A LAG BETWEEN ADOPTION OF A CODE UPDATE AND ITS FULL ENFORCEMENT.

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