

# PRELIMINARY OBSERVATIONS OF THE 2010 DARFIELD (CANTERBURY) EARTHQUAKES:

## AN INTRODUCTION

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### SUMMARY

This Bulletin of the New Zealand Society for Earthquake Engineering (NZSEE) is a collaboration with the New Zealand Geotechnical Society (NZGS) and the Structural Engineering Society New Zealand (SESOC), with papers on the preliminary observations of the 2010 September 4, 04:35 (NZST; September 3, 16:35 UTC) Darfield (Canterbury) earthquakes.

This Introductory paper summarises preliminary observations of the earthquakes and the performance of ground, structures, non-structural elements, and lifelines; the assessments of usability; and the communication of information amongst the science and engineering communities.

### INTRODUCTION

The Darfield moment magnitude ( $M_w$ ) 7.1 earthquake and aftershock sequence occurred in the South Island of New Zealand, 30 km west of Christchurch (Figure 1), New Zealand's second largest urban centre with a population estimated at 376,700 (Statistics NZ) [1].

The Darfield earthquake main-shock (also known as the "Canterbury" or "Christchurch" earthquake) is the first large earthquake close to a New Zealand urban centre since the surface wave magnitude ( $M_s$ ) 7.8 Hawke's Bay earthquake of 1931.

There were no fatalities and only two serious injuries. In part due to the good performance of most houses and modern buildings, in part due to the timing of the main-shock, in the early hours of a Saturday morning when few were on the streets or in the business districts.

The emergency response was effective, using planned arrangements, across local authorities, lifeline utility operators, engineering consultancies, and national agencies. Christchurch City, and Waimakariri and Selwyn Districts, all declared a State of Local Emergency for their districts under the Civil Defence Emergency Management Act 2002.

The full impacts and consequences of the Darfield earthquakes are still emerging. The costs of recovering housing and business interruption, compounded by non-structural damage, are both likely to be big contributors to economic losses that have been estimated at NZ\$4 billion (New Zealand Treasury) [2].

This Bulletin of the NZSEE presents preliminary observations of the Darfield earthquake sequence and impacts, with papers authored by members of the NZGS, the SESOC, as well as NZSEE, together with associates from New Zealand and from overseas, including representatives of Earthquake Engineering Research Institute (EERI), Australian Earthquake Engineering

Society (AEES), Pacific Earthquake Engineering Research Center (PEER), Geotechnical Extreme Events Reconnaissance Association (GEER), and Japanese Geotechnical Society (JGS).

The preliminary observations will be followed by more analytical papers and reports, based on yet more data, and will be published variously in New Zealand and overseas.

At press time, many key responders are fully committed on priority recovery efforts and are unable to report yet. Consequently, in spite of the extensive topic range, there are gaps in this volume, including building safety evaluations during the response, lifeline utility response and recovery, land and housing remediation, and the economic impacts and recovery of earthquake losses. Some aspects are highlighted in this introductory paper.

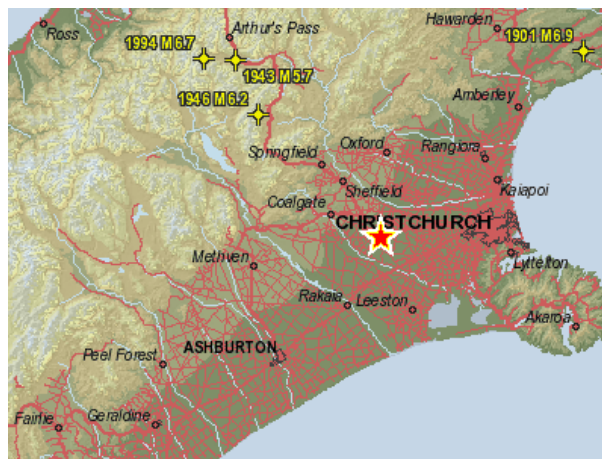


Figure 1 Location of epicentre

(<http://www.geonet.org.nz/earthquake/quakes/3366146g.htm>)

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## THE DARFIELD (CANTERBURY) EARTHQUAKES

The Darfield earthquake sequence commenced at 2010 September 4, 04:35 local time (NZST; September 3, 16:35 UTC). Earthquakes of the Darfield sequence were recorded and reported by the GeoNet project, the principal geological hazard monitoring system for New Zealand<sup>4</sup>; it informed responders, media, and the public well. Aftershocks up until 2010 Nov 28 included 135 greater than M 4, of which 13 were greater than M 5.

The main-shock is complex. Four rupture/energy sources have been identified, in close proximity in time and space (Gledhill et al., p.215 this volume; Cousins & McVerry, p.222; Beavan et al., p.228). The Greendale strike slip fault trace that disrupted the rural landscape of the Canterbury Plains (Quigley et al., p.236; Almond et al., p.432) is the most energetic of the sources.

Evidence for the complexity of the main-shock sequence includes a well constrained epicentre north of the Greendale surface fault trace, high near-source vertical accelerations, first-motion and regional moment tensor focal mechanisms that differ from teleseismic solutions, and a complex aftershock pattern (Gledhill et al., p.215) that together deformed the ground surface, detected by accelerograms and differences between pre- and post-earthquake GPS and INSAR observations (Beavan et al., p.228).

Main-shock accelerograms were recorded from 130 sites across the South Island, ten of which had peak horizontal accelerations in the range 0.3 g to 0.82 g. One near-fault record, from Greendale, had a peak vertical acceleration of 1.26 g. Eighteen records showed peak ground velocities exceeding 0.5 m/s, with three of them exceeding 1 m/s. The records included some with strong long-period directivity pulses, some with other long-period components that were related to a mixture of source and site effects, and some that exhibited the effects of liquefaction at their sites. There were marked differences between records on the deep alluvium of Christchurch City and the Canterbury Plains, and those on shallow stiff soil sites (Cousins & McVerry, p.222).

## GROUND DAMAGE

From an engineering viewpoint, it has been argued that the most significant aspects of the 2010 Darfield earthquakes were geotechnical in nature, with liquefaction and lateral spreading being the principal causes of the extent of damage (Allen et al., p.243).

Slope failures, other than lateral spreads, were relatively minor but did close roads, notably between Christchurch and the Port of Lyttleton.

The surface trace of the Greendale fault fortunately disrupted only the rural area to the west of Christchurch (Quigley et al., p.236, Almond et al., p.432).

<sup>4</sup> GeoNet is comprised of networks of geophysical instruments, automated software applications and skilled staff. GeoNet detects, analyses, and responds to earthquakes, volcanic activity, large landslides, tsunami and the slow deformation that precedes large earthquakes (<http://www.geonet.org.nz/index.html>). Teleseismic recording also contributed to understandings of the Darfield earthquakes (e.g. <http://earthquake.usgs.gov/earthquakes/eqinthenews/2010/us2010atbj/>), see Gledhill et al., p.215). GeoNet's establishment and operation is largely funded by the Earthquake Commission (EQC)<sup>5</sup>.

## EVALUATIONS OF USABILITY

Building assessments began within 12 hours of the main-shock, using the "Building Safety Evaluation during a State of Emergency" process developed during the 2009 NZSEE Learning From Earthquakes mission to Padang, Indonesia (Brunsdon et al., 2010) [3].

Members of the Padang Team inducted over 100 mostly volunteer engineers who, teamed with New Zealand Fire Service Urban Search and Rescue (USAR) technicians and council building officials, made the building safety assessments.

For Christchurch City, Waimakariri District, and Selwyn District, some 1,000 commercial and nearly 9,000 residential buildings were assessed, some more than once following damaging aftershocks. Each Council managed their assessment process well.

Level One triage assessment postings (Green, Yellow, Red) were made from an external inspection only. For some buildings, Level Two assessments were also made, with interior inspections, and providing for seven usability categories (G1, G2, Y1, Y2, R1, R2, R3; Brunsdon, *ibid.*). The Red R3 – "*UNSAFE - Do Not Enter or Occupy - At Risk from Adjacent Premises or Ground*" was posted in several situations on buildings that were undamaged but at risk from neighbouring building(s) assessed as unsafe.

Building Safety Evaluations and postings were also applied to houses (for the first time in New Zealand), addressing the safety of occupants. Two additional checks were added, "Sanitary?" and "Secure (lockable)?" Safe, sanitary, and secure, are three basic requirements for habitability.

The yellow "*RESTRICTED USE*" had to be modified for application to housing, from "*No Entry Except on Essential Business*" to "*Do Not Occupy Restricted Rooms*", for rooms at risk from, for example, a damaged chimney.

In some instances, such as at the University of Canterbury campus, structural inspections and green "safe" placards posted on buildings were required to assure people that the buildings were safe to occupy (Deam et al., p.368).

Building Safety Evaluation Postings only apply when a State of Emergency (under the Civil Defence Emergency Management Act 2002) is in place. The State of Emergency provides liability protection for the evaluators while they are acting under the direction of the Controller. The postings are superseded by Dangerous Building Notices posted under the Building Act 2004. Provisions of special emergency legislation, the Canterbury Earthquake Response and Recovery Act 2010, supported the early lifting of the States of Emergency and the transition from the Building Safety Evaluation Postings to the Dangerous Building Notices.

Building safety assessments were followed by owner initiated detailed inspections. The building evaluations and inspections are yet to be fully debriefed. Some areas for improvement are known.

Bridges were graded similarly to the triaged buildings. *Green* meant "safe for use with no visible damage"; *Yellow* stood for "safe for use but with visible damage", while *Red* was applied to bridges judged "unsafe for use" (Palermo et al., p.412).

Earth buildings have been assessed on a modified EERI scale (A through E; Morris et al., p.393).

Reservoirs were graded from 1 (no repairs required) through 5 (major repairs or replacement required) (Davey, p.429).

University of Canterbury campus printers, scanners and copiers have a single supplier who, post earthquake, inspected

and triaged the equipment with green, orange and red stickers to indicate their usability (Deam et al., p.368).

## BUILDING PERFORMANCE

Modern buildings and houses generally responded well, but the recorded strong ground motions indicate that for most the shaking was generally below NZ earthquake design levels for Serviceability Limit and Ultimate Limit States.

Extensive areas of liquefaction and associated lateral spreads inflicted damage on houses, some commercial buildings, and lifelines, particularly in areas close to topographic lows, such as stream channels, rivers and wetlands, and particularly in Christchurch and Kaiapoi (Allen et al., p.243).

The major impacts to building structures during the Darfield earthquakes were related to unreinforced masonry (URM) buildings (Dizhur et al., p.321) and residential areas where ground failure below or near the foundation was observed (Buchanan & Newcombe, p.387). Modern structures supported on stable ground in general performed well (Kam et al., p.340; Bruneau et al., p.351), as did most retrofitted URMs. Exceptions are known of but further detailed inspection is required before they are reported on. A detailed building-by-building post-earthquakes assessment may be warranted.

URM performed as expected, and as for previous earthquakes since their introduction to New Zealand. Old masonry (typically clay brick) buildings, chimneys, and fences failed and were life threatening. However, only two unoccupied URM buildings collapsed, and only after a shallow 5.1 aftershock centred about 5 km from them. Many URM structures, particularly in the Christchurch and Kaiapoi business districts, suffered partial collapse due to strong shaking while modern structures in the same area were generally unaffected. Many heritage URM buildings were compromised; some were demolished (Dizhur et al., p.321; Anagnostopoulou et al., p.374).

Some inter-building pounding damage occurred (Cole et al., p.382). Isolators were activated for the only base-isolated building in the area, the Christchurch Woman's Hospital (Gavin & Wilkinson, p.360).

Non-structural failures were widespread, life threatening, and impacted business continuity, even food supply chains (Dhakal, p.404; Deam et al., p.368; Crosier et al., p.425).

Christchurch City Council changed its earthquake prone building policy within a week of the main-shock.

## HOUSING PERFORMANCE

As a result of the Darfield earthquakes, some 3,000 houses need to be rebuilt; some 3,000 need to be made weatherproof.

The most common type of damage for older houses (more than 15 years old) was life threatening chimney collapse. Some 26,000 chimneys are claimed to have collapsed. Falling chimneys could be interpreted as a violation of the "life-safety" criterion required by New Zealand Standards (NZS1170.5, 2004) [4] for current building seismic design. Falling chimneys resulted in damage or piercing of the surrounding roof structure, damage to neighbouring properties and to vehicles, but (by good luck) no loss of life. Chimney collapse on to corrugated steel roofing often caused no further damage. Chimneys falling on to tile roofs (concrete or clay tiles, or slates) more often fell through into the house, causing further damage as well as potential loss of life (Buchanan & Newcombe, p.387).

The performance of housing founded in lateral spreads has not been good for the Darfield earthquakes, particularly those houses built in the last twenty years that are founded on a concrete slab on grade. The light timber frame buildings standard (NZS3604, 1999) [5] has no provision for foundations on potentially liquefiable soils or lateral spreads. Inadequacies of what was current practice are now evident, and the recent guidelines for geotechnical site investigation now has demonstrable relevance (McManus et al., 2010) [6].

The Earthquake Commission (EQC)<sup>5</sup> implemented its Catastrophe Response Programme like never before. Since the main-shock, insured homeowners have lodged 142,635 claims with EQC, as at December 1. EQC, with a base staffing of c. 20, now has over 1,000 staff processing and assessing the claims.

As so many residential properties were affected by earthquake shaking and many by liquefaction and lateral spreading (Allen et al., p.243; Buchanan & Newcombe, p.387) the investigations of land damage and remediation options became a priority recovery activity managed by EQC (Tonkin and Taylor, 2010) [7]. Public/private collaborations and sharing of relevant data to better inform recovery decisions is now occurring by agreement, managed by EQC.

An Engineering Advisory Group has also been established by EQC, to develop recommendations for a guide for house repairs and reconstruction, to be produced by the Department of Building and Housing.

## LIFELINE UTILITIES PERFORMANCE

Lifeline utilities (infrastructure) in the Canterbury region have addressed multi-hazard risks since the 1990s. Individual Lifeline Utilities that have been active members of the Canterbury Engineering Lifeline Group can be credited with the relatively high level of overall lifeline resilience.

There were outages. However, notable service restoration included power restored to 90% within 24 hrs (Watson, p.421); telecommunications to 90% within 24 hrs. Water supplies were mostly restored well within 5 days.

Waste-water restoration is ongoing and for a few relatively localised areas is expected to take more than 18 months. Temporary arrangements are in place.

## SCIENCE AND ENGINEERING RESPONSE COMMUNICATIONS - CLEARING HOUSES

Physical and virtual clearing houses were established after the earthquakes, following prior "learning from earthquakes" experiences and others practice such as Holzer et al. (2003) [8], and Holzer (2008) [9].

Physical clearing houses in the first few weeks comprised evening "daily catch-ups" that demonstrated an impressive collaboration and free exchange of information between scientists, engineers, government officials, and international

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<sup>5</sup> The Earthquake Commission is New Zealand's primary provider of natural disaster insurance to residential property owners. It insures residential buildings, land and personal belongings against damage caused by earthquakes, natural landslips, volcanic eruption, hydrothermal activity, tsunami, storm or flood damage (to land only), and fire caused by any of the above. EQC also encourages and funds research about matters relevant to natural disaster damage and it educates and otherwise informs people about what can be done to prevent and mitigate damage caused by natural disasters.

visitors. Some material reported in this volume was corroborated in those catch-ups. Subsequently, the frequency of the meetings reduced, but three months after the main-shock demand continues for the technical forums organised by NZGS, SESOC, and NZSEE.

Virtual clearing houses have been set up, including by the Natural Hazards Research Platform (for registered users), NZSEE (for both public and for registered users), AEES, and EERI. Hit rates demonstrate a demand.

### PLAUDITS

Hon Dr Nick Smith, Minister for the Environment (and a geotechnical engineer), said at the 2010 Institution of Professional Engineers New Zealand (IPENZ) Engineering Excellence Awards (Wellington, 24 Nov 2010):

*“... the New Zealand earthquake engineering profession as a whole can take pride in how our standards, design and professional training played an enormous role in protecting people from harm from that massive quake. I have met several delegates of international guests who are in awe of how we avoided loss of life from a 7.1 magnitude quake.*

*Also impressive was the magnitude of the voluntary response of our profession – in the first week almost 100 engineers worked as volunteers, particularly in building safety evaluation. I understand that hundreds of others made themselves available. Your professional body, IPENZ got stuck in, working to coordinate with those on the ground in Christchurch. Then there were many other engineers working extended hours in the restoration of utilities. The Government expresses its strong thanks for this.*

*There are huge challenges ahead in the rebuild and there is more to learn and improve on in how we manage the risk of liquefaction.”*

Royal Society of NZ Presidents Award to NZSEE – *“In recognition of contributions made by earthquake scientists and engineers for the prevention of loss of life in the Christchurch earthquake of 2010”.*

Hon Helen Clark, UNDP Administrator, reported on September 16 by *Stuff* that the *“World should emulate NZ”* -

*“Countries around the world should aspire to be as prepared as New Zealand for massive natural disasters like the Christchurch earthquake, former Prime Minister Helen Clark says. ...There were no deaths, mostly because there were years of a strong building code and anticipating that New Zealand, on the ring of fire ... around the Pacific, could suffer such an event”.*

<http://www.stuff.co.nz/world/4134034/World-should-emulate-NZ-Helen-Clark>.

### CONCLUSION

For the Darfield earthquakes, we can be pleased there has been no loss of life and only two serious injuries; that modern structures performed well; that infrastructure in general performed well and was restored very quickly.

We can be pleased with the emergency response, including the integration of USAR with the Building Safety Evaluation process of the three local authorities, and the support from over 100 volunteer engineers organised by IPENZ.

We can also be pleased with the recognition that earthquake risk research and mitigation of past decades has had a return through increased resilience.

However, we must recognise the fortuitous timing of the main-shock, which was good luck.

We have to be disappointed with yet more life-threatening URM failures; numerous life-threatening non-structural failures and the resulting business disruptions; and the failures, predominately of modern housing, on known liquefiable soils.

Can we increase the retrofit rate of earthquake prone buildings, given the number of un-strengthened URMs?

Can we learn to install or retrofit non-structural elements, including building services, according to existing standards?

Can we learn to design and construct better structures, in a sustainable and holistic manner, that are well founded, functional, and recoverable? Similar earthquake shaking is certain to occur again in New Zealand, including areas of known liquefaction hazard.

We can't continue to rely on good luck, but we can learn from the experience of the Darfield (Canterbury) earthquakes.

### ACKNOWLEDGMENTS

Henri Gavin took on the role of Guest Editor for the papers in this issue. Without his drive and focus you would not have this collection now. Henri's effort has been outstanding.

All authors and reviewers, as well as the staff at Caxton Press, are also thanked for the extra post-earthquake efforts to enable reporting in this manner at this time, for many this period included suffering aftershocks.

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