


Earthquake preparedness in South Australia: recommendations based on previous earthquakes in Australia, New Zealand and the United States of America

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ABSTRACT

Adelaide is the most earthquake-prone capital city in Australia, with earthquakes of a magnitude five to six on the Richter scale occurring frequently enough to be a potential danger. This paper explores the short and long-term physical and psychological consequences of earthquakes that have occurred in settings comparable to metropolitan Adelaide in order to make recommendations in terms of the lessons learned. The danger posed by unreinforced masonry buildings in Adelaide is highlighted and the importance of effective communication and collaboration between local and national providers of essential services is discussed. The paper concludes with recommendations, including the development and rehearsal of emergency plans, community education and preparedness, planning for longer-term health outcomes and availability of practical and financial support.

Introduction

Although Australia experiences few earthquakes by world standards (Gibson 2010, McCue 2010), Adelaide is the most earthquake-prone city on the continent, with moderate earthquakes (magnitude five to six on the Richter scale) occurring frequently enough to be a potential danger (Doyle *et al.* 1968). In the past 150 years, 15 earthquakes of magnitude five or greater were recorded in South Australia. Earthquakes of this magnitude lead to damage in the epicentre zone and can be felt over an area with a radius of approximately 200 km (Greenhalgh *et al.* 1994).

Earthquakes in South Australia primarily occur within two belts:

- the Adelaide seismic zone extending from Kangaroo Island, through the Mount Lofty and Flinders Ranges, to Leigh Creek in the state's north, and
- the Eyre Peninsula zone (Doyle *et al.* 1968, Sutton & White 1968, Greenhalgh *et al.* 1994) (Figure 1).

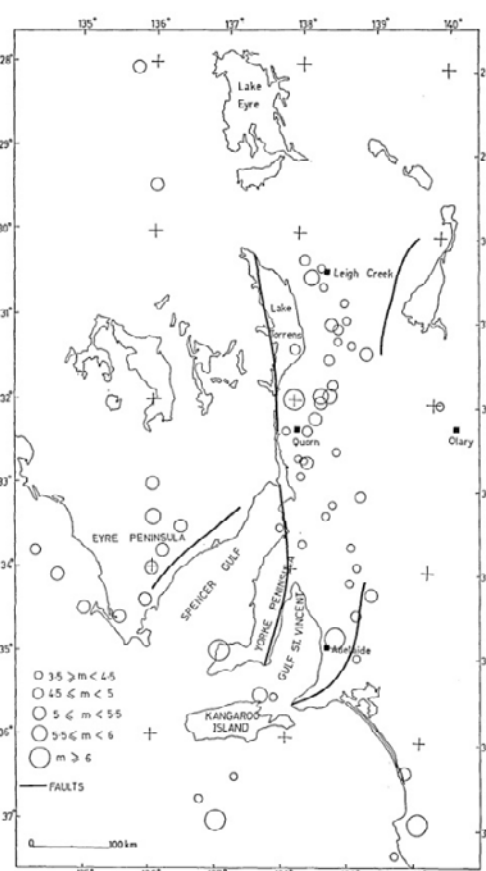


Figure 1: Map of earthquake epicentres in South Australia (Doyle *et al.* 1968).

Earthquakes occurring in urban areas pose a risk to residents and essential societal systems, including critical infrastructure (World Association for Disaster and Emergency Medicine 2003, McCue 2010). If an earthquake of a similar magnitude to the 1954 Adelaide earthquake (5.4 on the Richter scale) were to occur today, it would result in substantial loss of life, injuries and damage, with losses over AUD\$1 billion (Greenhalgh *et al.* 1994).

Aim

This paper examined earthquakes that have occurred in settings comparable to the physical and social environment of metropolitan Adelaide to make recommendations for South Australia in terms of lessons learned. The focus was on at-risk population groups and lifelines and the short and long-term consequences of selected events, including fatalities, injuries, psychological impact and damage to infrastructure.

Methods

A recent comprehensive review article by Doocy and colleagues (Doocy *et al.* 2013) was used for identifying relevant articles. Additional searches were performed on Medline, Scopus and Google Scholar to identify papers published after the period covered by the article. Earthquakes were selected based on the similarities of their location and environment to the South Australian context in terms of building stock, demographics and level of development. The details of the selected earthquakes are presented in Table 1. The South Australian Government *State Emergency Management Plan* (State Emergency Management Committee 2012) served as a starting point for the recommendations made in this paper.

Discussion

Australia

Australia has experienced a number of destructive earthquakes in the past, most notably the 1954 Adelaide and 1989 Newcastle events that caused widespread damage to housing and commercial structures, particularly unreinforced masonry buildings (Doyle *et al.* 1968, Gibson 2010). The Adelaide earthquake led to over 30 000 insurance claims being filed and the Newcastle earthquake resulted in between \$900 million and \$1.5 billion of property damage (Lewin *et al.* 1997). While the 1954 Adelaide earthquake did not result in any deaths and caused only 16 injuries (McCue 2010), the Newcastle earthquake caused 13 fatalities (Greenhalgh *et al.* 1994). In total, 105 individuals received injuries that were treated in Newcastle's public medical centres, with 30 of the injured being admitted to hospital. The main causes of injury included contusions and bone fractures. A further 800 people required emergency accommodation.

In the first month following the earthquake, 78 full and 173 partial demolitions were approved, 1 161 buildings were deemed a danger to the public and 3 812 were damaged but habitable. Several of the damaged structures housed important public infrastructure associated with essential services. The Royal Newcastle Hospital was evacuated due to structural damage, while two other hospitals and the City Fire Station and Ambulance Office sustained some damage, impacting on their ability to provide services (Carr *et al.* 1997).

The Newcastle earthquake was of moderate magnitude (5.6 on the Richter scale) and was the first recorded earthquake in Australia to result in loss of life. In the first six months following the earthquake, over 20 per cent of the adult population in Newcastle used general and/or disaster-related support services. Nearly 60 per cent used personal sources of support, including family, friends and neighbours, with over one-third of the population relying exclusively on these informal supports (Carr *et al.* 1997). However, the frequency of visits to doctors did not increase in the six month period, suggesting that earthquake-related issues were dealt with during consultations for other matters. Psychological problems were found to decline over time, but tended to stabilise at approximately 12 and 18 months for general psychological illness and trauma-related mental illness, respectively. Those who sustained injuries in the earthquake exhibited the highest level of distress. The degree of initial earthquake exposure (avoidance coping style, traumatic life events since the earthquake, ongoing disruptions, older age, a history of emotional problems and poor social relationships) contributed to ongoing psychological issues two years after the event (Carr *et al.* 1997).



Demolition of Newcastle Workers Club, the scene of the greatest damage to any building in Newcastle where nine people died and many others were injured.

New Zealand

While New Zealand differs from Australia in terms of earthquake frequency and severity (McCue 2010), there are similarities between the healthcare systems in each country considering building stock and demographics. Thus, the two recent earthquakes in Christchurch can inform planning in South Australia.

The first of the New Zealand events occurred 30 km west of Christchurch on 4 September 2010 at 4:35am, with frequent and unpredictable aftershocks continuing for months. The earthquake did not result in any fatalities, but caused two serious injuries. This was attributed to the performance of most modern buildings and the early morning occurrence, which meant that most residents were away from the business districts of Christchurch and Kaiapoi (Wood *et al.* 2010, Dorahy & Kannis-Dymand 2012). Unreinforced masonry commercial and office buildings in the two business districts performed poorly, with two buildings collapsing and many partially collapsed, which would have led to numerous deaths and injuries had the buildings been occupied (Wood *et al.* 2010).

The immediate emergency response to the earthquake was effective, with local authorities, lifeline utility operators, engineers and national agencies responding using planned arrangements. While outages occurred, power and telecommunications were restored to 90 per cent within 24 hours, with water supplies restored within five days (Wood *et al.* 2010). Despite the small number of injuries and swift emergency

response, residents of areas most affected by the earthquake were more likely to report depression and anxiety symptoms. This was due to stress and sleep disruption, which may be explained by property damage, increased fatigue and uncertainty about the future, including further aftershocks (Kemp *et al.* 2011, Dorahy & Kannis-Dymand 2012).

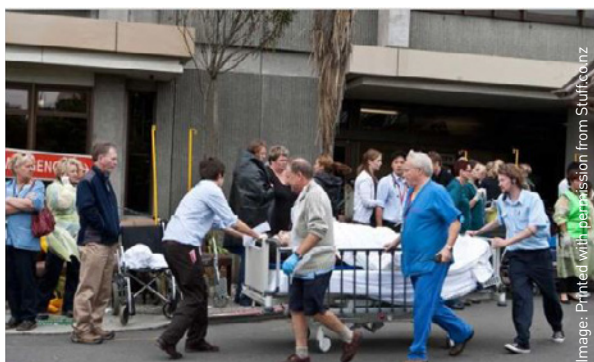
The following year a 6.3 magnitude earthquake occurred at 12:51pm on 22 February 2011 in Christchurch (Doocy *et al.* 2013). The earthquake resulted in 185 fatalities, 6 659 injuries and widespread damage to buildings and infrastructure, particularly in the central business district (Giovinazzi *et al.* 2011, Ardagh *et al.* 2012, Sibley & Bulbulia 2012). The collapse of two multi-storey office buildings and associated fires led to 110 fatalities. Falling debris crushed two buses, killing six individuals, with another 16 dying from falling debris and landslides (Sibley & Bulbulia 2012). While the majority of injuries were minor, serious injuries occurred as a result of falls and being struck by rubble. Patients who were trapped under rubble suffered crush syndrome, characterised by severe shock and renal failure following crushing trauma to skeletal

Table 1: Summary of included earthquakes.

Location	Event	Magnitude (Richer scale)	Day of week and time of day	Fatalities and injuries	Psychological impact	Impact on infrastructure
Australia	Adelaide 1954	5.4	Monday 3:40 am	0 fatalities 16 injuries	Not reported	30 000 insurance claims filed. Widespread structural damage.
	Newcastle 1989	5.6	Thursday 10:27 am	13 fatalities 105 injuries	20% of population sought formal support. Psychological morbidity still detectable after two years.	78 full and 173 partial demolitions. 1 161 buildings deemed a danger to the public. 3 812 buildings damaged, but habitable.
New Zealand	Christchurch 2010	7.1	Saturday 4:35 am	0 fatalities 2 injuries	Depression, anxiety, stress and sleep deprivation more common among those affected by earthquake.	Two buildings collapsed and many partially collapsed, with unreinforced masonry buildings performing very poorly.
	Christchurch 2011	6.3	Tuesday 2:51 pm	185 fatalities 6,659 injuries	Not reported	Two multi-storey office buildings collapsed, many more buildings partially collapsed.
California	Loma Prieta 1989	7.1	Tuesday 5:04 pm	63 fatalities 3 757 injuries	Not reported	Elevated freeway collapse, bridge damage, widespread structural damage.
	Northridge 1994	6.7	Monday 4:31 am	57 fatalities 7 000 injuries	Lower psychological symptoms among older residents.	Substantial damage to power lines, roads, bridges and property.

muscle. Soft tissue injuries and bone fractures were common (Ardagh *et al.* 2012). Emergency services were overwhelmed, hospitals exceeded their capacity, power, water and telecommunications outages were extensive and prolonged and many residents were displaced (Sibley & Bulbulia 2012).

Christchurch has one hospital with an emergency department, which is located on the edge of the central business district. It sustained significant damage, including loss of power, emergency generator failure, and collapse of a section of the ambulance bay. Damage to roads and communications failures contributed to difficulties in triage of patients. However, the hospital activated its well-developed and annually rehearsed incident plans, which ensured that staff were effectively managed, patients were identified using pre-labelled packs and wards were equipped with torches, headlamps and charged batteries. Thus, although the earthquake occurred during the day when many people were in high-rise concrete buildings and there were two full multi-storey building collapses, Christchurch's stringent building codes and the proximity to high quality and well-managed healthcare minimised fatalities (Ardagh *et al.* 2012).



Patients and staff outside the emergency department at the Christchurch Hospital.

United States of America

The 1989 Loma Prieta and the 1994 Northridge earthquakes in California highlight the potential for road destruction during earthquakes. The Loma Prieta earthquake occurred in Santa Clara County in Northern California on 17 October 1989 at 5:04pm and registered 7.1 on the Richter scale (Pointer *et al.* 1992). The earthquake caused 63 fatalities and 3 757 injuries, with 42 deaths among motor vehicle occupants and pedestrians resulting from the partial collapse of an elevated freeway ramp (Pointer *et al.* 1992). The earthquake occurred when many residents were in their homes preparing to watch a World Series baseball match, leaving the usually heavily congested freeways relatively quiet. Had this not been the case, the fatality and injury rates would have been much higher. Furthermore, two large sections of the San Francisco-Oakland Bay Bridge fell, resulting in one fatality and rendering the bridge unusable. Damage to 18 306 residential properties and 2 575 businesses resulted in

the displacement of 12 053 people (Nolen-Hoeksema & Morrow 1991, Pointer *et al.* 1992).

The most common injuries sustained during the Loma Prieta earthquake included falls, cuts, abrasions, fractures, burns and being hit by falling objects. While five local hospitals reported difficulties in treating patients due to staffing shortages and insufficient operating suites, most hospital resources were not overwhelmed. Although hospitals near the epicentre experienced a near doubling in the number of patients presenting to the emergency department, off-duty doctors and nurses were able to deal with the influx. The familiarity with and preparation for earthquakes in the region resulted in rapid triaging and expedited paperwork, ensuring that the earthquake did not impact negatively on patient care (Pointer *et al.* 1992).

The 1994 magnitude 6.7 Northridge earthquake occurred on 17 January 1994 at 4:31am in the San Fernando Valley of Los Angeles (Scientists of the US Geological Survey and the Southern California Earthquake Center 1994, Bolin & Stanford 1998, Peek-Asa *et al.* 1998, Knight *et al.* 2000). The damage was widespread, including fires, downed power lines and traffic signals, and property and road damage. Over 12 000 residential properties, businesses and hospitals sustained structural damage, leading to the displacement of over 20 000 residents. Schools experienced substantial non-structural damage such as falling lights, which would have resulted in fatalities had schools been in session. Disruptions continued for months due to damaging aftershocks and the collapse of freeway overpasses, which resulted in three major freeways remaining closed until they were rebuilt. However, the emergency response to the earthquake was efficient and preparations such as the retrofitting of masonry buildings prevented more widespread damage (Scientists of the US Geological Survey and the Southern California Earthquake Center 1994).

The earthquake resulted in 57 fatalities that were mostly due to building collapse leading to asphyxia and crush syndrome. Over 7 000 injuries required hospitalisation that were primarily due to falls or being hit by objects (Peek-Asa *et al.* 1998, 2000). Older individuals were more likely to be injured due to their decreased ability to move quickly to avoid falling debris and their lower tolerance to sustained injuries (Mahue-Giangreco *et al.* 2001). However, older individuals displayed the lowest levels of earthquake-specific negative thought patterns and those with prior exposure to earthquakes were less likely to experience post-earthquake depression (Knight *et al.* 2000).

Recommendations

Some work has already been done or is underway in South Australia that addresses the damage that could occur during an earthquake. An earthquake hazard mapping exercise has identified the areas of South Australia most likely to experience an earthquake and estimated the numbers of fatalities and injuries that would occur during earthquakes of various magnitudes

and epicentre locations. However, more can be done to expand on existing knowledge in order to improve South Australia’s preparedness.

Currently, there are no sufficiently strong motion recorders installed in South Australia to determine the manner in which the earth might shake during an earthquake (McCue 2010). It is not clear whether the movement would be different to earthquakes occurring in relatively similar locations. While the absence of these data leads to difficulties in predicting the impact that an earthquake of a given magnitude would have on existing structures, there are nonetheless important recommendations for Adelaide that can be drawn from the events reported on in this article. Key recommendations are summarised in Table 2.

Considering the damage sustained by unreinforced masonry buildings during previous earthquakes, it has been argued that the most significant earthquake risk mitigation in South Australia will be through improving building standards (Ramirez & Peek-Asa 2005, Gibson 2010). Some areas of Adelaide, particularly the inner-city and eastern suburbs, have buildings of similar age and construction to Christchurch, with substantial numbers of unreinforced masonry buildings. Due to the high level of earthquake hazard in New Zealand unreinforced masonry buildings have been seismically assessed and retrofitted where necessary, with most retrofitted buildings performing well during the 2010 Christchurch earthquake (Wood *et al.* 2010). Following the Adelaide and Newcastle earthquakes a number of school buildings in Adelaide and Newcastle were strengthened and a hospital in Adelaide was relocated away from what was thought to be an active fault in the southern suburbs (McCue 2010). It may be necessary to assess the economic viability of retrofitting unreinforced masonry buildings in Adelaide that may lead to high numbers of fatalities and injuries during an earthquake (Greenhalgh *et al.* 1994).

Bridges and roads are highly vulnerable to earthquake damage, resulting in numerous injuries and fatalities (Nolen-Hoeksema & Morrow 1991, Marmar *et al.* 1996, Peek-Asa *et al.* 1998, Ramirez & Peek-Asa 2005). Many bridges in South Australia are relatively old and therefore may be prone to cracking in the event of an earthquake (Templeman & Bergin 2008). The failure of infrastructure, such as traffic signals and road lighting, may also contribute to accidents and injuries (Ramirez & Peek-Asa 2005). Damaged roads and bridges may make it difficult to access essential services, including hospitals (Ardagh *et al.* 2012). Thus, alternate routes or modes of transport should be part of emergency plans.

The importance of each community’s level of preparation must be acknowledged. Research has demonstrated that social capital, or the degree of trust and connection between community members, is a strong predictor of post-disaster recovery. Communities should focus on developing social infrastructure, such as community networks and organisations, which contribute to greater resilience and rapid recovery (Aldrich 2010). Communities should develop knowledge and understanding of earthquakes and ensure the availability of essential supplies, transport and communications services (Templeman & Bergin 2008, Gibson 2010). Essential services, including hospitals, should have sound emergency power and communications systems and contingency plans in place. Emergency operation plans should be developed and rehearsed, including well-defined hierarchical structures for the management of staff and volunteers (Ardagh *et al.* 2012). In the event of a large earthquake, it is likely a national (and potentially international) response will be required during the response and recovery period (Templeman & Bergin 2008). Arrangements should be in place to enable effective co-ordination and communication between local and national service providers and for the endorsement and co-ordination of international disaster response teams.

Table 2: Key recommendations

Area	Recommendations
Building standards	<ul style="list-style-type: none"> • Focus on unreinforced masonry buildings. • Consider economic viability of retrofitting vulnerable buildings.
Transport and infrastructure	<ul style="list-style-type: none"> • Emergency plans for possible bridge and road collapse and failure of critical infrastructure.
Community preparedness	<ul style="list-style-type: none"> • Implement community resilience models and strategies. • Develop and rehearse emergency plans.
Health services	<ul style="list-style-type: none"> • Be prepared for profile of injuries routinely observed during earthquakes. • Make arrangements to collaborate with national and international health agencies.
Recovery and rehabilitation	<ul style="list-style-type: none"> • Plan for longer-term physical and mental health outcomes. • Ensure ongoing access to treatment and support services.
Practical and financial support	<ul style="list-style-type: none"> • Prepare for prompt repairs to homes and businesses. • Organise efficient settlement of insurance claims and financial support. • Organise flexible employment arrangements for affected workers.

The South Australia Department for Manufacturing, Innovation, Trade, Resources and Energy (Mineral Resources Division) manages earthquake monitoring devices in South Australia. Sites include Government House, Mt Osmond, Whyalla, Port Pirie, Napperby, Payneham, and Torrens Island. The stations are moved around the metropolitan area every two years.



Early trigger earthquake recorder used in metropolitan areas of South Australia.

Health services should be prepared to deal with the pattern of injuries routinely observed during earthquakes, including crush syndrome, soft tissue injuries and bone fractures (Ardagh *et al.* 2012, Doocy *et al.* 2013). Acute kidney injury is common in patients with crush syndrome and rapid provision of renal replacement therapy is important. Injured individuals are likely to attend the closest or most familiar health facility in the event of an earthquake and may present to facilities that would not normally receive seriously injured patients. Thus, robust emergency plans should be in place for all healthcare providers, not only major hospitals. Moreover, the state health system's capacity to manage a large mass casualty event needs to be maintained and practiced and plans put in place to collaborate effectively with national and international health agencies (Templeman & Bergin 2008).

Longer-term recovery and rehabilitation should be considered, not only in regard to physical trauma, but also taking psychological impacts into account. Although psychological problems among earthquake survivors decline substantially over time, a minority continue to experience significant and persistent mental illness (Lewin *et al.* 1998). It is important that these individuals be able to access treatment and support services, not only immediately after the

disaster, but throughout their recovery period. Those with elevated levels of depression and stress prior to an earthquake and a ruminative style of responding to these symptoms may benefit from engagement in relief efforts and other similar activities that have a positive influence on their sense of efficacy and overall mental state (Nolen-Hoeksema & Morrow 1991).

Earthquakes have ongoing and substantial effects on the lives of individuals and local businesses, rather than being events with a well-defined endpoint. Thus, it is important to recognise that sole reliance on initial earthquake exposure to identify individuals in need of support will exclude those for whom the impact is latent, occurring as a result of accumulation of ongoing disruptions and resulting stress. In order to decrease these disruptions, prompt repairs, speedy settlement of insurance claims, financial assistance and flexible employment arrangements should be made available to individuals and businesses affected by earthquake (Carr *et al.* 1997).

The level of preparation for an earthquake event and the characteristics of the impact, such as fatality and injury rates and damage to essential services, may be underestimated when the Adelaide context is compared in a crude fashion to the experiences of similar cities. The engagement of civil society through community awareness and preparedness is influenced by the community's recent experiences of disaster. In Adelaide, where significant earthquakes are infrequent, an earthquake may have a greater impact because the community, its public policy, organisations and individual community members, are less aware of the potential risks.

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