



Theoretical design and field deployment of a dense strong motion instrument network for the Alpine Fault, South Island, New Zealand

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ABSTRACT: A dense network of strong motion seismometers is being developed for the central South Island of New Zealand in order to investigate the complexities of the upper crustal rupture process and propagation of major seismogenic sources such as the Alpine Fault and strands of the Marlborough Fault System defining the South Island sector of the Australia-Pacific plate boundary zone.

The proposed network is designed as a dense array of approximately 20 accelerographs using the University of Canterbury 12-bit CUSP instrument, whose development is now nearing completion. It will be deployed immediately to the East of the East-dipping Alpine Fault in the central West Coast region of the South Island, and coverage will extend across the region at the Alpine-Hope Fault junction also.

The array layout is being designed utilizing the frequency-analysis MUSIC method (Multiple Signal Characterization) developed by Goldstein and Archuleta (1991a&b). Synthetic strong-motion records were computed using an empirical Green's function synthetic seismogram program EMPSYN (Hutchings, 1987). The process of finding an optimal configuration is dependent on the geometry of the array (study of the frequency analysis performance of the modelled earthquake data for various proposed array configurations), and on the instrument site conditions (geology, communications, accessibility, isolation etc).

1 INTRODUCTION

1.1 Dense arrays

Common methods of studying fault rupture processes involve the inversion of seismic waveforms to fit a proposed fault rupture model. These methods use various computations such as the genetic algorithm applied to strong motion and GPS observations (Zeng et al., 2001), waveform inversion of broadband teleseismic data (Olivieri et al., 1999), waveform inversion of multiple time window strong motion data (Sekiguchi et al., 2002), or broadband P wave inversion (Zobin et al., 2001). All these inversion processes make assumptions about the fault rupture model and therefore depend on our current knowledge and assumptions of the fault rupture mechanism.

Using a dense array allows us to study the rupture directly without assuming any model. With a dense array, a frequency-wavenumber spectrum analysis can be computed and then the spectra projected back onto their source on the fault plane thus giving an image of the source. By getting 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. Because dense array analysis does not make any assumption about the rupture mechanism, it is a powerful tool to understand the physics of the source.

1.2 The Alpine Fault

The Alpine Fault is the major geological feature in New Zealand. It is a dextral transform fault separating the Pacific plate on the east from the Australian plate on the west, crossing the South Island from Northeast to Southwest (Figure 1). It has an average slip rate of 40 mm per year and is the longest fault in New Zealand with a length on land of 650 km.



Figure 1. Canterbury-West Coast Region

The Alpine fault has been a source of strong earthquakes in the past. A recent field study led by Mark Yetton (2000) shows that the last rupture event occurred in 1717 AD, had a minimum estimated rupture length of 375 km and extended as far North as Haupiri River. It is assigned an estimated moment magnitude of at least 8.05(+/-0.15). An earlier event (dated between 1480 and 1645) is noticeable throughout a region from the Hokitika River to the Ahaura River and seems to be the most recent event North of Haupiri River. The rupture length was at least 200 km and the moment magnitude estimated to have been greater than 7.8(+/-0.1).

The Alpine Fault is a potential source of major earthquakes in the near future. The return period of the fault is around 270 years and no major event has been felt over the last 285 years. Yetton applied various probabilistic methods to assess the time of the next major event on the Alpine Fault. These all converged to give the likelihood of at least 50% of having a strong earthquake in the next 50 years. Using the slip rate and the elapsed time since the last event, Yetton estimates a moment magnitude between 7.5 and 8.4. Using the method of Coppersmith et al (Coppersmith et al., 1994) relating moment magnitudes to the rupture length of the fault Yetton estimates the two previous events to be of magnitude 8.05 and 8.0. This allows us to assign the expected next event a moment magnitude of at least 8.

Having such a high level of probability of a major fault rupture in the region provides a great opportunity to study directly the process of fault rupture.

2 ARRAY LOCATION

The ideal array location search has to take into account geographical, instrumental and environmental constraints in the region of Canterbury/West Coast (Figure 1) such as: a roughly level ground area of 4 km², power supply, accessibility, communication, geology, and isolation from cultural and environmental noise.

Of the three sites investigated so far, the most promising site is the Cass Basin near Arthur’s Pass (Figures 2(a) and 2(b)). Cass has good communication and power access. It is located on the dipping side of the Alpine Fault as well as being close to the Hope Fault, which is another potential source of strong earthquakes.

The major drawbacks of the Cass location are potential site effects due to the sedimentary basin, and noise due to its proximity to a major road axis and railway, especially to record small events when modelling strong motion.



Figure 2(a) Region around the Alpine Fault near Arthur’s Pass

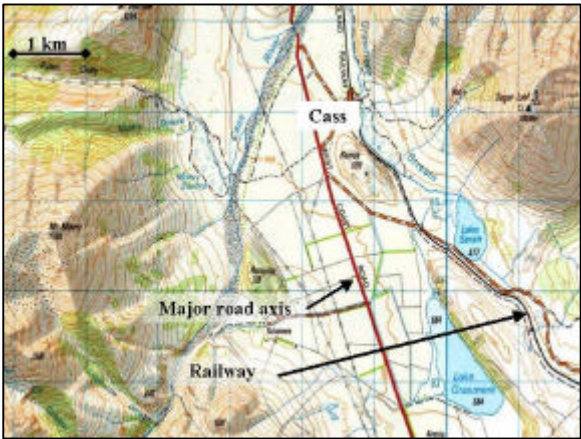


Figure 2(b) Cass Basin

3 ARRAY CONFIGURATION

The process of a fault rupture may be considered as the evolution in time and position 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.

3.1 Methodology and array efficiency spectrum

The methodology employed in this study is based on a Montecarlo search for the optimal array configuration using a fault grid of point sources (Figure 3).

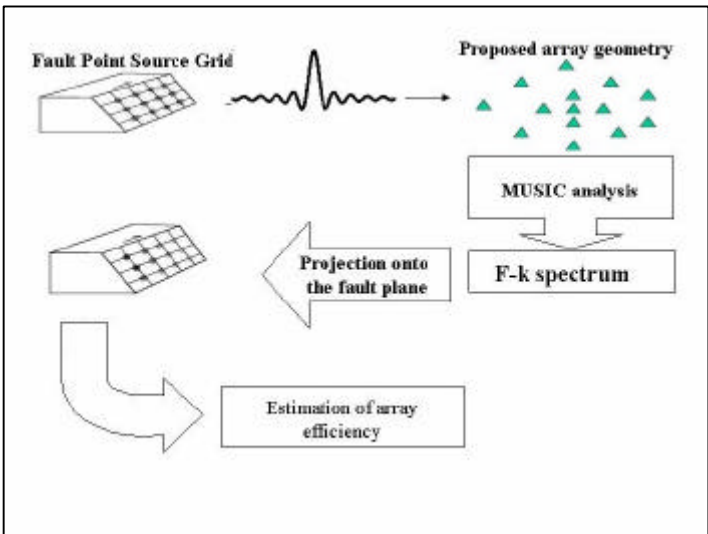


Figure 3. Proposed optimal array configuration search methodology

The fault plane is divided into a grid of points. Each point represents an impulsive seismic source with known intensity. Various array configurations are tested depending on the number of instruments, 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.

The point source seismograms are synthesized using EMPSYN (Hutchings, 1987), a synthetic strong motion computation program. The signal processing is computed using MUSIC, a frequency analysis method developed by Goldstein and Archuleta (1991a&b). Projection of the slowness spectra onto the fault plane is based on Snell’s law and computed using the formula of Goldstein (Chouet et al., 1998).

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.

Having studied the array efficiency for a fault grid of point sources, further studies are needed to assess the true array performance using synthetic rupture processes with EMPSYN (Hutchings, 1987).

3.2 MUSIC and EMPSYN

MUSIC is a frequency-slowness analysis performed over a collection of seismograms (Goldstein and Archuleta, 1991a&b). It uses the covariance matrix of the signals to extract ray parameters and their relative intensities. Programming of MUSIC as well as the other complementary processes has been done using Matlab.

EMPSYN stands for Empirical Green's function synthetic seismogram program (Hutchings, 1987). A measured earthquake signal is the result of the original source signal and its subsequent modification on its path from the fault source to the instrument and through the instrument itself. Mathematically this may be expressed as the convolution of the source signal function with a function representing the effect of the geology and the instrument, the Green’s function.

The empirical Green’s function approach is an attractive method in the case of a complex geology, which would be difficult to model, such as the geology of our region of interest. As the Alpine fault generates over a 100 earthquakes of magnitudes 2 to 4 per month, it is a good source of Green’s functions.

4 PRELIMINARY TESTS

Simple tests have been carried out in order to assess the relative importance of the geometry and instrument spacings on the array efficiency.

4.1 Input Model

Geological model:

- A 3-dimensional uniform block of velocity of 4km/s.
- A vertical fault: 100 km long, 20 km deep, and 0 degrees of strike.

Fault point grid: The fault plane is decomposed into a grid of 231 points spaced at 5 km in length and 2 km in depth. Point sources have been generated using a 3D wave equation.

Array location and configurations (Figure 4): the network is located 10 km from the centre point of the fault trace. Although the array should ideally be composed of nearly 20 instruments, it has been restricted to 9 in these first tests.

The concentric configuration comprises two concentric circles of 4 instruments each, surrounding a central station (Figure 4(a)). The L-shaped array is composed of two orthogonal branches of 4 and 6 instruments, with the longer branch being parallel to the fault line (Figure 4(b)). The design of the basket array is such that all the instruments are within the angular fault zone, in a radial configuration

(Figure 4(c)).

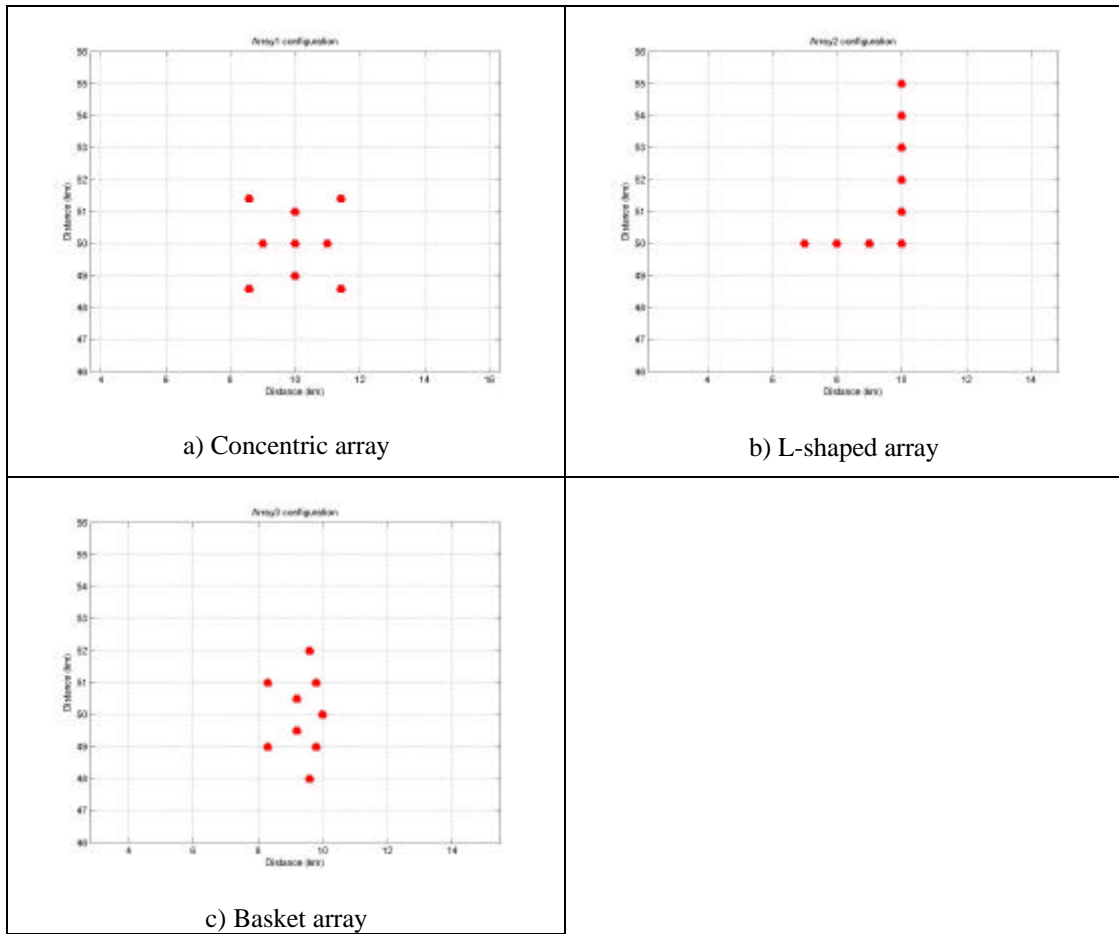


Figure 4. Proposed array configurations

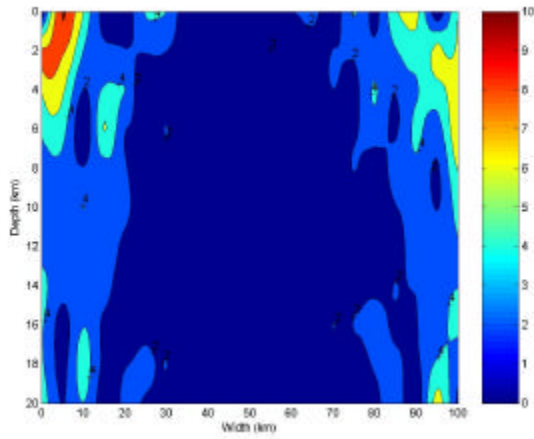
4.2 Results and first interpretations:

Using the same velocity and fault models, some proposed dense arrays have been tested firstly in various configurations, and secondly with various instrument spacings.

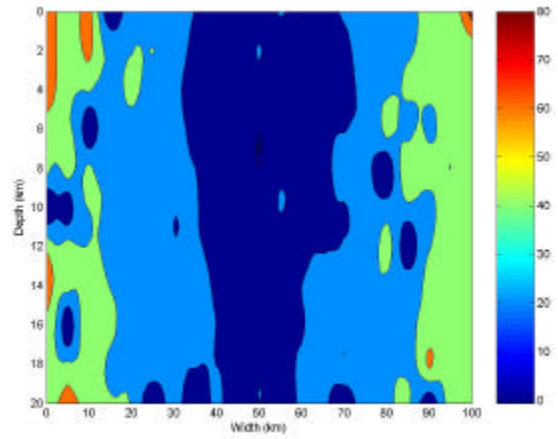
4.2.1 Efficiency of the network for various configurations

In this first series of tests, the spacing of the instrument is 1 km and only the geometry of the arrays is changed.

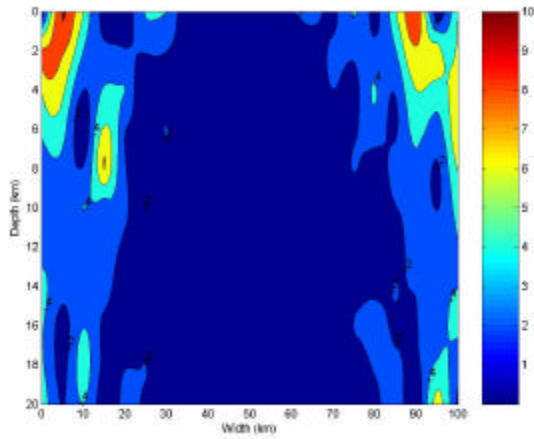
Figure 5 shows that the spectra all have the same pattern: in the central part of the fault plane the resolution of the sources is optimal, and then becomes lower for more distant parts of the fault. However they have distinctive features too. Comparing figures 5 a, b and c, it appears that the efficiency of the L-shaped array is much lower than that of the other arrays. Its optimal resolution zone is narrow and the peak distance value (the mismatch criterion) is 80 km, whereas it is only 10 km for the concentric and basket arrays. It also appears that, although the basket array was expected to perform better, its efficiency spectrum is very similar to that of the concentric array.



a) Concentric array – 1 km spacing



b) L-shaped array – 1 km spacing



c) Basket array – 1 km spacing

Figure 5. Efficiency spectra for various array configurations

From these simple tests, we can conclude that there is a major difference in the efficiency of the arrays depending on their geometry. The tests were useful to show that certain configurations expected to perform better do not, in fact, do so in the tests. It appears that a circular or basket geometry should be adopted. The drawback of a basket array is that it would miss out on the rupture of nearby faults in other directions.

4.2.2 Efficiency of the network for various instrument spacings

Here we compare two array configurations with varying instrument spacing. Figure 6 shows the array efficiency spectra for the concentric array and the L-shaped array with instrument spacings of 1 km and 200 m.

A smaller spacing has not improved the resolution for the concentric array (Figure 6 a and b). But it had a major influence on the L-shaped array efficiency spectrum (Figure 6 c and d). With 200 m spaced instruments, the L-shaped array efficiency spectrum becomes as good as the efficiency spectrum of the concentric array.

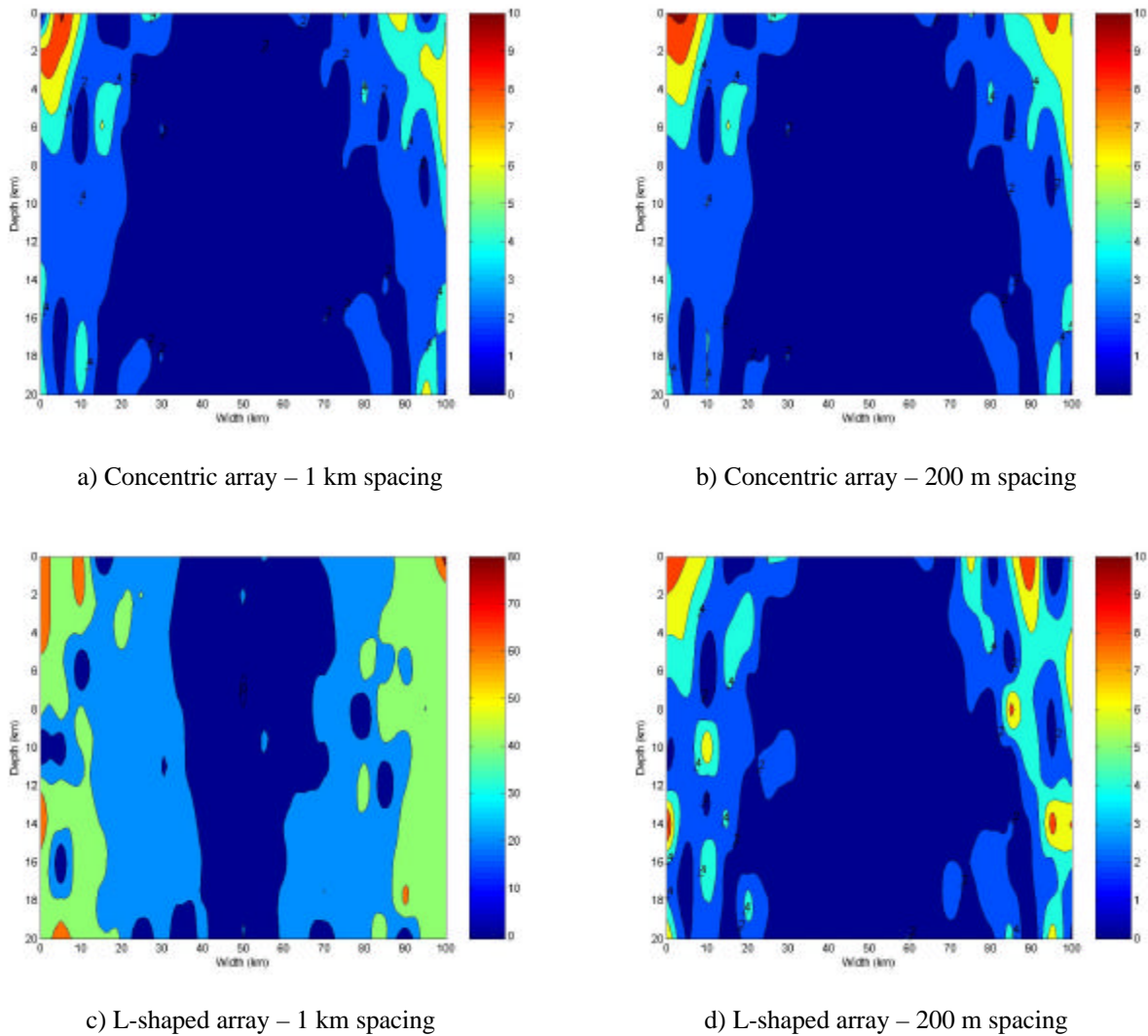


Figure 6. Various configurations and instrument spacings

Depending on array configuration, changing the instrument spacing can either have little effect on the efficiency of an array or improve greatly its efficiency spectrum. Because L-Shaped arrays might be the only possible configuration due to the field constraints, it is an important result to know that their array efficiency spectrum can still be improved.

5 REMARKS AND CONCLUSION

The Alpine fault is a potential source of major earthquakes for the Canterbury-West Coast region of the South Island, New Zealand. Having records from a dense array of strong motion instruments would provide a great opportunity to study directly fault rupture processes.

As shown from the preliminary tests, the array configuration has a major influence on the efficiency of the array to detect seismic sources on a fault. Amongst various proposed configurations, not only did the circular array prove to perform best but also it would allowed efficient recording of rupture on other faults in the region – such as the Hope fault, which also has high potential for rupture.

However the final configuration may be influenced by geographic constraints, which make circular array design impossible but allow an optimised L-shaped one, for example.

The computation scheme described is a general one and can be applied to other regions and other array configurations.

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