# New Zealand acquisition, spring 2011

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## ABSTRACT

The magnitude 7.1 Darfield earthquake occurred September 4, 2010, west of Christchurch New Zealand on the Greendale fault, which was not previously known to exist. Structural damage was sustained in Christchurch, but no loss of life. Don Lawton suggested it might be an idea to ship the University of Calgary's seismic equipment to New Zealand to try and delineate the fault, but at the time the cost was deemed prohibitive. Then, after many smaller aftershocks, a magnitude 6.3 earthquake centered near downtown Christchurch caused major structural damage (50-60% of downtown buildings need to be demolished) and loss of 182 lives. Shortly afterwards we were contacted and requested to undertake seismic surveys in and around the city.

The University of Calgary's INOVA (ARAM) Aries recording system with 600 channels of 1C marsh phones, boxes, batteries, cables and our IVI EnviroVibe were trucked to Chicago, air-lifted to Auckland, and completed the journey to Christchurch via transport truck. Four CREWES personnel flew to New Zealand to conduct the seismic surveys in conjunction with the University of Canterbury and Southern Geophysical. Six 1C-2D seismic lines with a total line length of 41 km were successfully acquired in the Christchurch area April 5-May 30, 2011, including two within the Christchurch metropolitan area, and one across the surface expression of the Greendale Fault.


## INTRODUCTION

The magnitude 7.1 Darfield earthquake had a hypocenter located at a depth of 11 kilometres, 40 kilometres west of Christchurch New Zealand. It occurred on the Greendale fault, which was not previously known to exist, at 4:35 am on September 4, 2010. The University of Calgary had already been discussing shipping our seismic system to New Zealand for some co-operative research projects there, and this prompted the suggestion that we could provide some insight into the structure around this just discovered fault to try to delineate the feature at depth. The idea was to share the cost of shipping the equipment between the various projects, but cost was still a major impediment. Discussions were still ongoing regarding this venture, when a magnitude 6.3 earthquake centered south of downtown Christchurch occurred at 12:51 pm on February 22, 2011, causing major structural damage (50-60% of downtown buildings need to be demolished) and the loss of 182 lives. The hypocenter was 10 kilometres south-east of Christchurch, 2 kilometres west of the town of Lyttleton and at 6 kilometres depth. Major liquefaction occurred in the eastern suburbs, with some areas being designated unrecoverable. Following this event, New Zealand Civil Defense contacted us with a request to mobilize as soon as possible to provide information on the structure below the city of Christchurch itself, and potential locations of future risk. This paper focuses on the acquisition program. Interpretation of the seismic data is discussed in a companion paper in the research report (Lawton, et al., 2011).

## CANADIAN EQUIPMENT

The original plan was to ship the equipment by container ship, but the urgency of the project was such that the New Zealand government agreed to transport the system by air. The co-ordination of the move was handled by DHL who determined that we could utilize a Qantas 747 transport from Chicago to Auckland. Because of the strict agricultural requirements for bringing any field equipment into New Zealand, the entire system of geophones, cables, batteries and RAMs was hand washed and disinfected before being packed in wooden shipping crates that were constructed at the University of Calgary. The wheels on the EnviroVibe were removed and re-installed backwards, as this decreased the total width of the unit to the point that it would fit inside a standard shipping container. Driver and passenger door mirrors were also removed. The diesel tank had to be one quarter full or less, and the cap for the diesel tank had to be secured in order for the vibe to be flown. The fire-extinguisher mounted outside the cab had to be removed, and the battery disconnected. Instructions on how to start and drive the vibe were printed and left inside the cab. The five crates of equipment were weighed by hanging from a scale attached to a chain hoist at the University. They were then loaded onto a University of Calgary flat-deck trailer and driven to Sterling Crane (Calgary), along with the Vibe on a separate flat-deck trailer. Everything was loaded onto a flat-deck semi-trailer by crane, as we had difficulty finding a suitable loading ramp in the time available. Our equipment was trucked to Chicago, transferred to the Qantas cargo plane, and flown to Auckland, arriving there on April 4, 2011.

We met our gear in Auckland, where the Vibe and our crates had to clear New Zealand customs (Figure 1) and bio-security before being loaded onto a truck (Figure 2) for transport to Christchurch. It was possible to drive the Vibe off of the cargo dolly, with the assistance of a loading ramp, and onto a truck with a low-boy trailer. This truck was able to move the Vibe and our five crates to a nearby business in one trip, where the Vibe was then driven onto the truck shown in Figure 2 using a loading ramp. The canvas sides of this truck made chaining the Vibe to the flat-deck much easier. The crates were placed in a trailer that was towed behind this truck (not shown). In Christchurch, the Vibe was unloaded using a loading ramp, then transported the remaining distance to the local operations bases at Southern Geophysical via low-boy. Transport between seismic lines was done by low-boy. The Vibe was parked on the line during acquisition, usually at a business or residence near where acquisition was completed for the day.

## NEW ZEALAND EQUIPMENT

Other than the Vibe, we used New Zealand vehicles that were either rented (Ford Transit cargo van, 3-ton Isuzu cargo truck, quad and quad trailer, sheep trailers), or provided for this work by the University of Canterbury (Toyota Hi-Ace van, Toyota Hi-Lux 4x4 truck, and moving trailer) and Southern Geophysical (quad and quad trailer, Honda generator). We did not ship any computer monitors to New Zealand for this survey, monitors were provided by the University of Canterbury. A 12-V high-amperage battery charger was purchased (and left after the survey) in New Zealand after the Canadian battery charger blew up on 240 V power. We had been told that it would handle the higher voltage, but were unaware that a jumper had to be de-soldered and removed internally before this would be true. Logistics and GPS were provided by Southern Geophysical, and the field crew consisted of University of Canterbury students.

## OVERVIEW OF PROGRAM

Figures 3 and 4 show the distribution of earthquake epicenters in the Christchurch area from September 4, 2010 to October 17, 2011. The overall trend is east-west, and appears to be aligned with the Chatham Rise, which is the offshore high to the east of Christchurch (Figure 3). An overview map of the Christchurch 2011 seismic program is shown in Figure 5, for comparison with Figure 4. Line locations were picked to cross earthquake activity. Six 1C-2D seismic lines with a total line length of 41 km were successfully acquired in the Christchurch area April 5-May 30, 2011 over the course of two separate three week long trips (six weeks of work) to New Zealand by the authors.

Recording system parameters are shown in Table 1. Note that recording with a 3 Hz low-cut filter and a sweep that starts at 10 Hz (EnviroVibe minimum) we could, and did, see earthquakes on the noise monitor in the recorder during production shooting, but cannot see them on the correlated shot gathers. Aries boxes and batteries were picked up and stored at Southern Geophysical every night in order to help prevent vandalism and/or theft. Time cost for this was approximately one hour at the start of the day and one hour at the end of the day. Geophones and geophone cables were left on the ground overnight.

All lines were acquired as rolling spreads with minimum 2 kilometer source-receiver offsets. For split-spread shooting with the vibe point centred on the spread, this results in 4 kilometer shot gathers. Note that these parameters mean that some lines (< 4 km) had shots where all receivers on the line were live. Maximum source-receiver offsets were 6 kilometers for end-on shooting, which was only achieved on the first line (New Brighton Beach). As we were rolling out the current line, the chaining and layout crews were working on the next line, so that production delays were limited to the time needed to move the recorder and Vibe to the new line. Useful offsets for seismic imaging in this area, for this equipment and these parameters, appear to be a maximum of 2 kilometers.

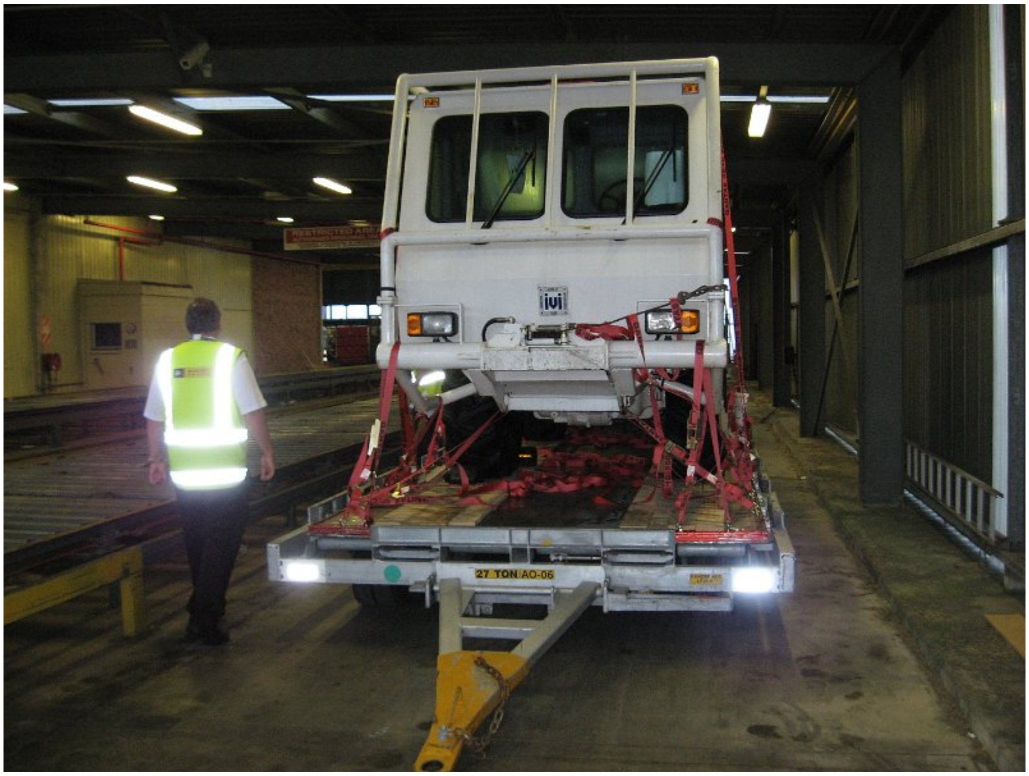

FIG. 1. EnviroVibe on aircraft cargo dolly in New Zealand Customs warehouse at Auckland airport.

FIG. 2. EnviroVibe on transport truck for road trip from Auckland to Christchurch.

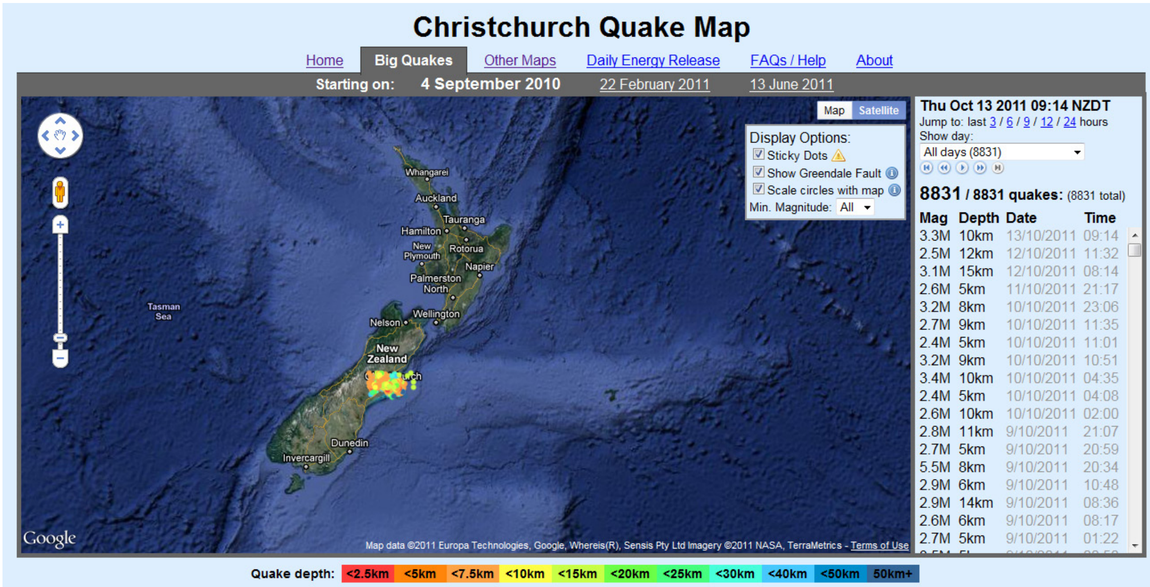


FIG. 3. New Zealand, showing all earthquake locations from September 4, 2010 to October 17, 2011. Map data © 2011 Europa Technologies and © 2011 Google and © 2011 Whereis® Sensis Pty Ltd. Imagery © 2011 NASA and © 2011 Terrametrics (Christchurch Quake Map, 2011).

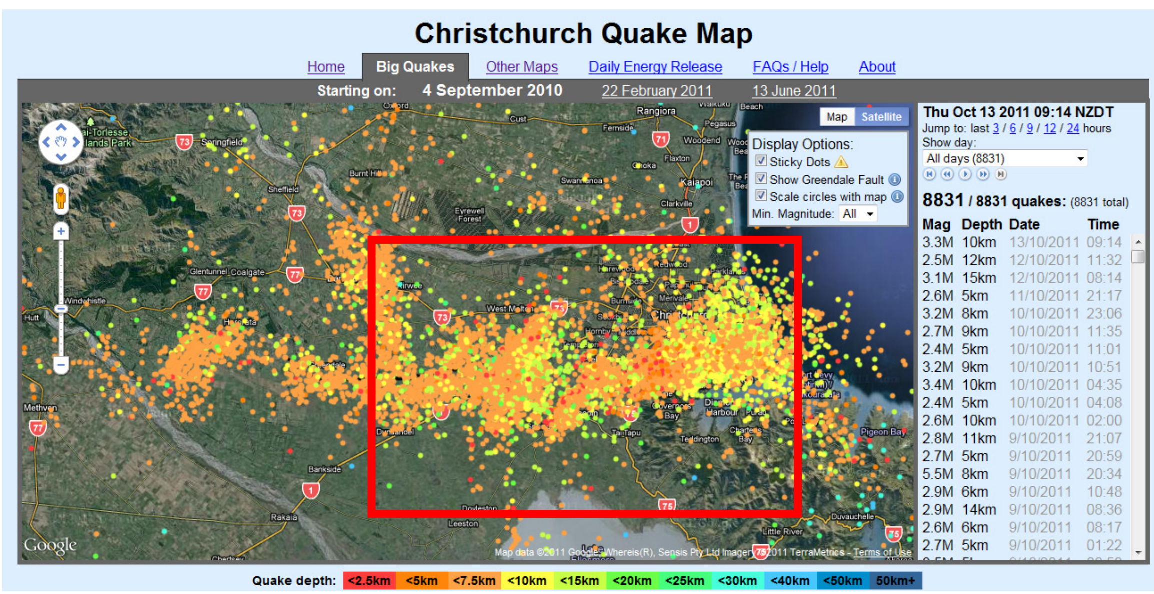


FIG. 4. Christchurch area, showing all earthquake locations from September 4, 2010 to October 17, 2011. Map data © 2011 Google and © 2011 Whereis® Sensis Pty Ltd. Imagery © 2011 Terrametrics (Christchurch Quake Map, 2011).

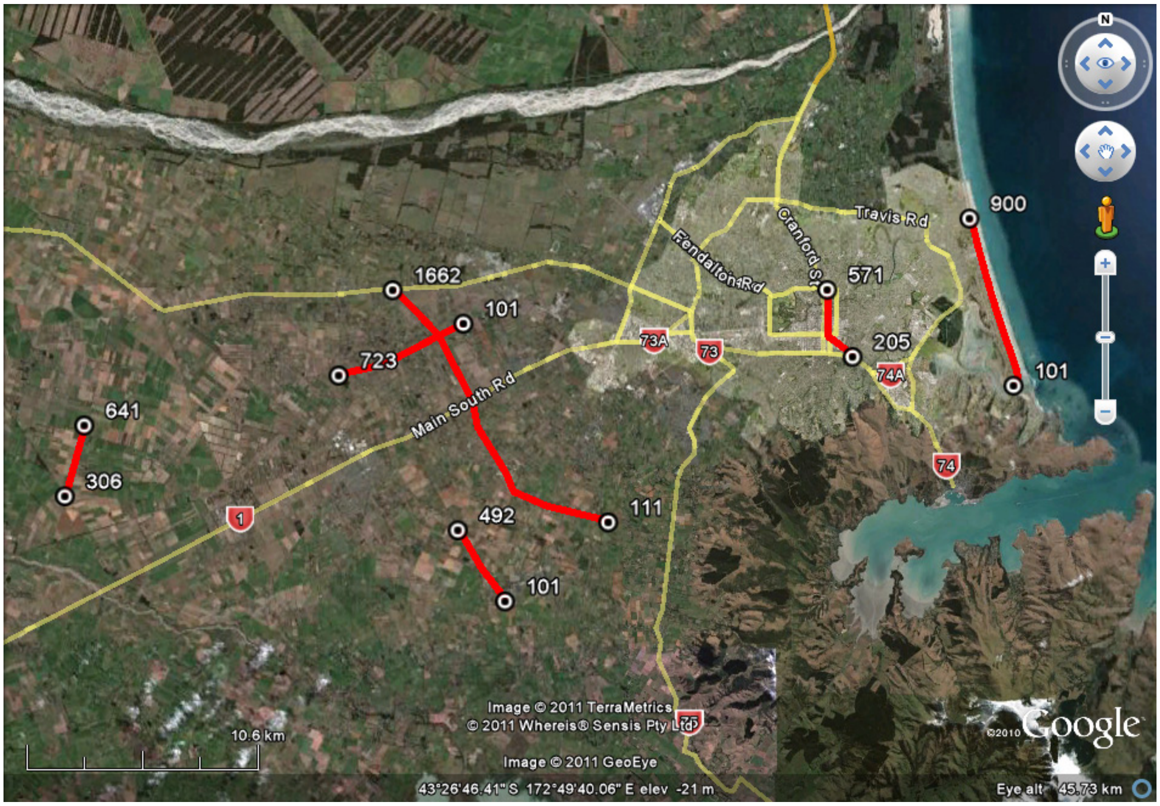


FIG. 5. Overview map of Christchurch seismic program (cf. red box, Figure 4). Image © 2011 TerraMetrics and © 2011 Whereis® Sensis Pty Ltd and Image © 2011 GeoEye (Google Earth, 2011).

Table 1. Christchurch 2011 seismic program parameters.

| | |
|---|---|
| **Recorder** | |
| **Length** | 4,000 ms |
| **Low Cut Frequency** | 3 Hz |
| **High Cut Frequency** | 410 Hz |
| **Sample Rate** | 1 ms |
| | |
| **Receivers** | |
| **Spacing** | 10 m |
| **Element Type** | SM-24 |
| **Case** | PE-8C Marsh |
| | |
| **Source** | |
| **Type** | IVI Envirovibe |
| **Hold Down** | 15,000 lbs |

## NEW BRIGHTON BEACH LINE (LINE 1, 8.0 KM LONG).

The New Brighton beach line was acquired in unconsolidated sand, generally just above the high-tide mark (Figure 6; Table 2). Sand quality ranged from loose and dry through damp and firm. The first day of production was quite windy, with large amounts of blowing sand. The weather was generally clear and calm after that. Other than wind, the largest source of noise on this line was the surf. The waves could be watched moving along the beach on the noise monitor.

We found that our hand-held radios, tuned to a University of Canterbury frequency, did not work over the kinds of distances we're used to in Alberta. Possible causes are poor antenna matching (mag-mount whip on the recorder), and operating above a highly conductive salty ground-plane. Figures 7-13 show pictures that were taken during acquisition of this line.

The stock advance pedal in the University of Calgary EnviroVibe had been replaced with an electronic controller before this trip, with the pedal in the usual place and the electronics bolted onto the side of the steering column. The cab air-conditioning was not working properly, and (speculation) the electronics were overheated. Symptoms were having the Vibe stop suddenly if the pedal was depressed too far, and the Vibe refusing to move after sweeps were completed at a Vibe Point. Vibe would regain the ability to move after resetting the electronics, initially by doing a full shut-down and re-start of the Vibe, and later by pulling and re-installing the fuse to force the electronics to reset once we figured out what was going on. Attempts were made to keep the electronics cool by acquiring with the cab doors open. The upside was a nice cross-breeze from the ocean and good views of the breakers. The downside was the ocean had raw sewage in it post-earthquake.

Some of the Vibe points were below the high-tide mark, when offsets were introduced to move VPs further from structures. If the sand was too wet, it would liquefy during a Vibe sweep (Figure 12). The solution was to skip some Vibe Points, or move up the beach to drier sand if possible.

High tide was 2 m higher than forecast one night (April 8), and washed out the line. Fortunately, as discussed earlier, none of the batteries or boxes was on the line at the time. Geophone cables were dragged by water containing sea weed and driftwood (Figure 13), which made pick-up more difficult than expected. Geophones disconnected from the take-outs and cable end caps did not necessarily stay on. Many cable and geophone connectors were filled with salt water and sand. Field crews sent down the line were instructed to spray out all connectors with WD-40 before re-connecting. Production start was delayed by 2 hours, but only two geophones were lost and the line came online like nothing had happened.

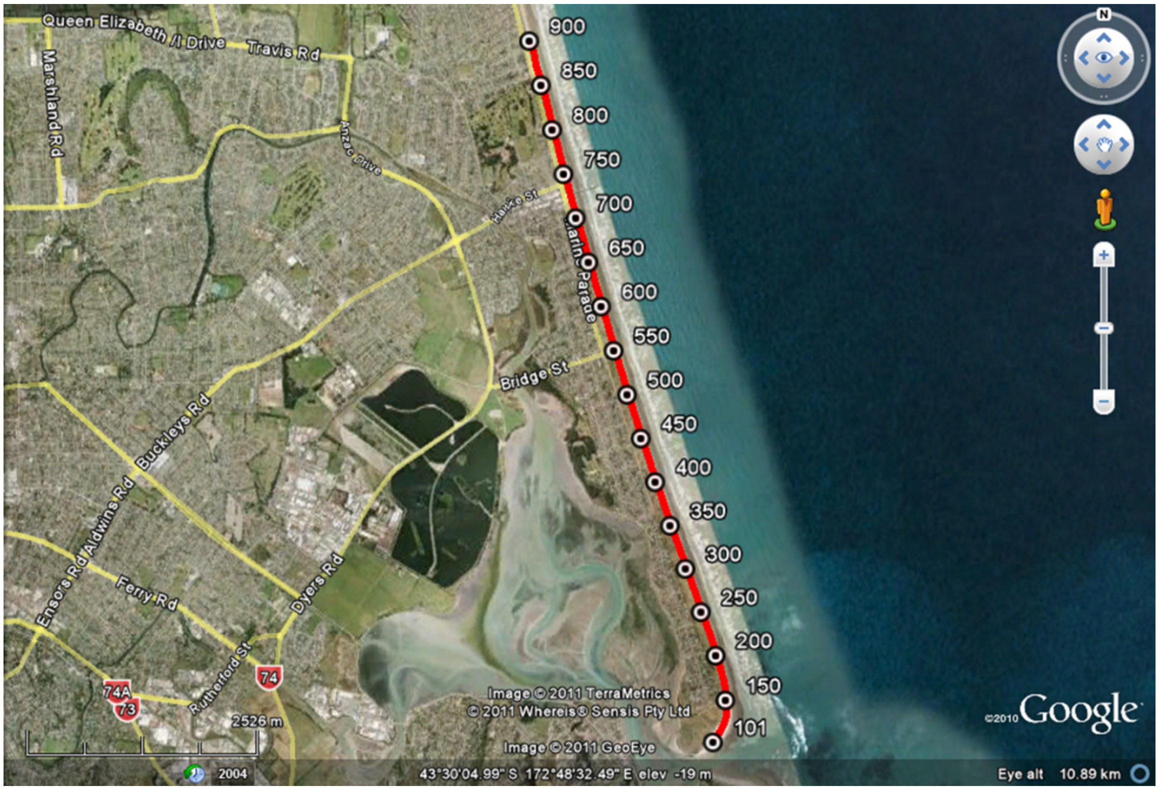


FIG. 6. New Brighton Beach line. Image © 2011 TerraMetrics and © 2011 Whereis® Sensis Pty Ltd and Image © 2011 GeoEye (Google Earth, 2011).

Table 2. New Brighton Beach line parameters

| New Brighton Beach | **April 6 - 11, 2011** |
|---|---|
| **Stations** | 101 – 900 |
| **Spacing** | 10 m for Stations 101 - 660 |
| | 20 m for Station 661 - 900 |
| **Number of Sweeps** | 4 |
| **Sweep Start Frequency** | 10 Hz |
| **Sweep End Frequency** | 120 Hz |
| **Sweep Type** | Linear |
| **Sweep Length** | 20,000 ms |
| **Start Taper** | 100 ms |
| **End Taper** | 100 ms |
| **Taper Type** | Cosine |


FIG. 7. Ford Transit van as seismic recorder.


FIG. 8. Toyota High-Lux with moving trailer filled with boxes and batteries.

FIG. 9. Staging area at a surfing-club building.

FIG. 10. Chaining crew marked every 10 m by kicking a line in the sand. Every 80 meters was marked with a wooden stake. The beach line was plowed to clear driftwood and sea weed (see Figure 13).

FIG. 11. Vibe and quad on the beach, looking south at the Port Hills (volcanic).

FIG. 12. Beach sand liquefied during Vibe sweep if sand was too wet. Solution: move vibe point higher up the beach, away from the ocean.

FIG. 13. Seismic cable after high-tide was higher than expected.

**BARBADOES STREET (LINE 2, 3.7 KM LONG)**

The second line acquired ran through metropolitan Christchurch, starting on the railway at the south end, then turning through a skate-board park, crossing Moorehouse Avenue and continuing up Barbadoes Street (Figures 15-20). The city kindly cut a quarter-inch trench in the road surface and epoxied one of our Aries communications cables into the road. We cut the cable and retrieved the cable heads, but most of that Calgary cable is now a permanent part of Moorehouse Avenue. Part of the Barbadoes Street portion of this line was inside the red zone, which was a military and police cordoned-off area of most of downtown Christchurch. Passes were required in order to be inside the red zone for any reason. There were no issues with traffic noise for this part of the line. When the section of the line along Barbadoes Street was first started, the EnviroVibe was having a problem staying coupled with the hard surface at low frequencies, so the sweep parameters were changed to improve coupling and reduce the chance of damage to the Vibe.

The Vibe was required to maintain a minimum distance from the center-line of the active railway tracks, which limited the number of Vibe Points that were available immediately to the southeast of Waltham Road. The next Vibe Points that were obtainable were on the north side of Moorehouse Avenue. All of the geophones in the skateboard park were pulled out of the ground, with one geophone case being damaged, during production shooting on the first day the spread crossed the skateboard park. After this, one of the field crew was posted to watch the equipment during the day, and geophones and geophone cables were picked up through the park, and hidden in the bushes on the railway line around the corner for the night.

Geophone plants were in grass if available. Holes were hammer drilled for the geophone spikes if not. Cables had to be tied down to the pavement, to prevent any possibility of them flipping up and looping over the wheels of passing vehicles.

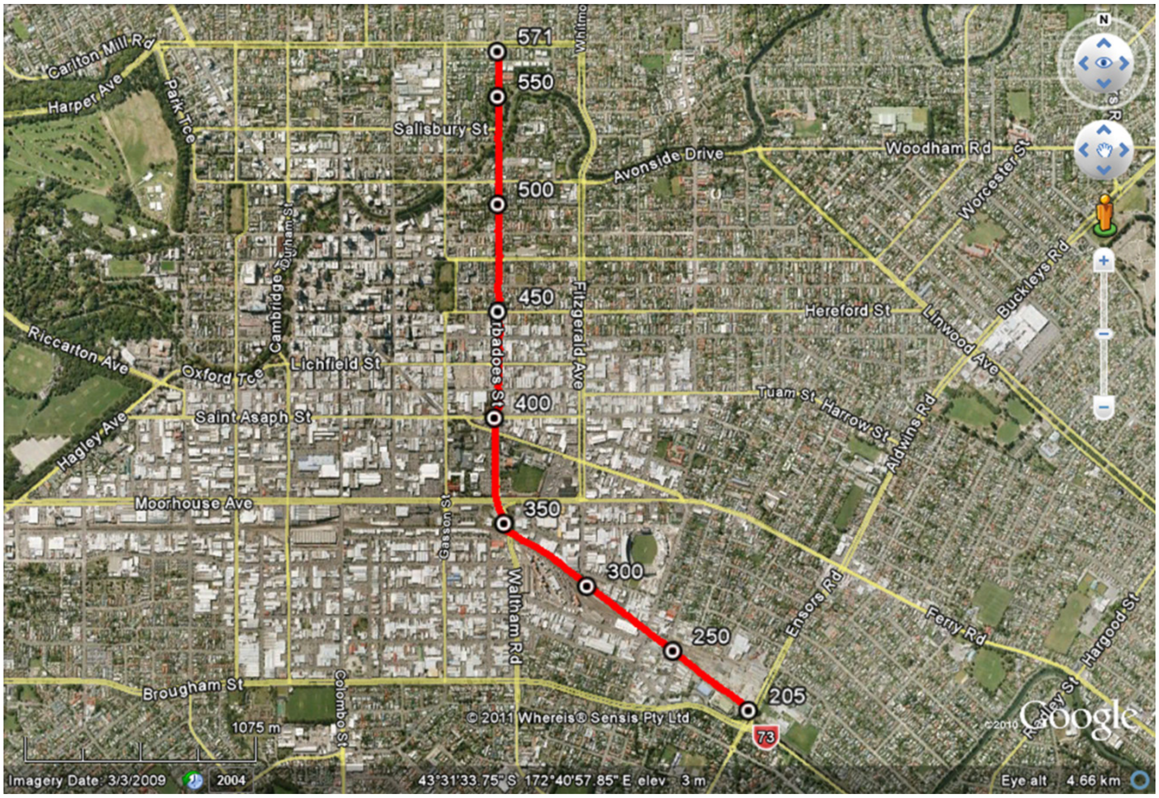


FIG. 14. Barbadoes Street line. © 2011 Whereis® Sensis Pty Ltd (Google Earth, 2011).

Table 3. Barbadoes Street line parameters

| Barbadoes Street | **April 12 - 14, 2011** |
|---|---|
| **Stations** | 205-571 |
| **Spacing** | 10 m |
| **Number of Sweeps** | 4 for Railway Portion of Line (Stations 205 - 336) |
| | 8 for Pavement Portion of Line (Stations 366 - 571) |
| **Sweep Start Frequency** | 10 Hz |
| **Sweep End Frequency** | 120 Hz |
| **Sweep Type** | Linear |
| **Sweep Length** | 20,000 ms for Railway Portion of Line (Stations 205 - 336) |
| | 10,000 ms for Pavement Portion of Line (366 - 571) |
| **Start Taper** | 100 ms for Railway Portion of Line (Stations 205 - 336) |
| | 3,000 ms for Pavement Potion of Line (366 - 571) |
| **End Taper** | 100 ms |
| **Taper Type** | Cosine |


FIG. 15. Quad and trailer parked on the railway.


FIG. 16. Some geophone plants.

FIG. 17. More geophone plants. New Zealand likes traffic cones.

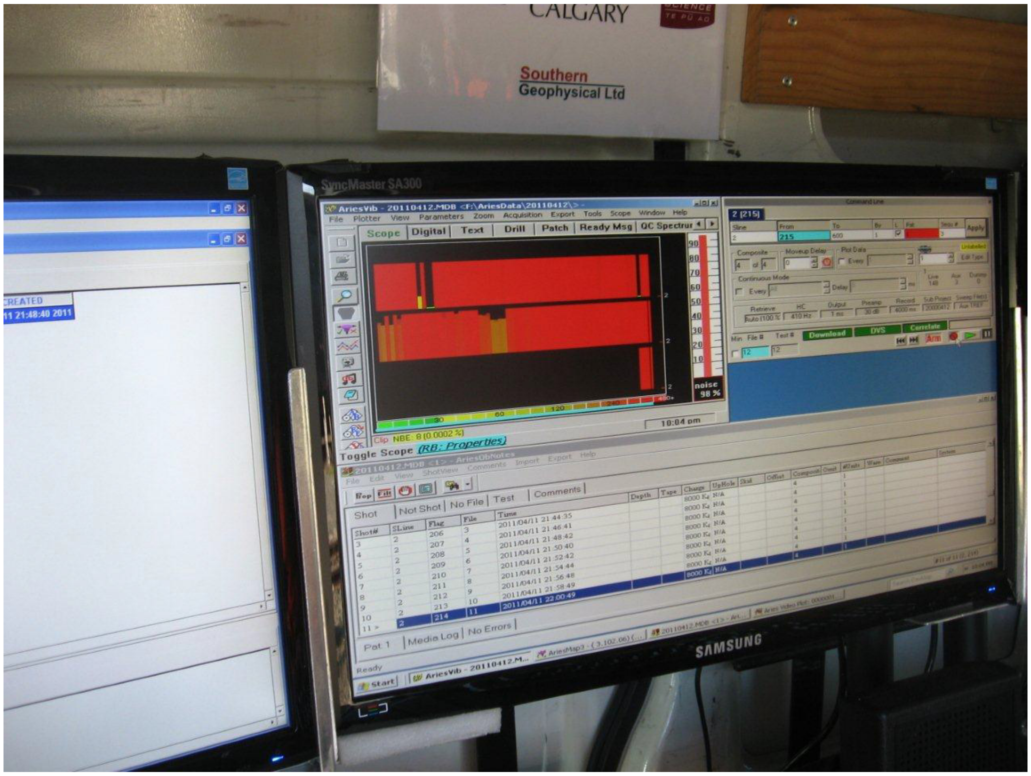


FIG. 18. Earthquake on noise monitor.

FIG. 19. Vibe point inside the red zone just past a Military checkpoint.


FIG. 20. Vital fluids. Oh,…the generator was running the recorder as well.

## HIGHFIELD ROAD (LINE 3, 3.4 KM LONG)

The Highfield Road line is the furthest west line that was acquired. It crossed the surface expression of the Greendale Fault (blue lines, Figures 22, 23 and 24), which was created during the Darfield earthquake of September 4, 2010. Maximum horizontal displacement at the surface on this fault is 4.5 meters, and the maximum vertical displacement is 1.5 meters. The hedges, road and fence in Figures 23 and 24 all used to be flat and straight.

Weather conditions were wet and rainy with wind gusts. There are fantastic views of the mountains from this line, which we only realized when the weather cleared on the last day of production.

Upon completion of this line, all equipment was picked up and transported to Southern Geophysical, where it was stored until phase two of the seismic program began in May.

FIG. 21. There are mountains here!

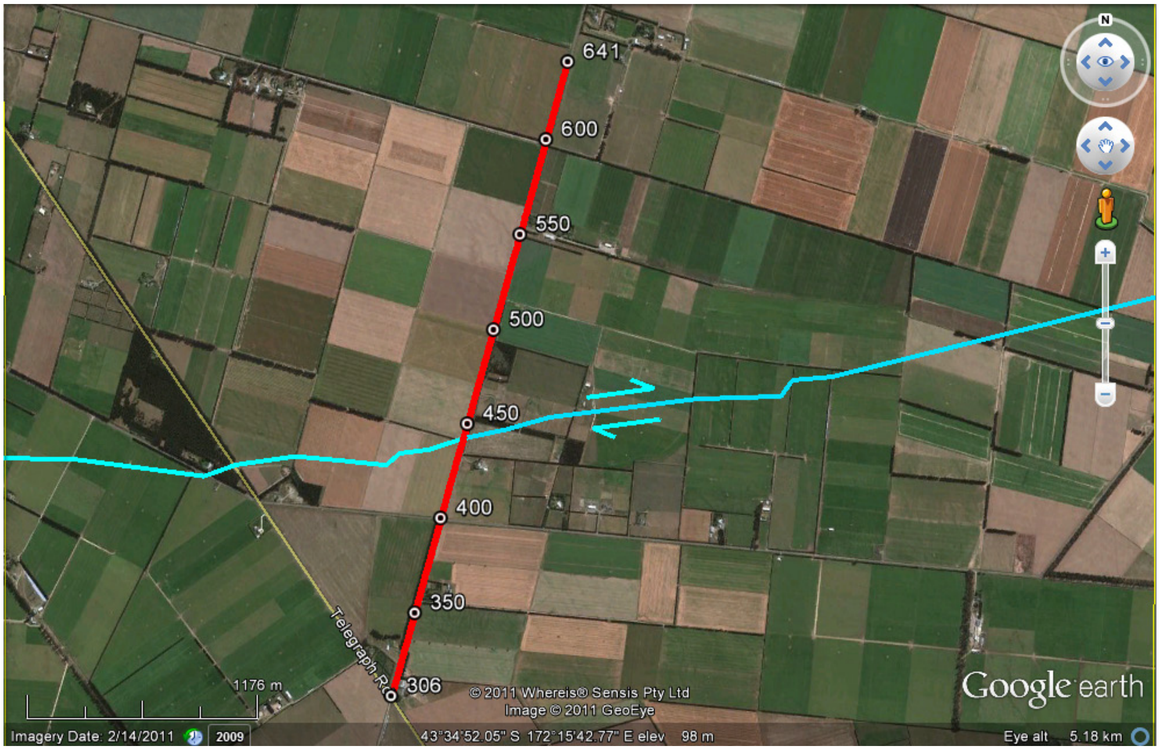


FIG. 22. Highfield road seismic line. Surface expression of Greendale fault in the vicinity of the seismic line is marked with a blue line. Image © 2011 GeoEye and © 2011 Whereis® Sensis Pty Ltd (Google Earth, 2011).

Table 4. Highfield Road line parameters.

| Highfield Road | **April 15 - 18, 2011** |
|---|---|
| **Stations** | 306 – 641 |
| **Spacing** | 10 m |
| **Number of Sweeps** | 8 |
| **Sweep Start Frequency** | 10 Hz |
| **Sweep End Frequency** | 120 Hz |
| **Sweep Type** | Linear |
| **Sweep Length** | 10,000 ms |
| **Start Taper** | 250 ms |
| **End Taper** | 100 ms |
| **Taper Type** | Cosine |

FIG. 23. Surface expression of Greendale fault, looking south. Note the formerly straight hedge and fence. Maximum offsets are 4.5 m horizontal and 1.5 m vertical.

FIG. 24. Looking north. Road used to be straight and flat.

## ROBINSONS ROAD (LINE 5, 15.5 KM) AND NEWTONS ROAD (LINE 6, 6.2 KM)

There is no line 4.

Robinsons Road is the longest line that was acquired. As a result, there were many road crossings, including highway 1 (main south highway) with 100 km/hr traffic. In all cases, the field crew was able to deal with road crossings by passing geophone cables through culverts under the roads. Weather was generally clear and calm.

A local school was passed on this line, and we did a show-and-tell for the children, who were also able to watch the vibe as it moved past their school. Geology students from the University of Canterbury came to visit this line as well (Figures 27 and 28).

It was on this line that we began using the rental Isuzu cargo truck and rental sheep trailers for layout. The Isuzu was affectionately known as ‘Gutless the wonder truck’ because of the amount of equipment that could be put on board and moved, slowly. Honestly, it was slow when it was unloaded. One of the University of Canterbury students wrote a song about it, but we don’t have the lyrics (Figures 29 and 30). General feeling amongst the Calgary crew is that we miss this truck.

It turns out that sheep trailers are very useful for field crew layout and pickup of seismic cables. Cable ends can be knotted to the wire mesh of the sides, and the cable quickly pulled into the trailer without spooling or horse-collaring (Figure 31). Lay-out was also faster using this method.

As mentioned, there was water, and culverts. Water was flowing through most of the culverts, and while most of the water flow was smooth and quiet (Figure 32), some culverts did represent a noise source on the seismic line (Figures 33-34).

The last two kilometers of receiver line on Robinsons Road was left on the ground, and recorded Newtons Road Vibe Points to create a pseudo 3D survey. Figure 34 is a photograph of the noise monitor for one of the early sweeps on this line, which shows the Vibe during a sweep (right), Recorder generator (at the intersection) and two cars, one on Robinsons Road (center, down). Two note-worthy noise sources on Newtons road were a fence-post pounder in a field, and a caisson vibrator. The mono-frequency caisson vibrator was shaking a large steel culvert vertically into the ground for use as a power-pole footing (after replacing sediments inside the caisson with concrete). The noise introduced on the line caused us to shut down production early that day, on their promise they would be finished before we started production the next morning.

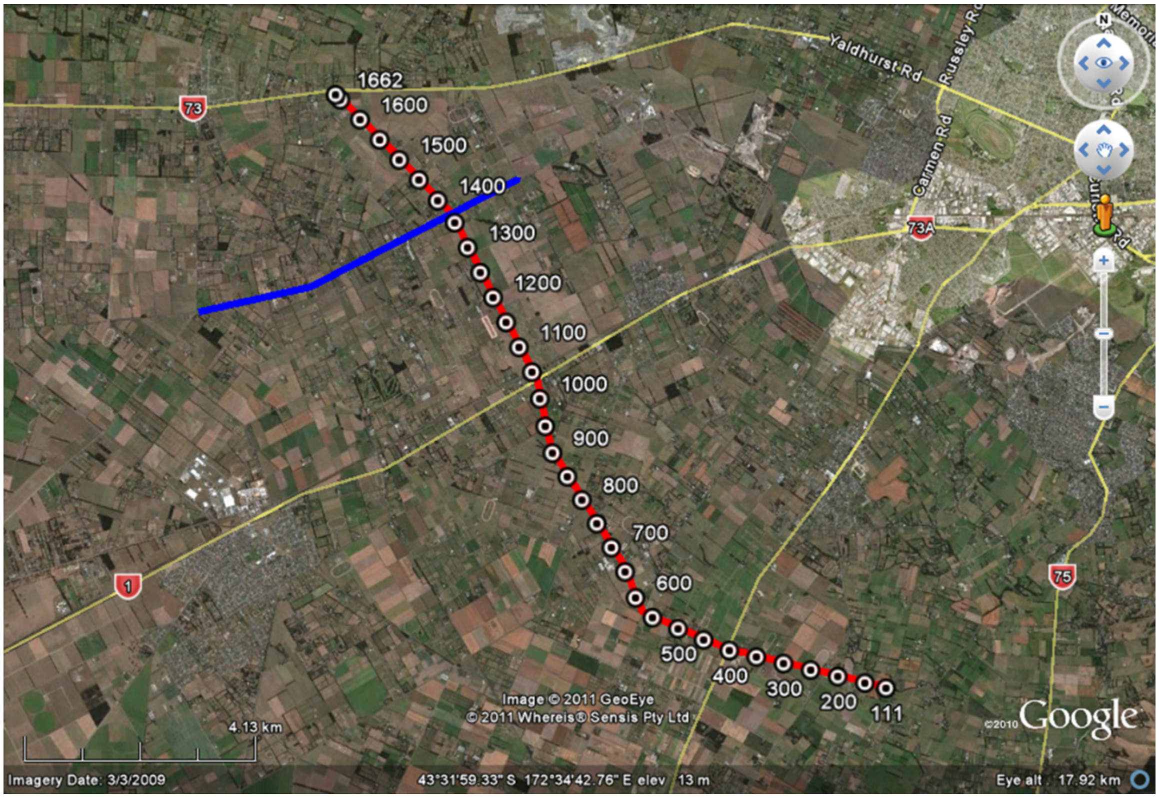


FIG. 25. Robinsons Road line. Image © 2011 GeoEye and © 2011 Whereis® Sensis Pty Ltd (Google Earth, 2011).

Table 5. Robinsons Road line parameters.

| Robinsons Road | **May 15 - 21, 2011** |
|---|---|
| **Stations** | 111 - 1662 |
| **Spacing** | 20 m for Stations 111 - 341, 473 - 1205 |
| | 10 m for Stations 343 - 471, 1207 - 1662 |
| **Number of Sweeps** | 8 |
| **Sweep Start Frequency** | 10 Hz |
| **Sweep End Frequency** | 120 Hz |
| **Sweep Type** | Linear |
| **Sweep Length** | 10,000 ms |
| **Start Taper** | 1,000 ms |
| **End Taper** | 100 ms |
| **Taper Type** | Cosine |

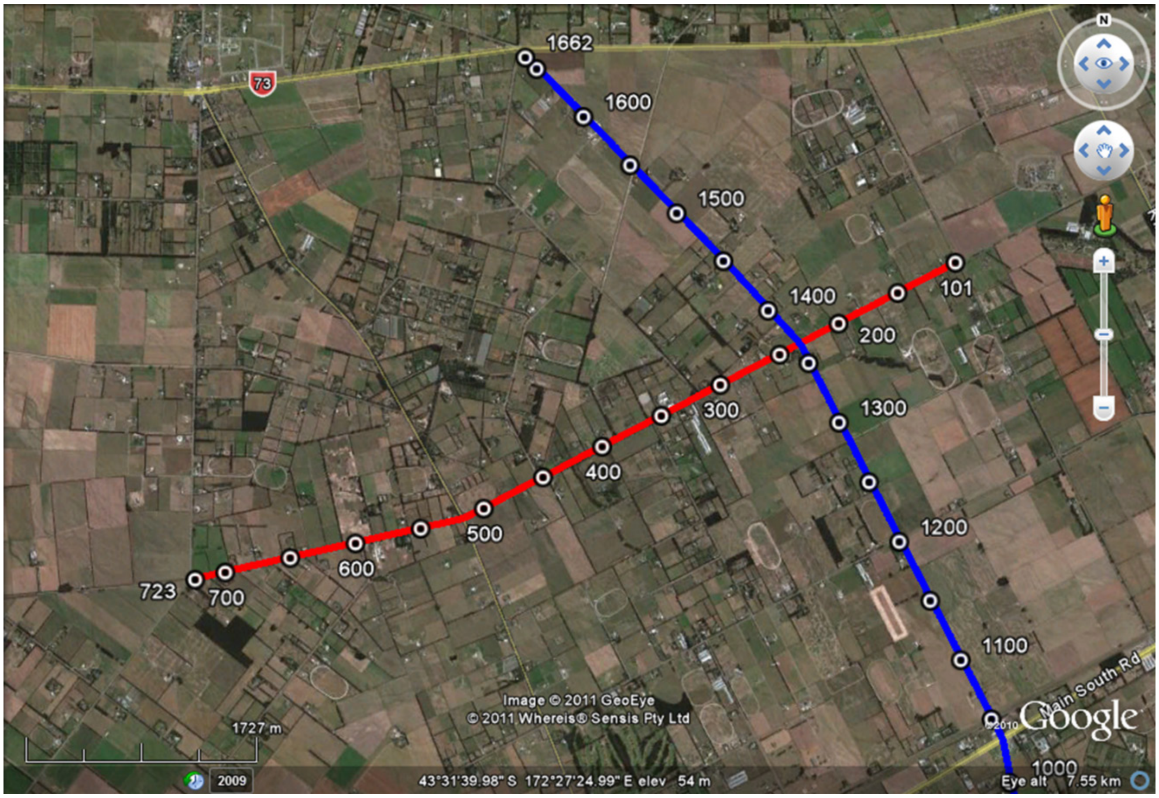


FIG. 26. Newtons Road line. Image © 2011 GeoEye and © 2011 Whereis® Sensis Pty Ltd (Google Earth, 2011).

Table 6. Newtons Road line parameters.

| Newtons Road | **May 22 - 25, 2011** |
|---|---|
| **Stations** | 101 - 723 |
| **Spacing** | 20 m for Stations 101 - 277, 317 - 723 |
| | 10 m for Stations 279 - 315 |
| **Number of Sweeps** | 8 |
| **Sweep Start Frequency** | 10 Hz |
| **Sweep End Frequency** | 120 Hz |
| **Sweep Type** | Linear |
| **Sweep Length** | 10,000 ms |
| **Start Taper** | 1,000 ms |
| **End Taper** | 100 ms |
| **Taper Type** | Cosine |

FIG. 27. Vibe observed by local school children.

FIG. 28. University of Canterbury geology field trip to see the seismic line.


FIG. 29. Gutless the wonder truck.


FIG. 30. Gutless the wonder truck.


FIG. 31. Sheep trailers with seismic gear!

FIG. 32. Cable in a culvert. Not noisy.

FIG. 33. Noisy culvert.

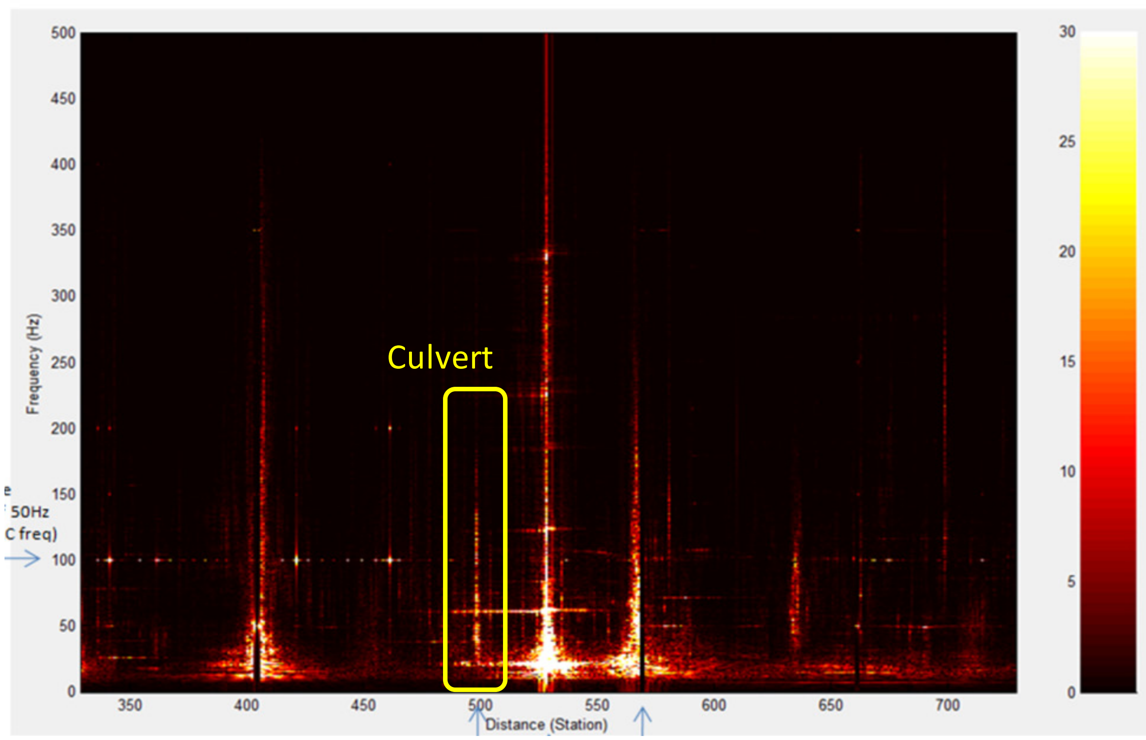


FIG. 34. Noise strip showing traffic, Powerline noise at 50 Hz (attenuated by recorder) and harmonics at 100 and 200 Hz and the noisy culvert (cf. Figure 32). Display courtesy of Henry Bland, Pinnacle a Halliburton Service.


FIG. 35. Noise monitor for pseudo-3D during a sweep. Vibe is to the right, recorder at the intersection.

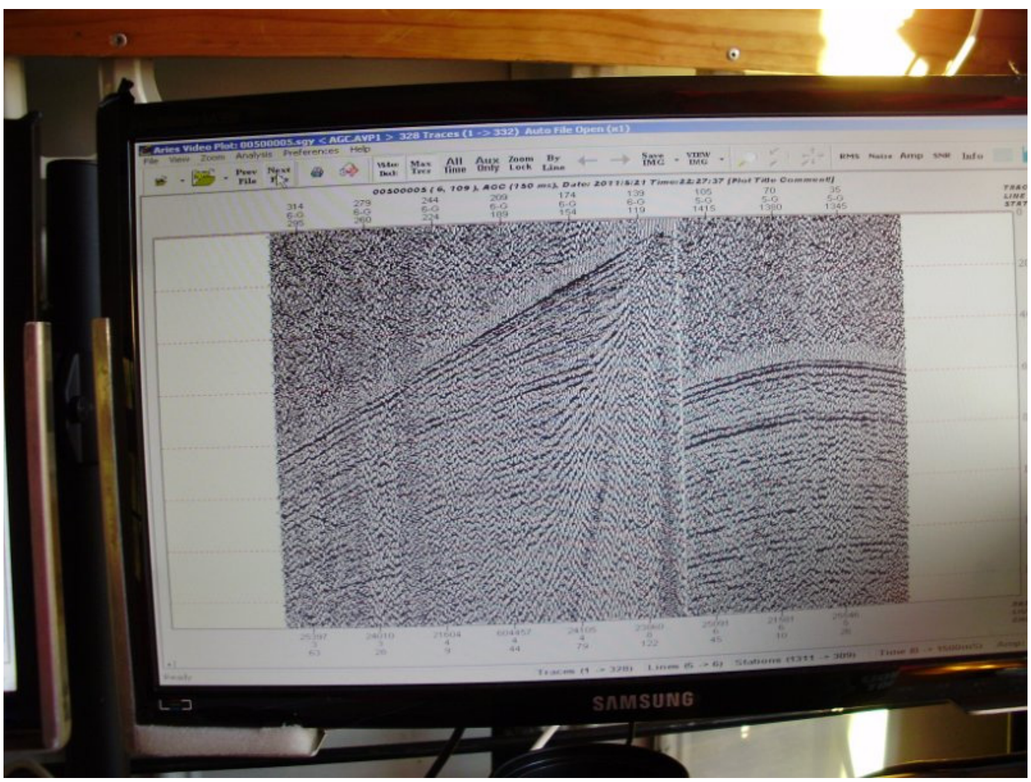


FIG. 36. Example shot record from pseudo-3D.

**WEEDONS ROAD (LINE 7, 3.9 KM)**

And then it rained again (Figure 38). The Weedons Road line, at least at the south end is notable for the large number of power lines in the area (Figures 38-41). The Aries recorder is able to attenuate 50 Hz or 60 Hz powerline noise by timing the start of subsequent sweeps at a given vibe point so the mono-frequency noise is removed by vertical stacking. The system was challenged in this area, but did a remarkable job.

The Vibe from Calgary herded New Zealand cows on this line. A herd was being moved from one field to another across Ellesmere Junction road, and the owner was worried the cows would damage the seismic cables and be scared by the Vibe. Production was halted, and the line broken at the gates to the fields. The Vibe was driven up the line and shut down just past the gate of the field that was the target. When the cows arrived, the noise made by closing the Vibe door was enough to make them turn and enter the desired field.


FIG. 37. Weedons Road line. Image © 2011 GeoEye and © 2011 Whereis® Sensis Pty Ltd (Google Earth, 2011)

Table 7. Weedons Road line parameters

| Weedons Road | **May 25 - 28, 2011** |
|---|---|
| **Stations** | 101 - 480 |
| **Spacing** | 10 m |
| **Number of Sweeps** | 8 |
| **Sweep Start Frequency** | 10 Hz |
| **Sweep End Frequency** | 120 Hz |
| **Sweep Type** | Linear |
| **Sweep Length** | 10,000 ms |
| **Start Taper** | 1,000 ms |
| **End Taper** | 100 ms |
| **Taper Type** | Cosine |

FIG. 38. Seismic line in the rain.

FIG. 39. Possible sources of 50 Hz power line noise (!!)

FIG. 40. Possible sources of 50 Hz power line noise

FIG. 41. Possible sources of 50 Hz power line noise


FIG. 42. CREWES/University of Calgary crew.

## SUMMARY

Four CREWES personnel flew to New Zealand to conduct the seismic surveys in conjunction with the University of Canterbury and Southern Geophysical. Six 1C-2D seismic lines with a total line length of 41 km were successfully acquired in the Christchurch area April 5-May 30, 2011. All gear was cleaned, packed and shipped to Canada on a container ship in time for the University of Calgary geophysics field school and the Hussar low-frequency experiment.

## ACKNOWLEDGEMENTS

Full funding for the project was provided by the Institute of Geological and Nuclear Sciences, a crown research institute in New Zealand, and the University of Canterbury. We particularly thank Dr. Jarg Pettinga (University of Canterbury), Mike Finnemore (Southern Geophysical) and students from the University of Canterbury for field and logistics support. We thank GEDCO and Sensor Geophysical in Calgary for data processing and software. We also thank Joanna Cooper from the University of Otago (formerly CREWES/University of Calgary) for assistance in field processing and QC during Phase I of the seismic acquisition program

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