# Rebuilding Christchurch in the Wake of the 2010 & 2011 Earthquakes – A Surveyor's Perspective

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## SUMMARY

After the 2010 Darfield Earthquake, a 7.1 magnitude earthquake near Christchurch, New Zealand's second city, the region had been hit by hundreds of aftershocks - many of them widely felt in and around Christchurch, and some of which have caused further damage. Nearly six months later, just as everybody was getting used to post-earthquake life, a magnitude 6.3 earthquake (technically an after shock of the earlier earthquake) hit - just before 1pm on Tuesday the 22nd of February 2011. This time, Christchurch was not so lucky - 185 people lost their lives, with many more injured. Many Christchurch buildings were badly damaged, with some collapsing and 1,200 requiring demolition or major repairs. At 1pm on June 13, a 5.7 magnitude quake rattled Christchurch again, only to be followed nearly two hours later by a 6.3 aftershock; one fatality was reported, and many buildings suffered further damage or collapsed.

This paper describes the activities of the private sector surveyors beginning with the 4 September 2010 initial response effort on through the many months of uncertainty to the vision for a new Christchurch.

Surveying, Surveyors and Spatial Information have all been identified as key aspects to the many response phases to these events. Many professional disciplines including surveying have played roles in gaining a better understanding of Christchurch now in the hope and preparation for a new future for the city.

There are many lessons that can be gleaned from this work and much learned by the surveyors involved through sharing their experiences with others in the wider national and international surveying communities.

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## 1. SETTING THE SCENE

### 1.1 4 September 2010

The Canterbury region of New Zealand's South Island was hit by a magnitude 7.1 earthquake at 4:35am NZST on Saturday, 4 September 2010. Centred on Darfield, 30km west of Christchurch, the South Island's most populous centre, at a depth of 10km, the initial quake lasted about 40 seconds and produced some of the strongest ground shaking ever recorded in New Zealand (a country that is seismically active), causing widespread damage in Christchurch, the surrounding towns of Kaiapoi and Rolleston (located to the north and south of Christchurch respectively) with damage or disruption to varying degrees experienced throughout Canterbury (GeoNet, 4/9/10). Fortunately there were no deaths directly attributed to this event. Fatalities were avoided largely due to there being few dwellings of unreinforced construction, although this was also aided by the quake occurring during the early hours of the morning.

The Darfield earthquake occurred as a result of strike-slip faulting on a previously unknown fault within the crust of the Pacific plate, near the eastern foothills of the Southern Alps at the western edge of the Canterbury Plains (NZSEE, 4/3/11).The peak ground acceleration (PGA) measured near Darfield was 1.26$g$ (12.36 $m/s^2$) and at the time was considered by GNS scientists as an "extremely rare seismic recording made near a fault rupture" (GeoNet, 4/9/10).

Geologically the Darfield earthquake was relatively complex, involving movement on at least three interconnected faults. The largest of these previously unknown faults (the Greendale Fault) ruptured through to the ground surface producing a 30km long surface rupture.

A feature of the Darfield Earthquake was the damage caused by soil liquefaction, which occurs when saturated, unconsolidated (loose) soils are severely shaken causing water and silt or sand to be ejected to the ground surface. This resulted in subsidence and, in places, lateral spreading (sideways movement) of the ground causing damage to dwellings and underground services. This was particularly the case in the riverside areas of Avonside, Dallington, Burwood, Avondale, and Kaiapoi, and in river delta areas near Bexley, Brooklands, Spencerville, Pines Beach, and Kairaki with other areas being affected to a substantially lesser degree or not at all (Tonkin & Taylor Ltd Stage 1 Report, 2010).

Damage from liquefaction may have been worsened by the high water table from a wet winter.

Liquefaction also caused problems for the gravity-fed sewer network. Buried pipes were forced to the surface, manholes popped out of the ground and sewer pump stations were damaged, causing extensive damage to the reticulated system.

Land movement and subsidence in areas affected by liquefaction and lateral spreading generally ceased as water pressures within the soil returned to normal. Although soils regained most of the strength they lost during liquefaction the level of the ground surface changed in many areas raising concerns about the increased risk of flooding due to the low lying nature of the topography (Tonkin & Taylor Ltd. Stage 1 Report, 2010).

Water mains were extensively damaged and in some areas, including the Rolleston water supply; supplies were contaminated as a result of the sewer main damage. Residents were asked to boil water until repairs were completed. (CCC Notice 8/9/10) Power to up to 75% of Christchurch was disrupted and Christchurch Hospital was forced to use emergency generators in the immediate aftermath of the quake, however 90% of the electricity in Christchurch was restored by 6:00pm on the day of the earthquake. The repair of electricity was more difficult and took longer in the outlying rural areas.

Although many of Christchurch's major landmarks survived intact, most of the badly affected structures in both Christchurch and the surrounding districts were older un-reinforced buildings, including several notable landmarks. Most modern buildings performed as they were designed to do, preserving life rather than keeping the interior in good order.

### 1.2 22 February 2011

A magnitude 6.3 earthquake hit Christchurch with devastating effect at 12:51pm NZDT on Tuesday, 22 February 2011, six months after the Darfield Earthquake. The Christchurch Earthquake (although technically an aftershock of the 4 September event), was one of the nation's worst natural disasters with 185 fatalities, by far New Zealand's costliest natural disaster and the third-costliest earthquake (nominally) worldwide (Murdoch, 2011).

The Christchurch earthquake occurred at a depth of 5km and GNS Science reported that the earthquake arose from the rupture of an 8km x 8km (again previously unknown) fault running east-northeast at a depth of 1 – 2km beneath the southern edge of the Avon-Heathcote Estuary and dipping southwards at an angle of about 65 degrees from the horizontal beneath the Port Hills. Unlike the Darfield event, the rupture was subsurface and initial satellite imagery indicated that the net displacement of the land south of the fault was 50cm westwards and upwards although land movement varied around the area horizontally and vertically (GeoNet, 22/2/11).

It caused extensive damage across Christchurch, especially in the central city and eastern suburbs. Damage was exacerbated by buildings and infrastructure already weakened by the 4 September event and its aftershocks.

The vertical acceleration was far greater than the horizontal acceleration. The PGA in central Christchurch exceeded 1.8*g* (i.e. 1.8 times the acceleration of gravity), with the highest recording of 2.2*g* at the Heathcote Valley Primary School, contrasting to the highest reading during the 4 September earthquake of 1.26*g*. This is the highest PGA ever recorded in New Zealand and one of the greatest ever ground accelerations recorded in the world. It was unusually high for a magnitude 6.3 earthquake and the highest recorded in a vertical direction. It is probable that 'seismic lensing' contributed to the ground effect, with the seismic waves rebounding off the hard basalt of the Port Hills back into the city (GeoNet, 22/2/11).

Liquefaction, particularly in the eastern suburbs, was worse than the Darfield earthquake, producing over 500,000 tonnes of silt (Rebuild Christchurch, 2011), and this time there were significant landslips and rockfalls on the Port Hills. The hill suburbs, largely unaffected by the 4 September earthquake, sustained considerable damage.

In central Christchurch the acceleration occurred mainly in a vertical direction and the upwards acceleration (positive) was greater than the downwards. The PGA was greater than many modern buildings were designed to withstand. Whereas the building code requires a building with a 50-year design life to withstand predicted loads of a 500-year event; initial reports by GNS Science suggested ground motion exceeded even 2500-year design motions and beyond maximum considered events (NZSEE, 4/3/11). By comparison, the earlier Darfield earthquake—in which damage was predominantly to pre-1970s buildings—exerted 65% of the design loading on buildings. The acceleration experienced on 22 February 2011 would totally flatten most world cities (Lin, 26/2/11), causing massive loss of life. Fortunately our stringent building codes limited the disaster although the most severe shaking lasted only 12 seconds, which perhaps prevented more extensive damage.

The 22 February 2011 event was the most damaging in an 18 month-long earthquake swarm affecting the Christchurch area. It was followed by a large aftershock on 13 June (which caused considerable additional damage) and a series of large shocks on 23 December 2011. To date, Christchurch has experienced over 10,000 aftershocks since the 4 September event (Quake Map, 2012).

## 2. IMPACT ON THE SURVEY SYSTEM

New Zealand lies across the obliquely convergent Australian and Pacific plate boundary. In addition to the plate motions, New Zealand experiences the effects of other deformation events such as large earthquakes, volcanic activity, and more localised effects such as landslides. To accommodate the effect of crustal motion, Land Information New Zealand (LINZ), the New Zealand government department responsible for land titles, geodetic and cadastral survey, implemented a semi-dynamic datum, New Zealand Geodetic Datum 2000 (NZGD2000), in 1998. This datum includes a deformation model to convert geodetic observations made at different times to a common reference epoch of 1 January 2000 to accommodate the effect of crustal dynamics (Blick, 2010).

New Zealand cadastral boundaries are defined by survey and for about 70% of land parcels, principally in urban and peri-urban areas; the cadastre is connected to the geodetic network and is considered to be survey accurate. LINZ manages geodetic, cadastral and title data in an automated digital database called Landonline.This is an observational database that enables the re-adjustment of coordinates as new or improved data becomes available.

Since the introduction of NZGD2000 there have been substantial earthquakes that have compromised the accuracy of the datum. However, to date these earthquakes have been located in isolated parts of the country, where population levels are so low that substantial efforts to re-establish the control system have not been deemed necessary.

The Darfield and subsequent Christchurch earthquakes changed this, centred as they were in a major agricultural area and New Zealand’s second city. Thousands of geodetic marks and millions of cadastral marks are estimated to have moved by significant amounts.

Immediate post-earthquake surveys were undertaken after the Darfield event by GNS Science to determine the initial extents of both vertical and horizontal ground deformation by way of deformation modelling (Beavan, 2010). Once subsequent surveys confirmed that post-seismic movement was subsiding, LINZ commenced work on more extensive surveys to resurvey 190 marks which comprise the existing 1$^{st}$ - 4th order networks across the affected area.

The survey results indicated significant displacements over a wide area. Close to the Greendale fault, horizontal movements of over 2m and vertical movements over a metre were measured. Across Christchurch the movements showed a generally systematic pattern, but some marks showed anomalous movements, both vertically and horizontally. These marks were generally located in areas where localized mark disturbance was suspected to have occurred due to liquefaction (Beavan, 2010).

Following the 22 February and 13 June earthquakes extensive surveys were again undertaken to quantify the extent and magnitude of ground deformation. However it was clear that there were more extensive areas of non-uniform deformation and that to use a displacement model to spatially correct positions of geodetic and cadastral survey marks for this event would be more difficult. More extensive geodetic surveys are required and this work is ongoing (Blick, 2010).

Immediately after the 4 September 2010 earthquake the Christchurch City Council, recognising that their level network is a fundamental asset, undertook survey work to determine the extent of the vertical shift in its Level Network by re-surveying a limited number of bench marks within the network. It was acknowledged that the Council level network was within the zone of potential deformation and pre-quake height values were unreliable until proven otherwise. The order of accuracy of the level network pre-quake was 0.030m.

A Fast Static GNSS survey was undertaken of the selected bench marks with connections to LINZ 1st or 2nd order control by four Christchurch firms and Council surveyors over a 4 day period. The GNSS observations were reduced in Trimble Geomatics Office (TGO) and independently quality controlled by least squares analysis. The processing included the adoption of the LINZ NZGeoid09 gravimetric quasigeoid model and a calibration plane involving the identification of benchmarks considered unlikely to have been disturbed and which the processing adjustment held fixed to obtain normal orthometric heights (CCC Report, 27/9/10).

Eighty percent of the surveyed marks were found to be within the GNSS height tolerance and so were unchanged from their pre- 4 September values with the remainder assigned new interim values. This gave surveyors and engineers the confidence to continue with existing construction works and commence the repair of damaged infrastructure.

This network was subsequently extended by precise levelling across the Waimakariri River to the north of Christchurch to enable repair and rebuild works in Kaiapoi, Pines Beach and Kairaki Beach.

The Council bench mark network has been re-observed with data processed in a similar manner and revised bench mark values issued after the 22 February, 13 June and 23 December 2011 events.

## 3. THE RESPONSE

The immediate focus of surveyors following the Darfield Earthquake and subsequent aftershocks was first and foremost the care of their homes and families. Following a period of structural inspections we were able to return to our predominantly city centre offices and respond to the effects of the earthquake and aftershocks. Our firm was involved in GNSS and precise levelling campaigns for both Christchurch City Council and Waimakariri District Council, the monitoring of essential infrastructure at Lyttelton Port and the provision of surveying services for geotechnical investigations undertaken predominantly in the eastern suburbs of the city for the Earthquake Commission. Although our structural engineers in particular were inundated with work we were able to a large extent continue on a business as usual basis. The earthquake related work was conducted in conjunction with our land development work.

The impact on Christchurch of the 22 February event was much more severe however and the immediate priorities of Christchurch surveyors changed. Whilst looking after home and family was once again the immediate priority, surveyors had to continue operating, often from home, while new premises were found. Most firms' offices in the central city had been badly damaged and, with the city centre a cordoned off red zone, the challenge was to retrieve as much as we could from our old ones to continue operating.

The initial professional focus of surveyors in aftermath of the Christchurch earthquake was the surveying and monitoring of damaged buildings and essential infrastructure with some involved with providing surveying services to search and rescue operations within the CBD red-zone. Some were involved in re-establishing level control, which was again a priority for repair and rebuild works to get underway. Land development work largely stopped in those early weeks following the earthquake and was replaced by infrastructure monitoring, building verticality surveys, topographical surveys of damaged dwellings prior to demolition in order to record existing building footprints (existing use rights) and other earthquake related work.

However as the aftershocks subsided and the situation gradually improved throughout the autumn and winter of 2011 (13 June notwithstanding) attention turned to the effects of the 22 February event on the definition of cadastral boundaries.

The cadastral fabric has been affected roughly in line with damage to land and property and surveyors pondered the ground distortions, misclosures and lack of reliable marks found in quake affected areas and the effects of these on the preparation and lodgement of cadastral survey datasets (CSD) in Landonline. It was becoming increasingly clear that the effects of ground movement on the reliability of survey and boundary marks in some areas meant that the time-honoured practices under which surveyors carried out cadastral surveys no longer applied and practitioners returned to first principles to address the problems they were facing.

In the aftermath of the Darfield Earthquake LINZ responded with the issue of *Rules for Rules for Cadastral Survey (Canterbury Earthquake) 2010* (RCS (CE) 2010) and associated guidelines.

Under RCS (CE) 2010 guidelines boundaries are categorised according to the damage sustained and it is up to the surveyor to decide which of the categories best fits the land parcel under survey. The underlying philosophy of these rules when dealing with boundaries affected by a fault rupture event (Greendale fault) is where deep seated movement has occurred the boundary is considered to have moved whereas in areas of surface layer movement due to soil liquefaction the boundary has not moved.

| | |
|---|---|
| Category One - Boundaries unaffected by the earthquake | *No change, the Rules for Cadastral Survey 2010 apply.* |
| Category Two - Boundaries affected by block shifts with relatively uniform movement. | *Parcel boundaries are expected to have maintained relativity with the adjoining parcel boundaries and with local witness and cadastral survey network marks.* |
| Category Three - Boundaries affected by deep-seated distortion which has caused boundary points to move but has retained a straight line between them | *Boundaries affected by deep-seated distortion may change the shape of the parcel but not to the extent that it requires the creation of new boundary angles.* |
| Category Four - Boundaries affected by distortion or shearing along the fault rupture | *Boundaries subject to distortion or shear movement along the fault rupture may require the creation of new boundary angles*. |
| Category Five - Boundaries in areas of localised surface layer movement due to liquefaction of soils or landslip, and may include block shift | *Boundary points and related boundaries affected by shallow movement of the surface must be reinstated in their original position relative to survey marks that retain the same horizontal relationship to each other as they held before the Darfield earthquake.* |

In terms of the effects of the Darfield earthquake, the RCS (CE) 2010 boundary redefinition rules were generally not inconsistent with the situation surveyors were finding on the ground. However, the 22 February Christchurch Earthquake did not neatly fall into the fault rupture scenario, principally because of the proximity of the epicentre and the shallowness of the event.

It became increasingly evident that the RCS (CE) 2010 boundary categories were not reflecting the problems surveyors were finding on the ground in many cases and Category 5 surveys in particular were problematic. Of course the reasons were not difficult to understand given the different ground movement characteristics experienced during and after the 22 February earthquake. However finding solutions to the boundary definition problems has been difficult, requiring considerably more field work to determine the extent of parcel boundary movement, more calculations and more discussion with colleagues and LINZ staff at the Department's Christchurch office.

The Canterbury Branch of the New Zealand Institute of Surveyors has held a number of meetings and workshops to consider post-earthquake cadastral and surveying issues. Feedback from these forums has been synthesized into a series of recommendations, addressing a number of issues of concern to surveyors working in Christchurch and surrounding quake-affected areas. The key external recommendations are summarised here.

1. <u>The Canterbury Earthquake Recovery Authority (CERA)</u>
   - Protection of survey marks and boundary evidence (walls/occupation etc) in CBD during building demolition.
   - Liaison with the Canterbury Branch to ensure surveying/cadastral constraints are taken into account in their decision making process.

2. <u>The Christchurch City Council (CCC)</u>
   - Development of a common GIS knowledge portal using Landonline as geodetic/cadastral base.
   - Ongoing maintenance of CCC Bench Mark network.

3. <u>Land Information New Zealand</u>
   - Re-establishment of geodetic control (x,y,z) and ongoing maintenance of survey infrastructure, including CBD.
   - The Canterbury Branch strongly rejects a 'limited as to parcels' solution to post-quake definition problems.
   - Zero fees for lodgement of redefinition CSD's.
   - LINZ to ensure (and actively police) CERA, CCC & SCIRT fulfill their obligations under the Cadastral Survey Act 2002, particularly with respect to the protection of survey marks.
   - Revision of RCSCE2010 required, particularly Category 5 boundaries.
   - Identify post-quake information (surveys/geotechnical) in Landonline (i.e. specific layers), colour code post-quake CSD's.

4. <u>Stronger Christchurch Infrastructure Rebuild Team (SCIRT)</u>
   - Protection of survey marks and boundary evidence in 'pod' (suburban) areas during infrastructure reconstruction.

## 4. THE FUTURE

From a surveying perspective progress is being made, albeit slowly despite ongoing aftershocks.

- The CCC bench mark network has been re-observed following each large earthquake/aftershock event and bench mark values issued soon after to enable ongoing survey work. Consistency of processing methodology has provided surveyors, engineers, designers, contractors and others working to rebuild Christchurch with a degree of confidence that the level differences found are the result of earth movement.
- In December 2011 LINZ issued a draft specification for the post-earthquake protection of survey marks and has provided SCIRT, CERA & Waimakariri District Council with delegated authority to remove marks under Section 55 of the Cadastral Survey Act 2002. However these organisations and others involved in reconstruction work are obliged to ensure survey mark protection surveys are undertaken prior to mark removal.
- LINZ now allows a wider range of boundary re-instatement surveys to be recorded on Monumentation CSD's.
- The replacement and protection of survey control in the Christchurch CBD is underway.
- Work on infrastructure repair/replacement projects in Selwyn and Waimakariri Districts is also underway.
- Some clarity has formed around the definition of Category 5 boundaries as more datasets are lodged. LINZ has accepted the use local groups of marks that have retained the same relationship relative to one another for parcel definition rather than finding distant marks on solid ground and adopting from those positions. It is now accepted that a definition of external boundaries that makes use of groups of local marks that retain the same horizontal relationship to each other therefore meets the rule's intent.
- From January 2012 (Bulletin 2) survey marks found that are considered to be undisturbed, but do not agree with the marks used for definition purposes within accuracy tolerances are recorded in Landonline using the existing mark name with the addition of the suffix '(UNPROVEN)' i.e. IT I DP 12345 (UNPROVEN). The new position is linked to the existing mark node so that if a later survey proves an unproven mark to be undisturbed that survey can remove the UNPROVEN suffix attached to it.
- As a consequence surveyors are able to undertake difficult redefinition surveys secure in the knowledge that Landonline is able to accommodate the distortions found on the ground.
- NZIS Branch meetings and seminars continue to provide a forum for practitioners to discuss definition problems with fellow members, who include LINZ staff, and the Canterbury Branch has agreed to review RCS (CE) 2010 for its practicality and relevance for future events.

Meanwhile the future hasn't arrived in Christchurch yet. We are still in the demolition phase with over 1,200 buildings in the central city and 6,000 residential dwellings predominantly in the eastern suburbs and Kaiapoi already demolished or scheduled for demolition before the rebuild can begin (CERA, 26/9/11).

The Council's plan for the new city centre is bold and exciting and there is general acceptance that we will ultimately have a modern, sustainable city that we can all be proud of. An Urban Design Panel has been set up to review central city development proposals as part of the Christchurch City Council's consenting process and New Zealand Institute of Surveyor's nominees will be playing an active role on the Panel, adding the voice of the land development professional to the assessment process. The redevelopment of Christchurch is an ongoing process and we are all excited to see how our city will rise from the rubble.

For the time being a member of the public who requires a side boundary to be redefined for fencing purposes or a builder who requires the relationship of formwork to a boundary certified prior to the pouring of the floor slab faces increased surveying costs. However most people understand why this is when the situation is explained. Distortions and differences are a daily fact of life and each job presents unexpected challenges. Although we've all been through difficult times and still have a long way to go, professionally it's a great time to be a surveyor in Christchurch.

We invite you to see the progress of the Christchurch rebuild for yourself at the 2016 Working Week.

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## BIOGRAPHICAL NOTE

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He is a member of the New Zealand Institute (NZIS) and is currently the Chair of the NZIS Canterbury Branch, serves on the NZIS Admission Panel and is the New Zealand delegate to FIG Commission 4. He also a member of the Surveying and Spatial Sciences Institute (SSSI) and serves on the SSSI Board, is Chair of the SSSI Hydrography Commission, a member of the SSSI Consultative Council and is a member of the SSSI New Zealand Region Committee.

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