Disaster Risk Management – The Christchurch Earthquake Experience (Climate Action 14)

Simon Ironside (New Zealand)

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Introduction

The knowledge, skills, and professional judgement of surveyors are fundamental to effective disaster risk management. The 2010–2011 Canterbury Earthquake Sequence—of which the 22 February 2011 Christchurch earthquake was the most severe event—is used in this paper as a case study to illustrate the critical contribution of surveyors to disaster risk management and reduction in practice.

In the aftermath of the second-deadliest earthquake in New Zealand's history, surveyors played a key role in enabling emergency response, supporting recovery, and reducing future risk through the re-establishment of spatial integrity, land stability understanding, and evidence-based decision-making for rebuilding and land use.

The Darfield Earthquake and the onset of the Canterbury Earthquake Sequence

The 22 February 2011 Christchurch earthquake formed part of the wider Canterbury Earthquake Sequence (CES), which began on 4 September 2010 with a moment magnitude (Mw) 7.1 earthquake centred near the rural town of Darfield, approximately 30 km west of Christchurch. (Moment magnitude is a measure of the amount of energy released at the source and is the authoritative measure of earthquake size, particularly for medium and large earthquakes.) The Darfield earthquake occurred at a depth of approximately 10 km which is shallow in seismological terms, capable of generating intense ground shaking.

The earthquake ruptured a previously unknown regional strike-slip fault within the crust of the Pacific Plate, now known as the Greendale Fault, producing a surface rupture of approximately 30 km. The discovery of this previously unmapped fault had significant implications for seismic hazard understanding and land-use planning.

The main shock lasted approximately 40 seconds and produced some of the strongest ground motions ever recorded in New Zealand, a country with high seismicity. Peak ground acceleration (PGA) measured near the Greendale Fault reached 1.26 g (12.36 m/s^2). This meant that structures were subjected to horizontal and vertical accelerations exceeding 1.26 times the acceleration due to gravity (approximately 9.81 m/s^2). By comparison, peak ground acceleration recorded in the Christchurch central business district (CBD) was 0.2 g.

Severe liquefaction was experienced across large areas of Christchurch, particularly in the riverside suburbs and estuarine environments. Saturated, unconsolidated soils were subjected to strong shaking, causing water and fine sediment (silt and sand) to be expelled to the surface. Liquefaction-induced ground settlement and lateral spreading—the horizontal movement of land toward waterways—resulted in substantial damage to land, buildings, and underground infrastructure, including potable water, wastewater and stormwater services.

Damage from the Darfield earthquake was widespread but uneven. Residential dwellings in liquefaction-affected areas experienced significant damage, while areas with firmer soils experienced far less ground shaking. Structural damage was largely concentrated in older unreinforced masonry buildings. Most modern buildings generally performed in accordance with their design standards, and notably, the event resulted in no loss of life.

Had this earthquake marked the end of the seismic activity, recovery would likely have been comparatively rapid and less traumatic. However, it was only the beginning of a prolonged earthquake sequence culminated in the far more destructive February 2011 Christchurch earthquake, fundamentally altering the physical, regulatory, and professional landscape for surveyors and disaster risk reduction practitioners alike.

The Christchurch Earthquake

A moment magnitude 6.3 earthquake struck Christchurch at 12:51 p.m. NZDT on 22 February 2011. Although officially classified as an aftershock of the September 2010 Darfield earthquake, the event was catastrophic. Since the Darfield earthquake, Canterbury had experienced thousands of recorded aftershocks, many of which had caused additional damage, and it is within this context that the February event was formally designated an aftershock.

The earthquake resulted from rupture on a previously unrecognised subsurface fault beneath the Port Hills, with an epicentre located 10 km from the Christchurch city centre at a depth of approximately 5 km. This shallow depth was a key factor in the extreme levels of ground shaking experienced.

The highest recorded PGA was approximately 2.2 g near the epicentre, with PGA values of up to 1.8 g recorded within the central city. Translated to the New Zealand Modified Mercalli Intensity (MMI) scale, shaking at the epicentre reached MMI X (Destructive), while extensive areas of the city experienced intensities of MMI IX (Violent) to X (Destructive). Vertical accelerations were higher than horizontal accelerations throughout much of the eastern and southern city.

Although smaller in magnitude than the Darfield earthquake, the February 2011 event was far more damaging due to its shallow depth, extreme ground accelerations, and direct impact on the city itself, New Zealand's second largest. There were 185 fatalities, making it the most lethal earthquake in New Zealand since the 1931 Napier Earthquake. It is widely acknowledged that modern building codes and construction practices substantially reduced what could otherwise have been a much higher death toll.

The earthquake generated the largest vertical ground accelerations ever recorded worldwide, with shaking exceeding design motions associated with a 2,500-year return period and building codes in use at the time. Numerous buildings were brought close to collapse, with the full collapse of the Pyne Gould Guinness (PGG) and Canterbury Television (CTV)

buildings resulting in significant loss of life. In several buildings, collapsed stairwells prevented occupant egress, further exacerbating casualties.

The immediate response was the establishment of a large-scale central city exclusion zone (‘red zone’) to manage collapsed and unsafe buildings and to support emergency response operations. The Christchurch central business district remained closed for over two years, with the final cordon removed in June 2013.

Liquefaction effects, already evident following the Darfield earthquake, intensified dramatically. The February event produced some of the most extensive urban liquefaction ever recorded, particularly in eastern Christchurch. Entire suburbs were flooded, underground infrastructure was severely damaged, and thousands of homes sustained irreparable harm.

The scale of land damage ultimately resulted in thousands of residential properties being designated as unrepairable and placed into government-managed ‘red zones’. These properties were acquired and demolished. Approximately 600 hectares of earthquake-damaged land is now considered unsuitable for rebuilding and has transitioned into extensive green space incorporating walking and cycling trails, community uses, and ecological restoration, managed by the Christchurch City Council.

Beyond the low-lying eastern suburbs, previously unaffected hillside areas were heavily affected this time. Rockfalls, cliff collapses, and slope instability caused widespread damage in the Port Hills suburbs, destroying homes and creating additional residential red zones. Significant permanent land deformation accompanied these failures.

The Christchurch earthquake was the most damaging event in the 18-month Canterbury Earthquake Sequence, which included numerous aftershocks exceeding Mw 5.0, causing repeated damage to already compromised structures. In total, Christchurch experienced more than 10,000 aftershocks during this period.

From a disaster risk perspective, Christchurch’s experience illustrates how earthquake impacts are governed not solely by magnitude, but by depth, proximity, ground conditions, and the exposure of the built environment.

For surveyors in particular, the event marked a fundamental shift in assumptions about land stability, spatial reference frameworks, and the role of surveying in emergency response, recovery, and long-term risk reduction.

Surveyors' response to the Christchurch Earthquake

Although the Darfield Earthquake caused considerable damage and disruption, for surveyors', professional life continued largely as normal. However, the Christchurch earthquake changed all that. The immediate response for Christchurch surveyors, including the author was ensuring families were safe and homes were secure. The earthquake struck at 12:51 p.m. on a weekday and simply getting home through damaged or blocked streets became a long and arduous undertaking.

In the immediate aftermath, surveyors were inundated with requests for assistance. Some supported Urban Search and Rescue (USAR) operations, while many were engaged in assessing damaged buildings, monitoring unsafe structures, and surveying compromised infrastructure. Across the profession, surveyors supported essential infrastructure repair and assisted landowners in understanding the extent of damage to their properties.

With large parts of the central city 'red zoned,' surveying firms faced significant disruption. Access to offices was prohibited, requiring staff to retrieve essential equipment and records under controlled conditions. Firms rapidly adapted, working from garages, spare rooms, and temporary premises while maintaining service delivery in an environment of high demand and uncertainty. By way of example, our firm transitioned from approximately 1,500 m^2 of central city office space housing 65 staff to 375 m^2 accommodating more than 70 staff during the recovery period.

As the initial shock subsided, the profession adapted to new ways of working. Building verticality surveys, topographical surveys of damaged land to establish existing-use rights, and ongoing monitoring of structures and infrastructure became routine work.

From very early on it became apparent that we were facing significant cadastral challenges. Although cadastral surveys were largely suspended until the aftershocks subsided, large misclosures in horizontal and vertical dimensions (X, Y, and Z) became evident, along with the widespread loss of reliable survey marks due to ground deformation and lateral spreading.

Resolution of cadastral and boundary definition problems became a priority, heightened by strong demand for replacement housing from residents whose homes had been deemed uninhabitable. This period required surveyors to exercise professional judgement under unprecedented conditions, working with degraded cadastral, geodetic and vertical control networks while maintaining the integrity of the spatial frameworks that underpinned recovery.

lateral ground movement problems

Toitū Te Whenua Land Information New Zealand (LINZ) is the national authority responsible for New Zealand's land information systems, including the cadastral, geodetic, topographic, and hydrographic frameworks that underpin land tenure and spatial certainty.

Within the cadastral system, regulatory oversight is provided by the Surveyor-General, who sets mandatory technical and procedural standards for cadastral surveying. At the time of the CES, those standards were prescribed in the *Rules for Cadastral Surveys 2010.* Compliance with these rules is a legal requirement for licensed cadastral surveyors, who alone are authorised to lodge cadastral survey datasets.

Cadastral survey datasets are lodged with LINZ electronically through Landonline, New Zealand's national digital cadastre and land title registration system.

All lodged datasets are independently audited by LINZ survey staff to determine compliance with the Surveyor-General's standards and their fitness to update the national cadastre. Datasets are either approved as to survey or requisitioned for correction, clarification, or additional evidence.

Following the Darfield earthquake, Canterbury surveyors and the Office of the Surveyor-General engaged in extensive discussion about the implications of earthquake-induced land deformation on cadastral boundaries.

In response, the Rules for Cadastral Surveys (Canterbury Earthquake) 2010 were promulgated as an emergency regulatory framework. These rules were founded on a set of guiding principles intended to distinguish between different types of ground movement and their cadastral consequences:

- **Deep-seated ground movement** (permanent tectonic deformation): *boundaries are considered to have moved*

- **Surface-layer movement** (lateral spreading, liquefaction, shallow displacement): *boundaries are considered not to have moved*

In the period immediately following the Darfield earthquake, these assumptions were broadly consistent with what surveyors were observing on the ground. The physical evidence generally aligned with a distinction between widespread shallow deformation and more limited areas of deeper structural movement, allowing cadastral reinstatement to proceed with a degree of confidence under this framework.

The Christchurch earthquake fundamentally changed the cadastral framework. Unlike Darfield, it did not conform neatly to a classical fault-rupture scenario. The close proximity of the epicentre, the shallow depth of the event, and the extensive and severe liquefaction resulted in complex and highly variable ground deformation across Christchurch.

Within this environment, the pre-existing assumptions embedded in the Rules for Cadastral Surveys (Canterbury Earthquake) 2010 became increasingly difficult—and in some cases impossible—to satisfy. In many areas:

- The cadastral fabric exhibited **distortion, compression, rotation, and lateral spread simultaneously**.
- Groups of survey marks frequently failed to retain coherent pre-earthquake horizontal relationships.
- Cadastral disruption broadly aligned with damage patterns, undermining confidence in reinstating boundaries to a notional "original" position.

The assumption that shallow surface movement did not move boundaries no longer held in practice.

Following further consultation with the Canterbury surveying profession, the Surveyor-General re-affirmed that boundary definition is a matter of a surveyor's professional judgment, skill, and experience, supported by evidence of the survey marks found on the ground.

Crucially, the Surveyor-General accepted that:

- Where **groups of survey marks have retained a consistent spatial relationship**, those groups may be relied upon for defining parcel boundaries—even where shallow surface movement has occurred.

This marked a significant departure from the earlier post-Darfield approach. The regulatory position shifted from recognising only deep-seated tectonic deformation as capable of moving boundaries to acknowledging that **major earthquake-related surface movement can also result in boundary movement**.

This shift in understanding ultimately required a statutory solution. The response was the **Canterbury Property Boundaries and Related Matters Act 2016**, which came into force on **30 August 2016**.

The Act:

- Acknowledges that, within greater Christchurch, **property boundaries move with earthquake-related land movement**.
- Provides a clear legal basis for the post-earthquake determination and definition of boundaries.
- Resolves the conceptual and practical conflict between cadastral theory and observed land movement exposed by the Christchurch earthquake sequence.

The vertical ground movement problem

The 2010–2011 Canterbury Earthquake Sequence (CES), particularly the Christchurch earthquake caused widespread and non-uniform land subsidence. Much of the central city and the eastern suburbs subsided by 0.5 to 1.0 metre, affecting floor levels and gravity-based infrastructure such as sewers.

Post-earthquake observations show that large areas of Christchurch, particularly in estuarine areas and the coastal margin, continue to experience ongoing land subsidence at accelerated rates of up to 10 mm per year—more than five times the pre-earthquake rate.

Recognising that low-lying areas, particularly adjacent to tidal rivers and estuarine environments, were at increased risk of coastal and fluvial

flooding as a result of the CES, the Christchurch City Council (CCC), together with the neighbouring Waimakariri District Council (WDC) and Selwyn District Council (SDC), substantially increased minimum floor level requirements for many properties.

Revised minimum floor level requirements as well as building, construction and infrastructure repair demands meant that re-establishing the vertical control network became (another) priority for surveyors.

At the time of the CES, the Lyttelton 1937 datum was the official vertical datum used in Canterbury, defined by the mean sea level at Lyttelton Harbour determined in 1937. It was one of 13 official vertical datums, referenced to local sea level at ports around New Zealand that formerly covered the country. Christchurch City Council had established its own datum, Christchurch Drainage Datum, in 1874, set at 9.043m below Lyttelton 1937 datum, and maintains a network of benchmarks throughout the city.

The reinstatement of the Lyttelton 1937 level datum in Christchurch and other affected areas was a massive undertaking, exacerbated by the significant aftershocks experienced throughout the period of the CES. LINZ, in conjunction with local surveyors, conducted comprehensive precise levelling surveys after the major shakes (September 2010, February 2011, June 2011, and December 2011) to create new benchmark datasets for construction. These surveys ensured vertical accuracy of approximately 0.005m for the Lyttelton Vertical Datum 1937.

Based on the recognition that the existing geoid model was not fit for purpose and influenced by the cost of re-establishing the Lyttelton 1937 datum post-CES, a new national vertical datum, the New Zealand Vertical Datum 2016 (NZVD2016), was introduced in 2016. It is a gravimetric geoid-based datum that provides a nationally consistent reference surface based on a geoid model derived from airborne gravity observations and Global Navigation Satellite System (GNSS) positioning. Christchurch Drainage Datum was updated to NZVD2016 in 2024.

The 2010-2011 Canterbury earthquakes sequence and the subsequent Mw 7.8 2016 Kaikoura earthquake demonstrated the advantage of a

national vertical datum providing a consistent reference surface from which vertical control could easily be re-established compared to re-establishing benchmark networks referenced to a local datum.

Building Codes, Land Deformation, and Vertical Datum Management

The post-earthquake reforms to New Zealand's building regulatory framework were closely intertwined with surveying practice and the management of land deformation. Many of the building failures observed during the Canterbury Earthquake Sequence were not necessarily attributable to structural design deficiencies, but to the interaction between structures and permanently altered ground conditions, resulting from liquefaction, lateral spreading, and differential settlement. These ground responses challenged traditional assumptions that land surfaces and reference heights are stable over time.

Updated building code requirements for foundation design and liquefaction mitigation depended heavily on improved site-specific ground investigations and accurate height information. Surveyors played a critical role in providing reliable horizontal and vertical control to support geotechnical modelling, foundation design, and compliance assessment. In areas affected by non-uniform subsidence, small errors or reliance on outdated benchmarks could translate into significant differences in building performance and flood vulnerability.

The strengthened management of earthquake-prone buildings (EPBs), including the adoption of a national 34% New Building Standard (NBS) threshold, further increased the need for accurate spatial and height data. Assessment of existing buildings often required re-establishment of floor levels, structural geometry, and ground relationships in environments where original survey control had been displaced. As a result, post-earthquake building assessment became inseparable from the task of re-establishing horizontal and vertical survey control.

Lessons learnt – build back better

The Canterbury earthquakes triggered one of the most complex post-disaster urban recovery programmes in the developed world. Before large-scale reconstruction could begin, approximately 1,200 commercial buildings in the Central Business District and around 6,000 residential

dwellings were required to be demolished. At the same time, many thousands of homes entered staged repair programmes, highlighting the scale and duration of recovery following a major seismic event.

From a disaster risk management perspective, the earthquakes presented Christchurch with a unique opportunity to rethink land use, urban form, and resilience, rather than simply restoring pre-disaster conditions. Risk reduction, hazard awareness, and long-term sustainability became central considerations in all rebuilding decisions.

This approach is embodied in the Christchurch Central City Plan, which represents a deliberate shift toward resilient urban design. The vision of a **'**City in a Garden**'** integrates green infrastructure, open spaces, and lower-intensity development patterns to support environmental sustainability, social wellbeing, and disaster risk reduction—particularly in relation to liquefaction, flooding, and seismic hazards.

Lessons learnt – the surveyor's role

Surveyors have played—and continue to play—a critical role in disaster risk management throughout the rebuild. Their contributions extend beyond traditional cadastral functions and include:

- Supporting post-disaster land damage assessment and red-zoning decisions
- Re-establishing secure land tenure and boundaries following widespread disturbance
- Contributing professional expertise to Urban Design Panels, ensuring development proposals align with planning controls, hazard information, and resilience objectives
- Integrating geospatial data and risk information into informed decision-making at all stages of recovery

The Canterbury Earthquakes Sequence demonstrates how surveying, land administration, and spatial governance are foundational to effective disaster risk management.

Appendix 1 – More detailed lessons learnt

Resilience and adaptability

1. The CES demonstrated the resilience and adaptability of the surveying profession in a major disaster context.
2. Surveyors move rapidly from emergency response to recovery support
3. Cadastral integrity, vertical control, and professional judgement become critical enablers of the rebuild when land itself can no longer be assumed to be stable.

Lateral ground movement and cadastral problems

4. Disaster-prone jurisdictions need flexible cadastral frameworks that can accommodate post-event realities, not just pre-event theory.
5. Legal cadastral systems must recognise that *boundaries move with land*, not merely with tectonic faulting.
6. Disaster recovery elevates the importance of the surveyor as a *trusted professional interpreter*, not just a technical rule-follower.
7. Existing cadastral law may be insufficient post-disaster; timely legislative mechanisms should be anticipated in disaster governance planning.
8. Maintaining cadastral functionality must be treated as a core element of disaster resilience and recovery planning.
9. Christchurch showed that cadastral systems must evolve from static legal abstractions into resilient, adaptive frameworks capable of responding to extreme ground deformation—while preserving trust, tenure security, and legal certainty.

Vertical ground movement

10. Earthquakes can create long-term hazard amplification: Major seismic events triggered large, uneven land subsidence, permanently increasing exposure to flooding and infrastructure failure well beyond the initial disaster.
11. Ongoing ground movement (millimetres per year) demonstrates that disaster impacts can persist for decades, requiring continuous monitoring rather than one-off recovery responses.

12. Land-use regulation is a critical risk-reduction tool**:** Raising minimum floor levels was essential to manage increased flood risk in low-lying areas, linking geophysical change directly to planning and building controls.
13. Critical systems depend on vertical accuracy**:** Gravity-based infrastructure (e.g. drainage and wastewater) is highly sensitive to elevation change, making reliable vertical reference systems central to resilience.
14. National reference frameworks strengthen recovery**:** Adoption of a consistent, GNSS-based national vertical datum enabled faster, more reliable restoration of control after earthquakes, reducing future recovery costs and uncertainty.

Building Codes, Land Deformation & Disaster Risk Management

15. Disasters permanently reshape risk landscapes**:** The Canterbury Earthquakes Sequence showed that land deformation (liquefaction, lateral spreading, subsidence) can drive building failure even where structural design meets code, fundamentally altering hazard exposure.
16. Vertical accuracy is a risk-reduction issue: Reliable height control underpins safe foundations, flood resilience, and infrastructure performance; small vertical errors can translate into major vulnerability in deformed terrain.
17. Surveying as a core DRM function**:** Surveyors provide critical horizontal and vertical reference frameworks that support geotechnical modelling, engineering design, and post-disaster compliance in unstable ground environments.
18. Codes must respond to ground reality**:** Updated building codes and earthquake-prone building assessments increasingly rely on site-specific data rather than assumptions of stable land and unchanged reference systems.
19. Resilience through reference systems: Effective disaster risk management depends on robust, re-establishable national spatial and vertical datums that enable rapid recovery and safer rebuilding after major events.

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