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The Performance of Residential Houses in the Darfield Earthquake of 4 September 2010

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ABSTRACT: The housing stock in the Christchurch area covers an age range from the late 19th century until the present day. A database of randomly sampled houses has been established and surveyed, in conjunction with the EQC inspection process. The paper describes the findings of the survey and comments on the effectiveness of the past and current design standards for such structures with regard to earthquake resistance. The need for modifications to the current standards is discussed.

1 INTRODUCTION

The Darfield Earthquake, which had a Richter Magnitude of 7.1, occurred at 4.35 am on 4 September 2010. Its epicentre was close to the township of Darfield, which is approximately 40 km west of the Christchurch CBD, at a depth of 10 km.

The earthquake presented an opportunity, not discounting the horror of the event for home owners, for researchers to gauge the effectiveness of New Zealand house building standards over the ages in mitigating the effects of earthquakes. To minimise the disruption to home owners, BRANZ arranged to visit properties with the EQC assessors. Intentionally, the BRANZ study aimed to separate shaking performance from the effects of ground spreading and liquefaction, mechanisms not previous considered in detail in New Zealand house design standards. However, the process of aligning the survey teams with the EQC assessor teams resulted in visits to several ground affected properties.

The effects of ground spreading and liquefaction are not included in this paper, nor are there comments on the behaviour of chimneys. It is well known that a very large number of chimneys failed in this event, and their performance requires a separate study.

The relative randomness of the survey and small sample resulted in the emphasis being on mainly timber-framed houses, which are the most common construction form in the region.

2 SURVEY LOCATIONS

At the time of writing this paper, a total of 110 properties had been surveyed. Surveys are on-going, with the aim of amassing a database of damage descriptions at approximately 100 houses that have no ground spreading or liquefaction effects. The distribution of survey sites is shown in Figure 1. To date, 93% of the properties surveyed are on flat sites.

3 GROUND ACCELERATIONS

There are a number of seismograph stations around the affected area. These seismograph instruments are capable of recording ground motions in both horizontal and vertical directions (triaxial) in terms of a time versus ground acceleration plot recorded at the site of the instrument. Of interest is the larger of the two horizontal acceleration components. In estimating the ground acceleration magnitudes relevant to the surveyed buildings, the surveyed buildings are grouped based on the nearest seismic station locations. Figure 2 shows the locations of the seismograph stations relevant to the surveyed building areas. All the selected stations are located on a “free-field” site with site subsoil conditions

"D" or "E" according to NZS1170.5. Figure 1 shows the correlations of the seismic stations to the surveyed building groups.

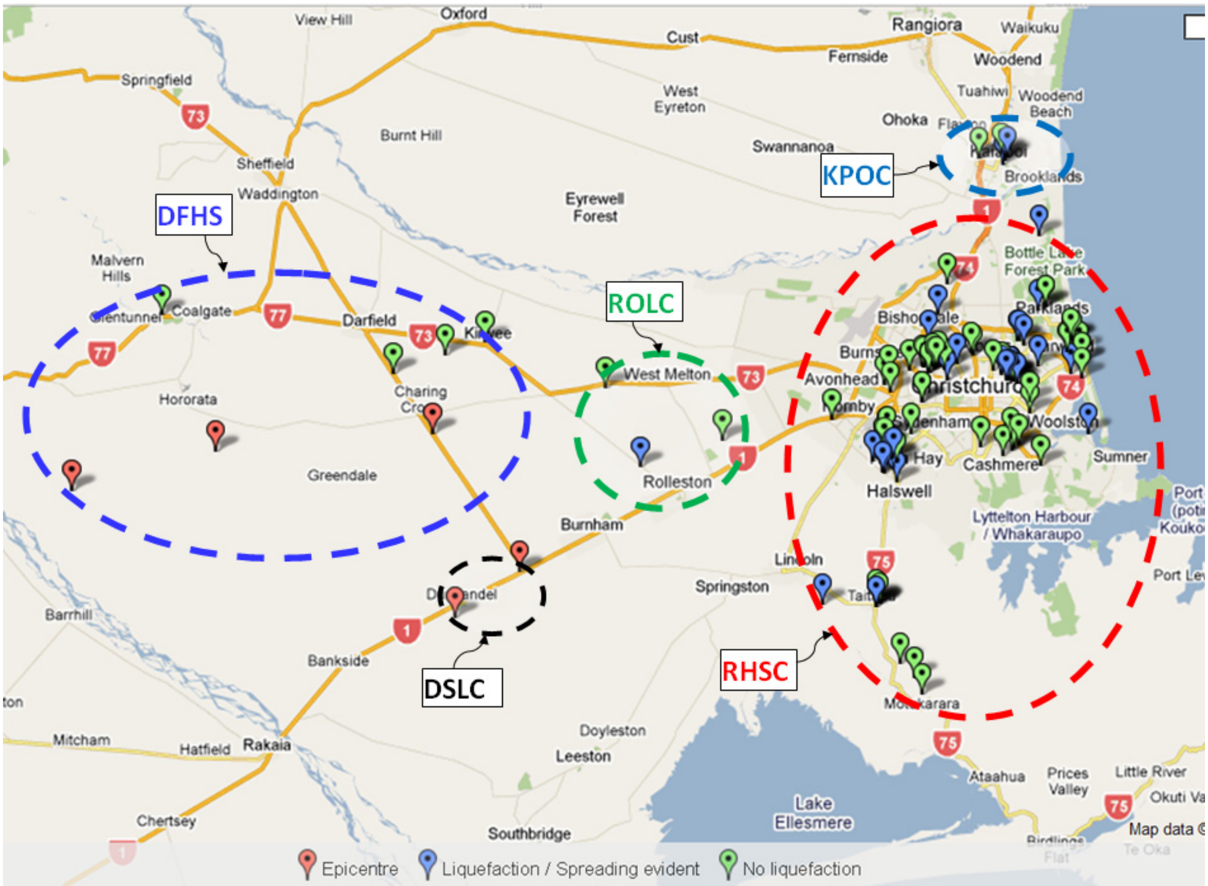

Figure 1 Distribution of house survey sites and their relationship to the strong motion recorder locations and the earthquake epicentre (Map credit: Google maps)

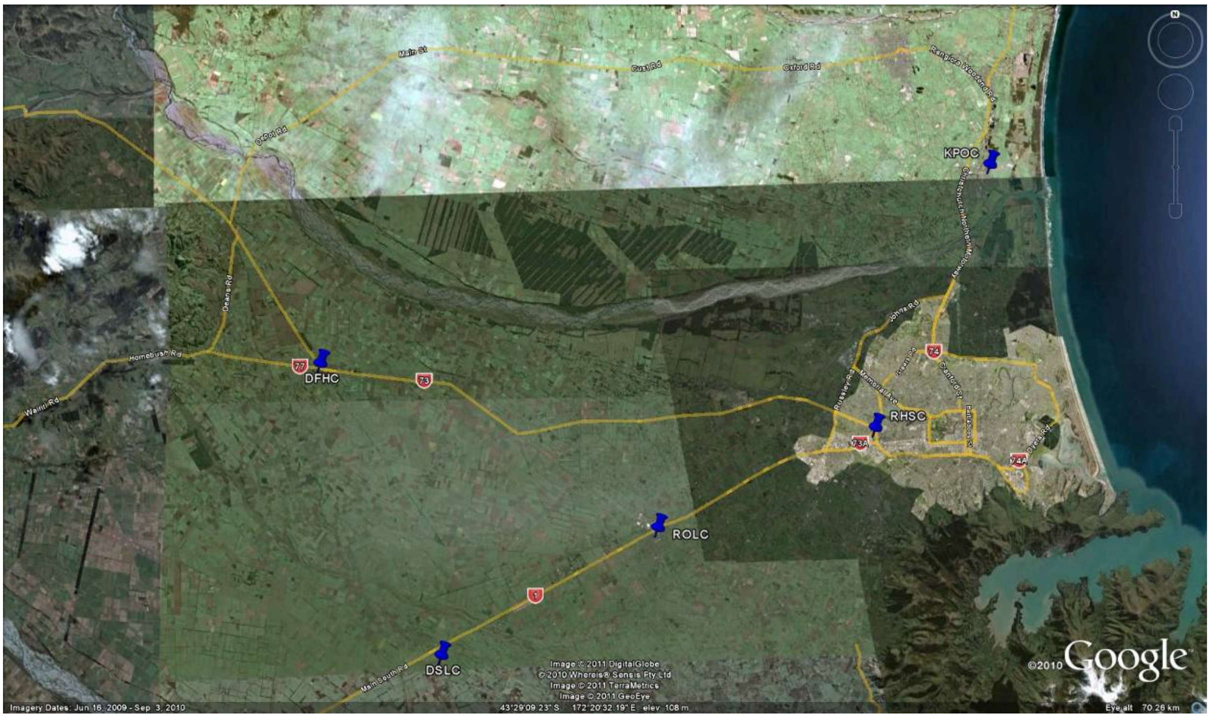

Figure 2 Locations of the selected seismograph stations (Credit: NZ GeoNet project, background map data copyright Google, 2010)

In current practice, the seismic design action for residential houses is based on a 10 percent probability of exceedance in a 50 year period. Table 1 lists the peak ground acceleration response spectra for the selected stations versus the design actions. The peak ground response accelerations for all the selected stations occurred in the period range 0.2 s to 0.35 s. Therefore, the Darfield Earthquake, although widely regarded as a moderately strong tremor, generated significant seismic actions, especially for shorter period structures. For conventional residential houses in NZ, the fundamental period is usually less than 0.45 s. Hence, the Darfield earthquake could be expected to cause moderate to severe damage to the residential buildings in the affected area.

Table 1 Effective Peak Accelerations versus Design Accelerations

Station Code	Soil Class	Design Spectral Acceln (g)	Peak Ground Response Spectral Acceln (g)	Z (Zone factor in NZS1170.5)	Spectral acceln peak / Design spectral acceln
RHSC	D	0.66	0.94	0.22	1.42
ROLC	D	0.60	0.94	0.20	1.57
DFHS	D	0.90	1.64	0.30	1.82
DSLC	D	0.66	1.09	0.22	1.65
KPOC	E	0.75	1.06	0.25	1.42

4 STRUCTURAL SYSTEM PERFORMANCES

4.1 Foundation systems

Three principal foundation types have been used for house construction in the Canterbury area. These are all-piled (generally timber) (3%), concrete perimeter foundation with concrete piles within (60%), and concrete slab on grade (including waffle type slabs) (37%). Unless affected by ground spreading or settlement, all three types of foundation system appeared to perform very well. Of the surveyed properties there were no foundation failures.

4.2 Wall bracing systems

Commonly, the lateral bracing system for a timber-framed house is contained in the house walls. The bracing can take the form of let-in flat diagonal timber braces, or fitted diagonal braces between the studs (commonly used from early settlement until the 1970s), or sheet lining materials such as gypsum plasterboard, plywood, hardboard and fibre-cement (used since the 1980s).

Not all wall lining materials have a recognised bracing function although they may provide some lateral load resistance by default. Lath and plaster systems and butted together rough sawn boards (sometimes horizontal and sometimes diagonal) with scrim overlay are probably the earliest internal wall linings used in New Zealand timber-framed houses. Lath and plaster will provide a small amount of lateral load resistance but fail at low loads in a brittle manner generally along the horizontal lines between the timber laths. For this reason, diagonal timber braces were generally fitted in lath and plaster lined walls. The butted together boards have greater ductility in that the nail couples securing the boards to the framing provide a small energy dissipation function, but the system is still relatively weak. Fibrous plaster sheets were developed to replace the lath and plaster systems. As the name suggests, the sheets were a gypsum plaster product “reinforced” with jute fibres. While they provided a flat surface for wallpaper, their bracing capacity was very low, and the timber diagonal braces were again relied on to provide the lateral load resistance. Softboard was also commonly used as a wall lining until the 1960s. It provided no bracing capacity, with the nails securing the sheets to the framing easily tearing through the soft wood fibres.

Because gypsum plasterboard provides most of the bracing in modern houses, the study team was keen to understand how well it worked in the earthquake. Damage observations ranged from "no damage" to diagonal cracking in the sheets. The incidence of diagonal cracking in the sheet was rare and was restricted to cracks that emanated from the top corners of large door openings in lower storey walls (Figure 3). While it will be necessary to replace the cracked sheets, such damage is expected in an ultimate limit state earthquake event. Plasterboard manufacturers recommend that sheet linings are cut around openings because this ensures that in normal circumstances seasonal variations in the framing are not expressed as cracks in the joints between sheets. However, this recommended practice is not always followed, and fine vertical cracks can be seen on the joints at the corners of windows and door openings (Figure 4). The racking that has occurred in the earthquake has sometimes exacerbated the damage at these joints, but it was found that rarely had the fixings "popped" and, the repair will be a simple racking out of the joint and re-stopping with the inclusion of paper tape reinforcement for added strength against seasonal movement.

Figure 3 Diagonal cracking of gypsum plasterboard sheet from top corner of door

There has been some discussion in the engineering community about the possible reduced stiffness of these houses after the earthquake. There is some anecdotal evidence that houses are responding more to high winds and minor tremors now than they were prior to the earthquake. This is quite possibly the case as it is known that at service loads in laboratory tests no "popping" of fixings shows up, yet small slots have been created in the plasterboard around the fixings through which the fixings must slide before taking up load. If this is proven to be a common behaviour, it may be necessary to re-fix some of the sheets during the post-earthquake repair work.

Figure 4 Earthquake induced cracking at joints between plasterboard sheets

The authors did not find any instances where walls of houses lined with fibrous plaster or other non-bracing panels were distorted sufficiently to suggest that there had been a failure of the hidden diagonal timber braces. No evidence has been gathered to date that suggests a greater flexibility of these houses.

Damaged lath and plaster linings were encountered on two occasions in the survey. As discussed above, such linings are non-structural. Minor damage can be repaired using appropriate fillers. However, for major damage it would be uneconomic to attempt to repair the lath and plaster, and a stronger structure can be achieved by removing the lath and plaster and replacing it with modern plasterboard linings. Thickness issues may need to be addressed with packing at architraves, etc.

4.3 House shape effects

As with commercial buildings, it has commonly been assumed that the plan shape and the vertical irregularity will be the catalyst for greater damage. The authors found that “L” and “U” shaped houses that were surveyed did exhibit greater damage at the intersection of the wings although the observed damage was not serious.

4.4 **Roof framing and roof cladding damage**

No major roof framing damage was observed in any of the surveyed houses that were affected only by ground shaking. Some framing had been broken by collapsing chimneys.

Metal roof cladding behaved well, and no evidence was seen of damage to either corrugated steel sheets and fixings or to metal roof tiles. Minor shaking damage occurred with heavy concrete tiles. A long, narrow garage structure located near the epicentre which had a brick veneer cladding experienced some roof tile damage, most likely caused by transverse flexibility of the structure (Figure 5). At the same property, some minor damage to the mortar pointing on the roof hips was also observed.

Figure 5 Dislodged roof tiles and ridge capping tiles

4.5 **Heavy veneer cladding performance**

Approximately 65% of the surveyed houses had a veneer cladding. The brick veneer generally performed well on houses subject only to shaking forces, even for properties close to the earthquake epicentre. Minor cracking of veneer mortar joints was common, but many of these instances were not earthquake related.

Often bricks had moved in the brick veneer top course, particularly the end bricks in isolated piers (Figure 6), or adjacent to air vent slots where a vertical joint between bricks (perpends) had deliberately not been filled with mortar. The likely reasons for the cracked mortar joints in this area are that the differential movement between the soffit lining and the veneer has caught hold of the bricks, or the veneer ties in the top mortar course (if present) have lifted the top brick as they have twisted with the differential movement. These can be easily and relatively cheaply repaired. Few actually fell as they tended to be become wedged against the soffit or retained by the wooden trim.

If these bricks did fall they would pose some risk of injury in single storey veneers and significant risk to life in two storey construction. The top one or two courses of brick, above the top level of brick ties, are not well restrained, and can easily be dislodged. In an earthquake they tend to act as a cantilever above the top row of brick ties, and have a lower natural frequency than that of the brick wall below. A possible solution to this weakness may be to require that the uppermost mortar course has ties included and further restraint could be provided by the inclusion of a timber trim, as is often the case by default, fixed to the soffit.

Prior to the introduction of screw fixed veneer ties in the late 1990's, the veneer was generally tied to the framing with twisted number eight wire (Figure 4) and staples. There was some evidence of the staples being pulled from the framing, but this was limited to properties where substantial lateral spreading had occurred and the foundation supporting the veneer had separated from the timber floor structure.

Figure 6 Dislodging of brick veneer beneath soffits **Figure 7 Old style wire veneer tie**

Two storey veneer clad structures did not appear to behave significantly worse than single storey houses, except near the epicentral area where the cracking was more severe but with little loss of bricks (Figure 8). One modern two storey property inspected in the central city was clad with Oamaru Stone veneer. Damage was limited to minor cracking of mortar joints and occasional fine cracks through the individual bricks.

Figure 8 Cracking in veneer at the junction of two storey and single storey sections

BRANZ inspections exposed some instances of poor brick veneer construction. In one case the mortar on the fallen veneer section was powdery, suggesting that it did not meet the requirements of the Standard (SNZ, 2001) for mixed mortar at the time of construction. This led to poor bonding between the bricks and the ties. On other occasions, the veneer failure was simply attributable to their being no ties installed over large areas!

5 EFFECTIVENESS OF STANDARDS

Generally, BRANZ's observations suggest that the building standards, both current and superseded, have resulted in resilient houses. Minor shaking damage was observed, and this is consistent with the intent of the NZ Building Code for an ultimate limit state event, where the intention is to "safeguard people from injury caused by structural failure". Damage is certainly expected to occur under this provision. A further objective is to "safeguard people from loss of amenity caused by structural behaviour". The satisfaction of this provision is a little more difficult to define. A loss of amenity occurred in houses affected by ground spreading and liquefaction, but this was generally not the case in other houses even though the event was greater than a serviceability event.

House styles have changed over the ages with a greater desire for larger open areas in houses than was the fashion 30 or more years ago. In parallel with this change, standards have improved, particularly with the introduction of the engineering based NZS 3604 Timber-Framed Buildings Standard (SNZ, 1999). This Standard has developed over several iterations and a further edition is due in 2011. While earlier standards were more "rule-of-thumb" in their requirements, the partitioned box-like nature of the houses built to these standards meant that there is adequate redundancy in their construction to resist large earthquakes.

Furthermore, the earlier style houses in Christchurch tended to have perimeter concrete foundations with piles inside the perimeter, all built to the standards of the day. This fortunately meant that there was no evidence observed by the BRANZ surveyors of house superstructures falling off their foundations, unlike that observed in Edgecumbe in 1987. The concrete perimeter foundations served to transfer shear forces from the superstructure to the ground, whereas in Edgecumbe the resistance was provided only by short, unbraced piles.

Modern houses that have been designed to NZS 3604 appear to have performed well, given the size of the event. Variable damage was noted in sheet bracing systems but there were no house collapses as a result of the damage sustained. The survey results suggest that there were no imminent collapses either.

6 CONCLUSIONS

The survey results to date suggest that nothing urgent is required to be done to the Timber-Framed Buildings Standard to ensure that the intentions of the Building Code are satisfied with regard to the effects of ground shaking. The observed behaviour is what would have been expected for an event of this size. This investigation has intentionally not addressed the effects of lateral spreading and liquefaction.

The survey is on-going at the time of writing, and further more detailed reporting on the findings can be expected in the future.

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