Proceedings of the 18th Association of Public Authority Surveyors Conference (APAS2013)
Canberra, Australian Capital Territory, Australia, 12-14 March 2013

The Impact of Natural Disasters on the Cadastre

Narelle Underwood
2011 NSW Surveyor General's International Fellowship in Surveying and Spatial Information
Registered Land Surveyor, Roads and Maritime Services
Narelle.Underwood@rms.nsw.gov.au

ABSTRACT

Natural disasters are a global phenomenon that can strike without warning. Our growing population and urbanisation means that these impacts are an increasing dilemma that needs to be addressed as they have a significant economic, social, environmental and political impact on the community. The surveying and spatial information sector plays a critical role in not only recovering from natural disasters but also in building our resilience to such catastrophic events. Our economy is underpinned by property values that rely on the correct definition of cadastral boundaries. Unfortunately, cadastral boundaries are affected by natural disasters, either through the destruction of survey marks by bushfires, floods and tsunamis or movement of the actual ground in landslides, subsidence and earthquakes. The confusion and uncertainty that result from this constitute a major economic problem. The guarantee of ownership under Torrens title in Australia is a significant benefit that we have over other countries where substantial time has been spent re-establishing land ownership following a natural disaster. But Torrens title does not guarantee dimensions or areas, and we rely on the use of survey monuments to define our cadastral boundaries. The question arises that if we cannot rely on the monuments due to deformation or because they are simply now gone, what do we use? This presentation investigates how the governments and surveying professions in Japan, California and New Zealand have responded to the destruction of their cadastral boundaries following a variety of natural disasters. It looks at the processes they have put in place to ensure the resilience of this important infrastructure. It also examines how Australia has reacted to the impact of natural disasters in the past. After comparing the different approaches taken by each country, this presentation concludes by making a series of recommendations for our government and the surveying sector. If implemented, these will strengthen our cadastre so that in the event of a natural disaster we will have a robust model to reinstate cadastral boundaries consistently and with certainty. This presentation is the product of research funded by the 2011 NSW Surveyor General's International Fellowship in Surveying and Spatial Information.

KEYWORDS: *Natural disasters, cadastral boundaries, New Zealand, Japan, California.*

PRELIMINARY RECOMMENDATIONS FOR NSW

Traditionally, in Australia, recovery of the cadastre or cadastral marks has been undertaken by the surveying and spatial information profession on a largely volunteer basis. Two examples of this are the 2009 Victorian bushfires and the 2010/11 Queensland floods where groups of volunteer surveyors assisted in recovery efforts by locating and coordinating cadastral reference marks or physically remarking affected property boundaries. While these efforts are extremely kind and honourable, in our current climate of increased occurrences and severity of natural disasters they are not economically sustainable.

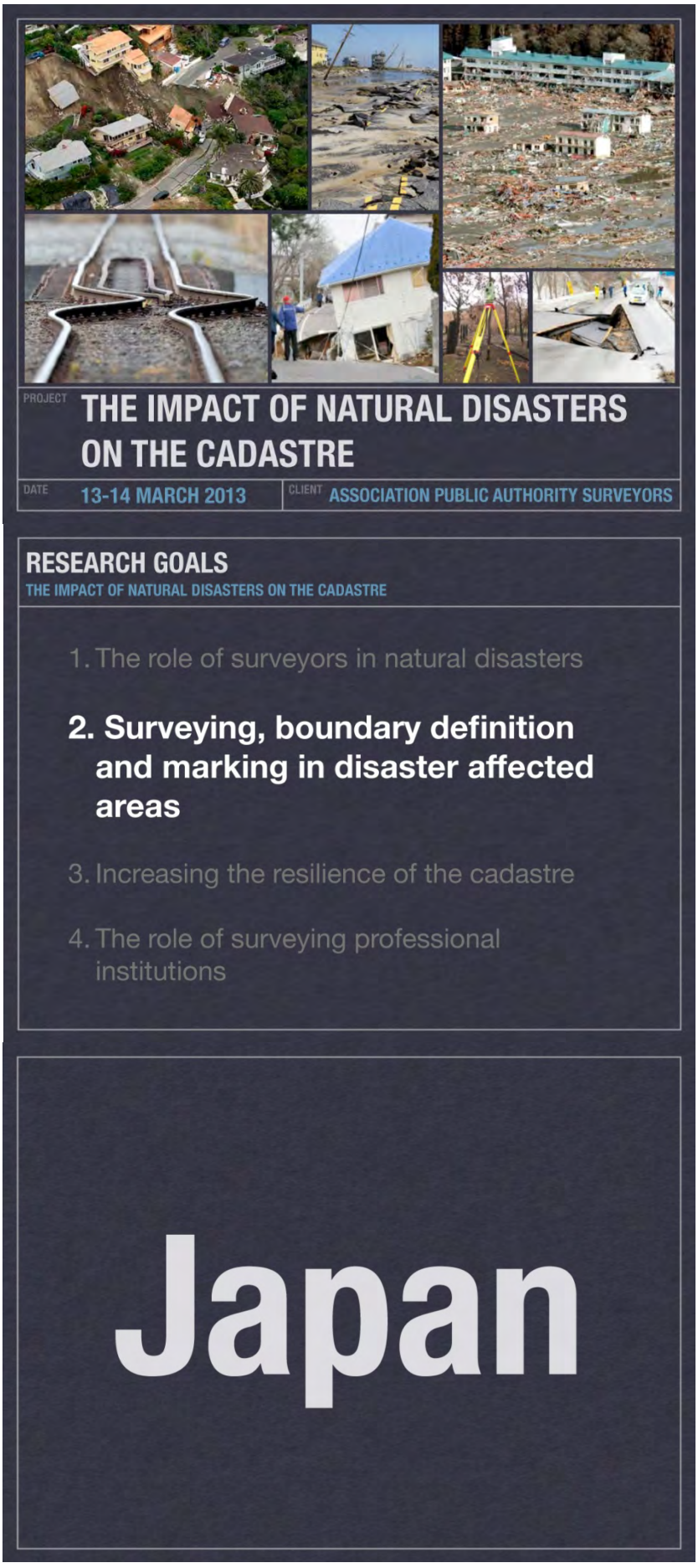
The key to being able to reinstate a cadastral boundary following a natural disaster is knowing with some certainty and accuracy where it was before the disaster occurred. Unfortunately, in NSW we cannot say that this is the current status quo. Our knowledge of existing cadastral boundaries varies significantly across the state due to a variety of reasons from the age and methods of surveys and plans to a variety of different datums and a lack of accurate state survey infrastructure in some areas.

Following research in Japan, California and New Zealand, a number of key factors were identified that require further investigation in order to increase our cadastre's resilience to the effect of natural disasters. The first of these is the need to continue to increase the density of our Continuously Operating Reference Station (CORS) network. As evidenced by overseas examples, in the event of a future earthquake, land subsidence or other land movement, a dense CORS network allows for the identification and monitoring of land movement and the determination of appropriate deformation parameters. The densification of the existing network would also support the further coordination of our passive control network and possibly open up possibilities for the use of Network Real Time Kinematic (NRTK) technology for cadastral boundary definition in the future.

The CORSnet-NSW network is unlikely to replace our existing passive control network, even if we were given the option in the future to use NRTK for cadastral boundary definition, and it will therefore always be critical state infrastructure. Presently the density and accuracy of our current network does not completely support our cadastral system as there are a significant number of marks in the ground that are not coordinated or connected to our cadastral fabric. If we ever want to move towards a system where every cadastral survey is on the one datum, then we need the infrastructure to support it. This idea is supported by the current thinking of Land Information New Zealand (LINZ), who continue to increase the density and accuracy of their passive control network while also supporting the densification of their CORS network.

While the author personally does not believe that a coordinated cadastre similar to that found in Japan will ever be feasible in NSW, we should be following the example of our New Zealand neighbours and create a survey accurate Digital Cadastral Database (DCDB) that includes not only cadastral boundaries but also our state survey control and all cadastral/reference marks. It is realised that this is a significant project that ideally would be funded by the government, realistically though it could be achieved by a combination of government and industry support. This could be realised through the adoption of LandXML for cadastral surveys and plans as it would allow us to build a survey accurate dataset over time. This would only work if all surveys were completed on the same datum, and for it to become economically feasible for the profession it needs to be an interactive database that allows surveyors to download existing datasets for their survey area. It is believed that this would be achievable through upgrades to the existing Survey Control Information Management System (SCIMS) and the Spatial Information Exchange (SIX) portal.

In conclusion, it appears evident that the NSW Government and the surveying and spatial information industry need to work together in order to develop an action plan on how the resilience of the cadastre to the impacts of natural disasters can be increased. Avoiding the issue or continuing with the status quo is not an acceptable alternative. Considering that within the past year NSW has suffered from both a number flood and fire events, we are neglecting our professional obligations if we do not begin protecting our critical survey infrastructure from such events.


PROJECT
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE
DATE
13-14 MARCH 2013
CLIENT
ASSOCIATION PUBLIC AUTHORITY SURVEYORS
RESEARCH GOALS
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE
1. The role of surveyors in natural disasters
2. Surveying, boundary definition and marking in disaster affected areas
3. Increasing the resilience of the cadastre
4. The role of surveying professional institutions
Japan


GREAT EAST JAPAN EARTHQUAKE & TSUNAMI
MIYAGI PREFECTURE
GREAT EAST JAPAN EARTHQUAKE & TSUNAMI
TSUNAMI BREACHING SEAWALL IN MIYAKO
GREAT EAST JAPAN EARTHQUAKE & TSUNAMI
SENDAI AIRPORT

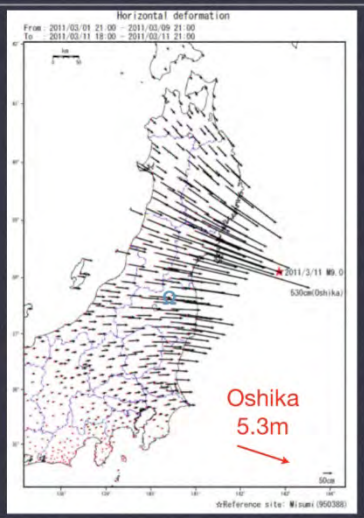
GREAT EAST JAPAN EARTHQUAKE & TSUNAMI

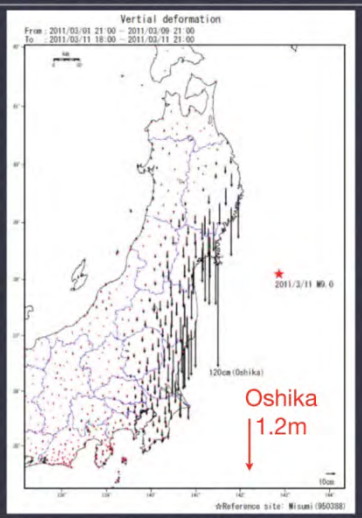
SOMA, FUKUSHIMA PREFECTURE

GREAT EAST JAPAN EARTHQUAKE

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

Date & Time	11/03/2011 14:46 (JST)
Epicenter	Off coast of Sanriku area
Depth	24km
Magnitude	9.0
Fault	length: 450km width: 200km
Tsunami Height	9.3m (limit of tidal gauge) >40m (field evidence)





GREAT EAST JAPAN EARTHQUAKE - LAND MOVEMENT

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

GSI - JAPANESE CONTROL NETWORK

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

Control Points in Japan (maintained by GSI)

Category	# of Stations	Sub-category	Average Interval
GNSS-based control stations (GEONET)	1,240		20 km
Triangulation Stations (horizontal)	109,074	1st order - 975 2nd order - 5,060 3rd order - 32,326 4th order - 70,713	25 km 8 km 4 km 1.5 km
Bench Marks (vertical)	18,239	fundamental - 86 1st order - 14,682 2nd order - 3,471	150 km 2 km 2 km
Total	128,553		(March 31, 2011)

GSI - ORIGIN OF THE JAPANESE CONTROL NETWORK

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

- The Survey Act provides that all survey data should be relative to the origins of the horizontal and vertical control networks
- The official origin coordinates and height are published in the Order for Enforcement of the Survey Act
- The Great East Japan earthquake moved the origin monuments such that there was a noticeable difference between their actual coordinates/height and their legal published values. Therefore a revision of the published origin values was required

GSI - ORIGIN OF THE JAPANESE CONTROL NETWORK

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

- One of the most critical decisions to be made was when to conduct the revision surveys following the Earthquake and Tsunami
  - A - "as soon as possible" to enable the quickest recovery possible as any delay in survey means a delay in national recovery
  - B - "stand by" and wait until subsequent ground movement has settled down to avoid needing future revisions and possible confusion
- Regulation of Public Survey Specification allows a maximum error of 2ppm between neighbouring stations
- Following mathematical modelling of slip it was decided that the new surveys could be conducted from the end of May 2011.

GSI - REVISION OF HORIZONTAL ORIGIN

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

1. Determine the coordinate of VLBI station Tsukuba as of May 24 2011

2. Carry out GNSS observations at Tsukuba and the Origin. This was supplemented by observations from surrounding GEONET stations

3. The coordinates of the stations were then calculated under the condition that the coordinate of the VLBI station Tsukuba is fixed

As a result of these observations the horizontal origin coordinate was shifted east by 27cm

GSI - REVISION OF VERTICAL ORIGIN

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

A precise differential levelling run (76km) was completed between the Aburatsubo Tidal Station and the Origin following the earthquake

This level run is completed annually and based on the assumptions of no long term sea level rise and no displacement at Aburatsubo caused by the earthquake they were able to calculate the new height of the Origin

As a result of these observations the vertical origin was shifted down by 2.4cm

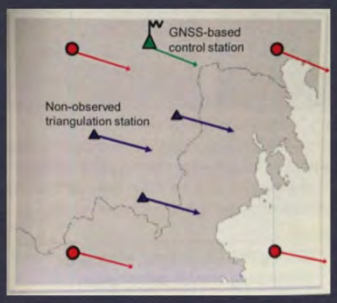
GSI - RE-ESTABLISHMENT OF CONTROL NETWORK

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

- 364 affected GEONET coordinates were suspended on March 14
- 438 Revised GEONET coordinates were made available May 31
- Approx. 44,000 passive triangulation marks were affected
- Nearly 1900 of these were resurveyed using GNSS by 70 private contracted companies
- All processing of the adjustment was done internally at GSI
- Results were published on October 31

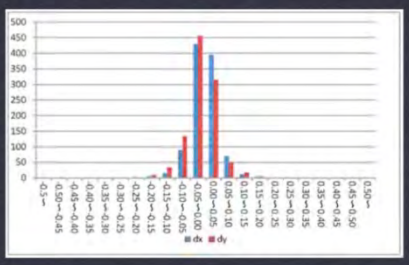
GSI - HORIZONTAL CORRECTION PARAMETERS

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE



Correction parameters were calculated and determined for a 1km grid which was then applied to all other marks

Correction vectors at a further 1300 stations were then checked by comparison between calculated and observed coordinates



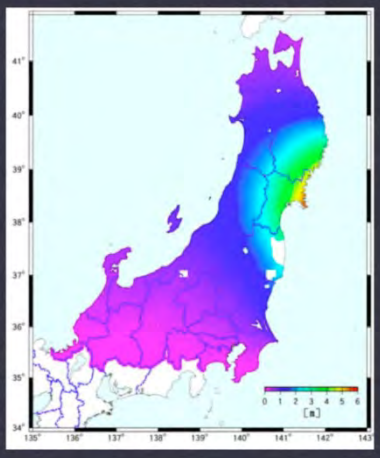
GSI - RE-ESTABLISHMENT OF CONTROL NETWORK

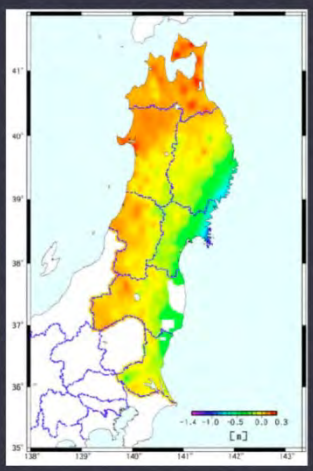
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

- Unfortunately the parameters developed using GNSS surveys were not accurate enough to be applied for height corrections
- Approx. 1900 1st order bench marks along a 3660km levelling route were resurveyed using differential levelling
- The survey was completed by 24 private companies under contract
- All processing of the adjustment was done internally at GSI
- Results were published on October 31

GSI - HORIZONTAL & VERTICAL CORRECTION PARAMETERS

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

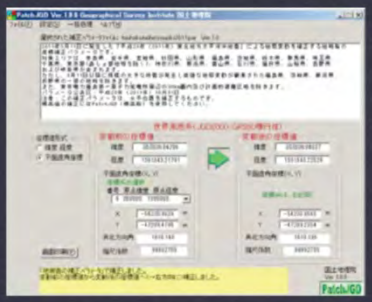




GSI - TOOLS FOR REVISION WITH CORRECTION PARAMETERS

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

* GSI developed software known as "PatchJGD" which can be downloaded from their homepage
* It contains all of the relevant correction parameter files so that they can be applied to all other control and boundary marks
* Revision of public survey data by these parameters is regarded as survey



MLIT - JAPANESE CADASTRE

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

MLIT
Ministry of Land, Infrastructure, Transport and Tourism

* The current cadastral system was introduced in 1951
* Approximately 50% of Japan is defined by cadastral survey which is based on a coordinated cadastre
* The Cadastre is the responsibility of each individual Municipal Government
* In normal circumstances the cost of cadastral surveys are the responsibility of the Government
  - 50% MLIT (National)
  - 25% Prefectures (State)
  - 25% Municipal Government (Local Council)
* Following the declaration of a natural disaster a special budget is developed and the National Government fund all recovery efforts

MLIT - ACCURACY OF CADASTRAL SURVEYS

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

* The Enforcement Order of the National Land Survey Law defines the required accuracies for cadastral surveys
  - 1 - 7cm in urban areas
  - ~25cm in paddy fields
  - ~100cm in mountain forests
* These accuracy requirements were not relaxed following the Great East Japan Earthquake
* Even though marks and monuments were destroyed as a result of the earthquake and tsunami, areas that were covered by cadastral survey had been digitised and coordinated. So although there may be no trace of the boundary on the ground they are able to re-establish the boundary based on the recorded or adjusted coordinates for the parcel

MINISTRY OF JUSTICE - LEGAL AFFAIRS BUREAU

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

* Following the South Hyogo Earthquake of January 7 1995, where horizontal movement of the earth's crust was confirmed, the Ministry of Justice decided to take the following measure:

  "In cases where the land surface has moved horizontally over a large are due to the crust movement caused by an earthquake, land boundaries shall be handled as they have also moved relatively. In cases of soil movement (landslide etc) on a local land surface, land boundaries are handled as if they did not move"

* Land and House Investigators conducted the work on behalf of the Ministry to assess land parcel distortion
* Status investigation - 300m meshes were plotted over the affected areas and the 4 corners and center were assessed to judge whether the error was within the cadastrally allowable range.

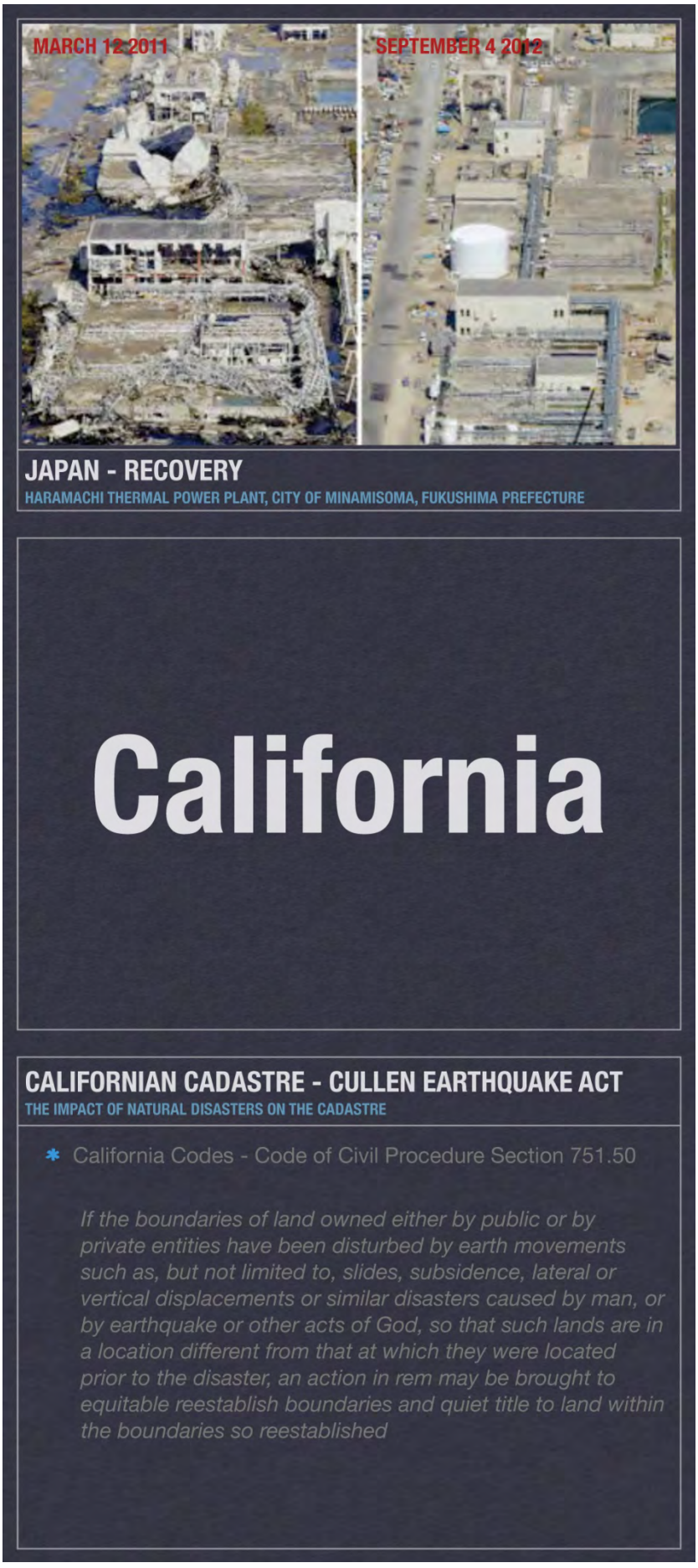
HOUSE AND LAND INVESTIGATORS

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

* Block correction method
  - Where the status investigation reveals that several locations or parts of boundary points in a block have moved regularly, block points are observed to identify the boundary points in a block. Only the block points are to be surveyed and each boundary point in a block is to be corrected by such methods as a Helmert conversion
* Cadastral map regeneration method
  - Where the status investigation reveals that boundaries have moved irregularly, block points and boundary points are surveyed to identify the boundary points for correcting maps. This method requires the same load of work for standard cadastral survey, much more time and cost than the block correction method, but it is necessary to use this method for areas with significant boundary movement

JAPAN - RECOVERY

TOWN OF MINAMISANRIKU, MIYAGI PREFECTURE


MARCH 12 2011
SEPTEMBER 4 2012
JAPAN - RECOVERY
HARAMACHI THERMAL POWER PLANT, CITY OF MINAMISOMA, FUKUSHIMA PREFECTURE
California
CALIFORNIAN CADASTRE - CULLEN EARTHQUAKE ACT
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE
California Codes - Code of Civil Procedure Section 751.50
If the boundaries of land owned either by public or by private entities have been disturbed by earth movements such as, but not limited to, slides, subsidence, lateral or vertical displacements or similar disasters caused by man, or by earthquake or other acts of God, so that such lands are in a location different from that at which they were located prior to the disaster, an action in rem may be brought to equitable reestablish boundaries and quiet title to land within the boundaries so reestablished

BERKLEY LANDSLIDE - 20 FEET IN 100 YEARS

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

LAGUNA BEACH LANDSLIDE - 2005

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

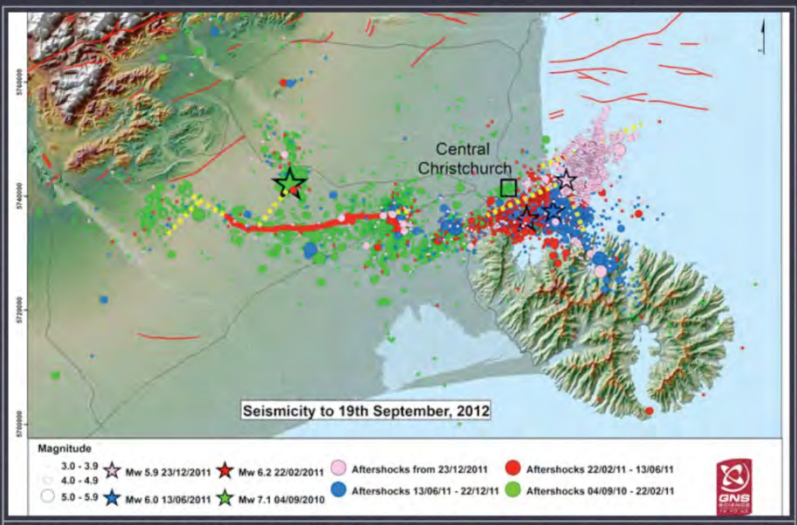
LAGUNA BEACH LANDSLIDE - 2005

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

LAGUNA BEACH LANDSLIDE - 2005

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

New Zealand



CANTERBURY EARTHQUAKES

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE


DARFIELD FAULT LINE
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE
DARFIELD FAULT LINE
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE
DARFIELD FAULT LINE
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE


UP TO 4m
DARFIELD FAULT LINE
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE
ROLLESTON RAILWAY
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE
CHRISTCHURCH CBD FEBRUARY 22 2011
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE


REDCLIFF FEBRUARY 22 2011
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE
BEFORE
AFTER
CHRISTCHURCH CATHEDRAL
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE
CHRISTCHURCH CATHEDRAL - JULY 2012
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

NEW ZEALAND - CADASTRAL SYSTEM

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

* The New Zealand cadastral system, like Australia, supports the Torrens title system with state guarantee of title
* Land Information New Zealand (LINZ) are the government body responsible for the cadastre
* Re-establishment of boundaries is based on the heirarchy of evidence in accordance with common law
* Monuments over measurements - where the original monuments are still in original position - given that that whole region has been affected by movement, what does that actually mean in practice?

NEW ZEALAND - CADASTRAL SYSTEM

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

* Despite being a seismically active locality, prior to 2010 there had been no major earthquakes in New Zealand that significantly affected cadastral boundaries since the Hawke's Bay (Napier) earthquake in 1931
* No statue law or regulation for re-establishing boundaries affected by movement due to an earthquake
* Previous New Zealand post earthquake surveys were dealt with on a case by case basis as there were only a small number of properties affected and were in mostly rural localities

NEW ZEALAND - CADASTRAL SYSTEM

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

* New Zealand has a semi-dynamic datum - New Zealand Geodetic Datum 2010 - which accommodates the effect of crustal motion - deformation patches
* New Zealand has a survey accurate Digital Cadastral Database - LandonLine - it connects the geodetic control, cadastral boundaries and survey monuments - based on LandXML data sets - it is compulsory for all cadastral survey data to be submitted as LandXML via LandonLine
* 70% of land parcels (principally urban and peri urban areas) are accurate to within 0.1m - the remaining 30% are usually within 1m and government funding is currently working on improving this

RULES FOR CADASTRAL SURVEY (CE) 2010

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

* **Category 1** - Boundaries unaffected by the earthquake
  - No change, the *Rules for Cadastral Survey 2010* apply
* **Category 2** - 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 3** - 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.

RULES FOR CADASTRAL SURVEY (CE) 2010

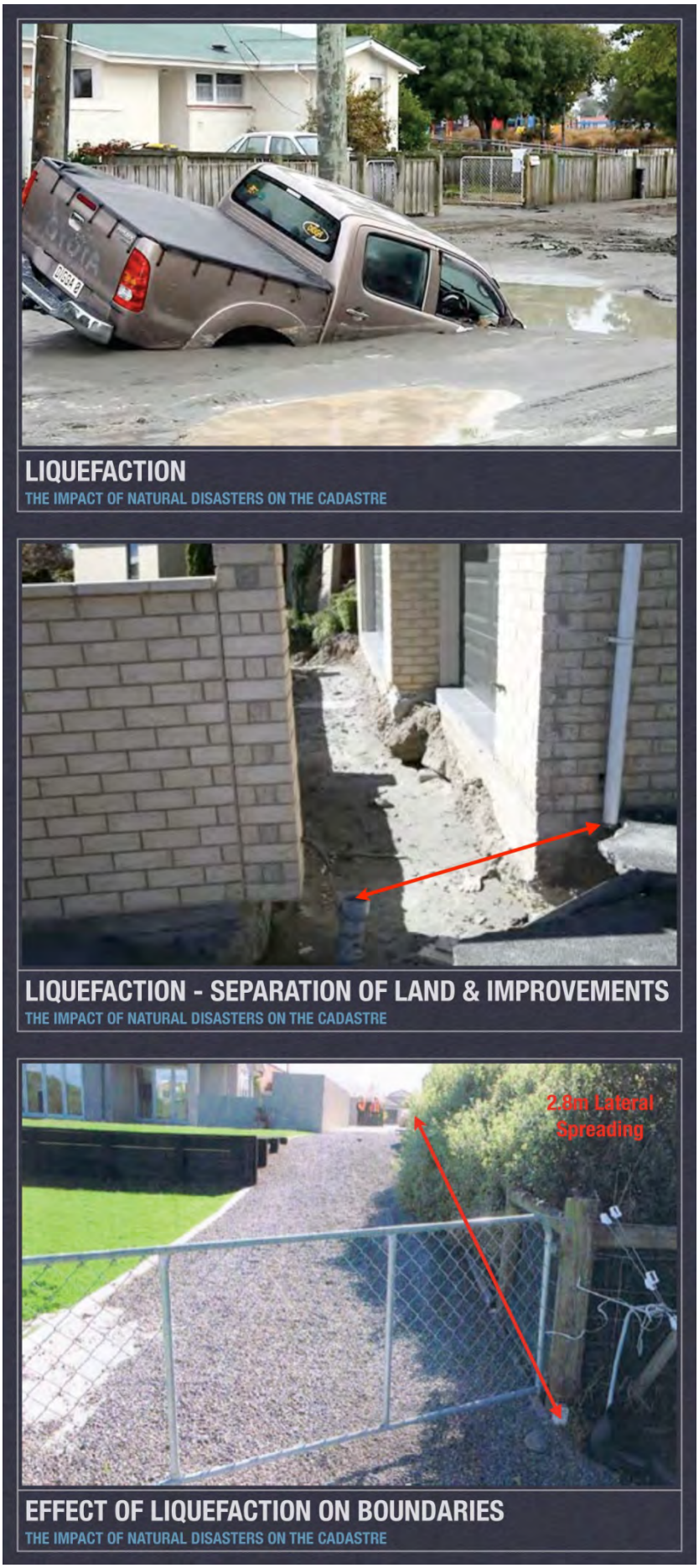
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

* **Category 4** - 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 5** - 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

LAND AFFECTED BY LIQUEFACTION SEPTEMBER 2010

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE


Legend
Areas of observed liquefaction
Port Hills area
LAND AFFECTED BY LIQUEFACTION FEBRUARY 2011
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE
LIQUEFACTION
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE
LIQUEFACTION
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE


LIQUEFACTION
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE
LIQUEFACTION - SEPARATION OF LAND & IMPROVEMENTS
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE
2.8m Lateral Spreading
EFFECT OF LIQUEFACTION ON BOUNDARIES
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

DEFINING BOUNDARIES POST EARTHQUAKE

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

- It is believed that approximately 50 properties are affected by the Greendale Fault (category 4)
  - To date only one redefinition survey has been received and registered (DP 440446)
- Despite the rules clearly stating that boundaries affected by shallow movement (liquefaction) must be placed back in their original (ie pre earthquake) position, in reality this is not what is occurring
  - Each case is treated on an individual basis based on local disturbed marks, occupations and the Surveyors professional opinion
  - While this makes sense it is not strictly in accordance with the current applicable legislation

DEFINING BOUNDARIES POST EARTHQUAKE

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE

- The Rules for Cadastral Survey (Canterbury Earthquake) 2010 expired on December 31 2012 - so the Rules for Cadastral Survey 2010 (Amended 2012) have been introduced
  - Rule 18 - Boundaries Affected by Ground Movement
  - The 5 individual categories have not been retained and rules relating to shallow surface movement have been removed as it is believed that common law covers this aspect adequately
  - The major benefit is that it allows the rules developed following the Canterbury earthquakes to be applied across the country following any future earthquakes.

NEW ZEALAND - RECOVERY

THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE


NOVEMBER 6 2012
NEW ZEALAND - RECOVERY
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE
NEW ZEALAND - RECOVERY
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE
Want to see how Christchurch is recovering?
FIG WW
2016
CHRISTCHURCH
NEW ZEALAND
RECOMMENDATIONS FOR NSW
THE IMPACT OF NATURAL DISASTERS ON THE CADASTRE
* Increase the density of our CORSnet NSW
* Increase the density & accuracy of our passive control network
* The creation of a survey accurate Digital Cadastral DataBase (DCDB)
* Inclusion of cadastral survey/reference marks in the SCIMS and further development of the SIX portal
* The use of GNSS (RTK) technology for cadastral boundary definition???