# The Kalgoorlie Earthquake of the 20th April 2010 : Preliminary Damage Survey Outcomes

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## Abstract

The seismicity of the Australian continent is low to moderate by world standards. However, the seismic risk is much higher for some types of Australian infrastructure. The legacy of older unreinforced masonry buildings, in particular, may contribute disproportionately to community risk.

At 8.17am on 20 April 2010 a $M_L$ 5.0 earthquake shook Kalgoorlie. The resultant ground motion was found to vary markedly across the town with the older masonry building stock in the suburb of Boulder experiencing a greater shaking intensity than buildings of a corresponding age and type in the Kalgoorlie business district 4 km away. The event has provided the best opportunity to examine the earthquake vulnerability of Australian buildings since the Newcastle Earthquake of 1989.

This paper describes the event and the staged collaborative survey activity that followed. The initial reconnaissance team of two specialists captured street-view imagery of 12,000 buildings within Kalgoorlie using a vehicle mounted camera array developed by Geoscience Australia. This information subsequently informed a systematic population based building survey using PDA data collection units. The work was performed by a team of nine from the University of Adelaide, the University of Melbourne and Geoscience Australia. This paper presents the preliminary findings of the work and outlines proposed future research.

**Keywords:**
Earthquake, Unreinforced, Masonry, Vulnerability, Australian

## INTRODUCTION

Australia has a low seismicity when compared to countries located along tectonic plate boundaries (Giardini, 1999). Seismic risk, however, is the combination of hazard, community exposure and infrastructure vulnerability. Lower seismicity can be offset by greater building vulnerability and predominance. The legacy of older unreinforced masonry buildings is a particular subset of the built environment that may contribute disproportionately to community risk due to a higher vulnerability. Documented information on the damage to buildings caused by earthquake events is fundamental to understanding this vulnerability and associated risk. Furthermore, it can point to cost-effective structural mitigation measures that have been shown historically to beneficially increase resistance to ground shaking.

On April 2010 a $M_L$ 5.0 earthquake occurred beneath the Western Australian mining town of Kalgoorlie causing significant damage to masonry structures. By virtue of its history, Kalgoorlie contains a significant stock of older masonry structures built during the Yilgarn-Goldfields gold rush of the late 1800s. These structures are typically heritage listed and clustered around the central business district of Kalgoorlie and the business district of the once separate community of Boulder (now a suburb of Kalgoorlie). The severity of ground shaking differed between these two areas of building exposure giving two hazard severities for which damage could be assessed. The event has provided the best opportunity to examine the earthquake vulnerability of Australian buildings since the Newcastle Earthquake of 28 December 1989, over twenty years prior (Institution of Engineers, Australia, 1990).

This paper describes the survey activity that was undertaken to obtain street level imagery of the entire community, to capture felt intensity information and to survey the severity of damage caused to buildings. The primary focus was the older building stock but included more contemporary masonry construction.

## EARTHQUAKE

The earthquake was shallow (1.7 km depth) and was located immediately south of the business district of Boulder (refer Figure 1). The severity of ground motion was found to vary markedly across the town with the older masonry building stock in Boulder experiencing a greater intensity of shaking than the corresponding building age group in the Kalgoorlie business district 4 km away. The duration of shaking was short with local residents describing the shaking as more of an impact that a sustained shaking.

## SURVEY ACTIVITY

Following the earthquake Geoscience Australia (GA) arranged a staged collaborative survey that would capture information useful for improving the knowledge of building vulnerability. The initial reconnaissance team of two specialists from GA performed a street-view imagery capture of 12,000 buildings within Kalgoorlie from 28 April to 1 May. The team used a vehicle mounted camera array developed by GA called the Rapid

Inventory Collection System (RICS). In total 230,000 geo-referenced high resolution images were captured within the urban area. In addition, the advance survey team was able to source a range of supplementary information from local agencies which included the heritage register of town buildings, images of damage captured by local Fire and Emergency Services Authority (FESA) staff immediately after the event, and building data from the local council. This information was reviewed in Canberra and utilised for planning of the follow-up detailed foot survey. In particular, survey templates developed for hand-held computer equipment were refined and reference data sheets developed that included a data dictionary and damage definition suite. The latter were developed to promote consistency of information capture in the field.

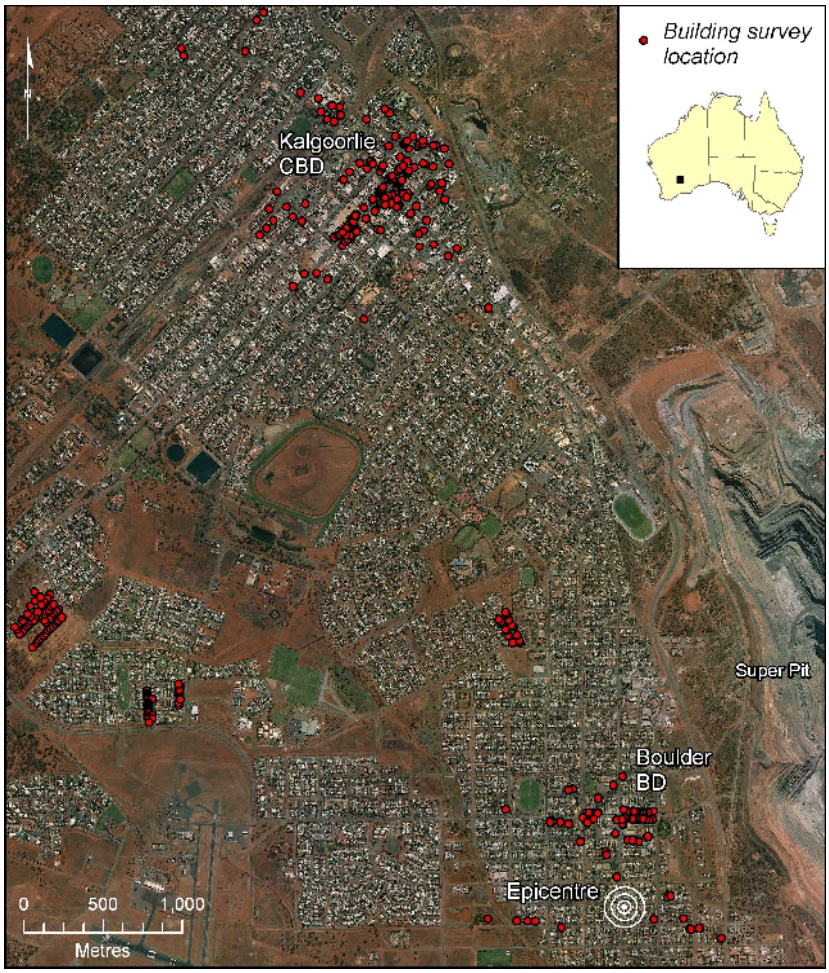


Figure 1. View of Kalgoorlie showing the epicentre of the 20 April $M_L$ 5.0 earthquake and the location of the building surveys subsequently performed from 18 - 22 May 2010. The "Super Pit" open cast mine workings over 500 m deep are visible to the right of the aerial view.

The survey template consisted of 290 data fields (some of which were mutually exclusive) to characterise the surveyed buildings and the severity and extent of earthquake damage. Despite the possession of the RICS images, these did not inform the development of a suitable template for capturing damage to building interiors. Deficiencies in this aspect of the survey template became evident in the field where it

was often found possible to conduct detailed surveys of damage to the interiors of buildings.

The subsequent foot survey targeted the capture of detailed information on building performance and was conducted from 18 - 22 May. Survey information was recorded on hand-held mini-computers which also incorporated a GPS and digital camera. Prior to broad field deployment the team of nine engineers and GIS specialists undertook a field training session in which several buildings were surveyed by all and the data capture reviewed to ensure a consistent approach. The team included two earthquake engineering researchers from the University of Adelaide and the University of Melbourne respectively. The survey initially targeted older masonry buildings but broadened to other building types when this building category was fully surveyed. Significantly, the survey was population based in that all buildings of the type selected were surveyed irrespective of whether damage was sustained or not.

At each survey location the local Modified Mercalli scale felt intensity was assessed using non-damage related metrics where possible. This was assisted greatly by the interview of building occupants who were present at the time of the earthquake. Occupants were also very obliging in affording access to buildings to examine internal damage to structural elements and architectural finishes.

Nearly 400 buildings were surveyed in three age categories. The sample size is considered just large enough to be statistically useful for vulnerability model development. The breakdown of building types is summarised in Table 1 and the survey locations are shown in Figure 1.

Table 1. Summary of Building Types Surveyed by Age Range and Usage

| Age Range | Usage | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Residential | Warehouse | Retail | Hotel | Office | Medical facility | Church | School | Other |
| <1914 | 25 | 3 | 93 | 25 | 20 | 10 | 8 | 4 | 19 |
| 1950-1979 | 2 | 0 | 7 | 0 | 0 | 1 | 1 | 0 | 0 |
| 1980+ | 168 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 1 |

## OBSERVATIONS

### Severity of Ground Motion

The Modified Mercalli Intensities (MMI) derived from direct interview were used preferentially for isoseismal map derivation and are plotted on Figure 2. The field team found that the severity of shaking in the Boulder business district was approximately 6 on the Modified Mercalli scale and 5 in the CBD of Kalgoorlie.

**Casualties**

Only a few minor injuries resulted from the earthquake and associated damage. Given the widespread loss of masonry chimneys and parapets more injuries and some fatalities might have been expected. The timing of the event of 8.17am was fortunate in that falling masonry in Boulder would have landed on school children if the earthquake had occurred just 15 minutes later. The severity of shaking beneath the Kalgoorlie business district was approximately 5 on the Modified Mercalli scale typically causing only slight damage to older masonry buildings.

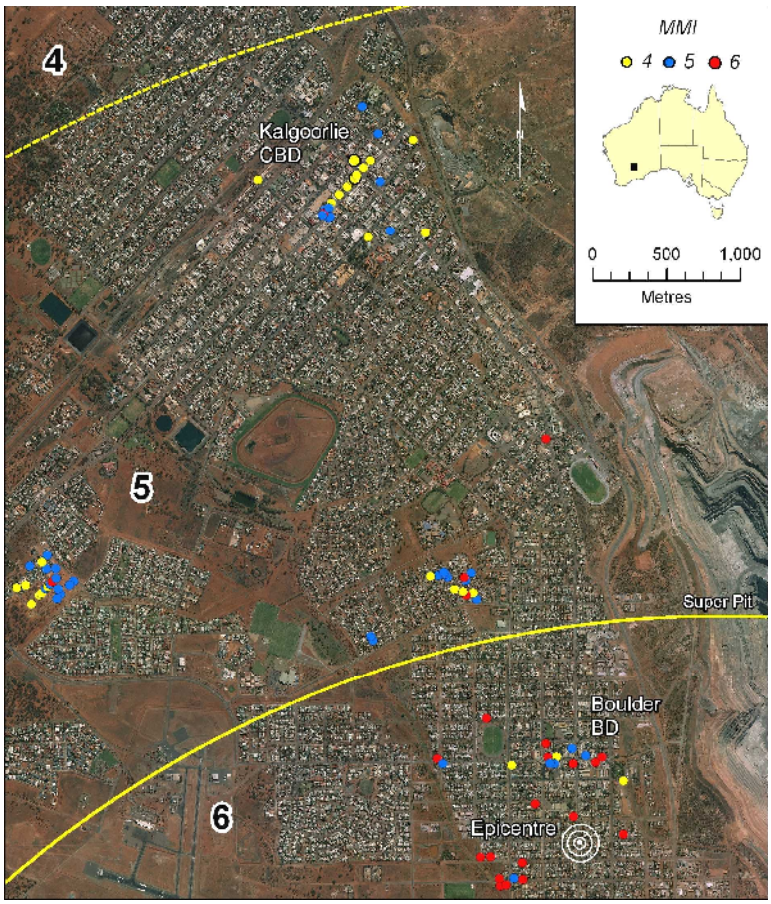


Figure 2. View of Kalgoorlie showing with Modified Mercalli Intensities obtained from direct occupant interview. Based on the intensities isoseismals have been plotted.

**Building Damage**

The level of shaking caused widespread damage to pre-World War One unreinforced masonry buildings. Loss of chimneys, gables and parapets was widespread along with extensive cracking of walls (refer Figures 3 and 4). Poor quality materials were also a factor. Weathering of stonework was evident as was poor quality mortar that had degraded to sand in some instances (refer Figure 5).

More modern masonry residential buildings also experienced some damage in the vicinity of Boulder. Internal damage in the form of minor wall cracking and cornice

damage associated with relative movement between the roof structure and the internal walls was found to be common in cavity brick homes in Boulder (refer Figures 6 and 7).

Figure 3. An example of typical parapet damage.

Figure 4. Vertical cracking at building corner showing separation between front and side walls with the side wall temporarily shored.

Figure 5. Weathering of mortar and masonry

Damage to framed brick veneer (BV) construction was not observed. One two storey BV home suffered damage due to the detachment of a toilet cistern from the wall of an upstairs toilet leading to water damage, but the house was otherwise undamaged. Timber clad framed structures were not surveyed but anecdotal discussions with owners indicated no discernable damage in this type of structure.

The severity of damage to each building was assigned a repair cost as a proportion of the reconstruction cost. This index was based on the following preliminary process:

1. Recorded damage to building elements was categorised into a damage state from None, Slight, Moderate, Extensive and Complete to match the HAZUS damage states (HAZUS, 1999), refer to Table 2.
2. A percentage damage was assigned to each element as shown in Table 2.
3. The percentage loss for a building was determined as the sum over all building elements of: (% of building cost contributed by the element) x (% damage) x (% of element so damaged). The results are presented in Tables 3 and 4.

Future work will revisit this process in a more detailed, quantity surveyor style process.

## FUTURE ACTIVITY

Further analysis of the event is planned which will include a computer simulation of the ground shaking of the event using Geoscience Australia's Earthquake Risk Model (Robinson et al 2005). The analysis will incorporate information obtained from seismic recordings of aftershocks that were obtained by GA over a period of 48 days following

the earthquake. The work will also include estimates of the repair costs derived from the survey data using quantity surveying techniques that can be linked to the predicted shaking.

Figure 6. Cracking in modern residential brickwork.

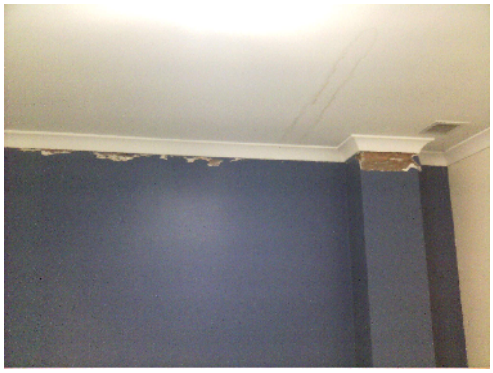

Figure 7. Cracking of cornices in residential construction.

Table 2. Assignment of damage states based on survey results. The numbers describing wall damage relate to pre-defined levels of damage to masonry walls.

| Damage state | Building Element | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Chimneys | Roofs | Verandah/ Awnings | Ceilings | Front parapet | LH Parapet | RH Parapet | Rear parapet | Front wall | LH wall | RH wall | Rear wall | Internal walls | Floors | Implied damage |
| **None** | None | None | None | None | None | None | None | None | None | None | None | None | None | None | 0% |
| **Slight** | Cracked | Dents | Dents | Some gaps around perimeter | Fine cracks and render fall | Fine cracks and render fall | Fine cracks and render fall | Fine cracks and render fall | 1 or 2 | 1 or 2 | 1 or 2 | 1 or 2 | Fine cracks | Some separation cracks | 2-10% |
| **Moderate** | Displaced | Minor collapse | Minor collapse | Some sagging | Coarse cracks and displacement | Coarse cracks and displacement | Coarse cracks and displacement | Coarse cracks and displacement | 3 or 4 | 3 or 4 | 3 or 4 | 3 or 4 | Coarser cracks with render fall | Loss of support at walls | 10-50% |
| **Extensive** | Leaning | Portions collapsed | Portions collapsed | Lots of sagging | Leaning | Leaning | Leaning | Leaning | 5,6 or 7 | 5,6 or 7 | 5,6 or 7 | 5,6 or 7 | Some severe cracks | Some sections fallen | 50-100% |
| **Complete** | 100% toppled | Wrecked | Wrecked | Require replacement | Toppled or severely cracked | Toppled or severely cracked | Toppled or severely cracked | Toppled or severely cracked | 8 or 9 | 8 or 9 | 8 or 9 | 8 or 9 | Severely cracked or collapsed | Collapsed | 100% |

Table 3. Preliminary calculated damage indices (DI's) expressed as population repair cost as a proportion of total rebuild cost. Higher DI's and vulnerability was evident for older buildings. Note that this is based on preliminary data processing and costing that will be refined in the near future.

| **Age Range** | **No. of obs.** | **Proportion in Damage State** | | | | | | **Average DI** |
|---|---|---|---|---|---|---|---|---|
| | | **Damage state** | **None** | **Slight** | **Moderate** | **Extensive** | **Complete** | |
| | | **Damage State Lower DI limit** | **0.00** | **0.02** | **0.1** | **0.5** | **0.9** | |
| | | **Damage State Upper DI limit** | **0.02** | **0.1** | **0.5** | **0.9** | **1.00** | |
| <1914 | 207 | | 0.79 | 0.14 | 0.07 | 0.00 | 0.00 | 0.019 |
| 1950-1979 | 11 | | 0.91 | 0.09 | 0.00 | 0.00 | 0.00 | 0.005 |
| 1980+ | 171 | | 0.92 | 0.07 | 0.01 | 0.00 | 0.00 | 0.005 |

Table 4. Partition older masonry between MMI 5 and MMI 6. Note that older masonry buildings in Boulder BD suffered approximately 3.5 times the average damage suffered in Kalgoorlie CBD.

| Age range | Kalgoorlie CBD (MMI 5) | | Boulder BD (MMI 6) | | Modern Suburbs (MMI 5) | |
|---|---|---|---|---|---|---|
| | No. of obs. | Average DI | No. of obs. | Average DI | No. of obs. | Average DI |
| <1914 | 143 | 0.011 | 64 | 0.037 | 0 | - |
| 1950-1979 | 3 | 0.000 | 6 | 0.009 | 2 | 0.000 |
| 1980+ | 1 | 0.001 | 5 | 0.021 | 165 | 0.004 |

## SUMMARY

Preliminary findings from this work have shown that older masonry buildings are particularly vulnerable to the nature of the ground motion experienced in the Kalgoorlie event. Damage was observed at MMI 5 in Kalgoorlie and MMI 6 in Boulder where hazard exposure resulted in some older structures experiencing severe damage. It was also noted that more contemporary cavity brick construction appeared to have experienced greater damage than equivalent framed construction, though damage was light.

Supplementary research utilising the data captured is expected to provide some useful validation data that can be subsequently used to constrain vulnerability functions. The damage costing process in particular will be refined with overall damage indices expect to increase. The objective will be to derive the greatest benefit from the survey effort to inform future assessments of earthquake risk and mitigation.

## ACKNOWLEDGEMENTS

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