Innovation from Disaster!!

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Keywords: Hydrography; Land management; Topography; reinstatement of infrastructure following earthquake displacement

Abstract

Following the major earthquakes of September 2010 (7.1M) and February, June and December 2011 (6.0M to 6.3M), we carried out hydrographic and terrestrial surveys at the local Port 'Lyttelton - Port of Christchurch' to assist Geologists and Engineers to determine displacement of structures and elevation changes to the seabed and Tide Gauges.

These surveys confirmed their modelling of seismic vulnerability. We will also show our use of a small RiB with a full RTK hydrographic system for seawall and culvert repair surveys.

The presentation will also show a multitude of surveys across rivers and streams affected by the earthquakes where bridges and submarine pipelines needed repair and reinstatement.

My presentation will also include infrastructure damage to roading, Port facilities due to earthquakes and liquefaction.

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1. INTRODUCTION

Innovation is inspired by a need to get things done using the resources at hand in a constrained environment. In many cases, the solution is the product of a little imagination and maximising the untapped resources already at hand. The resources for a surveyor are his systems, procedures, equipment and capability.

2. BACKGROUND

So it is, as I recall, five and a half years since the first earthquake of September 2010. Prior to that we had been operating CORS from 1996 with LINZ and, later, GeoSystems Ltd. We initially set up a Trimble Reference Station 'ESP1' on our seven storey building at 151 Kilmore Street for RTK-GPS with UHF telemetry. This had an operating range of 10-15km which covered most of the city. We further enhanced the system with an inclined plane site calibration and later, around 2007, a site calibration incorporating a geoid model for better coping with the minor geoidal undulations across the city. At about the same time we transitioned into Trimble iBase to have real time corrections via the internet and cellular systems. This was to be an integral part of our operation and ability to accurately survey and report damage when the earthquakes struck. Of course the Port Hills, which border the south-east side of the city, require specific calibrations to cope with the coarseness of the geoid undulation model which had a '2' of arc' Nodal Density.

Later, the 2009 geoid model with 1' of arc node made working along the Port Hills interface easier. However Lyttelton Harbour, Port of Christchurch is part of the Port Hills area as the harbour is a remnant volcanic crater which makes up the Port Hills. Here the geoid model doesn't cope particularly well with geoidal variation in the topography and Earth mass (volcanic rock) and, again, needed a specific site calibration to provide high accuracy vertical measurements.

We started the construction of the 'Wigram Skies' subdivision in early 2010 on the old New Zealand Air Force Base (airfield). This facility was fortunate to have a very robustly built (thick reinforced concrete) control tower on stable natural river shingle (gravels and silts). This development of 1800 residential sections was to be completed in 2028.

However, the earthquakes in 2010 & 2011 created a major shortage of sections as the eastern suburbs were destroyed and 'red zoned' and the house demolished. Wigram Skies is now finished after six years of intense design and construction.

3. CORS

A further Trimble Reference Station 'WIG1' was set up in the Wigram Tower specifically for use by our surveyors and for machine control of the contractor's excavators, bulldozers and graders. This Reference Station 'WIG1' was coordinated in terms of 'ESP1' in December 2009.

4. GREENDALE EARTHQUAKE OF SEPTEMBER 2010

This 7.1M earthquake had a huge impact on estuarine and riverine communities because liquefaction occurred in the silts causing the land and buildings to subside and severe flooding to occur from the release of groundwater.
Wigram Skies, however, suffered little of this damage, being on gravels. The owners, our local indigenous people – Ngai Tahu, made a decision to fast track the design and construction and finish the development and provide the city with stable building platforms.

Another change brought about by the earthquakes is lateral spread (creep) where land migrates downhill or towards a marine boundary, generally an unsupported embankment such as a stream, creek, river or coastal bank. When the banks move into the water body the land behind follows and large fissures or cracks appear.

Houses are literally pulled apart, foundations fracture and fence lines and driveways snap apart.

The idea of cadastral boundaries changing was born here and was to become an issue between the Government land agencies and the local survey profession.

In Kaiapoi, a small coastal town 20km north of Christchurch, we measured 2.7m of displacement over two residential sections (60m). The town suffered liquefaction with significant loss of height bringing the town closer to sea level.

In New Brighton, on the city's eastern seaboard, high tide brings flooding to the streets, adding further woes to an already stressed community in their day to day lives.

5. INFRASTRUCTURE ASSESSMENTS

One of the big tasks early on was to survey road centreline profiles and manhole invert levels to determine, in part, how well the gravity sewage system had coped.

Many pipeline flows changed direction as Canterbury is a very flat plain where pipelines were already at critical, self-cleansing gradients.

Many manholes became septic tanks requiring cleaning every day by suction trucks which were few in number at the time.

We had created a site calibration for the towns north of Christchurch for the local district council prior to the earthquakes for their engineering department to map their resources.

The infrastructure survey was extended to other survey companies in order to speed up the task along with the Council taking on unskilled students to supplement the work force.

Many people failed to appreciate that the local geodetic control was also damaged by the earthquakes and were unable to discern what was damaged and what was reliable.

Many surveyors calibrated their observations against unreliable (disturbed) benchmarks resulting in errors being embedded in their data. Some of their datasets were able to be reverse calculated to render the data better when their calibration marks were assigned new heights.

Many GPS survey systems were essentially short range systems due to their low power in-built telemetry.

Following the earthquakes, we were able to record Fast Static data files at our CORS and get LINZ to process and supply upgraded coordinates for us to seed our reference units. These new coordinates allowed us to deduce the shift in our CORS Antenna position and apply that to our calibration parameters.

We then reobserved many benchmarks and noted which ones were within an acceptable tolerance and what differences were recorded against others. In hindsight, it would have been good to have set up a forum to share the knowledge and techniques.

The Christchurch City Council did set one up for its post- September 2010 assessment of levels across the city as this would give them insight into the level of damage around some parts of the city.

This group focused on Fast Static observation being the only way to reliably measure heights across the city which, in the context of daily shakes, often meant the data is obsolete before it made publication.

Later on, we were to show that our preferred and ‘quick’ ‘obs-control’ method using RTK-GNSS was equally as effective and very cost competitive and had a timely reporting phase.

The Port facilities including the oil tank farm suffered from the September 2010 earthquake as the Harbour is essentially made up of reclaimed muds from harbour dredging. We monitored the differential settlement of the tank farm fuel tanks to assist the geotech engineers monitor the stability and load bearing capacity of the land and its stone column foundations.

High pore pressures beneath the tanks threatened the load carrying capacity of the ground and some tanks were kept at low volume levels and used to directly fill fuel tankers serving the city through the Tunnel.

Fuel supplies or restrictions created an inconvenience to the commercial operation of the city as people had to travel further and take longer to travel around the city because of the detours in place. The Christchurch-Lyttelton Road tunnel to the Port controlled the type and number of vehicles using the Tunnel when required.

6. SECOND EARTHQUAKE 22 FEBRUARY 2011 @ 12:45PM - 6.1M

To say this earthquake was violent would be an understatement. It was devastating! It brought the city and the Port to a standstill and severely disrupted services for a considerable period and five years on, infrastructure work is continuing with some core projects in the CBD still undecided whether to proceed.

Many businesses have relocated to the suburbs away from the CBD, especially to the more stable west side of the city and are unlikely to return to the central city in the foreseeable future. Much of the CBD suffered liquefaction, masonry failure, fractured buildings and two buildings collapsed with loss of approximately 200 lives.

Many of these buildings have been given ‘safe status’ from the September 2010 earthquakes, but that may have been a product of insufficient numbers of qualified and earthquake experienced engineers and the pressure from landlords to have their buildings reoccupied.

This new earthquake was so abrupt that it caused the roading system to fail and required a full evacuation of the CBD and adjacent industrial and manufacturing plants. The CBD went into ‘lockdown’ mode for security reasons as everyone just ‘ran away’ from their place of work to seek solace at their homes which, for many, was another traumatic event to be endured as many homes were terminally damaged, uninhabitable or in need of substantial work to initially make them habitable.

This was especially so for the Port Hills inhabitants, ‘site of the epicentre’, and the inhabitants of the land bordering the rivers and coastline already subjected to liquefaction.

Cell phone calls terminated mid-call, texting was unreliable but better.

Essentially many electrical substations self-destructed cutting power to businesses, houses and pump stations though, through all this, the traffic lights kept working!

People were stranded where they were and many people took 3-4 hours to return home for what had been a 20 minute journey in their car or bus that morning.

Many people abandoned the city if they could and had somewhere to go. Many others went into camping mode using resources at hand. For some it was a few days before they were back to some a semblance of normality, for others it went on for months depending on the damage in their area.

On Day Three we entered the CBD Cordon and extracted our survey gear and laptops and set up a temporary office in the north-west corner of the city, where damage was minimal.

Vehicles were reassigned to working survey parties, fuelled up whenever it could be found and set up to work measuring displacement out the oil and LPG facilities in the city and Port. Later the Port required our survey expertise to independently measure the magnitude of the shift of their structures. This assisted the geologists and enquiries in confirming the strength of their seismic modelling and assessment of damage.

We were able to use GPS-RTK to show the horizontal displacements around the Port as the magnitude of the shifts were considerable, e.g. 300mm. We were also about to quantify the vertical displacements to a few centimetres as our calibrations stayed intact.

We spent weeks precise levelling the Port and tank farms to monitor daily change, as new quakes continued to ravage the environment, so the facilities could be used safely and within capacity. We soon assessed that Lyttelton had lifted 100–150m. This affected the tidal measurement of the Port which required an ocean expert to confirm by comparing tidal data change or the lack of it with adjacent Port gauges at Kaikoura and Timaru, approximately 180km north and south of Lyttelton on the same East Coast.

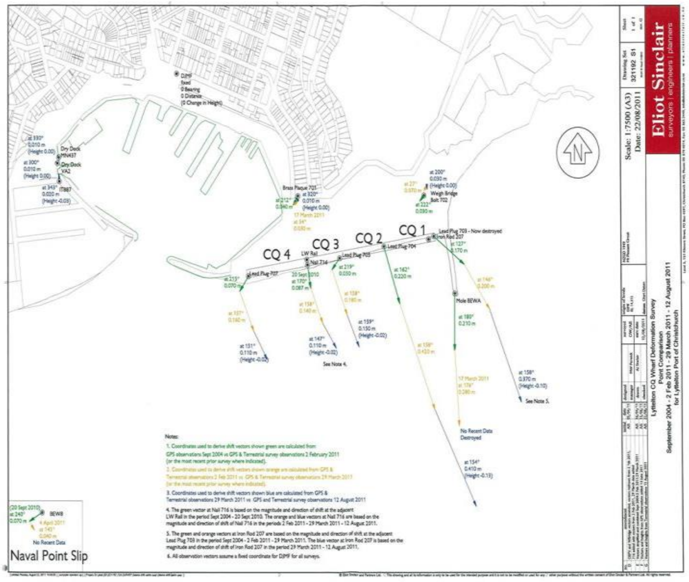
However, we adopted the philosophy to keep the level values of the primary benchmarks at the Port the same as we wanted to measure differential movement. These benchmarks are located on bedrock and proved to be in terms across the Port.

Interestingly the wharves remained at similar levels to pre-quake values, albeit displaced 150mm. This may have been a result that the piles are deep set in the Harbour muds. The land structure at the Port showed considerable collapse and migration towards the sea and when surrounded by the sea towards deeper sections of the Harbour.

7. MONITORING MOVEMENT AT THE PORT

Stability of land during a period of earthquakes is a temporal thing, although as time progresses the land does stabilise. The movement is on a parabolic curve, as after the first 100 aftershocks it slowly diminishes to where it becomes difficult to measure and report. This leads to the reports having credibility as the movements taper off as the displacement magnitude approaches the level of survey noise or accuracy.

As stated previously, we were able to survey existing control points around the Port, on wharves, hardstands, roadways and structures with GPS and that was suitable for the first week or so where the movements were large, i.e. 300mm Horizontal and 150mm Vertical. However, we also used our GPS observations to support Total Station traversing supported by precise levelling. This required multiple crews to effectively carry out the work at the same time, as the Port was continuously moving. Our Trimble Business Centre software processed these datasets.



We were able to report the displacement by way of Vector Diagrams exaggerated for scale on photo maps. These gave a very clear representation of movement and rate of movement for each survey. Further, the monitoring was in two parts; deep-seated infrastructure (light poles), and surface infrastructure (wharves, pavements, sheds, aprons). The big issue for the continued operation of the Port was two-fold; daily operation and movement from pavement to wharves and, longer term, repair of infrastructure (seawalls, embankments, high cost pavements).

Fingers and breakwaters suffered greatly as they were surrounded by water and although heavily armoured with rock, collapsed into the harbour muds. These were temporarily abandoned until other more important issues had been attended to.

As soon as our measurement results started to blur we had to further refine our terrestrial observations and traversing by incorporating observations to distant trig stations 3-8km around the Crater Rim. The dilemma here was that we were unsure of the actual post-earthquake coordinates of these marks as some are only accessible by boat and on top of the Port Hills – many hours walking! We iterated their position from our observations at our GPS control stations and we were able to bring our Horizontal residuals down to about 4mm while precise levelling was sub 2mm.

Thus engineers/geologists were pleased to see the reported movement diminish but when it got below 10mm it started to become subjective and we would be stood down for a few weeks until something further occurred.

The Oil Tank monitoring (Vertical) was continuous for weeks after 10 September 2010 and 22 February 2011. We were able to show the Horizontal displacement on some fuel tanks on stone column foundations to be negligible, however the associated pipework showed distinct signs of misalignment and stress as this was shallow surface mounted.

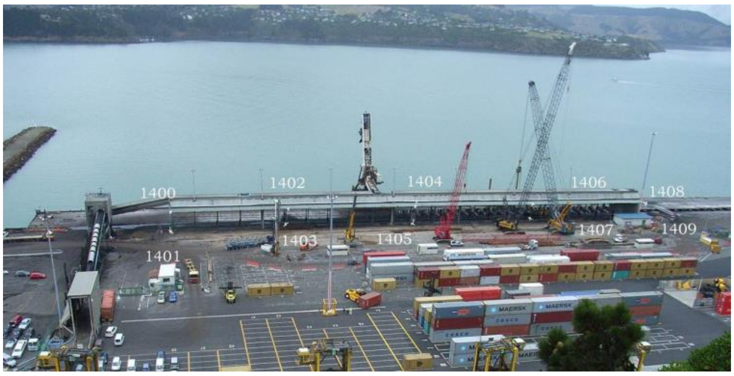
The precise level surveys were time consuming as the reclamation area became quite plastic and transmitted road traffic movement in waves through the ground. Road fuel tankers entering the Port area from the Lyttelton Road Tunnel would start a pulse through the ground which would start the pendulum in the Trimble DiNi oscillating. The area was surprisingly quiet, as most operations had ceased. When the truck had stopped and shut off its engine the ground motion would diminish and we could continue levelling.

We established survey monuments in all our operations, especially for levelling, as charge points, and on the wharves and hardstand areas as the land moved. Of course, construction works were repatriating the aprons and access roads around the point and many marks disappeared every day. Our spreadsheet report often terminated abruptly where marks were destroyed. However, we placed new marks and adjusted the previous data to provide continuity of movement so trends could be seen.

Working amongst big fuel tanks during aftershocks was terrifying as the tanks growled and wobbled.

8. WHARF REPILING

One other project of note at the Port was the precise remote monitoring of the piling of the Cashin Quay Coal Wharf. Large cranes were used to repile the wharf from back on the hardstand.



We set up a number of small prisms on the wharf and coal galley structure as well as on the land behind the wharf and further back as a reference line. The points were monitored for movement every 15-20 minutes for nearly one year using a Trimble monitoring application on the TSC3 Controller. We used a Trimble S8 Total Station with long range fine auto lock for robotic tracking of these points. The application reported the displacement and set off alarms where thresholds were exceeded. The piling operation caused the toe of the embankment under the wharf to fail with a resultant shift of the wharf and building structure.

Work was stopped and the piling continued but with the two cranes separated well apart.

9. HYDROGRAPHIC SURVEYS

10. HARBOUR SURVEYS

We carried out profiling surveys around the Port to see if any slumping of sea walls and embankments occurred with any resulting shallowing of the sea bed. This was problematical as the survey boat couldn’t pass under the wharves to complete the profile. We used a narrow 3° 200kHz Transducer to assist. We didn’t pick up any discernible differences in depths over the few repeat surveys we did which showed the Harbour seabed was fairly stable.

The New Zealand Navy were able to survey the Harbour channels and berths with a multi-beam system immediately after the February 2011 earthquakes as they had been working on coastal surveys in the region.

It was later discovered that the Lyttelton Port Tide Gauge was at a higher Reduced Level as the wharf structures had lifted and was reporting lower tides. It was downward reading! Comparison of tides with distant but adjacent tide gauges confirmed the problem.

11. HYDROGRAPHIC SURVEY – SEWERAGE TREATMENT PLANT

Two surveys where carried out:

1) To determine the loss of volume and depth in the shallow oxidation ponds.

2) To determine the structural failure of the clarifier tanks.

12. INTRODUCTION

The earthquake caused the 'horizontal infrastructure' to collapse and fracture, many pumping stations failed, though physical damage and loss in power.

The treatment plant was compromised in its ability to treat and separate solid waste, much of which had to pass through to the oxidation ponds.

The clarifiers were large concrete tanks with mechanical stirring and oxygen arms.

The violent uplift caused by the earthquake fractured these tanks and our task was to determine the extent of damage.

The pond survey was carried out as a hydrographic survey for the navigation of the vessel and measurement to the top of the sludge, whilst the pond bed was probed with a prism pole tracked by our long range Total Station at about 900m distance.

The clarifier survey was essentially a topographical survey from a small boat floating in the morass. The profiles and contour plots for each survey showed the extent of siltation in the ponds and fractures of the clarifier base.

13. SEAWALL & BRIDGE SURVEYS

The Redcliffs area, south-east of the CDB, has a long causeway separating McCormacks Bay from the Estuary as well as concrete sea walls around to Moncks Bay.

Heavy traffic was restricted from using the causeway until sufficient repairs had been completed.

The uplifting of the bridge culverts draining McCormacks Bay needed to be addressed to ensure that drainage of the bay continued. The rising main (sanitary sewerage) from the Mount Pleasant area was fractured and some product was pumped directly into the bay and required flushing.

We carried out detailed topographical surveys using GPS-RTK, Total Station and Hydrographic Echo Sounder surveys to produce 3D models of the causeway and Redcliffs seawalls. The seawalls are currently being reinstated this year.

Many bridges service Christchurch and its environs. Engineers used our small RiB to inspect fractures of piles and abutments. The rivers were typically surveyed with RTK-GPS or Total Station.

14. OCEAN OUTFALL SURVEYS

Two ocean outfall pipelines serve the coastal communities in Pegasus Bay.

We carried out inspections of these pipelines using divers and side scan sonar as visibility was limited under water. The heights of the structures were checked for any uplift or subsidence at the diffuser structures through the use of spar (pencil) buoys and RTK-GNSS measurement from our vessel.

15. SUMMARY

A robust survey infrastructure, and the ability to respond urgently and efficiently, meant that survey measurement was able to deliver meaningful data and reports to engineers, geologists and decision makers. It also allowed essential services to continue to operate by way of fuel supplied and input and export of goods.

Behind the scenes, the telemetry professionals kept the phone, digital and internet systems operative. This alone allowed us to work remotely from our temporary offices without the need to travel across a fractured city.

The goodwill and practical response by all parties (security, transport, telecommunications, administration, surveying, engineering, geotechnical, Local and National Government) helped get us through.

Preparation is the key to survival, but nothing can prepare you for responding to a disaster: save your own strength and imagination.

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