Re-establishment of Cadastral Boundaries Following the 2010 Earthquake in Canterbury, New Zealand

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Key words: Cadastral boundaries, earthquake, security of title

SUMMARY

The Canterbury region of New Zealand was subjected to a magnitude 7.1 (Richter scale) earthquake at 4:35am on 4 September 2010. While no lives were lost from the earthquake, there was significant physical damage to land and buildings in the Christchurch urban area and surrounding rural area. Despite the known seismic activity in New Zealand there had been no major earthquake affecting the cadastral boundaries of a large urban area since the Hawke's Bay (Napier) earthquake in 1931.

Cadastral boundaries were affected by the earthquake in a number of ways:

- shearing of up to 4 metres in rural areas where the fault line passed through land parcels
- extension, compression and distortion close to the fault line
- block movements and rotations throughout the Canterbury area
- irregular deformation due to liquefaction of soils

Few international examples of solutions for boundary re-establishment after such an event, that were applicable to New Zealand, could be located.

This paper describes the effects of the earthquake on cadastral boundaries in the region. It then discusses the steps that are being taken to provide certainty in cadastral boundary re-establishment by surveyors.

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1. CONTEXT

1.1 Canterbury (Darfield) earthquake

The Canterbury region of New Zealand was subjected to a magnitude 7.1 (Richter scale) earthquake at 4:35am on 4 September 2010. There was significant physical damage to land and buildings in the Christchurch urban area and surrounding rural area. Miraculously for an event of this magnitude there was no loss of life.

1.2 Location of Christchurch

Christchurch, population 390,000, is the second largest city in New Zealand and is situated approximately midway down the eastern coast of the South Island at 43°32’S, 172°38'E. The Canterbury region surrounding Christchurch is principally alluvial plains with small townships as residential commuter towns for Christchurch or supporting agricultural or horticultural activities on the Canterbury plains.

1.3 Location of the earthquake

The earthquake epicentre was located approximately 40 km west of Christchurch City near the town of Darfield and has been officially named the Darfield earthquake as a consequence, although it is more frequently referred to as the Canterbury earthquake and sometimes the Christchurch earthquake. Subsequently the major magnitude 6.3 aftershock, 22 February 2011, is now referred to as the Christchurch earthquake as it was centred only 10 km south east of the Christchurch central business district, near the port of Lyttelton.

A fault surface rupture, associated with the September earthquake, between the districts of Rolleston and Greendale, 10 km south of Darfield, has been named the Greendale fault.

Figure 1 illustrates the position of the fault in respect of Christchurch and the surrounding Canterbury Plains.

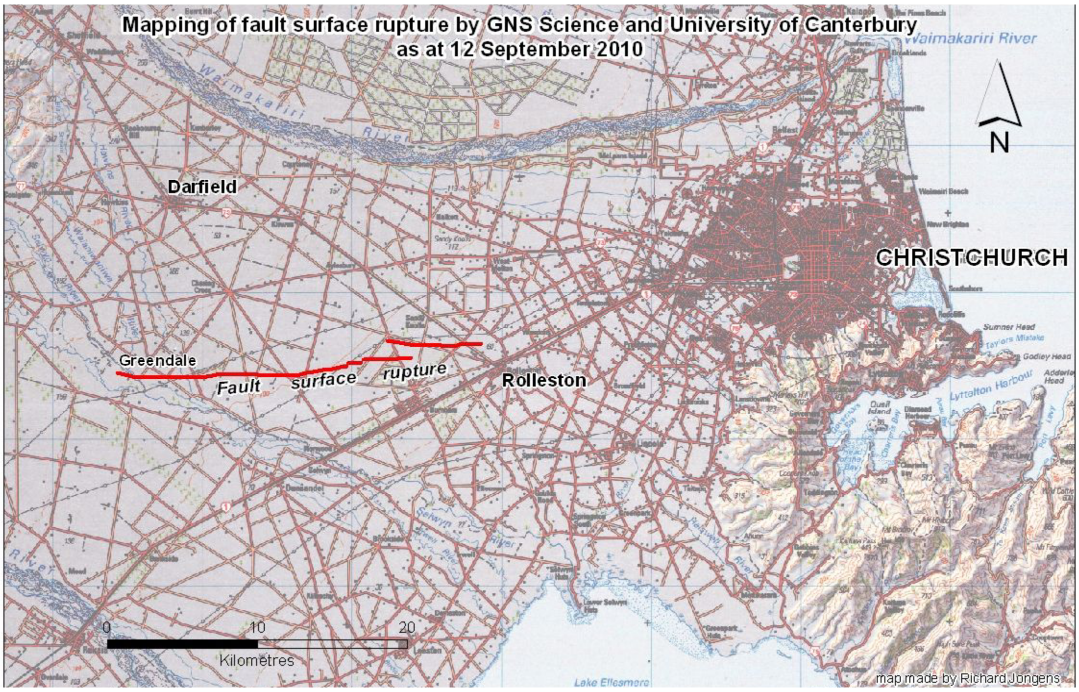

Figure 1 – Location of Greendale fault relative to Christchurch City

2. PHYSICAL OUTCOMES OF THE EARTHQUAKE EVENT

Earthquake events have the ability to cause a variety of physical effects on the land surface together with damage to buildings and their accompanying structures as well as to established on-ground and below ground utility infrastructure.

2.1 Physical effects of the Darfield earthquake on Structures

2.1.1 Building and property damage

Some buildings in the centre of the city were damaged by the shaking effect of the earthquake. Many heritage buildings lost masonry facings and decorations and older buildings with structural brick construction suffered structural damage through the failure of mortar, severe cracking or loss of bricks. A number of buildings were demolished following the earthquake including one non-reinforced brick six storey building. In general, these building were constructed prior to the 1931 Hawke's Bay (Napier) earthquake. The damage caused to buildings in Hawke's Bay in 1931 had resulted in a strengthening in building codes in New Zealand which is believed to have saved later buildings. A number of Christchurch's heritage buildings, including the Cathedral and the former Canterbury University buildings had received seismic strengthening works since 1970, and this work was considered to have prevented extensive damage to these buildings in the September 2010 earthquake.

Unfortunately some of these buildings subsequently suffered major damage in the 22 February 2011 aftershock, as described in section 6 below.

A large number of residential suburban homes were severely damaged. In many cases damage to these homes, and related structures, was caused by local areas of liquefaction resulting from the earthquake. The liquefaction and effects on the land is discussed later in this paper.

2.1.2 Damage to Utility Infrastructure

All commercial, industrial and residential areas of the city are fully reticulated with utility services and enjoy streets with high quality roads and footpaths. Mainly due to the liquefaction element of the earthquake, many road surfaces were rippled, concrete kerbs and channels distorted, bridges raised in respect to the roads they joined, stormwater and sewerage pipework broken and raised through the road surface, electricity cables stretched and severed, gas lines ruptured, and water services destroyed. Christchurch is a flat city which relies heavily on pumps to operate the stormwater and sewerage systems and riverside pumping stations were tilted and made inoperative.

Most surveying reference marks are placed within the road corridors of the city, and where the road surfaces were disturbed by liquefaction, these marks were moved from their original positions.

Figure 2 illustrates the extrusion of a stormwater manhole structure through the road surface due to the effect of liquefaction.

Figure 2 – A stormwater manhole raised by liquefaction (Photo from Wikipedia)

2.2 Physical effects of the Darfield earthquake on the land

2.2.1 Fault Shear

Parcels of land astride the 24 kilometre long fault line were offset in places by up to 4 metres. Fences, water races and road formations clearly show the extent of the offset.

The surface fault rift passes through approximately fifty separate cadastral land parcels in a rural area used primarily for agriculture and horticulture.

Figure 3 – Effects of fault rupture on previously straight fence and water race (Photo Survus Consultants)

The differential movement on either side of the fault is principally horizontal with local areas of vertical movement.

Figure 4 – Effects of fault rupture – previously straight road (Photo Survus Consultants)

2.2.2 Distortion adjacent to the fault

Parcels of land close to the fault are expected, upon survey, to exhibit distortion reflecting the east-west direction of the fault.

2.2.3 Liquefaction effects

A large amount of property damage was caused by liquefaction effects of the earthquake where an estimated 30,000 tonnes of water borne fine silt was extruded out of the subsoil to the surface. The liquefaction caused damage by itself but also allowed a shallow surface movement (lateral spreading) towards features of topographic weakness. For example, where a land parcel was close to a river bank or a terrace, the surface layer of that parcel, together with land improvements, could move towards the river bank. This movement included survey boundary monuments, fences and walls erected on boundaries and survey control monuments. The extrusion of material from subsurface layers created voids into which buildings subsided.

Figure 5 is an example of the rifts created between buildings and paving which were originally adjacent. In the case of wooden framed buildings on masonry foundations, the foundations often split and moved out from beneath the wooden framing.

Figure 5 – Displacement due to liquefaction (Photo from Eliot Sinclair and Partners)

In two suburbs adjacent to wetlands extensive shallow surface movement (lateral spreading) took place towards the water body. Figure 6 is a photograph of a gate at the rear of a property giving access to a riverside recreation area. The white peg at the base of the post is a legal boundary monument. These features appear undisturbed yet after the earthquake they had moved 2.8 metres away from the roadside which was only 80 metres away.

Figure 6 – Boundary point has moved 2.8 metres due to lateral spreading as a result of liquefaction
(Photo from Eliot Sinclair and Partners)

2.2.4 Block shift

Measurements of survey control stations following the September 4 earthquake completed by GNS Science and Land Information New Zealand (LINZ) showed that the whole region had been subjected to a shift in terms of previous positions. The average shift of all points was about 100mm in varying directions. The movement in relation to individual parcels of land in most cases is relatively uniform and is referred to in this paper as block shift.

Figure 7 below shows the displacement vectors.

2.2.5 Vertical Movement

Figure 7 below also shows the extent of vertical movement measured following the earthquake. Local government authorities maintain their own level networks about the city for infrastructure purposes and many of the benchmarks were the invert levels of sewer manholes. Liquefaction caused considerable changes to the levels of many of these manholes which are not reflected in the LINZ survey control displacement vectors – Figure 7.

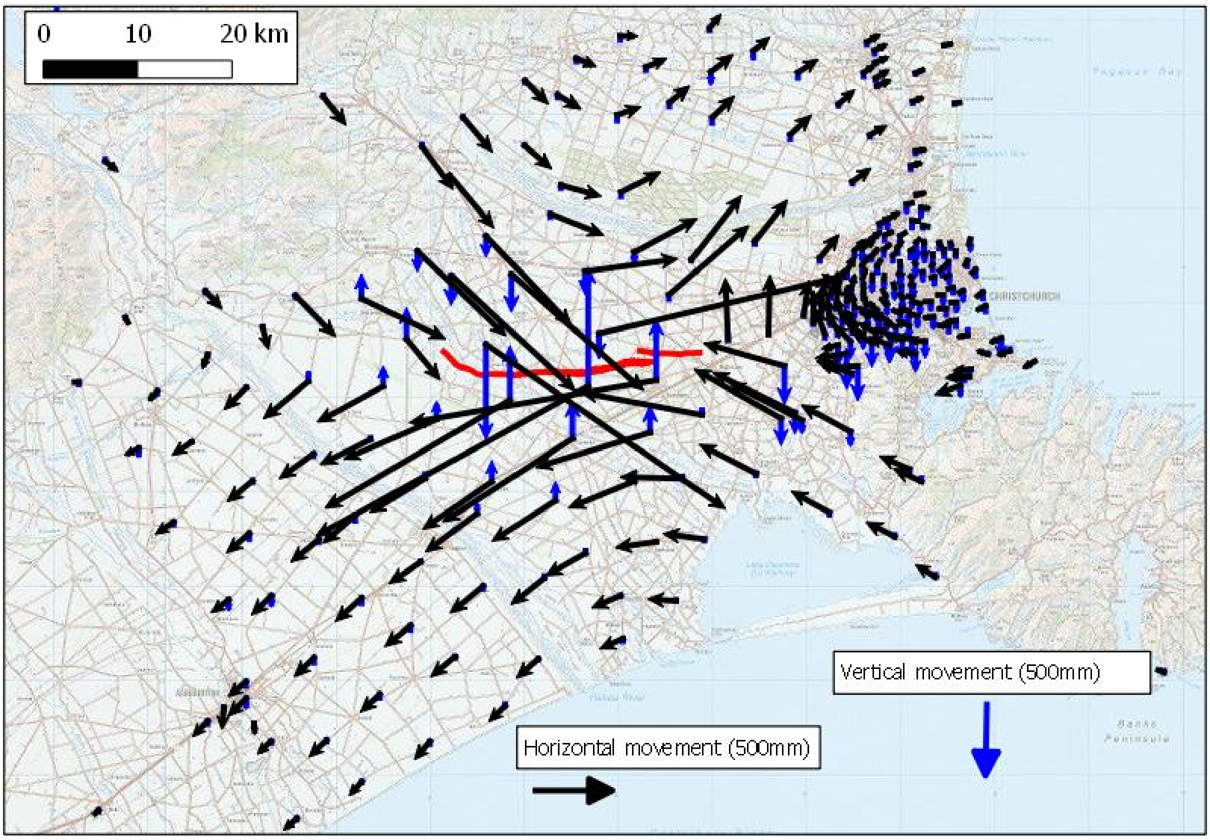

Figure 7 – Horizontal and vertical ground displacements

3. THE EFFECT OF THE DARFIELD EARTHQUAKE ON CADASTRAL BOUNDARIES

3.1 New Zealand Cadastral System

The New Zealand cadastral system supports a Torrens title system with a state guarantee of title. The survey system is based on a strong network of survey control marks to which boundary points and monuments are connected. Nowadays all boundary surveys are undertaken by private sector surveyors operating under the Cadastral Survey Act 2002 and the Rules for Cadastral Survey 2010. The Rules for Cadastral Survey 2010, which came into effect 24 May 2010, have the status of statutory regulations. Most of the guiding principles for the re-establishment of boundaries come from common law which has established a hierarchy of evidence for the re-establishment of boundaries and boundary points. The two highest levels in this hierarchy are firstly natural boundaries and secondly the location of an existing boundary monument in the position in which it was originally placed.

3.2 Inadequacies of Current Law

New Zealand has no prescriptive law or regulation for the re-establishment of boundaries following earthquakes or landslip. There is also a lack of common law to assist surveyors with precedents for re-establishing boundaries following an earthquake. Moreover, the movement experienced following the Darfield earthquake causes difficulty with the hierarchy of evidence when a boundary monument may appear undisturbed from its originally placed position but has moved considerably. See Figure 6 above.

When submitting a Cadastral Survey Dataset (CSD) for integration into the cadastre, a licensed surveyor is required to certify that the survey and dataset are in accordance with the Cadastral Survey Act 2002 and the Rules for Cadastral Survey 2010. The Rules require a surveyor, when defining a boundary by survey, to interpret all evidence found in accordance with all relevant enactments and rules of law.

3.3 Previous New Zealand Earthquake experience

The 1931 Hawke's Bay earthquake was the last major earthquake in New Zealand which impacted upon major residential and commercial districts. A result of that earthquake was the loss by fire of all official title and survey records for the district. The Hawke's Bay Earthquake Act 1931 and the Land Transfer Act (Hawke's Bay) Act 1931, inter alia, made provision for the reconstruction of records. The Napier Alignment Regulations 1932 provided for standard traverses to re-establish fixed width road alignments. These provisions are of little relevance to the re-establishment of Canterbury boundaries post 2010.

Other significant earthquakes, Inangahua 1968 and Edgecumbe 1987 have been in largely rural areas, and Fiordland 2009 was in a wilderness area largely within a National Park. Where boundaries have been re-established following those earthquakes decisions have been made by surveyors and where necessary discussed and endorsed by members of the Surveyor General's staff on a case-by-case basis. The number of boundaries affected by the Darfield event precluded a similar approach being taken in response to the Canterbury earthquake although the principles used for the re-establishment of boundaries are generally consistent.

3.4 Overseas precedents

In 2004 the Surveyor General commissioned a study to synthesize international best practices in re-defining parcel boundaries following a deformation event (Ballantyne 2004). The study found there is a dearth of rigorous principles to deal with such movement which could assist in preparing similar response for New Zealand. Two useful examples are the 1964 Anchorage, Alaska, earthquake and the 1971 San Fernando, California, earthquake. In those cases special legislation was used to deal with the effects of the earthquakes and while not directly relevant to the Canterbury situation, similar principles, where relevant, have been applied to the re-establishment of boundaries.

4. MANAGING THE SPATIAL CADASTRE

4.1 The New Zealand Spatial Cadastre

For 70% of land parcels, covering most urban and intensively-used rural areas, New Zealand has a survey-accurate spatial cadastre. For these parcels, boundary dimensions have been captured from paper plans, and subsequently new digital survey data, and adjusted in terms of the official geodetic datum to generate accurate coordinates. Generally these coordinates have a network (absolute) accuracy of 0.20m in urban areas and 0.50m in rural areas at the 95% confidence level. New Zealand has a monument and observation-based cadastre, so these coordinates do not define property boundaries. However the spatial cadastre that these coordinates represent is used by LINZ and surveyors to find marks and check the quality of new survey data. It is also used widely by the geospatial community, where it forms an important base layer to aid land management and other decision-making.

The movements caused by the Darfield earthquake are significant enough to require the updating of a large number of coordinates to realign the spatial cadastre.

4.2 Re-measurements required

Before the spatial cadastre can be realigned, it is necessary to update the geodetic survey control system in the affected area. Three separate types of geodetic survey are required to update the control system so that the spatial cadastre can be updated. For full details on the re-establishment of the control system following the earthquake, refer to Donnelly et al (2011).

4.2.1 Initial Deformation Survey

In the week following the earthquake, GNS Science (New Zealand's geological research organisation) carried out a survey of 70 control marks in the area expected to have been affected by the earthquake. These 70 marks all had accurate pre-earthquake coordinates to enable a reliable estimate of deformation to be determined. This survey was repeated one month later to assess the extent of ongoing post-seismic deformation.

4.2.2 Regional Control Survey

Based on the results of the initial deformation survey, a further 250 marks were surveyed. This provided additional information about the extent of displacements as illustrated in Figure 7. In particular, this survey focussed on re-surveying control in urban areas, such as Christchurch city.

4.2.3 Regional Control Survey

Denser geodetic surveys are required in areas of localised deformation (such as that caused by liquefaction) and areas in the vicinity of the fault rupture. These surveys were at the advanced planning stage when the 22 February Christchurch earthquake occurred, so have not yet taken place.

4.3 Re-adjustments required

To update the spatial cadastre without resurveying every affected point, a model of the earthquake movements is used. This model is based on one developed by GNS Science, modified by LINZ so that it can be used to update cadastral data. A description of the general procedure used to update New Zealand's deformation model after an earthquake is given in Winefield et al (2010).

In areas of localised deformation (such as liquefaction), the movements are generally so non-uniform that full least squares adjustment, rather than a model, will be required to achieve the required accuracy. Until updated cadastral data is collected, the accuracy may be comparatively low, but the results of the adjustment will be used to assign appropriate accuracy orders.

As shown in Table 1, the number of coordinates needing to be updated is likely to be at least several hundred thousand, and could be up two million if measurements show that updates are required up to 200km from the epicentre.

Maximum Range (km)	Geodetic marks (order 5 or better)	Cadastral control (order 6 or better)	Total marks
0-20	223	4816	56835
20-40	1269	49538	565892
40-60	3176	28632	387606
60-80	673	3681	143593
80-100	487	2182	103995
100-120	701	5256	141675
120-140	1388	6771	206350
140-160	1683	2924	131968
160-180	1359	2115	109825
180-200	1314	3162	151680
TOTAL (up to 200km)	**12273**	**109077**	**1999419**

Table 1 – Number of geodetic and cadastral marks potentially requiring update

4.4 Timing of spatial cadastre update

To avoid the confusing situation of having a combination of pre and post-earthquake coordinates in the Landonline database, geodetic control and cadastral coordinates will be updated at the same time, once the necessary geodetic survey work has been completed. For most surveyors, doing surveys over a small area, the pre-earthquake coordinates are still in terms with each other, so the fact that post-earthquake coordinates are not made available immediately is usually not a problem.

Until the update occurs, coordinate changes due to the earthquake are being provided to surveyors and local government officials who request them.

While this update was initially expected to occur in the first half of 2011, due to the February earthquake and the additional work now required, it is now expected that the coordinate update will occur in the first half of 2012.

5. STATUTORY AND REGULATORY RESPONSE

5.1 Canterbury Earthquake Response and Recovery Act 2010

Following the 4 September 2010 earthquake, the Government of New Zealand determined that, to facilitate the response to the earthquake, and to provide adequate statutory power to assist with the response, some relaxation of requirements in existing statutes would be required and allowance made for circumstances where the compliance with existing legislation could not be reasonably met as a result of the earthquake.

As a result the Canterbury Earthquake Response and Recovery Act 2010 was passed on 14 September 2010. The Act allowed for Orders in Council to be issued allowing exemptions, modifications or extensions of certain Acts including the Cadastral Survey Act 2002.

5.2 Rules for Cadastral Survey (Canterbury Earthquake) 2010

5.2.1 Meeting with Surveyors

Following the earthquake, the Surveyor-General, and other LINZ representatives, attended a meeting of Canterbury surveyors to discuss post earthquake survey issues and to determine how LINZ could assist with the earthquake response and recovery effort. At the time some indicative surveys had been carried out on areas exhibiting the greatest movements due to liquefaction surface flow and reports were available as to the slip movement across the Greendale fault.

5.2.2 Issue of Bulletin

With information gained from the surveyors and from local government authorities and from visiting sites with geotechnical advisors to the Earthquake Commission, a Bulletin was issued to surveyors in the region on 18 October 2010 providing guidance for the definition of boundaries in the affected areas. A point of contact with a Surveyor- General’s staff member located in Christchurch was also provided. Very few surveys were carried out in this period but the Bulletin was available to minimise any dislocation to work in progress.

5.2.3 Special Rules for Cadastral Survey.

The Surveyor-General then used the powers provided by the Canterbury Earthquake (Cadastral Survey Act) Order 2010, made under the Canterbury Earthquake Response and Recovery Act 2010, to prepare the Rules for Cadastral Survey (Canterbury Earthquake) 2010 (CEQ Rules). The Order allowed these Rules to be prepared without the extensive consultation normally required for statutory regulations. However feedback was sought from the Canterbury Branch of the New Zealand Institute of Surveyors and representatives of the Institute of Cadastral Surveying.

The CEQ Rules are only temporary and expire on 16 December 2011, in accordance with the Order in Council, unless superseded by new rules before then. LINZ is proposing to develop longer term rules, with wider application, for post earthquake surveys before the temporary rules expire. This will involve full consultation with surveyors, and other stakeholders, as required by the Cadastral Survey Act 2002.

5.2.4 Provisions of the Rules for Cadastral Survey (Canterbury Earthquake) 2010.

The new Rules for Cadastral Survey (Canterbury Earthquake) 2010 (CEQ Rules) and a corresponding Guideline were published 23 December 2010 and came into effect 31 January 2011. These Rules and Guideline apply to surveys for the re-establishment of boundary points, and boundaries, which have been affected by movement due to the Canterbury earthquake. They apply in conjunction with the existing Rules for Cadastral Survey 2010 (RCS2010).

Where there has been deep-seated movement due to the earthquake then cadastral boundaries are deemed to have moved with the resulting land surface movement which can be displacement or deformation due to a fault rupture or relatively uniform block shift.

The CEQ Rules state that re-established boundary points and related boundaries must hold the same relationship to physical evidence, including survey marks and boundary occupation, as they did prior to the earthquake.

Where the deep-seated movement results in a relatively uniform block shift of an entire land parcel, then the relative positions of the parcel's boundaries to survey marks will remain the same as before the earthquake.

Where a parcel boundary has been displaced or distorted by deep-seated movement, such as a fault rupture, that exceeds the applicable accuracy tolerances of the RCS2010, the re-established boundary must reflect that displacement or distortion which may require the creation of new boundary angle points.

In the case of shallow surface movement due to liquefaction this is similar to land slip in which case survey and legal precedents indicate boundaries will normally be reinstated to their original positions after taking into account any deep-seated block movement.

The CEQ Rules also provide for some relaxation of the normal requirements for orientation of surveys and for adoption of boundaries in certain circumstances.

In a particular case where compliance with the rules is impractical or unreasonable the Surveyor-General can grant an exemption from the requirements, or specify alternative requirements, as provided for by section 47(5) Cadastral Survey Act 2002.

The CEQ Rules and Guideline can be accessed from the Canterbury Earthquake page on the LINZ web site (LINZ 2010)

5.3 Effect of the Rules for Cadastral Survey (Canterbury Earthquake) 2010

The CEQ Rules have provided some authority for the re-establishment of boundaries affected by the earthquake. Cadastral surveys have been small in number following the earthquake and the large number of re-establishment surveys which will be required as building owners replace or renovate their buildings had not commenced at the time of writing this paper.

The provisions of the CEQ Rules have allowed the licensed surveyors to confidently certify the datasets, for compliance with the Rules, and facilitate their integration into the cadastre.

In general, boundaries will only need to be resurveyed for the purpose of subdivision, or reconstruction of buildings close to boundaries, therefore it may be decades before many of the boundaries affected by movement due to the earthquake are resurveyed.

The remediation of land damaged by liquefaction is being funded and managed by the Earthquake Commission and they have indicated that the re-establishment of boundaries will be included in this work.

6. AFTERSHOCKS

Over one thousand aftershocks of up to magnitude 5.1 had been reported up until 22 February 2011. Some of these aftershocks resulted in further building damage however they did not cause significant ground displacement or liquefaction. The control survey network re-measurements were not compromised by these aftershocks.

At 12.37 pm on 22 February 2011 a magnitude 6.3 aftershock centred 10 km south east of the centre of Christchurch, at a depth of 5km, caused further extensive damage to land and buildings in the city. Scientists have identified a 10 km long sub-surface fault rupture running ENE, between the Christchurch suburbs of Halswell and Sumner, associated with this aftershock. (GNS Science, 2011)

Although the magnitude of the 22 February 2011 aftershock was less than the 4 September 2010 earthquake, the consequences were more devastating due to the location being close to Christchurch city, the shallow depth, much higher than normal ground accelerations (the highest ever recorded in New Zealand), during the middle of a working day when severely damaged commercial buildings were occupied. The death toll as a result of this aftershock is likely to be about 180.

There are significantly more areas affected by new or further liquefaction, and consequential property damage, as a result of the 22 February aftershock.

Initial measurements of surrounding survey control network points have been made indicating horizontal shifts of up to 20cm and vertical movements of up to 10cm on marks near the fault although there is no visible surface fault rupture. Numerous aftershocks are still occurring.

It is anticipated that the Rules and Guidelines promulgated in response to the 4 September 2010 earthquake will also be suitable for dealing with survey issues resulting from the 22 February 2011 aftershock. For the purpose of the CEQ Rules 'Canterbury earthquake' includes the aftershocks.

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BIOGRAPHICAL NOTES

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