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

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4 September 2010 Earthquake

4 September 2010 Earthquake

- M7.1 Darfield Earthquake hit the Canterbury Region of New Zealand's South Island at 4.35am NZST on Saturday 4 September 2010.
- Earthquake epicentre was situated near Darfield, 30km west of Christchurch, at depth of 10km.
- Quake lasted 40 seconds and produced some of the strongest ground shaking ever recorded in New Zealand – a seismically active country.
- The peak ground acceleration (PGA), measured near Darfield, was 1.26g (12.36 m/s^2).
- PGA in the Christchurch CBD was approx. 0.2g.

4 September 2010 Earthquake

- Strike-slip faulting on a previously unknown fault within the crust of the Pacific Plate.
- Geologically complex, involved movement on several interconnected faults.

4 September 2010 Earthquake

- Previously unknown Greendale Fault ruptured through to the ground surface, producing a 30km long surface rupture.

Near Rolleston on the Main Trunk Line - Courtesy of Malcolm Teasdale of KiwiRail

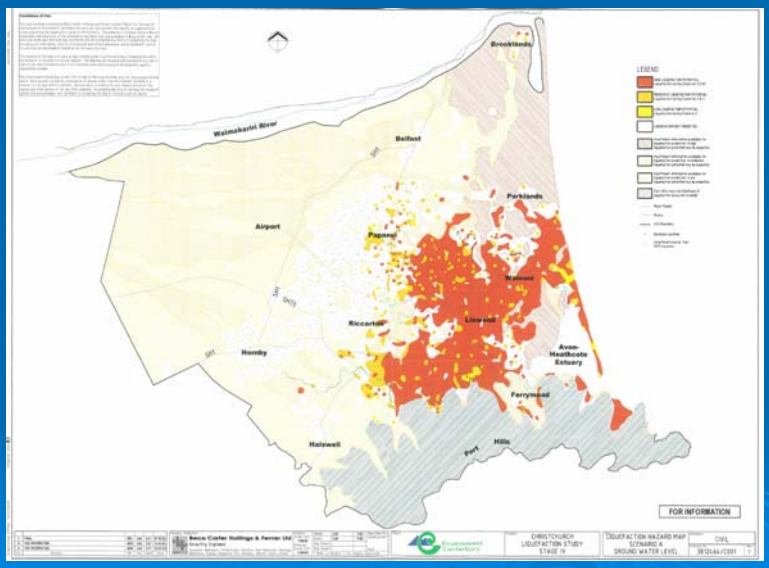
4 September 2010 Earthquake Liquefaction

- Liquefaction occurs when saturated, unconsolidated soils are severely shaken causing water and silt or sand to be ejected to the ground surface.
- Predominant in the riverside suburbs of Avonside, Dallington, Burwood, Avondale, Halswell and in Kaiapoi.

4 September 2010 Earthquake Liquefaction

- Also the river delta areas of Bexley, Brooklands, Spencerville, Pines Beach, and Kairaki.
- Ground settlement and lateral spreading caused by liquefaction resulted in considerable land and building damage, including underground services.

Previous Liquefaction Modelling



4 September 2010 Earthquake

- No fatalities.
- 'Chimney killer' but damage to residential dwellings largely restricted to areas affected by liquefaction.
- Structural damage largely confined to older un-reinforced brick masonry buildings.
- Most modern buildings performed in accordance with building code design criteria.
- Exceeded a Serviceability Limit State (SLS) event.
- Probably less than an Ultimate Limit State (ULS) event i.e. design level earthquake

4 September 2010 Earthquake

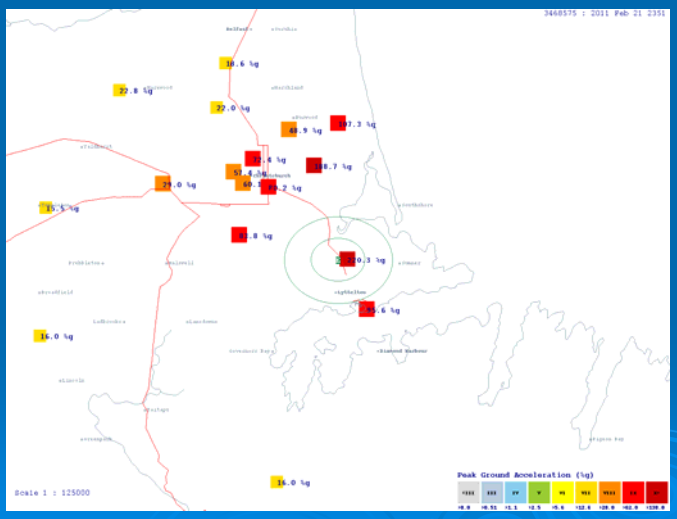
4 September 2010 Earthquake

22 February 2011 Earthquake

22 February 2011 Earthquake

- M6.3 ‘aftershock’ struck Christchurch at 12.51pm NZDT on Tuesday 22 February 2011, with the most severe shaking lasting only 12 seconds.
- Subsurface fault rupture with epicentre situated underneath Port Hills at depth of 5km.
- PGA 1.8g in the central city, highest reading of 2.2g recorded at Heathcote Valley Primary School – close to epicentre.
- 185 fatalities but strict building codes credited with limiting the number.
- Largest vertical acceleration ever recorded in the world.
- Extensive structural damage to many building types

Peak Ground Accelerations



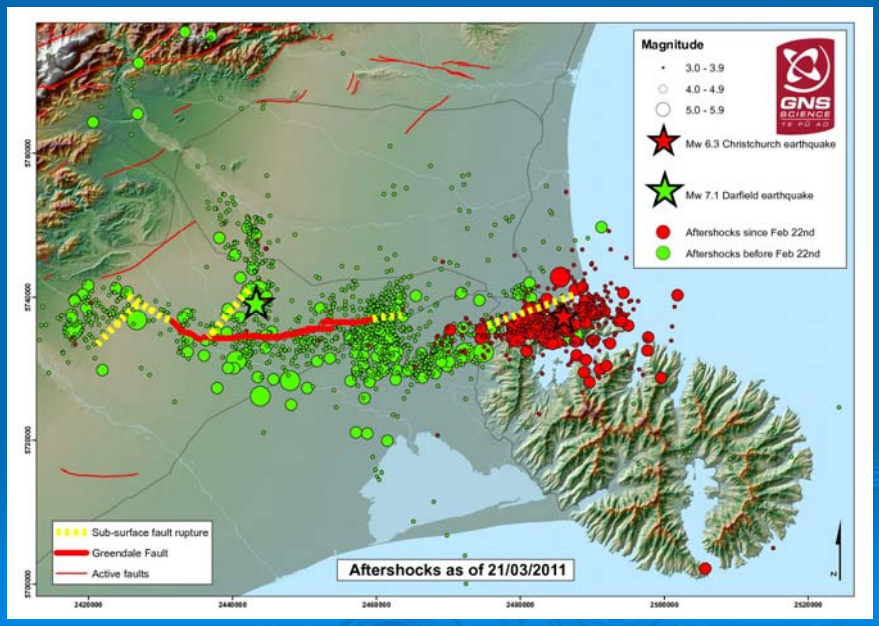
22 February 2011 Earthquake

- Occupants unable to egress some buildings due to collapsed stairs
- Full collapse of PGG and CTV Buildings
- Large number of buildings came very close to collapse
- Ground motion exceeded 2,500-year design motions and beyond maximum considered events (MCE)
- CBD closed and still closed
- Extensive liquefaction across eastern suburbs, CBD, Fendalton – 500,000 tonnes of silt produced
- Hillside suburbs extensively damaged

22 February 2011 Earthquake

22 February 2011 Earthquake

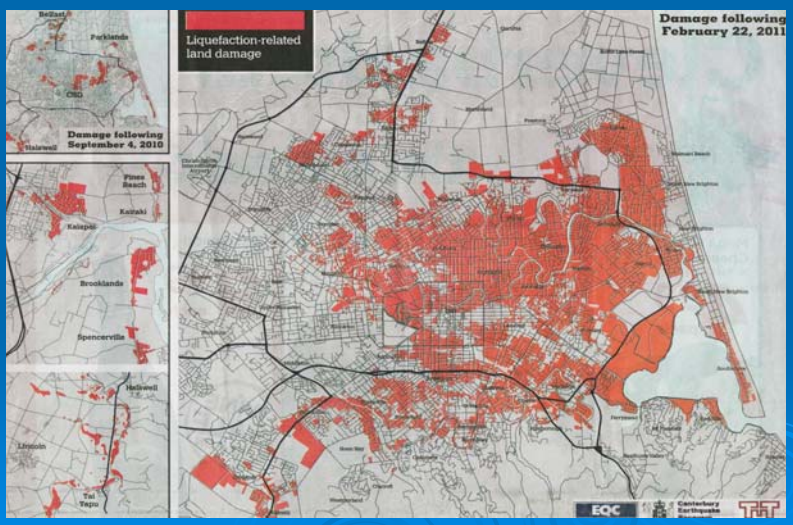
- 22 February was the most damaging event in an 18-month earthquake swarm
- Although significant, it was an isolated event and not the 'Big One' – Alpine Fault Rupture
- Significant after shocks i.e. >M5
  - 26 December 2010,
  - 13 June 2011,
  - 23 December 2011.
- Christchurch has experienced >10,000 aftershocks since 4 September 2011
- Thankfully they are now declining



22 February 2011 Earthquake

22 February 2011 Earthquake

22 February 2011 Earthquake - Liquefaction



22 February 2011 Earthquake - Liquefaction

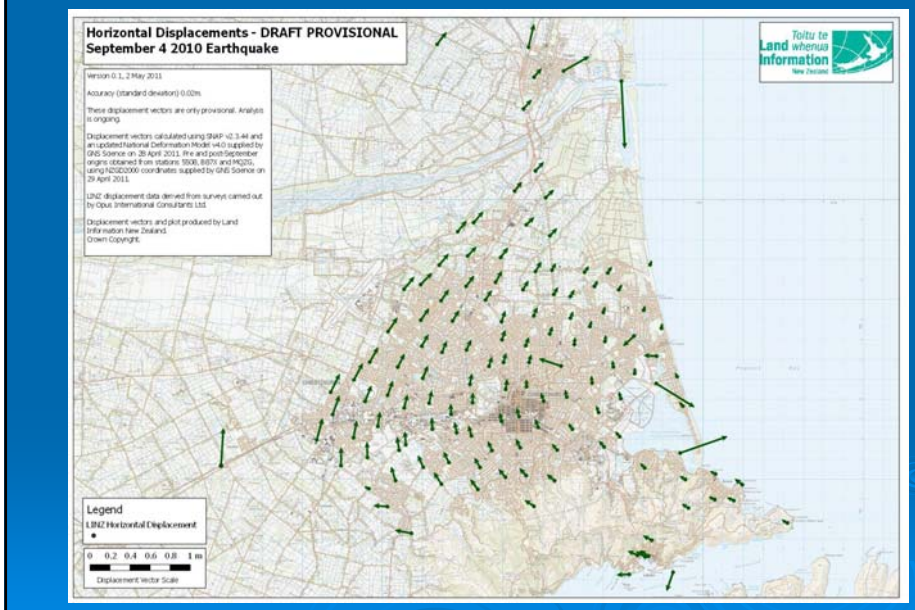
22 February 2011 Earthquake - Liquefaction

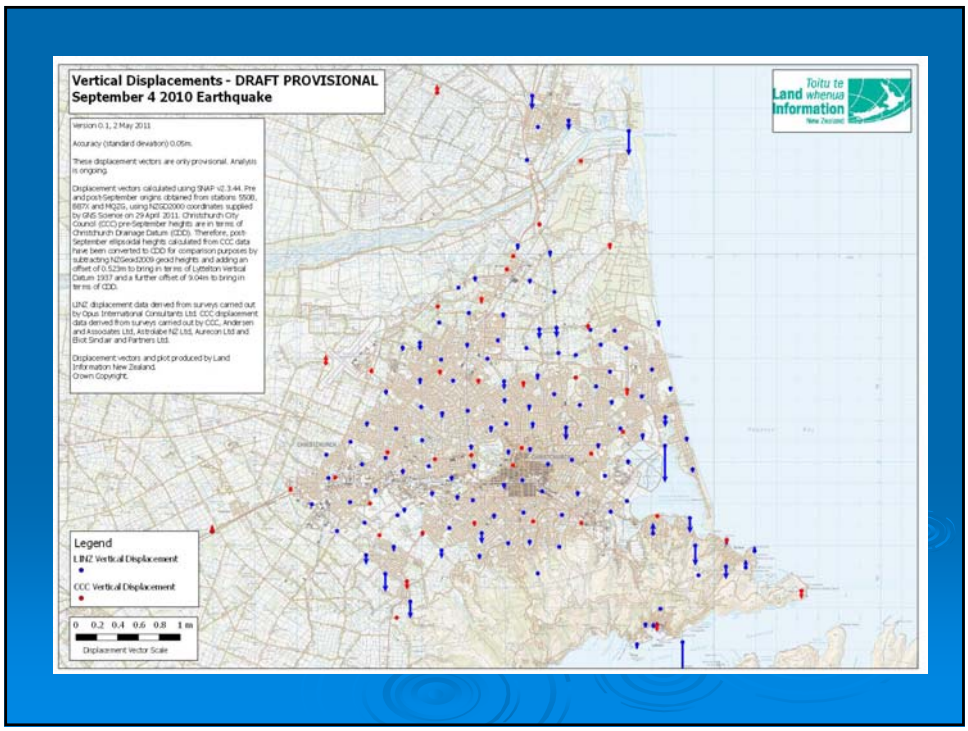
Impact on the Survey System

- New Zealand Geodetic Datum 2000 – semi-dynamic datum to accommodate the effect of crustal motion.
- NZ cadastral boundaries are defined by survey.
- For 70% of land parcels – principally urban & peri-urban – the cadastre is survey accurate.
- Geodetic, cadastral & title data is managed in an automated digital database – **Landonline.**
- Observational database enabling the re-adjustment of co-ordinates as improved data becomes available.
- Cadastral surveyors operate under the *Rules for Cadastral Survey 2010.*

Impact on the Survey System

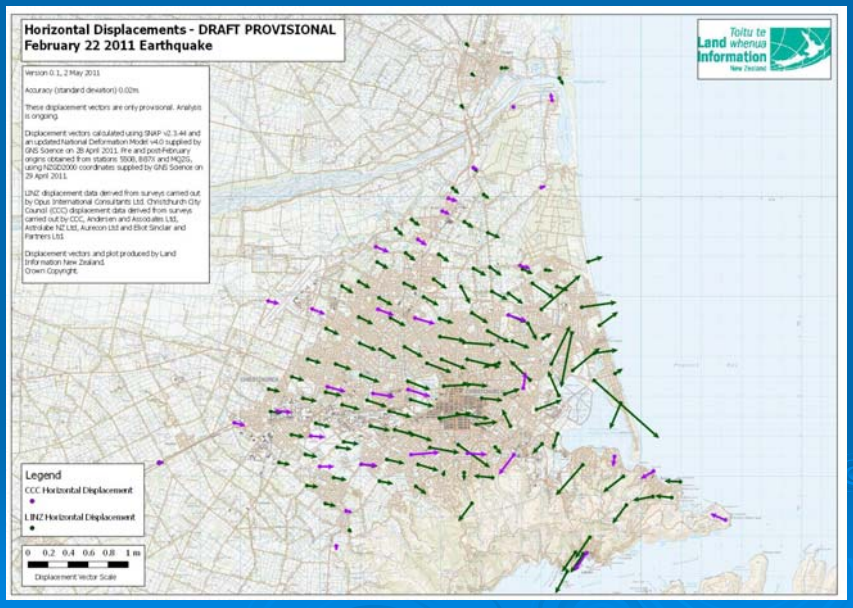
- Thousands of geodetic marks and millions of cadastral marks estimated to have moved by significant amounts.
- Immediate post-Darfield surveys were undertaken by GNS Science to determine extent of vertical & horizontal ground deformation – deformation modelling.
- LINZ subsequently re-surveyed 190 high order geodetic marks across affected areas (XYZ).
- Results showed significant displacements over a wide area with generally systematic patterns but many anomalies due to liquefaction.

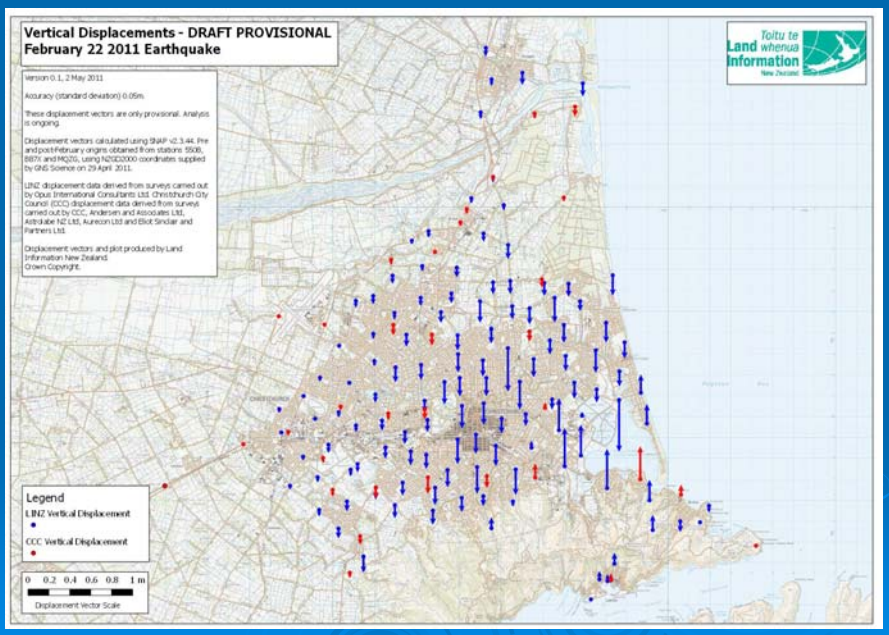

Horizontal Displacements - DRAFT PROVISIONAL
September 4 2010 Earthquake
Version 0.1, 2 May 2011
Accuracy (standard deviation) 0.02m.
These displacement vectors are only provisional. Analysis is ongoing.
Displacement vectors calculated using SNAP v2.3.44 and an updated National Deformation Model v4.0 supplied by GNS Science on 28 April 2011. Pre and post-September origins obtained from stations SSOB, BX07Y and MQZG, using NZGD2000 coordinates supplied by GNS Science on 29 April 2011.
LINZ displacement data derived from surveys carried out by Opus International Consultants Ltd.
Displacement vectors and plot produced by Land Information New Zealand.
Crown Copyright.
Toitu te Land whenua Information New Zealand
Legend
LINZ Horizontal Displacement
0 0.2 0.4 0.6 0.8 1 m
Displacement Vector Scale


Vertical Displacements - DRAFT PROVISIONAL
September 4 2010 Earthquake
Version 0.1, 2 May 2011
Accuracy (standard deviation) 0.05m.
These displacement vectors are only provisional. Analysis is ongoing.
Displacement vectors calculated using SNAP v2.3.44. Pre and post-September origins obtained from stations SSOB, BX07Y and MQZG, using NZGD2000 coordinates supplied by GNS Science on 29 April 2011. Christchurch City Council (CCC) pre-September heights are in terms of Christchurch Drainage Datum (CDD). Therefore, post-September ellipsoidal heights calculated from CCC data have been converted to CDD for comparison purposes by subtracting NZGeoid2009 geoid heights and adding an offset of 0.523m to bring in terms of Lyttelton Vertical Datum 1937 and a further offset of 9.04m to bring in terms of CDD.
LINZ displacement data derived from surveys carried out by Opus International Consultants Ltd. CCC displacement data derived from surveys carried out by CCC, Andersen and Associates Ltd, Astrolabe NZ Ltd, Aurecon Ltd and Eliot Sinclair and Partners Ltd.
Displacement vectors and plot produced by Land Information New Zealand.
Crown Copyright.
Toitu te Land whenua Information New Zealand
Legend
LINZ Vertical Displacement
CCC Vertical Displacement
0 0.2 0.4 0.6 0.8 1 m
Displacement Vector Scale

Impact on the Survey System

- Post 22 February (and 13 June) surveys were again undertaken to quantify ground deformation
- The results showed more extensive areas of non-uniform deformation
- The use of a displacement model to spatially correct positions of geodetic & cadastral marks was not considered feasible
- Extensive geodetic re-survey work (XYZ) is ongoing under LINZ control





Impact on the Survey System - Levels

- Post Darfield the Christchurch City Council recognised their city-wide level network as their fundamental asset.
- The network's pre-quake network accuracy was 0.030m and a limited number of Bench Marks within the network were re-surveyed to determine reliability.
- 4-day fast Static GNSS survey connected to LINZ 1st & 2nd order control by Council and Consultants.
- 80% of surveyed marks within GNSS height tolerance – unchanged.
- Remainder assigned new interim values.

Impact on the Survey System - Levels

- Network re-surveyed after 22/2/11, 13/6/12 & 23/12/11 events and revised orthometric height values for Bench Marks published.
- More pronounced ground movement post Christchurch quake (22/2/11) were reflected in the level values.
- Considerably less agreement with pre 4 September 2010 values this time.
- Data processed in a similar manner – changes in level reflect ground movement.
- Fundamental importance for infrastructure rebuild/repair.

Surveyors Response – Post Darfield

- First and foremost care of families & home.
- Our offices sustained only minor structural damage and this was the case for most Christchurch firms.
- Council offices sustained damage and staff were forced to work from libraries and service centres.
- Essentially business as usual for Consultants with more earthquake related work.
- GNSS & precise levelling campaigns.
- Essential infrastructure monitoring.
- Surveying services for geotechnical investigations.
- Structural engineers very busy assessing damage

Surveyors Response – Post Christchurch

- First and foremost care of families & home.
- Centre of the city red-zoned and firms had to retrieve essential items, find new premises and keep operating
- Initially we and others operated out of garages and the homes of staff until we found new premises
- Then 1500m^2 / 65 staff – now 375m^2 / 70+ staff
- In the immediate aftermath –
  - monitoring of damaged CBD buildings,
  - monitoring of essential infrastructure, and
  - some surveyors involved in USAR support.

Surveyors Response – Post Christchurch

Surveyors' Response – Post Christchurch

- Building verticality surveys, topographical surveys (to establish existing-use rights), building & infrastructure monitoring became the order of the day.
- Land development and cadastral surveys on hold for several months until aftershocks subsided.
- Ground distortions, misclosures and lack of reliable marks in quake affected areas caused and are still causing boundary definition problems.
- Several areas of the city red-zoned, land too badly damaged to re-build on, 6,000 dwellings affected to date.
- Demand for new housing meant cadastral problems had to be overcome.

Response to Cadastral Problems

- Since Darfield there were ongoing discussions between Canterbury surveyors and LINZ on the effects of the earthquake on the cadastre.
- Rules for *Cadastral Surveys (Canterbury Earthquake) 2010* published by LINZ post Darfield.
- Underlying philosophy of RCS (CE) 2010
  - Deep seated ground movement = boundary has moved
  - Surface layer movement = boundary has not moved
- Post Darfield these assumptions were not inconsistent with the situation surveyors were finding on the ground.

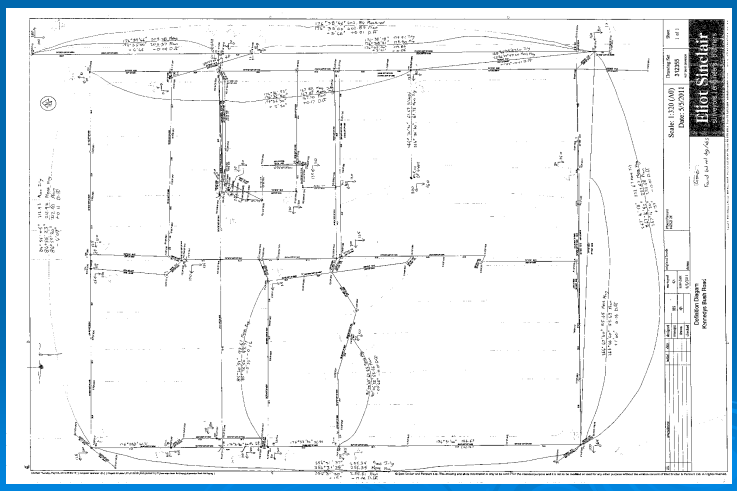
Category One - Boundaries unaffected by the earthquake	*No change, the Rules for Cadastral Survey 2010 apply.*
Category Two - Boundaries affected by block shifts with relatively uniform movement.	*Parcel boundaries are expected to have maintained relativity with the adjoining parcel boundaries and with 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.*

Response to Cadastral Problems

- Christchurch earthquake did not fall neatly into a fault rupture scenario – proximity of the epicentre and shallowness of the event.
- The cadastral fabric had been affected roughly in line with damage to land and property
- Post 22 February Category 5 boundaries in particular were becoming difficult to re-define.
- In some situations surveyors were finding distortion, compression, rotation, lateral spread/liquefaction all within the area under survey.
- Ongoing discussions with local LINZ staff to find solutions

Category 5 Boundaries

Category 5 Boundaries



Category 5 Boundaries

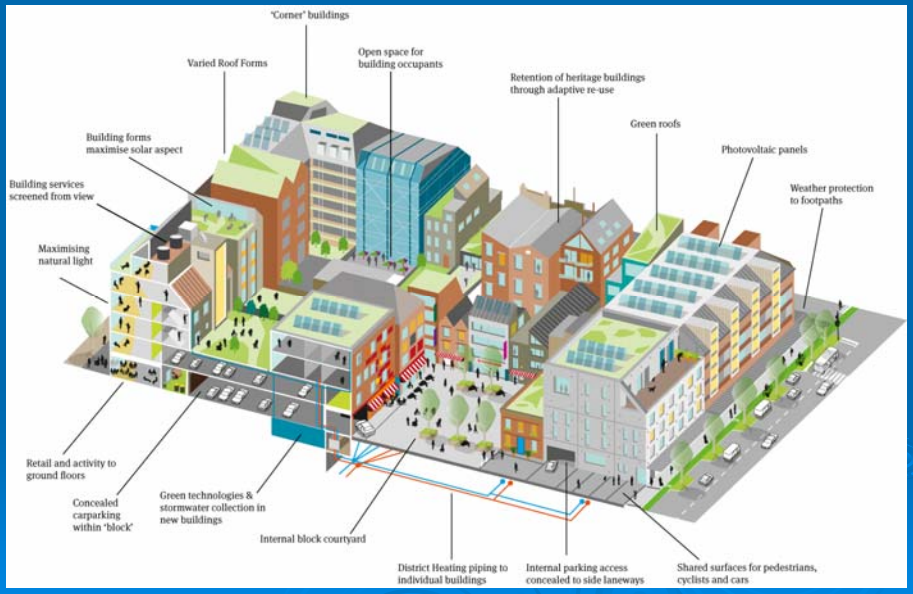
- Some clarity around Category 5 boundaries.
- LINZ now accepts that groups of local marks that have retained the same relationship relative to one another may be used for parcel definition.
- Marks found that appear to be undisturbed but do not agree with the marks used for the boundary definition can now be recorded in Landonline (UNPROVEN).
- Landonline now able to accommodate the distortions found on the ground.
- Boundary definition is a matter of a surveyor's judgement, skill and experience substantiated by evidence of the survey/boundary marks found.

The Present

- Review of *RCE (CE) 2010* underway for future events.
- Aftershocks settling down and surveyors are very busy.
- Post earthquake protection of survey marks now a LINZ priority.
- Many marks lost during building demolition in CBD and infrastructure upgrade/rebuild.
- Survey marks may be removed but mark protection surveys must be undertaken prior to removal.
- NZIS Canterbury Branch meetings provide a forum for practitioners to discuss surveying problems and address issues of concern.
- Recommendations to CCC, CERA, LINZ, SCIRT

The Future

- Not here yet!
- 1,200 buildings in CBD to be demolished before the rebuild can get underway - 50% complete to date
- 6,000 residential dwellings to be demolished
- Thousands of homes undergoing repair
- The earthquakes have provided Christchurch with the opportunity to re-invent itself
- New Christchurch City Plan for the central city is bold and exciting – ‘City in a Garden’
- Surveyors serving on Urban Design Panels that review city development proposals


"Corner" buildings
Varied Roof Forms
Open space for building occupants
Retention of heritage buildings through adaptive re-use
Green roofs
Photovoltaic panels
Weather protection to footpaths
Building forms maximise solar aspect
Building services screened from view
Maximising natural light
Retail and activity to ground floors
Concealed carparking within 'block'
Green technologies & stormwater collection in new buildings
Internal block courtyard
District Heating piping to individual buildings
Internal parking access concealed to side laneways
Shared surfaces for pedestrians, cyclists and cars

The Future

- The redevelopment of Christchurch is an exciting process
- Surveyors actively engaged in the process
- We've been through tough times but professionally it's a great time to be surveyor in Christchurch

We invite you to see for yourself a new and invigorated Christchurch rising from the rubble at the 2016 Working Week.