BRANZ

ISSUE551 BULLETIN

DISTRIBUTION NOTICE

BRANZ has issued this technical Bulletin free-of–charge and with no restrictions on use or forwarding to other parties for the benefit of the New Zealand building industry.

In allowing free distribution, we request users check the following information:

- Nothing from this document should be removed or altered and re-supplied to another party as a BRANZ document. If you believe this information has been altered in any way please refer to the BRANZ web site to check the original.
- This document is supplied without any logo's or statements from other parties. As above please refer to the BRANZ website if you believe the document has been altered.
- BRANZ has excused normal copyright and distribution conditions on this bulletin for the purpose of sending the electronic copy to other parties and / or for the printing of hard copies for distribution to interested parties. However, no part of this bulletin should be reproduced or photocopied in isolation from the whole of the document.
- We would appreciate knowing how many hard copies or electronic copies users distribute to other parties – please advise us at branz@branz.co.nz
- All other BRANZ bulletins maintain strict copyright and distribution requirements. No other BRANZ bulletin can be electronically sent or printed without the express permission of BRANZ Ltd

LEARNINGS FROM THE CANTERBURY EARTHQUAKES

August 2012

- Four earthquakes of magnitude 6.0 or greater hit Canterbury between September 2010 and December 2011. Smaller aftershocks continue.
- 185 people died and over 143,000 building claims have been lodged with the Earthquake Commission. Total losses are estimated at $30 billion.
- This bulletin gives an overview of the learnings that came from examination of damaged buildings.

1.0 INTRODUCTION

1.0.1 Four earthquakes of magnitude 6.0 or greater struck Canterbury between September 2010 and December 2011:

- **Darfield earthquake, 4 September 2010,** 4.35 am
  - Magnitude 7.1
  - 40 km west of Christchurch
  - 10 km deep
- **Lyttelton earthquake, 22 February 2011,** 12.51 pm
  - Magnitude 6.3
  - 10 km south-east of Christchurch
  - 5 km deep
  - More than 180 deaths
- **Christchurch earthquake, 13 June 2011,** 2.20 pm
  - Magnitude 6.3
  - 10 km east of Christchurch
  - 6 km deep
- **Christchurch earthquake, 23 December 2011**, 2.18 pm
  - Magnitude 6.0
  - 10 km east of Christchurch
  - 6 km deep

1.0.2 The series was unique in New Zealand and the world because:

- there were several major events in a short timeframe
- the quakes were centred close to each other
- there were high vertical accelerations
- there was widespread liquefaction.

1.0.3 BRANZ engineers travelled to Christchurch following the earthquakes to conduct building safety evaluations and research damage in the housing stock. Two engineers were in the city during major events. One was in Christchurch by chance during the September 2010 event; he and another BRANZ engineer were undertaking Department of Building and Housing Engineering Advisory Group work in the city during the June 2011 event.

1.0.4 BRANZ staff surveyed approximately 140 houses after the September 4 event for research purposes. The most obvious learning from this stage was that timber-framed houses generally experienced minimal damage unless they were affected by liquefaction or lateral spreading.

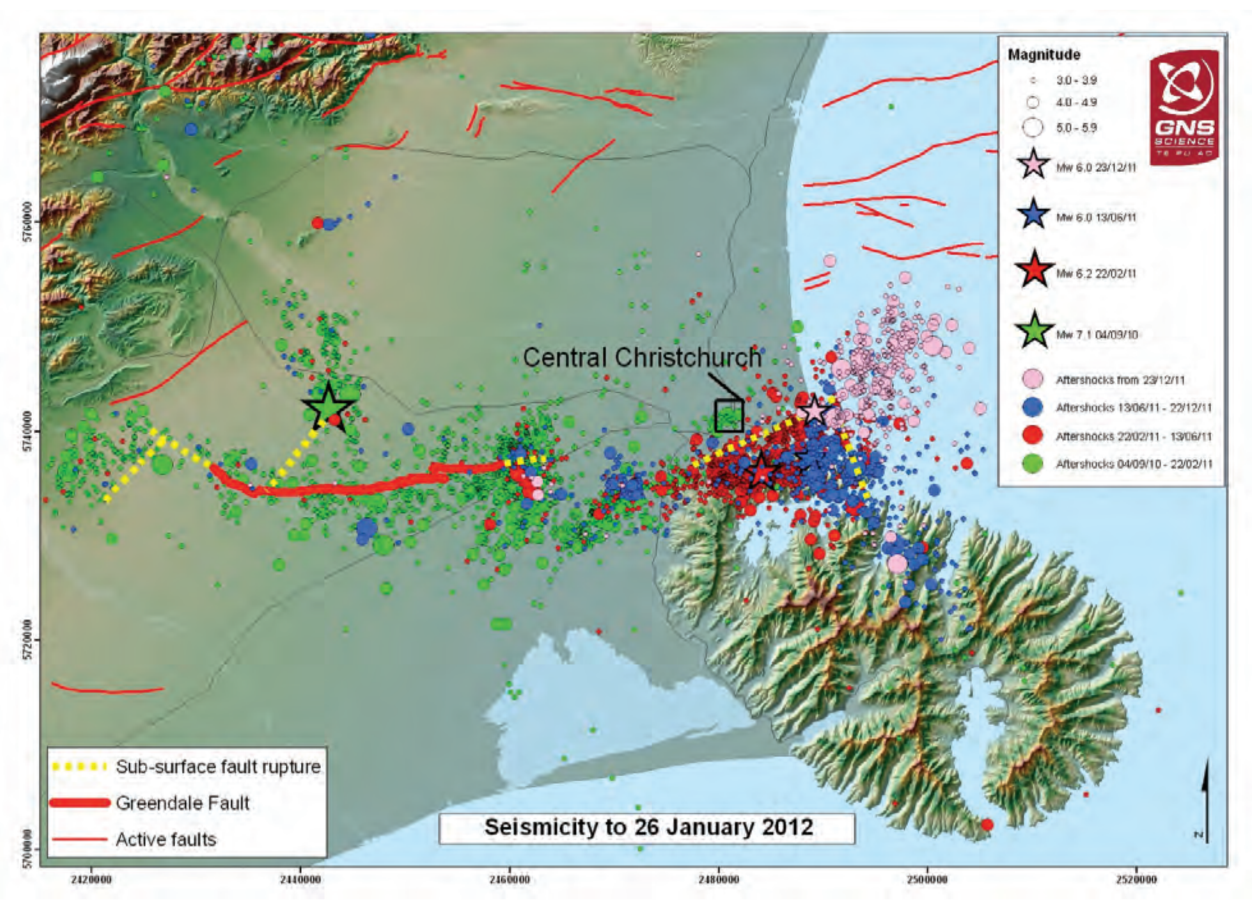
1.0.5 After the February 2011 event, BRANZ engineers took part in Operation Suburb, which made initial (level 1) safety assessments of 75,000 houses in the eastern and southern suburbs over 10 days.

1.0.6 BRANZ staff subsequently conducted an extended research survey of 340 houses randomly selected over Christchurch city.

2.0 ROLE OF THE BUILDING CODE

2.0.1 New Zealand Building Code clause B1 *Structure* has the objectives:

- to safeguard people from injury caused by structural failure (technically referred to as 'ultimate limit state' or ULS)
- to safeguard people from loss of amenity caused by structural behaviour ('serviceability limit state' or SLS).



Locations of the main shocks and aftershocks greater than magnitude 3.0, 4 September 2010–26 January 2012. There were around 10,000 shakes in total; note how the shift has been towards the east. It is estimated that the last movement on Greendale fault was 14,000 years ago. (GNS Science graphic)


Careful design and construction meant this 2 storey masonry veneer house performed well, with only minor damage inside.


Lateral spreading is clearly visible in the grounds around this house.

2.0.2 Modern buildings generally satisfied these objectives considering the level of shaking.

2.0.3 Most houses, regardless of age, also satisfied these objectives.

2.0.4 In some cases, however, there was significant damage.

3.0 LIQUEFACTION AND LATERAL SPREADING

3.0.1 Soil liquefaction occurred on a large scale as a result of several of the large earthquake events.

3.0.2 Soils most likely to liquefy are low density sands and silts with a high water table, so the space between the grains is filled with water.

3.0.3 During an earthquake, the loose granular soil starts to behave like a liquid. It cannot support the weight of what is above it – surface layers of soil or concrete foundations. The liquid is forced up through cracks and crevices and flows to the surface, taking sand and silt with it and creating sand volcanoes.

3.0.4 Liquefaction can result in:

- settlement of the ground surface (and all or part of a building on the ground) due to underground soil compaction and ejection of sand
- loss of support to building foundations
- surface soil layers close to sloping ground surfaces (such as riverbanks) slide sideways – this is called lateral spreading.

3.0.5 Having one liquefaction event does not mean there will be no more at the same site. Some Canterbury sites experienced liquefaction during several events.

4.0 GROUND SHAKING

4.0.1 How much the ground shakes at a particular location depends on how far it is from the epicentre of the earthquake and the type of ground below the site:

- Rock sites respond to short-period jolts.
- Soft soil sites respond to longer-period motions.

4.0.2 The vertical accelerations were unexpectedly high in the Canterbury events. In design, vertical actions are assumed to be 0.7 times the horizontal actions, but on the Port Hills, they were recorded at over 2.5 times the design level, and on occasions were greater than the horizontal accelerations.

4.0.3 The hill suburbs were affected most by ground shaking and distortion, with many examples of ground slumping/sliding affecting houses.

5.0 HOUSING STOCK

5.0.1 The foundations of houses on flat land that BRANZ examined:

- with older houses, were mainly concrete piles with concrete perimeter foundations
- included a small number of all-piled houses
- newer houses were mainly slab on grade (sometimes unreinforced).

5.0.2 The foundations of houses on the hills:

- were often benched slab on grade (for newer houses)
- often had perimeter foundations (concrete, masonry, stone) for older houses with suspended timber floors


There were many examples of ground slumping/sliding affecting houses.

- included some cut-in basements with slab-on-grade floors and retaining walls
- included some pole foundations.

5.0.3 Most houses were timber framed, although a number of newer hill houses were of concrete masonry.

5.0.4 A large proportion of wall claddings were clay or concrete brick veneer, and there were some weatherboard, fibre-cement, EIFS and stucco-clad houses as well. A few houses BRANZ visited were built of reinforced masonry, and a few were other systems such as concrete sandwich panels.

6.0 LEARNINGS FROM THE EARTHQUAKES

6.1 HILL SITES

6.1.1 Hill sites can be difficult and have unique risks from earthquake events that need to be addressed:
- Complexity of structures on hillsides will often increase.
- There may be a risk of falling boulders or cliff falls.
- Ground instability can be a problem.

6.1.2 The increased complexity comes from the fact that hillside homes are often outside the scope of NZS 3604 *Timber-framed buildings* – specific engineering design is often required. There may be split levels, plan irregularity and vertical irregularity. These houses can involve a mix of structural systems and stiffness.

Plan irregularity increases the risk of damage.

6.1.3 BRANZ examined a number of hillside houses that had large open internal spaces and panoramic windows along one wall designed for a view. These houses often suffered because the front of the house (with the windows) was much less stiff than the rear.

6.1.4 Pole-framed houses generally performed well, although there were examples of failed diagonal braces.

6.2 CONNECTIONS

6.2.1 The type and extent of damage that occurred to the houses BRANZ examined clearly shows the crucial nature of connections. Tying things together properly is crucial:
- with structural and non-structural elements
- with cladding attachments.

6.2.2 Connections between alterations and the original building were a frequent source of problems. They need to be tied together, and closely related to this is the requirement that they have similar foundations.

6.2.3 Good roof and floor design generally hold the building together, but BRANZ observed damage to roof valleys where roof shapes were complex.

The connections failed on this precast concrete panel.

6.2.4 Gables are often vulnerable if they are poorly attached to the roof framing and not braced.

6.2.5 BRANZ also saw damage resulting from the tops of rafters being inadequately connected to the ridge board.

6.2.6 BRANZ saw some connection problems in houses built with precast concrete panels.

6.3 SLABS AND FOUNDATIONS

6.3.1 Slabs generally performed well, except where they:

- were affected by liquefaction
- were unreinforced
- had reinforcement mesh (used for many years as

crack control) that proved to be brittle, or
- were not tied to foundations.

(The last three issues were subsequently addressed by Amendments 10 and 11 to B1/AS1.)

6.3.2 Damage from inadequate slab reinforcement ranged from cracks a few millimetres wide to cracks wider than a handspan. A lack of continuity of reinforcing at slab corners led to the corner breaking open in some slabs.

6.3.3 Where slabs were not tied to foundations, BRANZ sometimes found complete disconnection of the slab from the foundation where the slab had moved separately from the foundation.

6.3.4 Many wall foundations had inadequate reinforcement or none at all, and this resulted in damage ranging from small cracks opening up to one whole side of a foundation breaking away from the other sides.

6.3.5 Piled floors with a perimeter foundation often performed well, and the damage that occurred was relatively easy to fix.

6.4 HEAVY ELEMENTS AND CLADDING

6.4.1 Heavy elements require care. There were numerous instances of unreinforced chimneys falling and causing damage to roofs and walls. Heavy appendages are best avoided.

6.4.2 Unreinforced masonry performed poorly:
- Commercial and residential buildings were both affected.
- Double-skin brickwork and unreinforced concrete blocks typically suffered severe damage.
- BRANZ saw construction with natural stonework that performed poorly.

6.4.3 These problems and others, such as old wire veneer ties inadequately fixed to framing, are well known, but there are a large number of older buildings all over New Zealand that have these types of construction.

6.4.4 Modern veneers performed much better because of their lighter weight, better ties and better mortar. Damage that did occur was typically where ties had pulled out of the mortar or where the veneer foundation had separated from the frame foundation.

6.4.5 Concrete roof tiles suffered damage in a number of houses, even some of recent construction. High vertical accelerations and inadequate fixing of tiles created a falling hazard. Their design and installation need to take account of wind as well as earthquake loading. NZS 4206:1992 *Concrete interlocking roofing tiles* requires fixing of alternate tiles.

6.5 WALLS

6.5.1 Anchoring the frame properly to the slab is vital.

6.5.2 Timber claddings performed very well, especially weatherboards.

6.5.3 Sheet-based claddings were also generally good, although with monolithic cladding, corners at openings were vulnerable to cracking.

6.5.4 Many heritage types of construction performed poorly, for example, lath and plaster walls often had a poor bond, resulting in large pieces of plaster falling off. This applied to external walls as well as internal walls and ceilings.

6.5.5 Concrete and, in particular, concrete columns can be brittle if not detailed properly.

6.5.6 Internal walls must be correctly attached to the floor slab and adequately braced to ceiling or floor above.

6.5.7 Plasterboard linings performed much as expected, excluding the consequences of liquefaction distortion. Some owners/occupants complained about ‘softening’ of the lining after an earthquake and greater noise in the house. Sheet-joint cracking may be repairable – tape-reinforced stopping helps. (See BRANZ Bulletin 548 *Repairing plasterboard after an earthquake*).

6.6 NON-STRUCTURAL COMPONENTS

6.6.1 Non-structural components such as hot water cylinders and log burners need to be properly secured. They must be able to cope with structural movement, for example, having flexible pipe connections.

6.6.2 In the houses BRANZ engineers examined, hot water cylinders were often inadequately fixed to walls; where the cylinder is wedged into a small cupboard, it may perform adequately, but this should not be relied on. Cylinders that come loose can cause water damage to adjacent or lower parts of the building, and there were examples of this.

6.6.3 With windows, there should be glazing clearances to the structural frame. BRANZ saw a number of cases where structural movement had shattered a window, especially on hillside houses. The structure should be stiff enough to protect non-structural components or provision made for movement to occur without causing damage.

6.7 OVERALL HOUSE PERFORMANCE

6.7.1 Houses built to NZS 3604 or NZS 4229:1999 *Concrete masonry buildings not requiring specific design* and that were not affected by liquefaction or ground distortion behaved well in terms of the Building Code.

6.7.2 Shaking damage was sustained (and expected under the loads), but few collapses occurred.

6.7.3 BRANZ found numerous examples of poor behaviour of additions and alterations to existing houses.

6.7.4 Irregularly shaped houses generally fared worse than regularly shaped houses.

7.0 CRUCIAL LEARNINGS SUMMARY

7.0.1 Designers and builders need to be very aware of the special requirements of a site, for example, a hillside site, and recognise the natural hazards.

7.0.2 Complex designs can bring more difficulties and risks than is often realised. Exacting designs will inevitably cost more.

7.0.3 Properly designed and constructed connections are vital to maintain the integrity of load paths.

7.0.4 Provide adequate stiffness – building movement damages finishes and non-structural components.

7.0.5 Heavy claddings and chimneys need to be well reinforced and secured.

7.0.6 Floor slabs are relatively easy to get right, and changes to the relevant Building Code compliance documents as a result of the earthquakes have already been made.

8.0 MORE INFORMATION

PUBLICATIONS

Repairing plasterboard after an earthquake, BRANZ Bulletin 548, June 2012.
Key changes to B1/AS1 and E2/AS1, BRANZ Bulletin 545, February 2012.
Concrete floor slabs, BRANZ Bulletin 541, December 2011.
Upgrading piled foundations to resist earthquakes, BRANZ Bulletin 536, June 2011.
Repairing cracks in concrete, BRANZ Bulletin 535, June 2011.
Revised guidance on repairing and rebuilding houses affected by the Canterbury earthquake sequence (November 2011), Department of Building and Housing.

WEBSITES

BRANZ – www.branz.co.nz
Department of Building and Housing – www.dbh.govt.nz
Standards New Zealand – www.standards.co.nz
NZ Society for Earthquake Engineering – www.nzsee.org.nz
Structural Engineering Society NZ – www.sesoc.org.nz
Canterbury Earthquake Recovery Authority – www.cera.govt.nz
Seismic Retrofit Solutions – www.retrofitsolutions.org.nz

NON-RESIDENTIAL CONSTRUCTION

While BRANZ engineers mainly examined houses, they did look at non-residential buildings and made some findings.

- Unreinforced masonry (URM) generally performed poorly. This is brittle construction with discrete elements that have no chance of adequately resisting earthquake forces experienced. URM boundary walls on many residential properties collapsed.
- Some strengthening systems for URM appear to perform better than others. Tying components together is critical. It is also important to make sure that the stiffness of the strengthening system matches that of the URM being strengthened.
- Multi-storey buildings of modern design (post-1992) generally behaved according to Building Code expectations, but may not be economic to repair.
- Regularity in lateral force-resisting systems is important or otherwise structural behaviour in earthquakes is hard to predict with certainty.
- Soil structure interaction is an important consideration.

CHANGES TO BUILDING CONTROLS

B1/VM1 changes

In the Verification Method, the hazard factor (Z) for the Canterbury earthquake region (Christchurch City, Waimakariri District, Selwyn District) has been increased from 0.22 to 0.3

The return period factor for serviceability level earthquakes – Rs – has increased from 0.25 to 0.33.

NZS 3604 seismic zones

Zone 2 now extends to parts of Selwyn District and Christchurch City that were previously zone 1.

NZS 4299 zone boundaries based on NZS 4203

All of Selwyn District must now be designed for a zone factor of >0.6

NZS 3604, NZS 4229 and NZS 4299 for concrete slabs

All slabs must now be reinforced with ductile reinforcing steel (class E), and slabs must be tied to perimeter foundations.

NZS 3604, NZS 4229 and NZS 4299 ‘good ground’ provisions for the Canterbury earthquake region

Land where liquefaction or lateral spreading could cause movement of more than 25 mm is excluded from the definition of ‘good ground’.

When liquefiable soil is present, standard floor slab details are insufficient and stiffer floor slab options are required – refer to the DBH publication *Revised guidance on repairing and rebuilding houses affected by the Canterbury earthquake sequence* (November 2011).

BRANZ

THE CORE PURPOSE OF BRANZ IS TO IMPROVE PEOPLE'S LIVES THROUGH OUR RESEARCH AND OUR DRIVE TO INFORM, EDUCATE AND MOTIVATE THOSE WHO SHAPE THE BUILT ENVIRONMENT.

BRANZ ADVISORY HELP LINES

FOR THE BULDING INDUSTRY

0800 80 80 85

FOR THE HOME OWNER AND PUBLIC ENQUIRIES

0900 5 90 90

Calls cost $1.99 per minute plus GST. Children please ask your parents first.

HEAD OFFICE AND RESEARCH STATION
Moonshine Road, Judgeford
Postal Address – Private Bag 50 908, Porirua 5240,
New Zealand
Telephone – (04) 237 1170, Fax – (04) 237 1171
www.branz.co.nz

Standards referred to in this publication can be purchased from Standards New Zealand by phone 0800 782 632 or by visiting the website: www.standards.co.nz.

Please note, BRANZ books or bulletins mentioned in this publication may be withdrawn at any time. For more information and an up-to-date list, visit BRANZ Shop online: www.branz.co.nz or phone BRANZ 0800 80 80 85, press 2.

ISSN 1170-8395