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THE CANTERBURY UNIVERSITY STRONG-MOTION RECORDING PROJECT

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SUMMARY

Recent dating of past events on the Alpine Fault, together with an apparent seismic gap over much of the length of the fault suggests that an earthquake of M8 or greater is likely within the next few decades in the central South Island of New Zealand. Motivated by this likelihood, the Engineering Seismology Group at the University of Canterbury is preparing to install a dense strong-motion network of about 80 instruments in the region. The Canterbury network has three aims. Firstly, two dense arrays of 10 to 20 instruments each, with spacing of the order of 500 m, are being designed to capture details of the rupture mechanism. Secondly, 25 instruments will be distributed around the region in order to record regional attenuation, especially in the fairly uniform 80–km wide sedimentary plain between the Southern Alps and the major East Coast cities. These will supplement the 20 or so instruments of the National Network already in place on the Plains and operated by GeoNet. The third objective is to study the local response of the highly variable 20–25 m layer of post-glacial soil beneath the city of Christchurch. In order to deploy such a number of instruments at affordable cost, the group collaborated with the Electrical Engineering Department of the University to design a low-cost digital accelerograph. The CUSP (Canterbury University Seismograph Project) accelerograph is web-based for ease of monitoring and downloading of data and uses MEMs accelerometers, whose performance is enhanced by careful calibration and over-sampling. In addition to focusing on the Alpine Fault event, the network will be configured so that rupture on the North Canterbury faults, which splay off the Alpine Fault, can also be well recorded.

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INTRODUCTION

Since our knowledge of the historic activity of the Alpine Fault was refined in the late 1990s, the Engineering Seismology Group at the University of Canterbury has worked towards setting up a dense regional network of about 80 strong-motion instruments in the central South Island of New Zealand, in anticipation of a large earthquake on the Fault. The aim of this paper is to outline the project, starting with the geological investigation of the Alpine Fault whose results provided the incentive for the network, through its various elements, including the design of a dense array of accelerographs to record details the mechanism of the expected rupture and the design and proving of a low-cost, Internet-capable, digital accelerograph as the principal instrument of the network.

Before the work of Yetton [1] in dating recent earthquakes on the Alpine Fault, it had been thought that the average recurrence interval for large events on the Fault was about 500 years. Yetton found convincing evidence for a recurrence interval of about 250 years, with characteristic earthquakes of around M8, and with the last event dated precisely at 1717; that is, about 290 years ago. This result, together with clear evidence of a seismic gap several decades long in the central South Island, suggests that a great earthquake is likely on the Fault within the next few decades, providing an excellent and rare opportunity to record comprehensively strong shaking from such an event, in both the near and the far field,. The region is already served by a backbone of instruments, generally 18-bit accelerographs, in the national network operated by GeoNet. The University group sought to add about 80 instruments, the "Canterbury Network", in three sub groups, as follows:

1. A dense array near the Alpine Fault, designed to follow the progress of rupture on that or nearby faults. This would comprise about 20 instruments.
2. A group of about 20 instruments at selected sites in the city of Christchurch, to record site effects on the highly variable fluvial and estuarine soils beneath the city.
3. About 30–40 instruments spread over the Canterbury Plains and the coastal plains of the Buller and West Coast regions, to record regional attenuation of strong ground motion.

At the time of instigation of the project, the range of available instruments was limited. The traditional manufacturers were focusing on high dynamic range instruments with consequent high development and construction costs and thus high selling prices. This left the earthquake engineering community little choice in the performance they could select, with instrumentation budgets being spent on fewer, higher specification instruments. This is unfortunate, since as Trifunac and Todorovska [2] point out, typical earthquake engineering applications require high spatial resolution, not high amplitude resolution. To address the problem of cost, both initial outlay and ongoing maintenance, the Engineering Seismology Group worked with the Electrical and Electronic Engineering Department at the University of Canterbury to design a simple, low-cost, low-maintenance 13-bit accelerograph that employed the Internet comprehensively for instrument monitoring and maintenance as well as for data transfer.

In parallel with development of the instrument, work also progressed on various components of the fault-rupture array design [3]. These included:

1. The improved coding of the MUSIC algorithm [4] for use both in designing the array itself and in inverting data obtained from it.
2. The selection of potential sites.
3. Finding the optimal array configuration at the selected sites.

Aspects of the overall project are now described in further detail, starting with a description of current understanding of the Alpine Fault, followed by a sketch of the approach taken to design the dense fault-rupture array and concluding with a description of the low-cost digital accelerograph designed to serve in the Canterbury Network, including the dense array.

THE ALPINE FAULT

The 800 km-long Alpine Fault, and its northward continuation as the Wairau Fault, form the largest active fault in the South Island (NZ) extending from offshore southern Fiordland in the SW, to near Blenheim in the NE [5,6] (Figure 1). The Alpine Fault is an

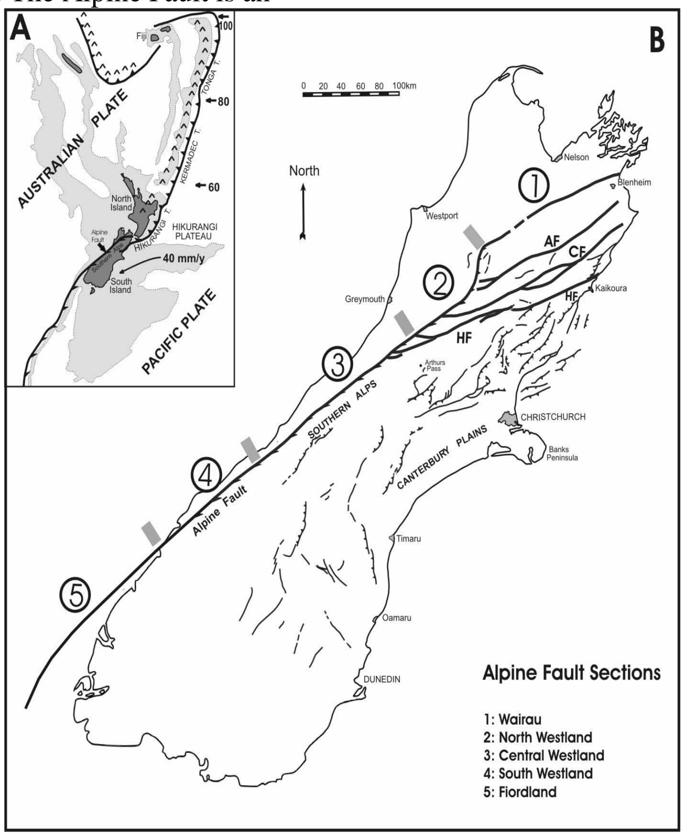

Figure 1: The South Island of New Zealand, showing the Alpine Fault

oblique dextral strike-slip fault accommodating ~60–90% of the relative plate motion across the obliquely convergent Australia-Pacific plate boundary zone in South Island [5,7]. The fault forms the western range bounding structure to the Southern Alps, which in turn are forming in response to the shortening component of plate motion oblique to fault strike. The dominant component of fault movement is that of dextral shear with average horizontal slip rates reaching a maximum in the central section of 25–35 mm/yr [7,8] and average single event displacements ranging from about 4–8 m [1]. Maximum uplift rates are recorded along the central section of the Alpine fault, coincident with the maximum elevations recorded along the crest of the Southern Alps, and are estimated at ~7–8 mm/yr [1,7].

Berryman *et al.* [5] originally divided the fault into four sections (Wairau; north Westland; central Westland; south Westland) (Figure 1). More recent studies document a further section at the southern continuation of the Alpine Fault south into offshore Fiordland [6,9]. These sections are defined primarily on the basis of geomorphology and structural style. Berryman *et al.* [5] also suggested these sections may represent fault rupture segments, but noted a lack of data in support of this inference. Bull [10] also inferred rupture segment boundaries, the first at the Taramakau River, and the second at the "big bend" of the Alpine Fault in the northern South Island.

Although the fault daylights along the west side of the Southern Alps in the central South Island, based on geological and geophysical evidence the fault dips east beneath the Southern Alps at seismogenic depths [11,12,13,14]. The importance of the Alpine Fault as a potential seismic source in seismic hazard analysis for the South Island has previously been recognized e.g. [15,16,17]. However, prior to the recently completed studies of Yetton *et al*. [18]and Yetton [1] there has only been limited paleoseismic data available with respect to the Alpine Fault [19].

There has been no historical surface rupture on the Alpine Fault, and the traditional view has been that levels of recorded crustal seismicity since 1944 are relatively low. This led to the term "seismic gap" (e.g. Adams [15]) to describe the pattern of shallow seismicity in the region of the central Westland section of the fault. Recent improvements in the seismograph network indicate more seismicity is occurring than was being recorded in the old network [20]. Seismicity extends to a depth of about 10 km, and while levels of activity are still relatively low, it is comparable to the Mojave section of the San Andreas Fault which last ruptured in 1857, and is estimated to have at least 10 large earthquakes in the last 1400 years [21]. The Alpine Fault is now widely considered to be a major "locked" seismogenic source [1,18,19,22].

Most early assessments of paleoseismicity on the Alpine Fault were based on Adams (1980). He obtained a limited number of radiocarbon (^{14}C) dates from landslides and aggradation terraces in central and south Westland spanning the last 2000 years. Based on this indirect evidence he inferred Alpine Fault earthquakes at approximately 500-year intervals over the last 2000 years, with the most recent event around 550 years ago. Adams acknowledged that this paleoseismic record was likely to be incomplete. Further work on paleoseismicity of the central Alpine Fault includes that by Bull [10] and Bull and Brandon [23]. These authors infer a quite different pattern of past earthquakes on the Alpine Fault based on lichenometric dating of rockfalls. However, the rockfall sites used are all well east of the fault, the closest being approximately 18 km away and the majority more than 25 km. Based on the lichenometry data Bull [10] infers earthquakes on the Alpine Fault at 1748 ± 10 AD, 1489 ± 10 AD and 1226 ± 10 AD respectively. A less distinct event is also proposed around 967 ± 10 AD. The implied recurrence interval is a remarkably constant 261 ± 14 years [10].

Prior to 1998 the only other significant paleoseismic investigations of the Alpine Fault includes the work of Cooper and Norris [24] in Fiordland, near Milford Sound, and Sutherland and Norris [25] near Lake McKerrow in South Westland. Cooper and Norris [24] ^{14}C dated material excavated from sag ponds near the fault scarp and estimated the age of trees that appeared to have lost their crowns as a result of earthquake shaking. They concluded that the last large earthquake in the area due to movement of the Alpine Fault occurred in the period between 1650 AD and 1725 AD. Sutherland and Norris [25] used displaced river channels to estimate the ground displacements of the last two earthquake ruptures on the Alpine Fault, and provided an estimate of the timing for the last rupture at 370 ± 150 cal. yr B.P.

Since 1998 a number of studies have addressed Alpine Fault paleoseismicity, extending over the region from central to south Westland [1,18,26,17,28]. These studies now form the basis of the best paleoseismic information available to date, with data obtained from the direct trenching of the fault, landslide and terrace chronologies, forest disturbance events, and disturbance to individual trees as reflected in anomalies of the tree ring growth patterns.

Data from the central Westland section of the Alpine Fault, north from Franz Josef area, indicates at least five ground rupture events over the last 1400 [18,28]. Dates for three of the last four strong ground shaking events are consistent, and include ~1210 AD; 1425 ± 15 AD, and 1717AD. However, based on tree ring patterns at the Waitaha River site, Wright [27] and Wright *et al.* [28] prefer a date for the penultimate earthquake of 1580 ± 5 yr, as opposed to the Yetton *et al.* [18] and Yetton [1] estimate of 1620 ± 10 years.

Studies of the southern onshore section of the fault, south from Haast, have yielded evidence for three ground rupturing events over the last 1000 years [24,25,26]. Berryman *et al.* [26] carried out trenching at Haast and Okuru Rivers in south Westland. They recognized three ruptures of the fault in this area in the last 1000 years, each with around 8 m of strike-slip offset. Constraints on event timing are limited but they conclude their paleoseismic evidence is consistent with a date for the most recent event of 1717 AD.

The tree ring data from 1717 AD implies simultaneous rupture along at least 375 km of fault strike [29]. This provides a minimum estimate of earthquake magnitude based on the magnitude to rupture length regression estimates of Anderson [30] and Wells and Coppersmith [31] These methods suggest a range of magnitude from M = 7.9–8.2.

To date paleoseismic information for the northern section of the Alpine fault, extending from the Ahaura River north to Nelson Lakes, is more limited, but is consistent with a most recent earthquake event at around 1620 AD [32]. Estimates for strike slip rates range from 6 ± 2.5 mm/yr [18,32] to 10 ± 2 mm/yr [5], and it is evident that slip is progressively partitioned off to the north, onto the various strands of the Marlborough Fault System.

The last earthquake crossed the Alpine Fault "segment" boundaries proposed by Bull [10] and the "section" boundaries of Berryman *et al*. [5]. These boundaries had been tentatively proposed on geomorphic and structural grounds. While the division into geographic sections [5] may still be useful for location description it appears there may not be persistent segmentation in the rupture sense.

Recurrence intervals for inferred Alpine Fault events over the last 1500 years appear to vary considerably, from 100 years to more than 380 years, with an average around 250 years and a standard deviation of ~96 years. This amount of variation is not unusual for other large plate boundary faults in similar geologic settings. For example Sieh *et al*. [21] in their work at Pallet Creek on the Mojave segment of the San Andreas fault, demonstrate a range in recurrence interval of 45–332 years about an average of ~160 years and a standard deviation of 102 years.

In summary, research to date clearly indicates that the Alpine fault is capable of generating large to great earthquakes at upper crustal depths along the western and central South Island. Furthermore, given the estimated Magnitude range for such an Alpine fault event, it constitutes a major ground shaking hazard for much of the South Island. Based on the available new paleoseismic data the calculated probability of a large magnitude rupture on the Alpine fault over the next 50 years ranges from 22%–65% (±15), depending on the probability model that is preferred for the analysis [1,18,33]. In view of the substantial lapsed time since the last event (280 years); the observed single event offsets in previous events (4–8m); and the high long-term slip rates (25–35mm/yr), the authors consider that the higher range of these estimates is the most realistic.

In northern South Island the Marlborough Fault Zone (MFZ) (refer Figure 1) includes a series of more NE trending dextral strike-slip to oblique strike slip faults (Hope, Clarence, and Awatere) which link to the northern section of the Alpine Fault, and progressively reduce the long-term slip rates recorded here, from ~10 mm/yr in the south, immediately north of the Alpine-Hope fault junction, to ~ 4.5 ±1 mm/yr along the Wairau section of the Alpine Fault in the northernmost South Island [32]. Commensurate with this reduced long-term slip rate, paleoseismic data suggest more variable and longer return periods for large coseismic rupture events in this most northeastern area [32,34].

DESIGN OF THE DENSE FAULT RUPTURE ARRAY

Dense array analysis allows direct imaging of the mechanism of fault rupture. Through processing dense array recordings, frequency-wavenumber spectra are computed for successive moving time windows, which are then projected back onto the fault plane, thus giving a moving image of the continuum of sequence of sources comprising the fault rupture. By having a direct image of the rupture process, one can estimate basic source parameters such as rupture velocity, direction of rupture, rise-time, and the position and extent of asperities. Given that dense array analysis does not make any assumption about the rupture mechanism, it is a powerful tool to understand the physics of the source.

The signal processing method chosen to perform the dense array analysis is the MUSIC (Multiple Signal Characterization) approach of Goldstein and Archuletta, (In the MUSIC method, a frequency-slowness computation is applied to a set of seismograms recorded at the dense array. It uses the covariance matrix of the signals to extract ray parameters and their relative intensities. The slowness spectra are then projected back onto the fault plane following Snell's law.

The search for an optimal array involves two elements: the array location and the array configuration. The optimal array location is governed by instrumental and environmental constraints (power supply, accessibility, communication, geology, and its isolation) as well as by seismological ones. Finding the optimal array configuration is a geometric problem. The principles are detailed in the following paragraphs.

Optimal array configuration

The process of a fault rupture may be considered as the evolution in time and space of a sequence of point sources rupturing on the fault plane. Therefore, to find the optimal array configuration for a fault rupture process we seek an array that best receives any source coming from the fault. The problem thus becomes one of geometry.

The methodology employed in this study is based on a Monte Carlo search for the optimal array configuration using a grid of synthetic point sources. The fault plane is divided into a grid of points. Each point represents an impulsive seismic source. Various array configurations are tested varying the number of instruments, their spacing and geometry. The optimal array is the one that best processes and projects back the sources onto the fault plane. By analogy, if the seismic sources were light points, the optimal array configuration would be the one that gave the best "illumination" of the fault plane.

A simple way to assess the efficiency of a proposed array is to compute the distance on the fault plane between a known input point source and its array-processed and fault-projected image. This distance is computed for every point source of the grid, therefore giving a fault efficiency spectrum for the proposed array. The fault efficiency spectrum is like a visual image of the fault plane whose quality depends on the ability of the array to capture the upcoming waves from the fault.

Simple tests have been carried out in order to assess the relative importance of the geometry and instrument spacings on the array efficiency. Although many configurations are possible, we compare the efficiency of a circular and an L-shaped array for a simple vertical fault in homogeneous medium (Figure 2). The circular array has been chosen for its complete angular coverage. Nevertheless in a mountainous region such as Canterbury/West Coast, valleys might be the easiest place to set up instruments and therefore an L-shape array may be the most practical configuration.

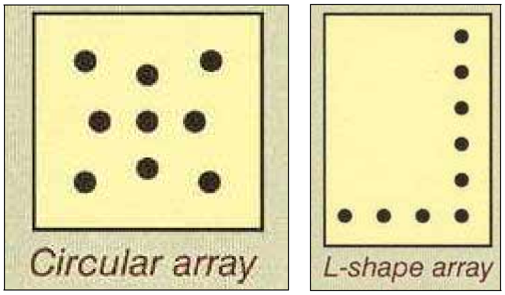

Figure 2: Geometry of the arrays proposed for testing

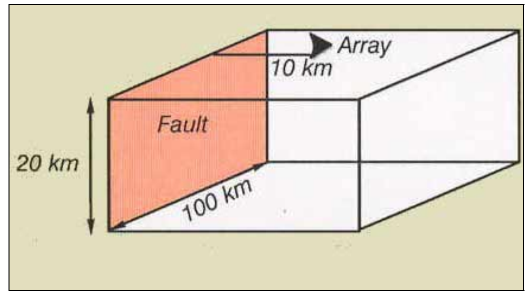

Figure 3: Array-fault configuration

Each of the trial arrays is comprised of 9 instruments at the same location but with various instrument spacings and configurations. The networks are 10 km away from a 100 km long vertical fault (Figure 3). They are first tested with an instrument spacing of one kilometre then again with a spacing of 200 m. Figure 4 shows the results for the proposed arrays. Although the circular configuration has a better efficiency with instruments spaced at one kilometre, the results show that L-shape and circular arrays have a similar efficiency with 200 m spacing.

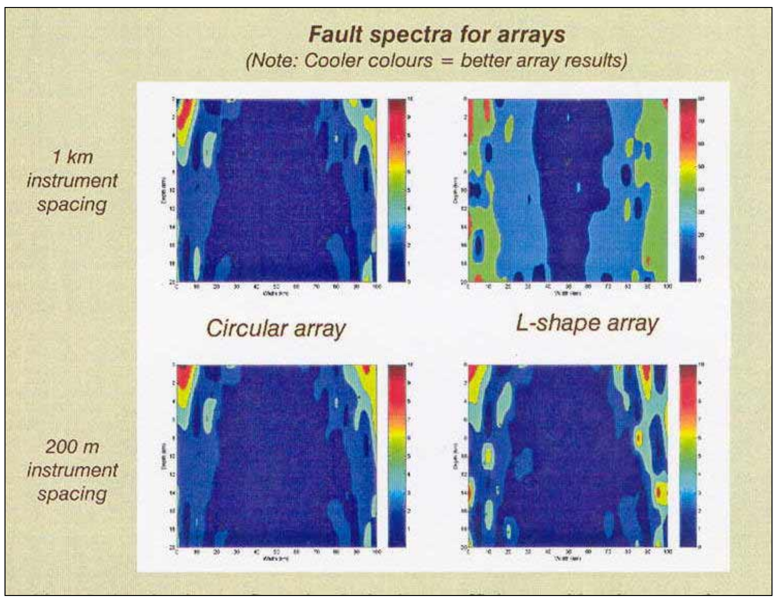

Figure 4: Efficiency spectra for various configurations and instrument spacings

Site selection

Setting up an array of many closely spaced seismic recording instruments in a remote region involves regional constraints associated with, the size, location and orientation of the fault plane and the local geology as well as constraints associated with the instruments.

Regional constraints

1. *The array should be located on the eastern side of the fault plane.* The Alpine Fault is dipping to the East at an angle of approximately 45 degrees. By locating the array on the eastern-dipping side of the fault, seismic waves will be recorded earlier by the instruments than if they were coming from a fault plane dipping away from the array. By doing so, the signals are recorded with less attenuation and complexity. The source signal is also better resolved when ray-traced back onto the fault plane. This is a major constraint given that the relief of the eastern area is mostly composed of high mountains whereas the topography is much flatter on the western side of the fault.

2. *The optimal distance from the fault sources to the array is between 40 and 70 km.* The proposed range of distances combines two opposing requirements: to be far enough from the fault plane to capture as many sources as possible as well as to be close enough to the sources to get good resolution of the signals.

3. Ideally *two arrays would be necessary to monitor the entire surface of the fault* that could potentially rupture. Given that studies have shown that the northern segment running from Hokitika to Spring Junction is the most likely to rupture, the research will focus on one array located in the northern part of the region of interest.

4. The Hope Fault belongs to the North Canterbury fault system and splays off the Alpine Fault about half way through the northern segment. (Figure 5) Recent studies have shown a rupture is likely within a short period of time. *An array aimed at the northern segment of the Alpine Fault will have the advantage of being able to monitor the Hope fault as well as the Alpine Fault.*

Finally, to avoid amplification of the recordings caused by site effects *the instruments must be installed on bedrock*.

Figure 5 shows the regional area that comprises potential sites for an optimal array location. The area shaded in grey represents the eastern side of the Alpine Fault plane, east of the Hope Fault, and within the required distance range of 40 to 70 km away from the fault trace.

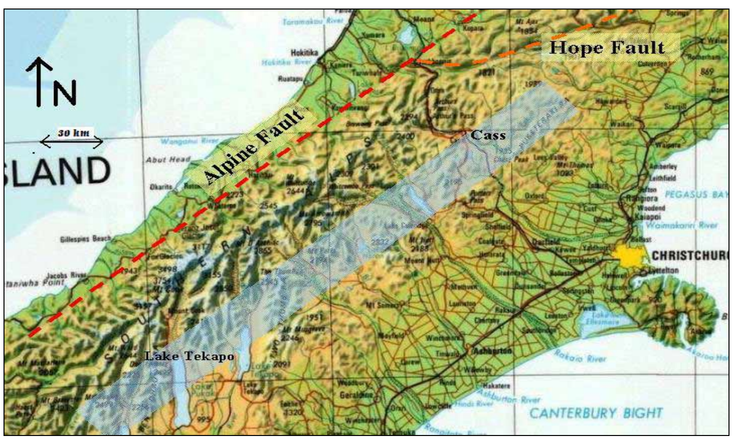

Figure 5: The Canterbury–West Coast region

Instrumental constraints

It is important to set up the array far enough from populated areas to keep the *instruments away from cultural and environmental noises* as well as to protect the costly equipment from unwanted visitors. Nonetheless, installing and maintaining the instruments requires numerous trips to the sites. The ideal site will be a compromise between having easy access and being in a secure and quiet location.

Power and communication are a constraint for the installation and maintenance of the array. They would be minimised by *setting up the array in an "Open" Area of 2x2 km^2*. The available surface will determine the geometry and aperture of the array.

Solar panels are the only way to provide long-term power in remote areas. They require at least 4 hours a day of sunlight to be efficient. Thus *the proposed sites have to be located in an area that gets sunlight every day of the year for 4 hours or more.*

Finally, communication to and from the instruments is an important aspect of the array location. It is unlikely to have a nearby phone landline. There is then the solution of cell phone communication. But cell phone coverage is usually very poor in our region of interest. As a last resort radio linked instruments is an option but that is rather costly and would most probably require a relay-station.

Proposed site

So far, one site, Pylon Gully, shows most of the required qualities listed above. Pylon Gully is a narrow 2-kilometre-long rocky valley separating Mount Horrible and Mount Misery and is located west of Cass village as shown in Figure 6. It is a straight feature that would allow only for a T-shape array, with the second branch of the T being along the side of the surrounding mountains mentioned above.

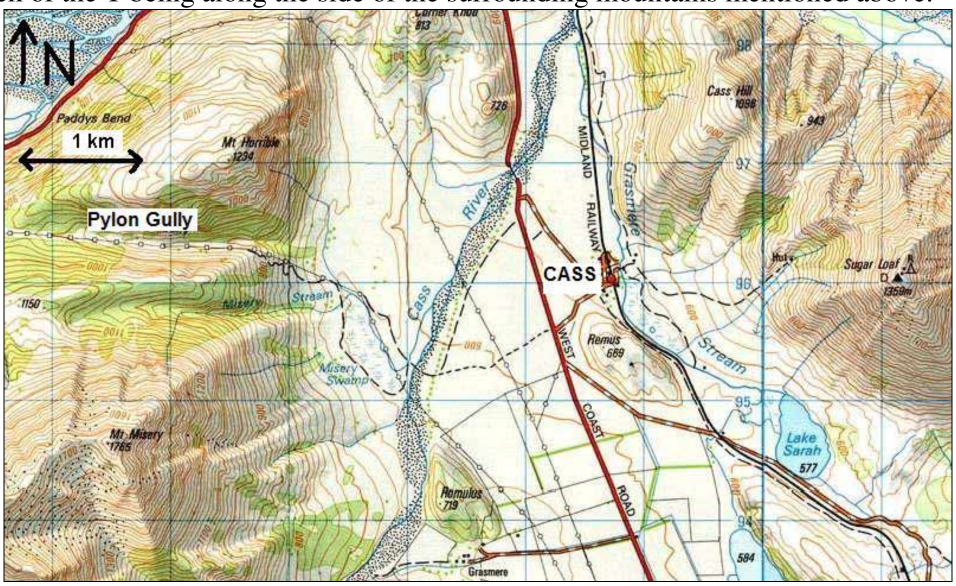

Figure 6: Location of Pylon Gully relative to Cass Village

Pylon Gully presents many advantages. It is a solid rock site with a relatively easy access. It is also quiet and isolated but with possible vehicle access (the gully has a 4WD track used by the electrical power company). The southern side of the gully is the sunny side as it is facing north and open enough to not get sun all year round. Not only is the gully very close to the Cass Station owned by the University of Canterbury, but also it is aligned with the University chalet. This is an ideal location for a potential radio network with a main receiver being located at the chalet.

Optimal array design depends on the efficiency from the point of view of seismic computation and on field conditions. There is no perfect site location; Pylon Gully is a compromise between security, easy access, power supply and good rock site on one hand, and high communication cost on the other hand. Although the chosen site will constrain the array geometry, computations have shown that the optimal design can still be achieved by varying the instrument spacing.

DESIGN AND REALISATION OF THE CUSP ACCELEROGRAPH

Figure 7. Cusp strong motion accelerograph

In designing the accelerograph, shown in Figure 1, there were three main design objectives: The first was to keep the initial cost of the instrument low, the second, to minimise maintenance costs, and the third was to protect against component obsolescence. Of the first two, the latter is more important in the overall cost of running of a network. Experience in operating a small network of 9 film-recording strong-motion instruments in the South Island since the late 1970s showed that the main cost in operating a network was in the routine maintenance of the instruments, with most of that cost being in travel to the dispersed sites. Thus, in designing the CUSP instrument much effort was given to minimising the need for site visits by remote monitoring of instrument status and remote down loading of records via the Internet. The construction cost was kept down by the use of micro machined (i.e. MEMs device) accelerometers, originally developed for the automotive industry to trigger car air bags, but subsequently made available with characteristics more suitable for seismology. Much of the design effort went into extracting better performance from these mass-produced devices by extensive calibration and data processing. Because strong-motion accelerographs have a long working life, a further design objective was to minimise vulnerability to obsolescence.

The system

It was sought to achieve these aims by using as many standard components and standard communications routines as possible to reduce both the cost of hardware and development expense. Thus, the core of the CUSP system is a commercial single board computer (SBC) running a real-time derivative of the reliable and efficient Linux operating system. Completing the CUSP system is a seismic acceleration transducer circuit, a GPS receiver and a power supply.

Single-board computer with Linux operating system

The use of a standard single board computer with Linux as the basis of the instrument has wide effects on the ease of design, construction, and operation as well as facilitating up-grades and maintenance and in reducing exposure to component obsolescence.

The seismic acceleration transducer circuit

The seismic acceleration transducer circuit contains an orthogonal set of micro-machined accelerometers. Additional signal conditioning circuitry is required to both filter and convert the signal to a digital representation. A small microprocessor performs the coordination of this procedure and transmits the resulting data to the SBC. The micro-machined accelerometers present several undesirable characteristics that must be mitigated, and the correction is performed both in the dedicated circuit and in the SBC. This method has been chosen to reduce as much as possible the cost of the sensor system circuitry. The most serious of the adverse characteristics is the drift of the quiescent zero point with temperature. The remaining problematic characteristics are the temperature dependence of the gain and the misalignment of the sensor axis relative to the instrument axes, due to both internal error and construction tolerances. These characteristics are all determined by a complex calibration process which effectively maps the characteristics of each sensor with temperature and removes the errors in software. The misalignment is corrected by applying a real-time correction matrix to the measured triaxial data. The resulting misalignment error rivals or betters that of the best available instruments.

The conversion circuitry results in a 16 bit digital representation sampled at 800Hz. This high sampling rate allows the adoption of extremely phase-linear analogue filters in the 0-100Hz band. Then a 4, 8 or 16x digital FIR decimation is performed by the SBC, reducing the sample rate to the required recording bandwidth.

The acceleration transducer circuit is designed to be replaceable, allowing advances in the transducer technology to be capitalised on with minimal component upgrade costs. The remainder of the system is capable of recording up to 32 bits of signal resolution.

GPS receiver

The GPS receiver is required to provide accurate time stamping of the recorded data. Additionally position is also measured and utilised for record identification by assigning a unique time and position for every record. Accurate timing is considered vital to a serious strong motion instrument and is thus a standard feature. The potential use of the instrument in buildings has resulted in a system whereby the GPS sensor can be remotely mounted and can communicate with the CUSP instrument via pre-existing Ethernet wiring in the building.

Power supply

In most installations, the instrument would be powered by an external 12-volt lead-acid battery with a float charger. Significant design effort has been put into the CUSP power supply to provide battery protection. The system monitors the supply voltage and can be shut down automatically when a predetermined low voltage condition is detected, preventing over-discharge of the battery. The system can also be configured to automatically switch on when the supply voltage rises above a preset safe threshold to ensure continued operation. Over-voltage and under-voltage protection is provided in order to provide protection from fault conditions. Further to these features, the system temperature is also measured and, together with battery voltage, is available for remote monitoring to aid diagnostics. Several LED indicators are provided to indicate the system status (power on, operational, event in progress and GPS lock).

Operation

The system can be connected to the Internet either via an Ethernet network or by a modem (cellular or telephone). Direct connection to a laptop computer is also possible and is used for the initial configuration of the instrument. Once the system has booted and normal operation has commenced (indicated by status indicators) the system can be interrogated via a standard personal computer over standard dial-up or direct Ethernet connection. A standard web browser serves as the main interface, secured by operating under the SSL 128bit encryption system. Two user interfaces are provided: either an administrator logon or a general user logon. No unauthorised access is permitted.

The administrator has access to the following menu of operations, as shown in Figure 2:

- View, download and delete records
- View and delete diagnostics information
- View access logs to the website
- Configure instrument automated outputs
- Configure instrument operational parameters – sample rate, trigger types, trigger levels, trigger filters etc.
- Configure instrument communications parameters
- View instrument status – battery levels and system temperatures (minimum and maximum included), GPS position and lock status, serial numbers, software versions, recording status and disk space remaining, reset triggers and position information etc.
- View a real-time stream of the current data

The general user access provides a basic interface to view day-to-day useful information and to download data but does not allow any ‘unsafe’ operations to take place.

Further access capability, mainly limited to system administrators or the system developers, allows connection to the Linux operating system via an SSH connection, which is a secure form of the popular Telnet interface. This allows the remote upgrading of software. The RSYNC function is provided, to give an advanced data retrieval interface, but it is anticipated that scripts interfacing with the web server will provide simpler functionality.

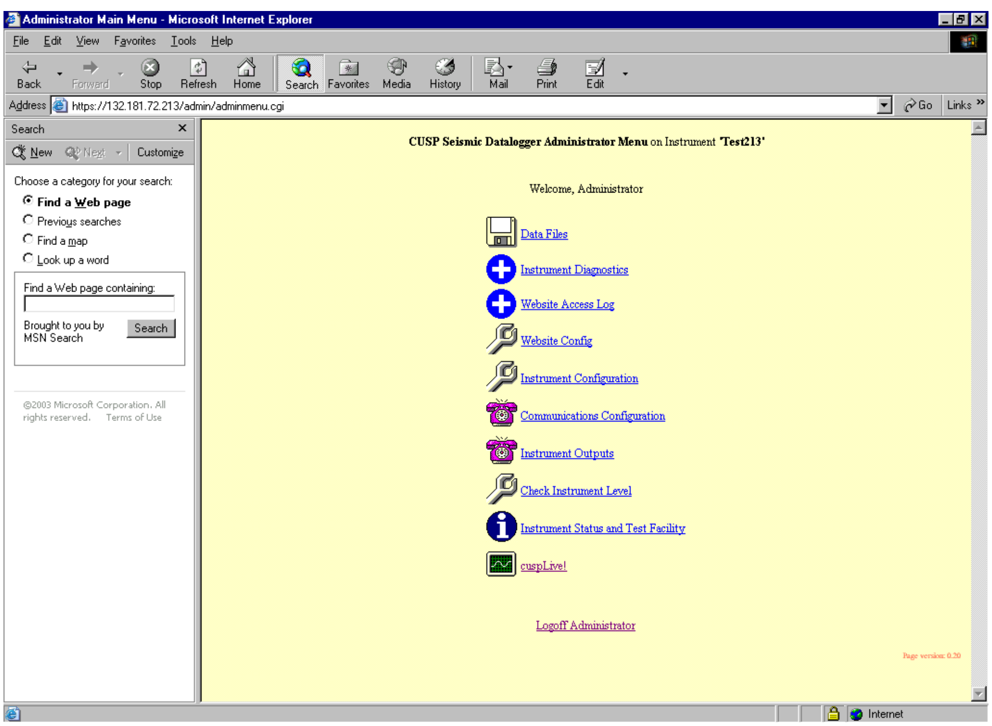

Figure 8. Main menu, viewed by standard web browser.

Testing
The project was fortunate to have the University shaking table to use for instrument development and for final proving. Early shaking-table tests showed up a software error in internal timing and suggested other functional improvements. Long-term testing of the overall system was carried out by leaving an instrument on the shaking table for four months, while the table was used for about 30 routine shaking tests on structural models. In all cases, the instrument system and communications functioned correctly. Finally, beta prototypes were tested in the field at Ilam and at Wellington and again on the shaking table beside the table reference accelerometer and a well-established 18-bit commercial accelerograph. Fourier amplitude spectra from the CUSP instrument and the established machine were indistinguishable except over a small band about 40 Hz. This discrepancy caused considerable concern, since it was believed that the CUSP transducers behaved linearly until well above that frequency. It was a relief to learn later that it is known that the other instrument does not record correctly in that range.

The first real earthquake was recorded at Ilam in late September 2003 from a M4.9 earthquake at an epicentral distance of 40 km, in Pegasus Bay. The low peak acceleration, of 0.015g, provided a strong test of the triggering system, which was set to 0.006g. The record, whose N-S component is shown in Figure 3, barely rises above the noise level, which has an r.m.s value of 0.001g.

In summary, the cusp instrument fulfils the requirements of a cheap, basic strong motion accelerograph and includes much additional functionality at minimal increase in instrument costs. The use of off-the-shelf technology combined with a proven operating system results in a high performance, high reliability, low cost and obsolescence resistant platform ideally suited for long term strong motion monitoring networks.

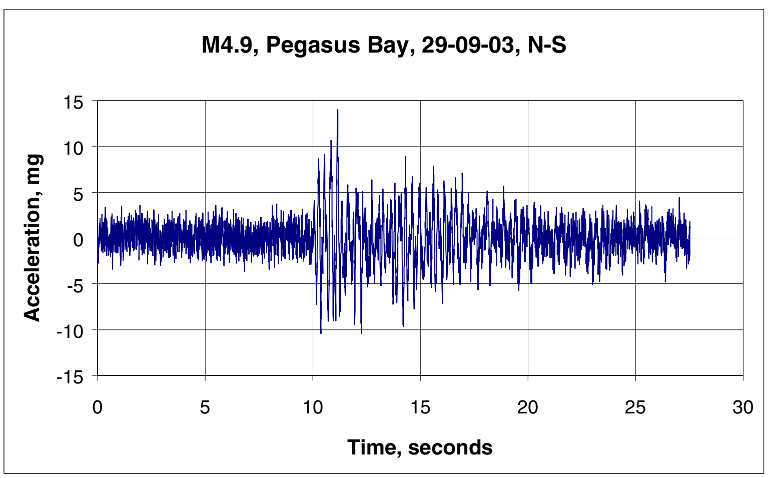

Figure 9 The first field record obtained by CUSP, recorded on the ground floor of the School of Engineering, University of Canterbury.

CONCLUSIONS

Rupture of the Alpine Fault is likely in the next few decades and a network of about 80 instruments is being installed in the region to record site effects in the Recent soils beneath Christchurch, to observe regional attenuation and to record details of the rupture process. To design the dense rupture-mechanism array, and to process data obtained from it, the MUSIC method has been refined and re-coded. To have more instruments on the ground at an affordable cost, a simple, digital accelerograph that makes easy and extensive use of the Internet for monitoring and data transfer, has been developed and tested

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