Re-establishment of the New Zealand Survey Control System Following the 2010 Darfield (Canterbury) Earthquake

Nic DONNELLY, John RITCHIE and Matt AMOS, New Zealand

Key words: Earthquake, control survey, deformation

SUMMARY

On 4 September 2010, a magnitude 7.1 earthquake struck the Canterbury Region of New Zealand. The fault dislocation and liquefaction resulting from the earthquake severely compromised the integrity of the survey control system in Canterbury. The control system serves two primary purposes: providing control for cadastral surveys (primarily horizontal) and providing vertical control for provision of gravity-dependent infrastructure such as sewer and irrigation systems.

In consultation with local authorities and geotechnical engineers working in the affected areas, priorities for re-survey were identified. The re-surveys were carried out in several phases, with each phase providing information to help plan the next. Initial deformation and regional control surveys using GNSS was undertaken shortly after the earthquake. This provided a broad indication of the scale and extent of horizontal and vertical displacements. This was used to identify areas for denser control surveys, where localised deformation was apparent.

An extensive precise levelling campaign is being carried out to re-establish accurate height control throughout the region. The flat topography of Canterbury means that the provision of reliable height control is critical for the reconstruction and operation of infrastructure such as sewer systems and irrigation schemes.

Provisional data from these surveys were made available to affected parties as it was collected. A feature of this work was close collaboration with other central and local government agencies and the private sector to ensure that no duplication of effort occurred.

The magnitude 6.3 aftershock which struck Christchurch on 22 February 2011 resulted in widespread liquefaction throughout the city and caused further damage to the survey control infrastructure, which will necessitate a greater level of re-survey work.

Re-establishment of the New Zealand Survey Control System Following the 2010 Darfield (Canterbury) Earthquake

Nic DONNELLY, John RITCHIE and Matt AMOS, New Zealand

1. INTRODUCTION

1.1 Canterbury (Darfield) earthquake

The Canterbury region of New Zealand's South Island experienced a magnitude 7.1 earthquake on 4 September 2010. The earthquake was centred near the town of Darfield, about 40km west of Christchurch, the South Island's main city. It caused substantial damage to property, but no loss of life. Further information about the earthquake can be found in Smith et al (2011).

1.2 Christchurch earthquake

The Christchurch earthquake hit on 22 February 2011. Considered to be an aftershock of the Darfield quake, it measured 6.3 on the Richter scale and resulted in massive property damage and loss of life. At the time of writing, it is expected that the final death toll will be about 180.

1.3 The New Zealand Survey Control System

The New Zealand Survey Control system is divided into a number of networks, each of which serves a different purpose (Donnelly and Amos, 2010). For example, the National Height Network is comprised of precise-levelled benchmarks and provides accurate vertical control for activities such as engineering and hazard monitoring.

Since the introduction in 1998 of New Zealand Geodetic Datum 2000 (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 earthquake changed this, centred as it was in a major agricultural area near the city of Christchurch (population 390,000). Thousands of geodetic marks and millions of cadastral marks are estimated to have moved by significant amounts.

This paper outlines the steps taken to re-establish the control system in the wake of the Darfield earthquake.

2. IMMEDIATE RESPONSE

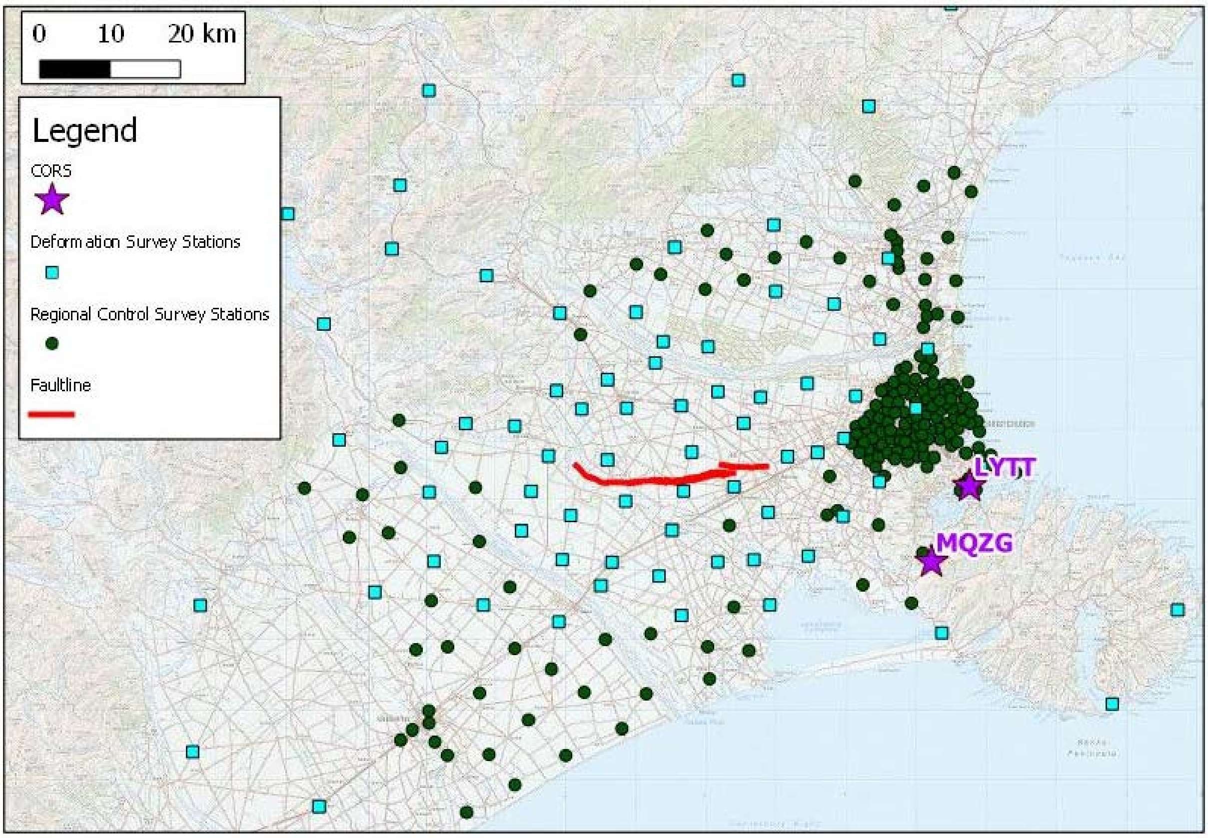

Figure 1: Location of survey stations and CORS

2.1 CORS Data Processing

Within hours of the earthquake, staff from LINZ had commenced processing of Continuously Operating Reference Station (CORS) data from the station MQZG, located 40 km from the epicentre (Figure 1). At this preliminary stage, no significant vertical deformation was detected, but approximately 15cm of horizontal movement was apparent. The movement detected was sufficient to suggest that the impact on the survey control system would be substantial.

2.2 Initial Deformation Survey

Three days after the earthquake, a field team led by GNS Science, New Zealand's geological scientific agency, travelled to Canterbury to commence a survey of approximately 70 survey control marks (Figure 1). Each of these marks had high-accuracy pre-earthquake coordinates. Some were part of the GNS Science deformation monitoring network, which is resurveyed every 7-10 years. Others were LINZ marks which were originally surveyed to provide control for lower accuracy geodetic surveys.

The GNSS data collected during this survey were used to estimate ground displacements at each mark. These displacements gave a clear indication of the magnitude and extent of land movements. The largest movement identified was 2m horizontally and 0.75m vertically, at a mark within 2km of the fault rupture (Figure 1).

For a fuller description of this survey and the data processing carried out, see Beavan *et al* (2010).

2.3 Geodetic Surveys to Support Urgent Infrastructure Re-Establishment

In New Zealand, individual local councils typically operate their own height control networks, which connect to the LINZ survey control system. In the days after the earthquake, portions of some of these local systems were surveyed by the respective councils to estimate the extent of vertical displacements. The primary aim of these surveys was to obtain accurate height information to support the re-establishment of gravity-dependent infrastructure such as sewer systems and monitor hazards such as flooding.

For example, the Christchurch City Council resurveyed about 30 of their benchmarks using GNSS to support re-establishment of the approximately 70km of sewers damaged in the earthquake.

2.4 Second Deformation Survey

Four weeks after the initial deformation survey, a repeat survey of the same 70 marks was carried out. Again the survey was led by GNS Science with LINZ field support. This survey indicated that post-seismic displacements were in accordance with expectations for an earthquake of this magnitude.

2.5 Suspension of Non-Earthquake Geodetic Survey Activities

LINZ has an active programme to enhance and extend the survey control system in New Zealand. A key component of this programme is the survey of new control marks in areas where existing control is scarce, or fails to meet modern accuracy standards.

In New Zealand, geodetic fieldwork is carried out by private survey companies under contract to LINZ. In Canterbury, Opus International Consultants Ltd had been engaged to carry out routine geodetic survey work prior to the earthquake. Given the expected ongoing post-seismic movement, there was little point continuing with this work in the short term. In agreement with Opus, the previously planned geodetic survey work in Canterbury was suspended and their efforts were redirected to assist with the work to recover the survey control system.

Consideration was also given to diverting geodetic contractors working in other parts of the country to assist with the control recovery effort, although in the end this was not necessary.

2.6 Pre-Earthquake Data

Most of the high accuracy geodetic surveys in Canterbury were carried out in the late 1990s, as part of the establishment of NZGD2000. Consequently, LINZ did not hold a large amount of high accuracy data for the years immediately preceding the earthquake. Accurate pre-earthquake positions are required to reliably determine movements at control marks.

LINZ made a request to local surveyors for any data they might hold on key control marks for the two years preceding the earthquake. Data meeting the following characteristics was requested:

- at least one hour of GNSS data collected
- antenna heights accurately measured
- complete metadata for the setup available (eg antenna type, antenna reference point)
- dual-frequency carrier phase data logged (ie survey-quality data)

A number of private companies supplied data to support the analysis. In some cases this data was very useful. In other cases, the work required to format and check the data meant that it could not be of immediate benefit.

3. PLANNING FOR FULL SURVEY CONTROL RECOVERY

3.1 Consultation

To ensure that geodetic resources were used in the most appropriate way to support the recovery effort, LINZ consulted with officials from the local and regional councils in the affected area. As a result of these discussions, re-establishment of the height control network was identified as the most urgent priority. Several councils were undertaking or planning precise levelling surveys, and wanted to connect to the National Height Network, the precise levelling network maintained by LINZ. Meetings were also held with Tonkin and Taylor Ltd, engineering consultants for the Earthquake Commission[1]. They provided information on the extent of liquefaction zones, and the likely ground movements within these zones.

3.2 Additional Funding

To support the timely re-establishment of the survey control system, a request was successfully made to Government to secure additional funding. A major focus was the need to re-establish the height system via precise levelling much of Canterbury to support the re-establishment of infrastructure such as sewers and monitoring of flood hazards.

[1] The Earthquake Commission is a state insurance agency providing natural disaster insurance for property owners who hold fire insurance

4. GEODETIC SURVEY ACTIVITIES

4.1 Regional Control Survey

Once the second deformation survey had confirmed that post-seismic movement was subsiding consistent with expectations, work commenced to resurvey the 190 marks which comprise the LINZ 1st-4th order networks in the affected area. The fieldwork was carried out by Opus, and each mark was surveyed at least twice, with 30 minutes of fast static GPS data being collected. Control for this survey was provided by the marks surveyed during the earlier deformation surveys carried out by GNS Science.

To support this survey, data was provided free of charge from CORS operated by Trimble and GeoSystems, two private companies in Canterbury. This data was useful for strengthening the survey in areas where there was very little higher order control. Displacements determined from a combination of data from GNS Science surveys and the Regional Control Survey are shown in Figure 2 below.

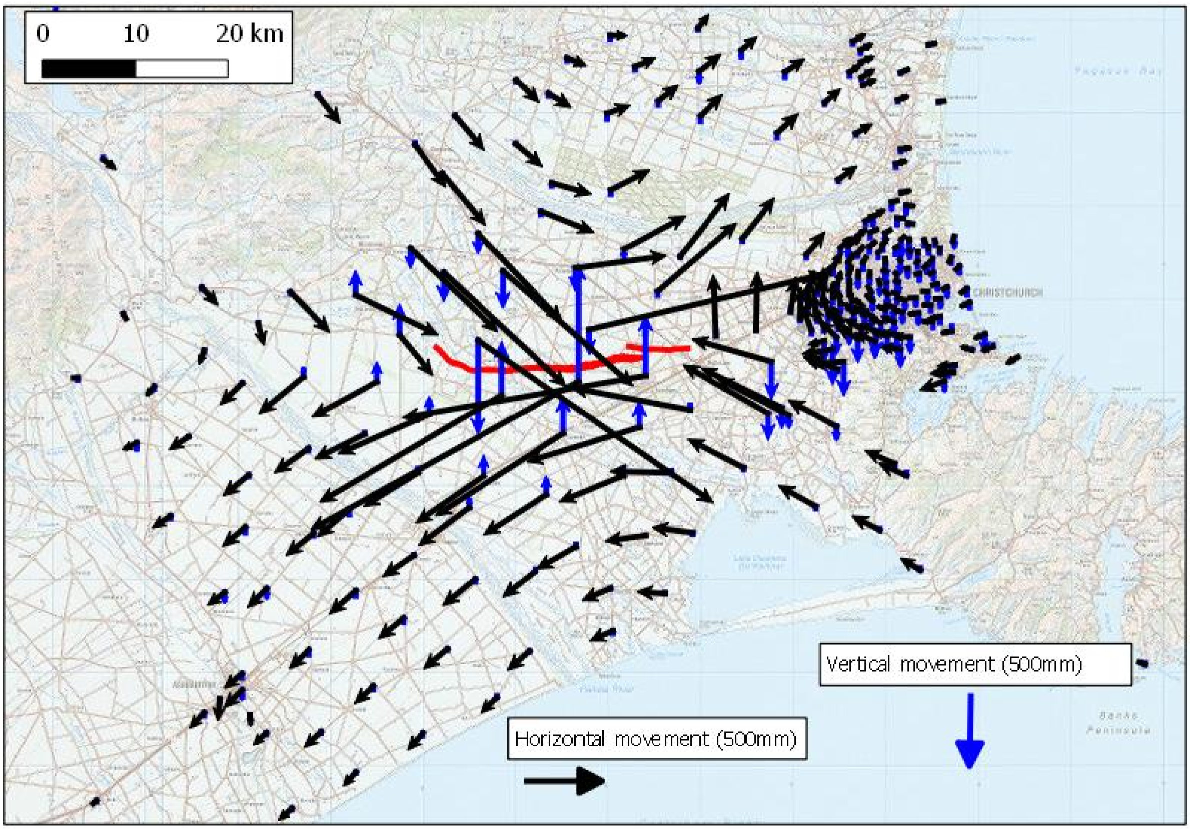

Figure 2: Horizontal (black vectors) and vertical (blue vectors) displacements in Canterbury resulting from the Darfield earthquake

An interesting feature of these movements is the apparent rotation of Christchurch city, shown in Figure 3. The rotations represent about 2 seconds of arc, so are not significant for most localised survey activities.

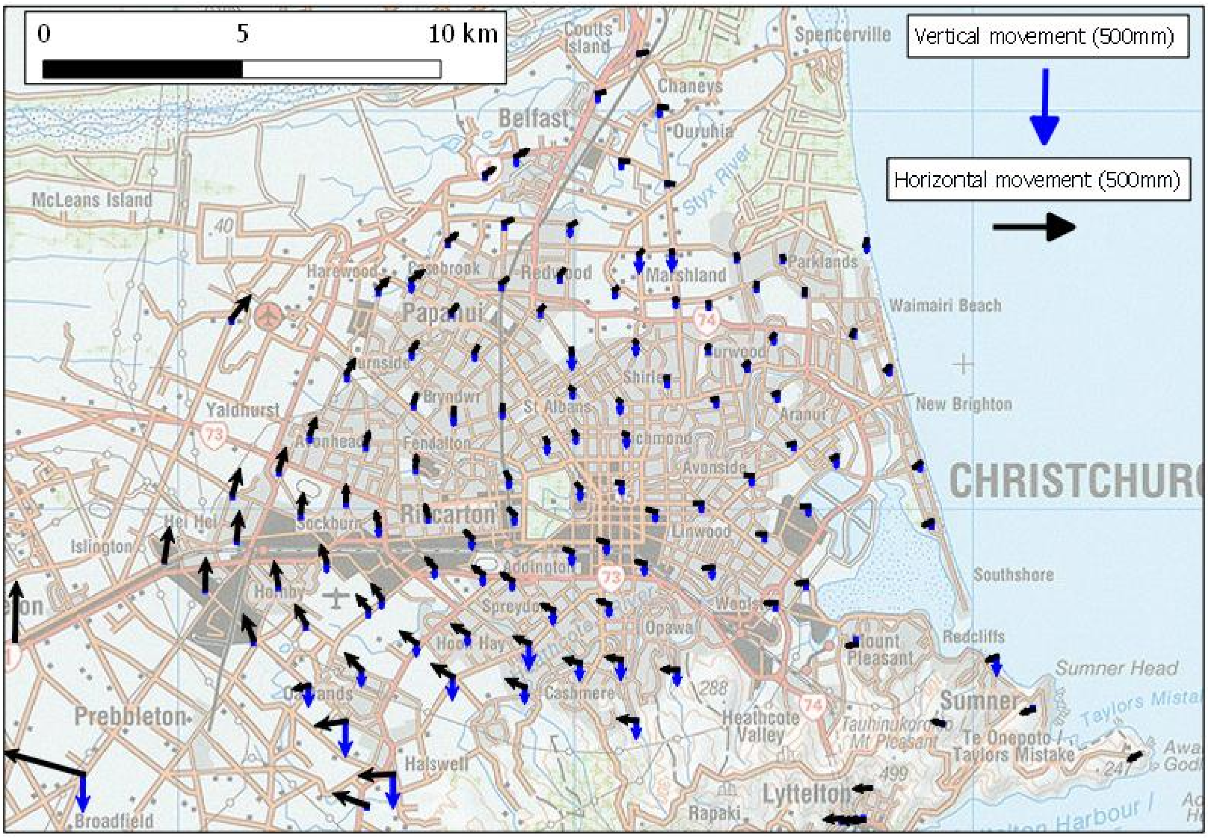

Figure 3: Horizontal (black vectors) and vertical (blue vectors) displacements in Christchurch resulting from the Darfield earthquake

4.2 Precise Levelling

Consultation with local councils had identified a precise levelling run from the town of Kaiapoi (north of Christchurch) to the centre of Christchurch as being the highest priority (Figure 4). This precise levelling was carried out during November and December and provisional results provided to the councils.

One of the significant challenges with the precise levelling is identifying a stable reference point to act as an origin of heights. For the levelling run from Kaiapoi to Christchurch, a mark to the north of Kaiapoi was held fixed. This mark was located in an area that had been identified in the Regional Control Survey (see section 4.1) as having negligible vertical movement.

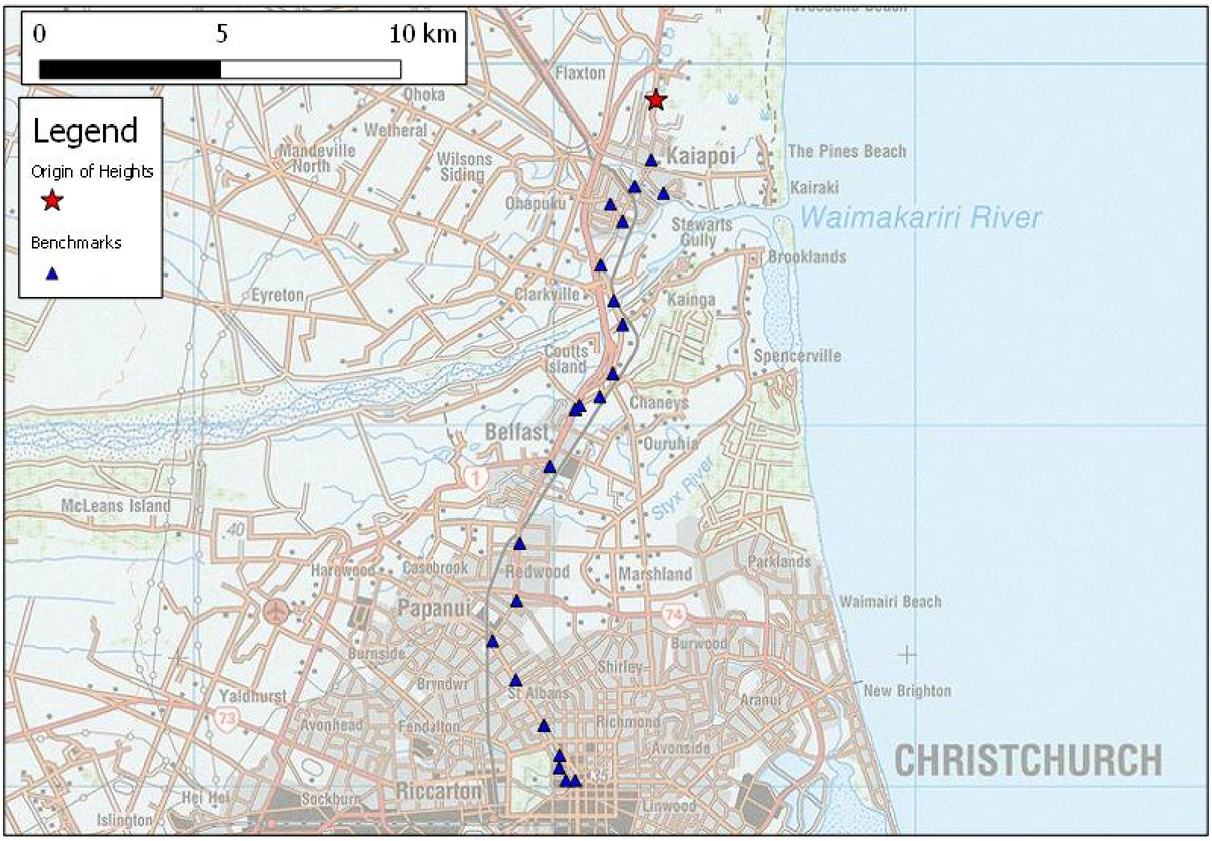

Figure 4: Precise levelling route from the town of Kaiapoi through to central Christchurch

While this urgent precise levelling was being completed, planning and tendering for a larger precise levelling survey covering the bulk of the Canterbury Plains was being completed.

As part of the planning, a reconnaissance of the existing precise levelling benchmarks was carried out. This identified that approximately 40% of benchmarks (many of which were installed in the early twentieth century) were either destroyed or in inaccessible locations. Some marks were located in live traffic lanes of major highways. In particular, the LINZ National Height Network runs along State Highway One, New Zealand's main highway running the length of the country. Traffic management considerations made it impractical to precise level along this highway for any significant distance.

Based on this reconnaissance, extensive portions of the LINZ network were replaced with benchmark runs originally surveyed by the Ministry of Works in the 1980s. These replacement runs were on roads with much lower traffic volumes and the benchmarks were generally off the formed carriageway (Figure 5).

The precise levelling was tendered, and work awarded to three companies. By splitting the work among three geodetic contractors, results could be obtained more quickly. In addition to the precise levelling, half the marks were also to be surveyed with GNSS. As well as providing an accurate horizontal fix on a significant proportion of the marks, the GNSS data could be used to quickly re-establish the height network in the event of significant aftershocks or other earthquakes. This work commenced in January 2011.

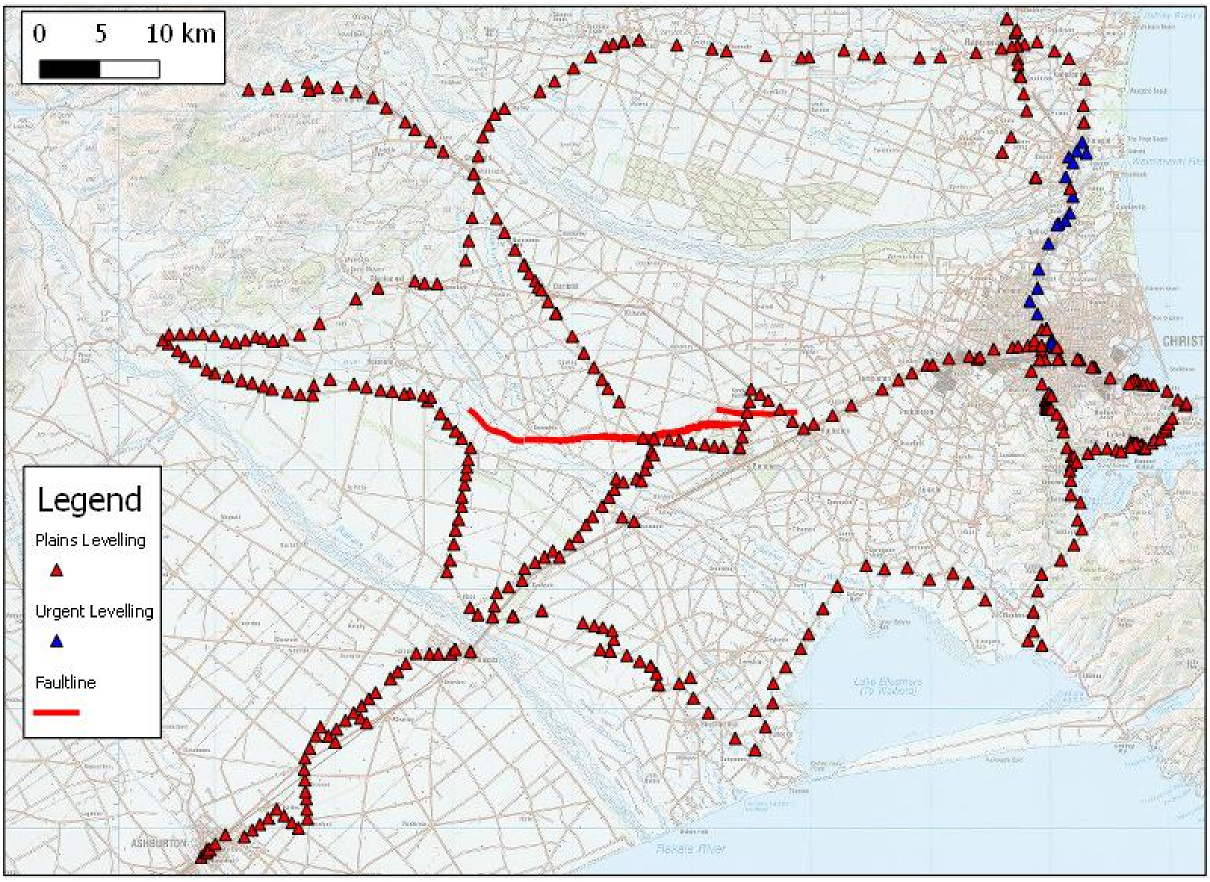

Figure 5: Benchmarks scheduled for precise levelling in Canterbury Plains

4.3 Localised Deformation Surveys

In some areas, deformation is so non-uniform that it is not possible to model it to the level of accuracy required of the survey control system. For example, in the area within 10km of the fault rupture, all existing control marks are scheduled for resurvey.

Likewise, areas affected liquefaction in Christchurch city need to have all control marks re-surveyed (or new control marks installed) due to the non-uniform movements.

5. CHRISTCHURCH AFTERSHOCK

On 22 February 2011 a major aftershock occurred in Christchurch City causing additional damage to already compromised infrastructure. At this time, precise levelling surveys were underway and final planning for localised deformation surveys was being completed.

In the days following the earthquake, LINZ staff collected data at a number of key geodetic marks in the city and surrounding area. This data was processed by GNS Science to develop an initial model of land movements.

The largest movement was 0.20m horizontally and 0.10m vertically at a mark close to the fault, just to the south of the city.

Precise levelling surveys were temporarily halted while the contractors, all of whom were based in Christchurch, re-established their business operations. They have now recommenced work and expect to be finished by the end of May.

Initial surveys carried out by the Earthquake Commission indicate that liquefaction in Christchurch is now far more extensive than that resulting from the Darfield earthquake. Consequently, LINZ is now planning to resurvey a large number of geodetic marks in Christchurch city and the surrounding area. These surveys will be carried out in late 2011 with results expected to be available in early 2012.

6. CONCLUSIONS

Although work is ongoing, already there are some useful conclusions that can be drawn:

1) The private sector can be a valuable source of pre-earthquake data, but it helps to have some formatting and quality measures in place.
2) The provision of height control is more urgent than horizontal control.
3) Partnerships are key to obtaining data as quickly as possible. The partnership between GNS Science and LINZ was particularly valuable in this regard.
4) A balance needs to be struck between re-establishing the control system quickly and waiting until significant aftershocks become statistically unlikely.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the contributions of John Beavan (GNS Science) who provided some of the data used to produce Figures 2 and 3.

We also wish to acknowledge the many survey and GNSS companies who provided data, often at no cost, in support of the recovery effort.

REFERENCES

Beavan, J, Samsonov, S, Motagh, M, Wallace, L, Ellis, S and Palmer, N, 2010, The Darfield (Canterbury) Earthquake: Geodetic Observations and Preliminary Source Model, *New Zealand Society for Earthquake Engineering Bulletin*, Vol 43, No 4, December 2010.

Donnelly, N and Amos M, 2010, *Implementation of a New Survey Control Standard for New Zealand*, in Proceedings of XXIV FIG Congress, April 11-16, Sydney, Australia. Available at: http://www.fig.net/srl/

Smith, M, Thompson, M, Donnelly, N and Grant D, 2011, *Re-establishment of Cadastral Boundaries Following the 2010 Earthquake in Canterbury, New Zealand*, in Proceedings of FIG Working Week, May 18-22, Marrakech, Morocco.

BIOGRAPHICAL NOTES

Nic Donnelly BSurv (Hons), BSc (Otago University). Nic is a Geodetic Surveyor within the National Geodetic Office at LINZ. His interests and responsibilities include geodetic adjustments and maintenance and enhancement of the geodetic cadastre.

John Ritchie BSc (Otago University). John is Deputy Chief Geodesist for New Zealand. His interests and responsibilities include overseeing survey control and geodetic audit activities at LINZ.

Matt Amos PhD (Curtin University of Technology), MSurv, BSurv (Otago University). Matt is a Senior Advisor to the Surveyor-General. His interests and responsibilities include geodetic standards and vertical reference systems.

CONTACTS

Mr Nic Donnelly
Land Information New Zealand
PO Box 5501
Wellington 6145
NEW ZEALAND
Tel. +64 4 460 0191
Fax + 64 4 498 3837
Email: ndonnelly@linz.govt.nz
Web site: www.linz.govt.nz

Mr John Ritchie
Land Information New Zealand
PO Box 5501
Wellington 6145
NEW ZEALAND
Tel. +64 4 460 0563
Fax + 64 4 498 3837
Email: jritchie@linz.govt.nz
Web site: www.linz.govt.nz

Dr Matt Amos
Land Information New Zealand
PO Box 5501
Wellington 6145
NEW ZEALAND
Tel. +64 4 460 0559
Fax + 64 4 460 0112
Email: mamos@linz.govt.nz
Web site: www.linz.govt.nz