THE PERFORMANCE OF HOUSES AND GYPSUM PLASTERBOARD LININGS DURING THE CANTERBURY EARTHQUAKES

Hans Gerlich and Richard Hunt[1]

The Canterbury earthquakes subjected many structures to loads greater than what they were designed for. Following the September 2010 'Darfield' earthquake the Canterbury region has experienced many aftershocks including the devastating February 2011 'Lyttelton' earthquake. This paper considers these two main events and looks back at the performance of houses and gypsum plasterboard linings. Houses constructed from the early 1980s relied to a significant degree on these linings for lateral bracing resistance. In areas subjected to liquefaction, subsidence and lateral spread, damage to houses, contents and plasterboard linings was largely a consequence of foundation and slab movement. Houses with light-weight cladding materials fared much better than houses with heavy brick veneer and clay roof tiles. Well designed and constructed regular shape buildings performed well. Taped and stopped plasterboard linings in light framed buildings are the stiffest element, will attract earthquake forces first, and must be designed and installed to resist these forces in order to minimise damage.

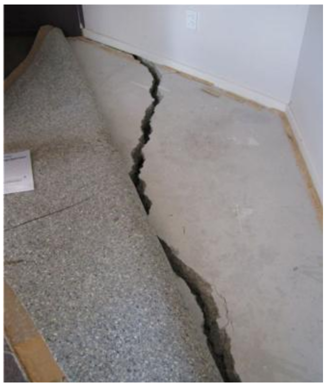
Darfield September 2010

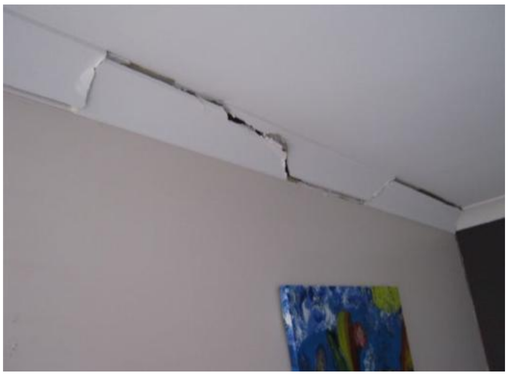
On Saturday 4 September 2010 a strong earthquake centred at Darfield, violently rocked the city centre and its surrounding suburbs. The earthquake caused significant damage to older brick buildings and un-reinforced facades in and around the city CBD. No lives were lost which has been mainly attributed to the fact that the earthquake struck in the early hours of the morning. Although the city centre was all but deserted at that time of the morning, most people were asleep at home. Residential buildings performed very well and most material damage was confined to contents, un-reinforced chimneys, and block or brick veneer claddings.

Violent shaking of soft and wet soils causes lighter silt particles and water to rise to the surface. Significant increases in ground water level were recorded and many occupants described water and silt rushing around their homes "like a river" immediately following the earthquake.

Damage on 'soft soil' sites resulted mainly from movement due to liquefaction, subsidence and lateral spread. As such, this damage can be considered 'consequential' and was not as a direct result of ground shaking. Although consequential structural damage was worse on 'soft soils', contents damage and damage due to ground shaking appeared worse on 'good ground' sites. Two homes with fish tanks illustrate this further. One home sustained significant consequential structural damage due to soft soil subsidence. The house was on a severe lean but the fish tank in the lounge was still intact. In contrast a second house on 'good ground' was still level, but a similarly sized fish tank emptied its contents over the lounge floor with fish being found against the opposite lounge wall.

Damage on soft soils has been greatest to brick veneer homes on un-reinforced concrete slabs. Subsidence and lateral spread (ground cracks opening up) caused slabs to slump and break, and the rest of the structure to follow. The repair of many such structures is complex and expensive, if possible at all. Although older houses with concrete perimeter footings and timber floors on shallow piles suffered similar movement, they are often easier and cheaper to repair.





Broken residential un-reinforced concrete slab and consequential damage to internal linings due to lateral spread

[1] Engineers for Winstone Wallboards Limited

Lyttelton February 2011

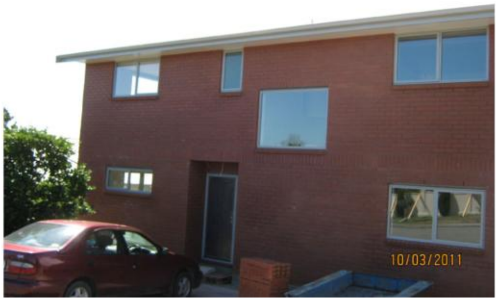
In the early afternoon of Tuesday 22 February Christchurch was struck by a devastating earthquake causing large scale damage in the CBD and surrounding suburbs. Earthquake records show that some buildings may have experienced shaking more than twice the intensity a new building would currently be designed for. The event has been widely reported in the media.

Although the main damage to houses caused by the September earthquake as a result of liquefaction, subsidence and lateral spread of ‘soft soils’, the February earthquake added violent shaking of houses constructed on rock and the hillsides of suburbs like Mt Pleasant, Sumner, Cashmere and Lyttelton.

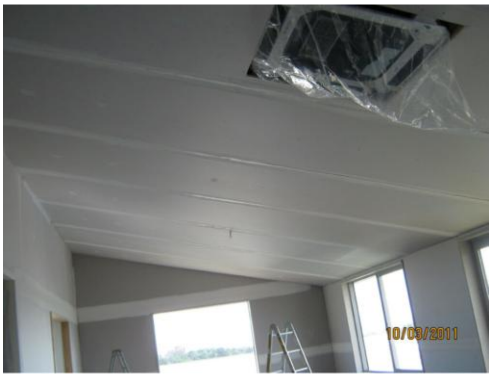
Damage on soft soils included cracked, broken, or tilted concrete slab, cracked or fallen chimneys and brick veneers, shifted pile foundations, and internal lining damage as a result of settlement, typically cracking at sheet joints around window and door openings. Not surprisingly concrete slab houses with brick veneer and heavy tile roofs suffered most on soft soils.

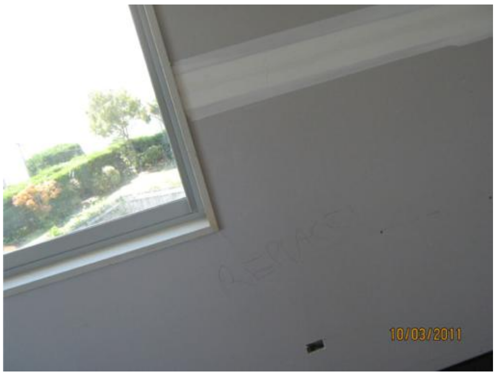
Damage on rock and hillsides was similar, but could be more directly attributed to shaking. Internal gypsum plasterboard sheet linings fared well and in most cases provided significant bracing resistance. Without having building plans, design calculations, and ‘as built’ information available, it is difficult to analyse in detail how bracing systems in individual houses performed.

However, houses under construction provided important information. An example is a two storey brick veneer home located in the severely affected suburb of Mt Pleasant. This house was carefully designed by the building inspector / owner with designated gypsum plasterboard bracing elements clearly marked on the floor and installed in accordance with manufacturer’s instructions. The plasterers were at work when the earthquake struck and plastered sheet joints were still fresh. Apart from expected shear failure of these joints, the house stood up very well.



Building inspector’s Mt Pleasant home under construction lost some of its brick veneer, but performed well supported by gypsum plasterboard bracing systems.



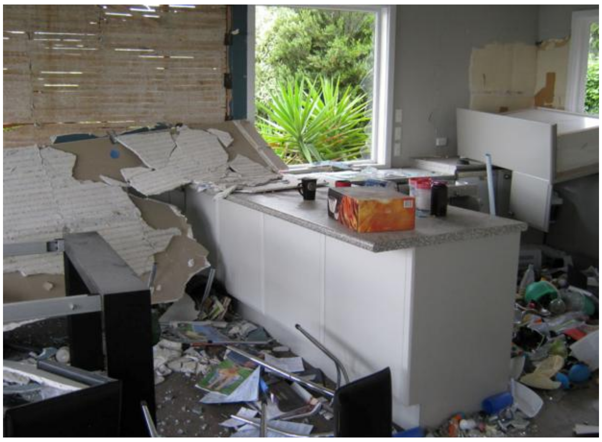


Note: This information is provided by Winstone Wallboards Ltd as general guidelines. They do not replace specific technical information provided to the market.

Just down the road an older two storey 1960s clay brick and concrete roof tile home suffered severe damage. The house had an original internal lath and plaster interior finish which had been modernised by overlaying and decorating with gypsum plasterboard sheet linings which were predominantly glue fixed to the lath and plaster.

Lath and plaster was common in older Christchurch homes and consist of 20 – 25 mm thin timber strips, nail fixed to framing and plastered with two coats of cement-based plaster often followed by a final gypsum-based coat for paint or wall paper finish. The first coat of cement based plaster squeezes through the gaps between the timber strips forming a 'key'. These cement 'keys' are very brittle and during an earthquake they easily break rendering the wall without or with very little bracing resistance.

In the case of this house the lath and plaster failed and the new plasterboard linings had not been designed or installed to resist the imposed earthquake forces.



Violent shaking on hillsides has resulted in severe damage to contents and structures. This older home lost its brick veneer cladding, window glazing, and internal wall linings glue fixed over lath and plaster.

The performance of houses and gypsum plasterboard linings

Poor design and workmanship will be exposed during extreme events. Failures have been observed due to poorly constructed sub-floor and roof framing connections, poor workmanship employed in installing brick veneer wall claddings including lack of mortar bond and ties, heavy weight roof tiles without ties, asymmetry in designs, poor distribution of bracing resistance, etc.

When designed and constructed to a good standard, houses and gypsum plasterboard wall linings have performed remarkably well, protecting people and their homes. *However, considering the severity of the events, and like a car in a serious crash, material damage has to be expected.* This is often not understood by the general public. Ironically even professional engineers have commented that many modern and now 'deconstructed' buildings in the CBD have performed 'beautifully' but plasterboard linings in houses have not. It seems that, in a professional capacity, engineering concepts might be easier to explain than when damage occurs closer to home.

It must be understood that, once all sheet joints are taped and plaster stopped, the internal gypsum plasterboard lining system is very stiff and will attract wind and earthquake forces first, before they can be transmitted to more flexible bracing elements such as cut-in braces or plywood sheathing. If not designed and installed to accept these forces, far greater damage to gypsum plasterboard linings can be expected. For further information see GIB® Information Bulletin 'Bracing light timber framed buildings using sheet materials'.

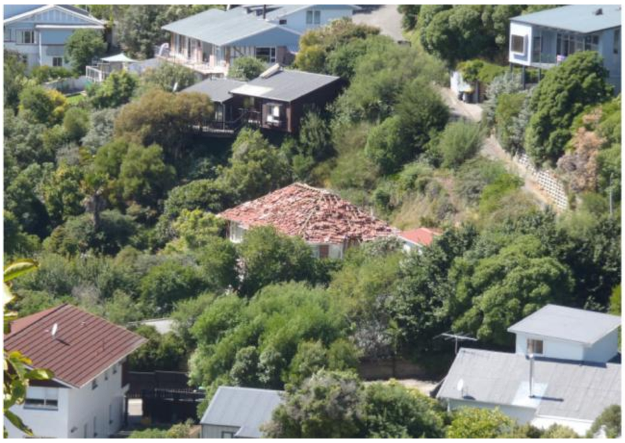
In addition to reports by Buchanan et al. (2010, 2011) and Beattie et al. (2010) the following words are also worth noting and were received from an EQR assessor who has previously been a building official and architectural designer.

" … after having now visited over 200 homes, I am very confident to be able to say that when people involved with building or altering a home, have followed the manufacturers and code requirements, that home seems to have suffered less damage than a home of similar type/design … that had not obviously followed those requirements. Having been a designer and regulatory officer for many years, I feel very justified that all the times I enforced that plans and construction be done to these various requirements, was well worth the efforts. Although unfortunately we could not as a regulatory officer enforce manufacturer's recommendations … we would still often at least recommend them. It is … pleasing to see that when these recommendations have been followed, the home stood up much better …"

Questions have been raised whether we should continue to build houses on soft and liquefiable soils. If we tighten the criteria too much, then how much flat land near waterways, around Canterbury or anywhere else in New Zealand becomes unsuitable for residential development?

Reinforcing has now been mandated for residential floor slabs. This is a step forward and likely to reduce direct damage and consequential damage which has resulted from broken slabs. However, slab reinforcing doesn't stop subsidence and will not necessarily stop slab tilt which has also caused the need for extensive remedial work.

Is it a question of "whether" we should build on soft ground, or should the question be "what" can be constructed on such land? Light-weight structures with shallow piles and non-brittle claddings on perimeter footings have generally performed well and can be readily levelled and repaired following similar events. Although we can design structures on soft soils to survive earthquakes with minimal damage, it is recognised that susceptibility of infrastructure such as roads and services often dictates suitability of land for development.



Houses with heavy-weight roofs were more prone to damage. In addition substantial loss of untied or poorly tied heavy-weight tiles was observed.

It is worth noting that significant damage has been observed to buildings with heavy claddings. A heavy-weight roof cladding increases earthquake demand by as much as 50% when compared with a light-weight roof. When wall and roof claddings are specified as heavy-weight the earthquake demand can more than double compared with light-weight claddings.

Asymmetry of design and uneven bracing resistance distribution has also resulted in torsion effects and damage, particularly in the lower levels of two storey houses and in architecturally designed houses designed around large windows to capture views.

The bracing distribution rules of NZS3604:1999 (and previous versions) have been particularly loose. It was possible within these rules to design entirely unsatisfactory structural shapes. For example a 10 by 15 metre building with 5 bracing lines in the across direction could, depending on total demand, have around 80% of all its bracing resistance in one end wall and 20% distributed over the remainder of the structure.

NZS3604:2011 has tightened the distribution rules and linked them to total demand by requiring each nominated bracing line to have 50% of total demand divided by number of lines used. Although an improvement, the rules can still be abused. The worst case scenario in the above example would result in 60% of all resistance on one line and 40% distributed over the remainder of the structure.

Further reading

Andrew Buchanan and Michael Newcombe, 2010. Performance of Residential Houses in the Darfield (Canterbury) earthquake (M 7.1) 4th September 2010. Department of Civil and National Resources Engineering. University of Canterbury. First Draft September 2011.

G. J. Beattie, R. H. Shelton, S. J. Thurston & A. Z. Liu (BRANZ). The Performance of Residential Houses in the Darfield Earthquake of 4 September 2010. Paper Number 165. Proceedings of the Ninth Pacific Conference on Earthquake Engineering Building an Earthquake-Resilient Society 14-16 April, 2011, Auckland, New Zealand.

Andrew Buchanan, David Carradine, Graeme Beattie and Hugh Morris, 2011. Performance of Houses during the Christchurch Earthquake of 22 February 2011. Bulletin of the New Zealand Society for Earthquake Engineering, Vol .., 2011.

Winstone Wallboards Limited, 2011. Bracing light timber framed buildings using sheet materials. Information Bulletin. November 2011. And further information relating to gypsum plasterboard performance, damage assessment and repairs www.gib.co.nz/canterburyearthquake/