How did houses perform?

BRANZ research shows that houses built to the current Building Code and standards generally stood up well to the Canterbury earthquakes. However, more complex specifically designed houses often had issues.

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This house was effectively destroyed because of damage to foundations resulting from liquefaction.

THE EARTHQUAKES that have struck Canterbury since 4 September 2010 have provided an opportunity for earthquake engineers to compare the actual performance of a wide range of engineering structures against theoretical expectations.

This has been particularly true for BRANZ structural engineers who have been closely involved from the initial event, first in the emergency responses to the main earthquakes of 4 September 2010, 22 February 2011 and 13 June 2011, and then in the recovery operations centred on the region's housing stock.

Both authors have had a close relationship with the Ministry of Business, Innovation & Employment (MBIE) through their participation in the Engineering Advisory Group (EAG), providing guidance on the repair and rebuilding of houses in the region.

House and ground performance

Following the June 2011 earthquake, BRANZ conducted a comprehensive random survey of over 300 houses in Christchurch to gain a better appreciation of the performance of the range of house types, including the effects of ground conditions.

Houses on the flat had either been affected by ground failure resulting from the earthquakes (liquefaction) or by earthquake shaking. While predominantly affected by shaking, some hillside houses were also affected by ground instability such as rock fall, rock roll, and slope and cliff failure.

To varying degrees, liquefaction affected a large proportion of houses on the flat. Of the properties surveyed on the flat, 30% experienced liquefaction of the site, with half of these having liquefaction in all three major earthquake events before the survey.

Christchurch foundation styles

The survey sample confirmed that there have been two predominant foundation styles in Christchurch over the history of the city. Houses built in the early and middle 20th century generally have floors on piles with perimeter concrete foundation walls, while most houses built since 1980 have concrete slab-on-ground foundations.

When the ground liquefied, neither foundation style was sufficiently robust, and many houses were left uninhabitable.

Many of the perimeter concrete foundation walls supported heavy brick or block claddings and heavy concrete or clay tile roofs. When the liquefaction was severe, these walls settled into the ground at a greater rate than the more lightly loaded piles, resulting in a badly distorted house.

The slab-on-ground floors were also hit hard by the soil liquefaction. Many of the slabs were unreinforced (acceptable in NZS 3604 construction before the earthquakes), and those that were reinforced had brittle reinforcing mesh that fractured as the slab distorted. The then Department of Building and Housing issued an amendment to its citation of NZS 3604, requiring all new floors to be reinforced with ductile reinforcing, applicable over the whole of the country.

Need for stronger foundations

The Engineering Advisory Group has developed a range of more robust foundation systems for new houses on properties where there is a likelihood of liquefaction in future earthquakes. Some foundations are expected to accommodate the associated ground distortions with minimal distortion of the house – stiff rafts – while others have been designed so that relevelling is a relatively easy process – suspended timber floors.

Other solutions involve treating the ground before the house is built to contain the liquefying soils and provide a stiff soil platform for the foundation. Repairs would still be required in many instances, but these would be minor and the disruption to occupants is expected to be low.

Now, Christchurch probably has the best database of subsoil information of any territorial authority (TA) in the country, allowing a more informed selection of appropriate foundation system for the conditions.

Other TAs with known areas of liquefiable soils, particularly where there is also potentially high seismicity, should be considering what are the most appropriate house foundations or ground treatments to ensure resilient performance.

Geotechnical study for new subdivisions

The greatest opportunity comes with new subdivisions, where global treatment can be undertaken to improve the soil characteristics of the whole area before new houses are built, if required. The Engineering Advisory Group has developed guidance for geotechnical assessments of proposed new subdivisions in the Canterbury earthquake region that are also likely to be applicable in other areas of the country.

Best structural performers

The performance of light timber-framed and steel-framed houses generally confirmed predictions that these structures are resilient to violent shaking. The authors are not aware of any of these structures – which generally fit within the constraints of NZS 3604 – collapsing in any of the earthquakes.

Undeniably, damage was sustained, but these houses had sufficient energy dissipation capability to resist the earthquakes and remain standing, allowing occupants to escape injury or death – the primary performance objective of the New Zealand Building Code.

Bracing stood up

Modern, framed houses rely heavily on plasterboard linings to provide the primary bracing resistance, while older houses have diagonal timber braces fitted into the wall framing behind the linings.

Both methods of bracing provided adequate resistance to lateral loads, although the stiffness of the plasterboard sheet linings is greater than the diagonal braces, which meant that linings were damaged as the diagonal braces took up load.

Where liquefaction was not experienced, there was little observed major damage to the sheet bracing systems, suggesting that no changes were required to NZS 3604:2011.

Stiffness issues in complex houses

Greater levels of damage were observed in more complex specifically designed houses that fell outside the scope of NZS 3604. This tended to be caused by discontinuities in floor plates – split level styles and irregularity, both in plan and vertically. It was also clear that, while houses with uneven stiffness distribution did not collapse, there was often significant non-structural damage.

An area of specific design requiring greater consideration is the need to check the likely response of structural designs with stiffness irregularities – often the case when houses have been built with large window openings.

These designs need appropriate measures to either mitigate the stiffness incompatibility or ensure that windows and other non-structural items can accommodate the expected deflections.

Codes and standards passed the test

Overall, the performance of the houses of Christchurch and Canterbury was very encouraging from the life safety viewpoint. While there was a lot of costly damage and loss of amenity, this sequence of events produced levels of shaking significantly above the design values.

The overriding lesson for our industry is a better application of existing Codes and standards rather than wholesale changes on a countrywide basis.

Loss of a non-loadbearing wall has rendered this house uninhabitable.