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THE NEW STRONG MOTION SEISMIC NETWORK IN SOUTHWEST BRITISH COLUMBIA, CANADA

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SUMMARY

The Geological Survey of Canada has designed a new type of low-cost strong motion seismometer and is currently updating its strong motion seismic network with the new instruments.
As of January 2004 about fifty instruments are in operation in Southwestern British Columbia and in a dense urban demonstration network in the cities of Vancouver and Richmond.
With a noise floor of 0.5 mg (with g beeing the earth's acceleration) and a range of +- 4 g over a frequency band 0 - 42 Hz the instrument is ideally suited for urban strong motion networks. The instrument can also be fitted with external velocity sensors for use in studies of building structural dynamics.
Continuous full waveform data are recorded and stored in an internal ring-buffer by each instrument. Data can be retrieved with standard Internet protocols like FTP and SSH/SCP at any time.
Parametric data such as peak ground acceleration (PGA), velocity (PGV) and spectral intensity (PSI) from an event as measured by an individual instrument are reported in near real time and are used to generate an experimental shake-map as a tool for emergency response agencies.
The instruments employ solid-state sensors and are virtually maintenance free. Instrument network configuration and acquisition parameters can be managed remotely over the Internet.
The techniques to maintain continuous Internet connections with the instruments have proven to be robust and reliable.

INTRODUCTION

Modern approaches to earthquake hazard research, risk assessment and strategies for efficient disaster mitigation require a network of strong motion seismic instruments, which continuously acquire full waveform data and communicate real-time parametric information.
The *Geological Survey of Canada* (GSC) has designed a low cost three-component strong motion seismograph for operation in large networks. The concept differs radically from conventional ways to record strong motion data.

- The instruments record **continuous** data; recording is not based on detected events.

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[2] now retired

- Instruments automatically synchronize to UTC.
- Parametric data, Peak Ground Acceleration (PGA), Velocity (PGV) and Peak Spectral Intensity (PSI) from an event are reported to a data centre in near real time.
- Data from events with Spectral Intensity (SI) greater than a certain threshold are stored in non-volatile memory.
- The instrument can be fitted with external velocity sensors for the study of building structural dynamics or other weak motion studies.

INSTRUMENT DESCRIPTION

The GSC instrument is fully self-contained. Accelerometers for three orthogonal channels, digitizer, recorder, Internet data server and an uninterruptible power-supply all fit into an enclosure $25\times18\times12$ cm.
A re-chargeable internal battery provides for about six hours of operations without external power.
An embedded computer controls data acquisition, computes continuous data streams of derivative ground motion parameters and provides full Internet connectivity for several standard protocols.
Continuous short-time long-time average (STA/LTA) ratios are computed for signal detection. High-pass acceleration, velocity and displacement time series as well as spectral intensity values are also computed continuously in real time.
The instrument itself has only a standard computer quality internal clock but achieves synchronization to UTC automatically by means of the Internet Network Time Protocol (NTP) [6] with an accuracy of typically $\pm10ms$, equivalent to one sampling interval in the digitized data.

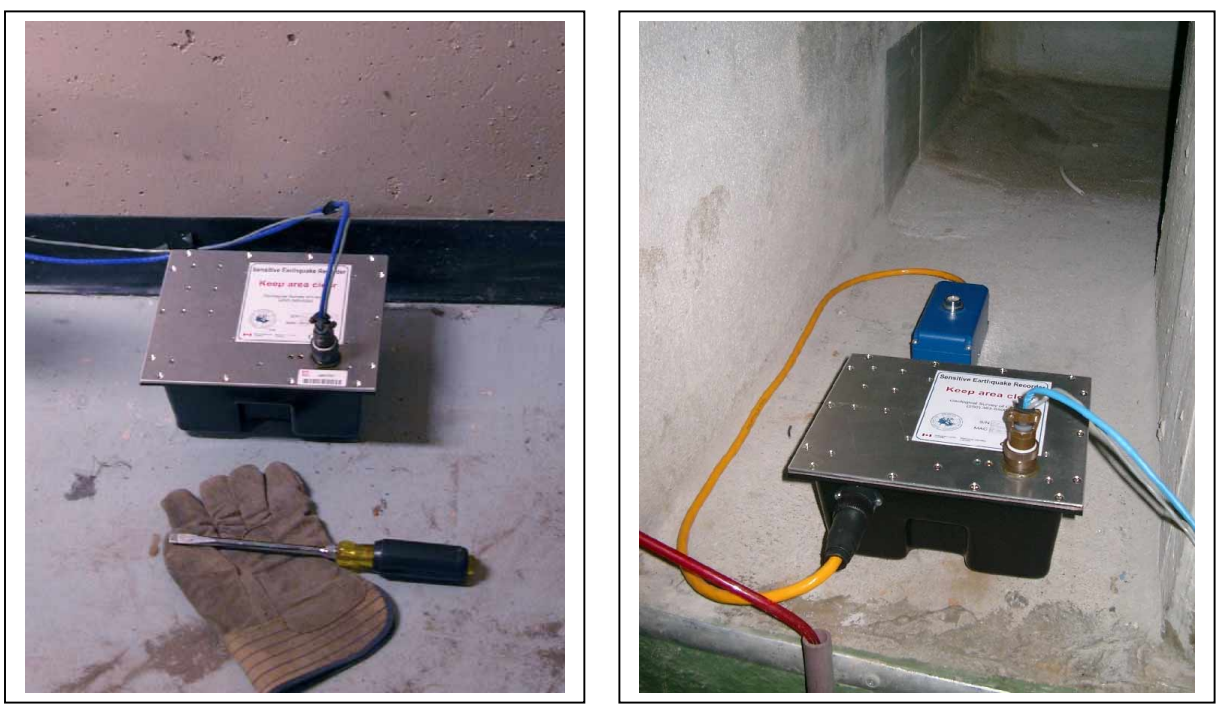

Figure 1. a) The instrument is self-contained and normally just bolted to the concrete basement floor; b) Studying building dynamics: IA with external velocity sensor in a high-rise in Zürich, Switzerland.

Data are acquired and stored in a ring buffer, irrespective of whether an event was detected or not. The ring buffer has a capacity of about two and one half days worth of data before older data are finally overwritten. This ring buffer is organized in five-minute miniSEED files which can be directly retrieved over the Internet at any time.
MiniSEED is a non-proprietary seismic data format maintained by the Incorporated Research Institutions for Seismology (IRIS).
Based on a SI threshold, event data are additionally saved as miniSEED files to a (non-volatile) Compact Flash memory, also in ring-buffer fashion and are rotated according to their peak SI values. Thus, the strongest events will always survive in permanent memory. The currently used 32Mb Campact Flash card can store about 400 events of 65 seconds duration.
As soon as an event is detected and a post-trigger observation time interval has expired, peak values for acceleration (PGA), velocity (PGV), displacement (PGD) and spectral intensity (PSI) are reported over the Internet to our data-centre.
The instrument is typically installed at ground level or in the basement of a one or two storey building. We operate our instruments in schools, hospitals, churches, on private business premises and in private residences.
A version of the instrument with external velocity sensors was successfully employed in a building dynamics study of the Zürich high-rise of the Swiss Society of Engineers and Architects conducted by GeoSIG Ltd. and Basler & Hoffmann AG of Switzerland.

CONTINUOUS COMPUTATION OF DERIVATIVE DATA

The instrument is equipped with solid state micro electro mechanical (MEMS) acceleration sensors. Velocity is computed from high-pass filtered ($T = 10s$) raw acceleration data in order to enable continuous integration [4]. Displacement in turn is the result of a high-pass ($T = 10s$) filtered integration of velocity. Filters and integrators are realized as scaled cascaded second order system (CSOS) infinite impulse response (IIR) implementations.
Spectral intensity ([3])

$$SI = \frac{1}{T_1 - T_0} \int_{T_0}^{T_1} PSV(T, \eta) dT [MKS : m/s], \tag{1}$$

was found in several studies (i.e. [2]) to be in good correlation to actual earthquake damage (or Modified Mercalli Intensity). PSV in the above equation stands for *pseudo spectral velocity*. In contrast to [3] we use the true velocity response in the numerical simulation of two single degree of freedom (SDOF) damped oscillators for the estimation of SI as suggested by [5]. The transfer function for a (velocity response) damped SDOF system is

$$sY(s) = F(s)\tilde{H}(s),$$

$$\tilde{H}(s) = \frac{s}{s^2 + 2h_0\omega_0 s + \omega_0^2},$$

with ω_0 and h_0 being the eigenfrequency and numerical damping constant respectively.
Using the bilinear transform to find the Z-Transform representation [9], the required two SDOF systems can be simulated in a set of second order difference equations which in turn are also implemented as CSOS IIR filters.
The two SDOF systems have a numerical damping of 20 % and natural periods of $1.5s$ and $2.5s$ respectively. Katayama [5] estimates total spectral intensity from the maximum response of either system which is then used to compute the sum of the rectangular and triangular spectral areas as shown in figure 2.

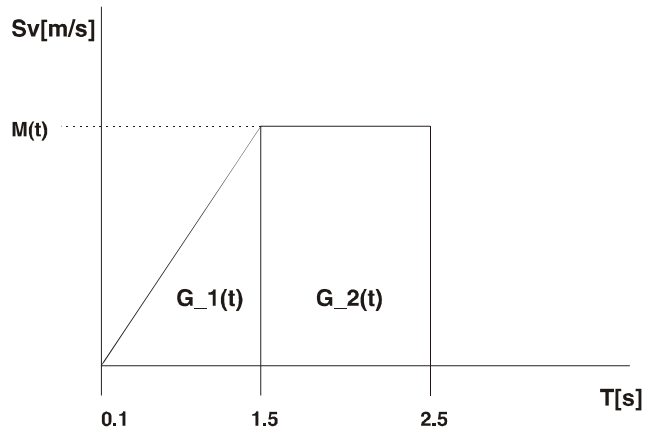

Figure 2. Approximation of true SI after Katayama: $SI(t) = G_1(t) + G_2(t)$

Since SI is computed continuously in real-time, as are the other derivative ground motion values, it can be used in a signal detection and triggering scheme. We use SI to generate (near) real-time event reports and to determine if data should be backed up to non-volatile memory because damage to power and Internet infrastructure is possible in a large earthquake. One horizontal component and the corresponding SI estimate for a simulation of the $M_W 7.3$, 1992, Landers earthquake is shown in figure 3. SI reaches levels of 30 cm/s seconds before acceleration peaks and SI levels remain high while acceleration has dropped considerably. SI mimics the behaviour of structures which continue to absorb resonant energy even at low excitation levels. On the instrument, SI is computed as vector modulus from both horizontal components.

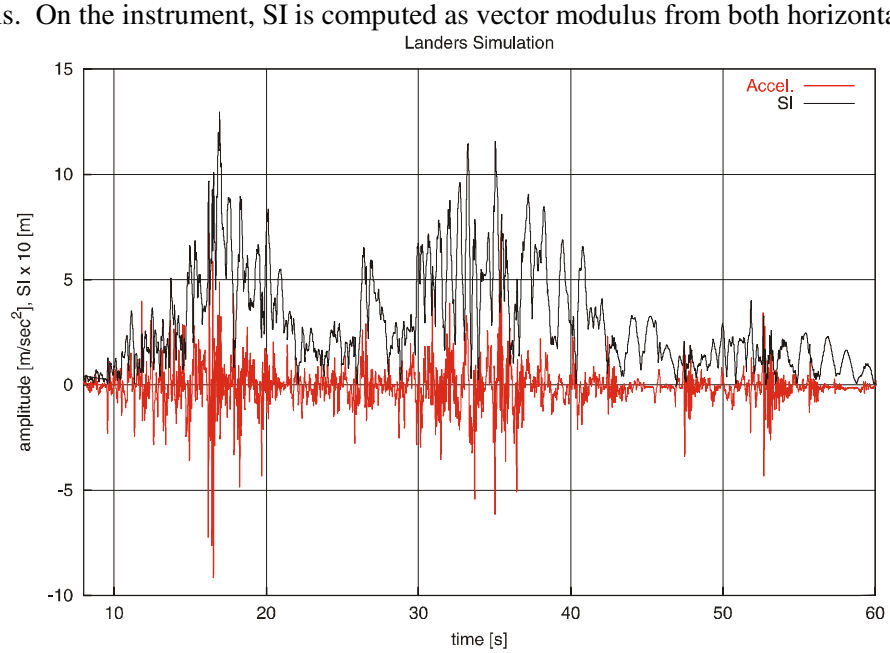

Figure 3. Spectral Intensity (SI) estimated from a single horizontal acceleration component. Data are from a simulation of the 1992, $M_W 7.3$, Landers earthquake.

NETWORK OPERATIONS

We are in the process of replacing the non-communicating instruments in the existing strong motion network in western Canada [8] with the new Internet Accelerographs. This will save significant servicing costs and allow for immediate retrieval of data. In some instances we have used the same site but in other cases we have moved to a nearby location to obtain Internet access. Elementary schools and small footprint two storey buildings are our most common deployment sites.
We have also begun to install dense networks of instruments in Vancouver to study the known high amplitude site response near the edge of the Fraser River delta [1] and in Victoria where the glacially scoured terrain within the urban region features many small pockets of soft soils surrounded by firm ground that exhibit a range of narrow band seismic amplifications [7].
A snapshot of deployed instruments as of January 2004 is shown in figures 4, 5 and 6.

We depend strongly on the co-operation of school-boards, hospital administrators and private citizens to install our instruments in the field since we generally ask our partners to donate resources with respect to Internet connectivity and electrical power. Since we are only using very small amounts of these resources (5.7 W of electrical power and an average Ethernet bandwidth of less than 20 bits/s), we have gained full support from all people we have approached.

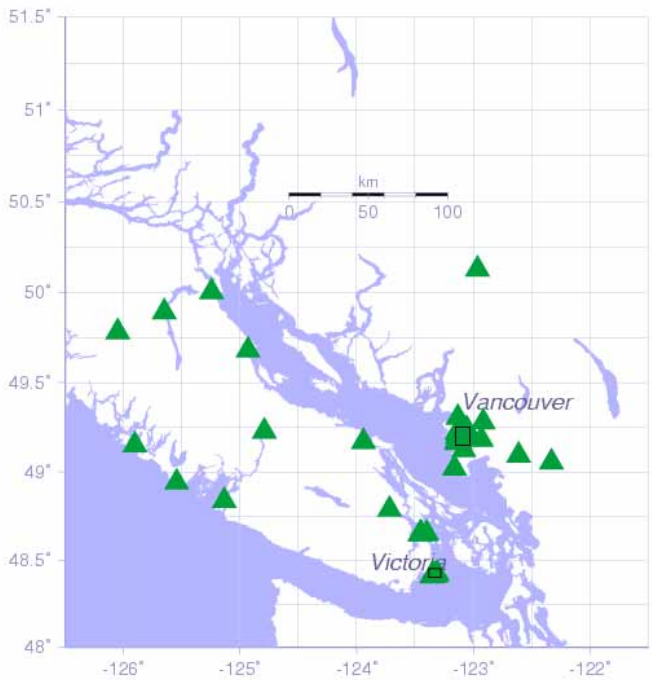

Figure 4. Internet Accelerographs in Southwestern British Columbia, Canada. The Vancouver/Richmond and Victoria areas are enlarged in the figures 5 and 6.

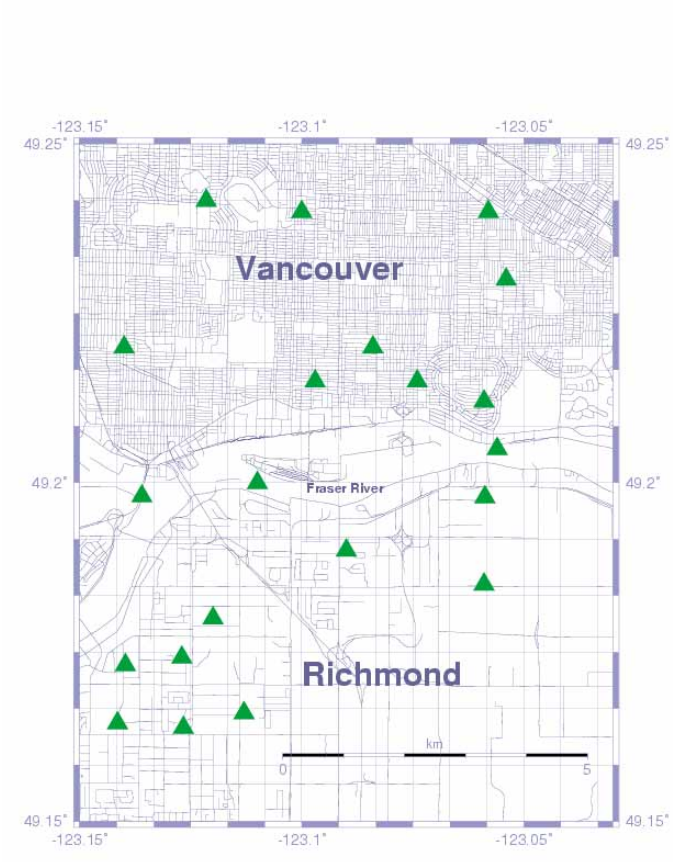

Figure 5. Internet Accelerographs in Vancouver and Richmond, B.C., Canada.

Figure 6. Internet Accelerographs in Victoria, B.C., Canada.

The instrument easily adapts to almost any network configuration (see figure 7) and can be installed on networks with private, non routable IP-addresses as well as on networks with increased security requirements and several Firewalls separating the instrument from the Internet.

All instruments currently connect to one relay host at the Geological Survey of Canada, Pacific Geoscience Centre in Sidney, B.C., which doubles as Network Time Server for most instruments. Several relay hosts can be set up for redundancy.

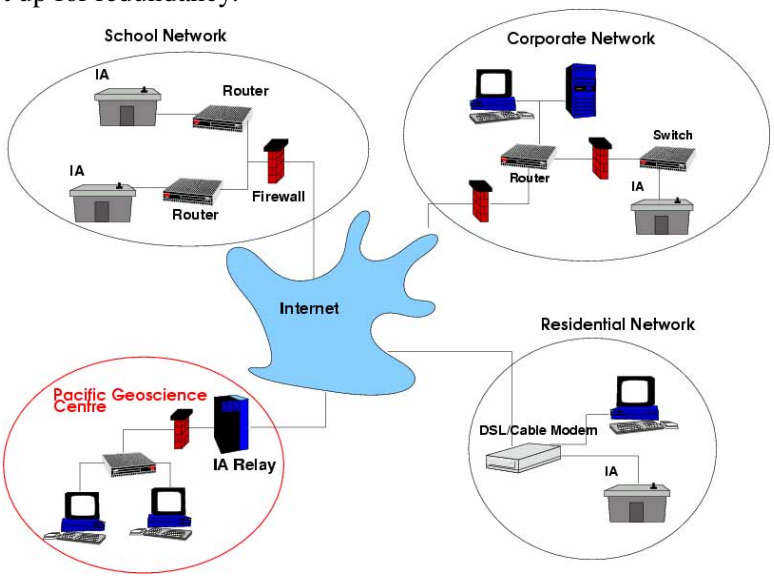

Figure 7. IAs adapt easily to different network environments and security requirements. All instruments communicate with a relay host at Pacific Geoscience Centre in Sidney, B.C.

Within this scheme we operate seven instruments in Switzerland, where our industry partner, GeoSIG Ltd., has set up a demonstration network.
Data from all instruments can be gathered in an instant over the Internet and each individual instrument can be completely remote controlled by a secure authenticated and encrypted Internet connection.
Each individual instrument and the current network as a whole have proven to be very reliable. With two exceptions, where instruments were accidentally disconnected from electrical power over a longer time, we have not yet revisited instruments we originally installed starting November 2002. The very first instruments in operation have passed 365 days of un-interrupted operation and so far the network has always automatically recovered from any widespread Internet outage, due to virus or worm attacks.

Several small earthquakes have been recorded todate, none large or close enough though, to be recorded on the whole network. As an example, recordings from the April 25, 2003, Magnitude 4.2 earthquake with epicentre 100 km south of Victoria, B.C., Canada are shown in figure 8. The shear-wave triggered instruments in Victoria, Sidney and 60 km further north in Richmond. Abbreviated parameter reports from the instruments are shown in figure 9.

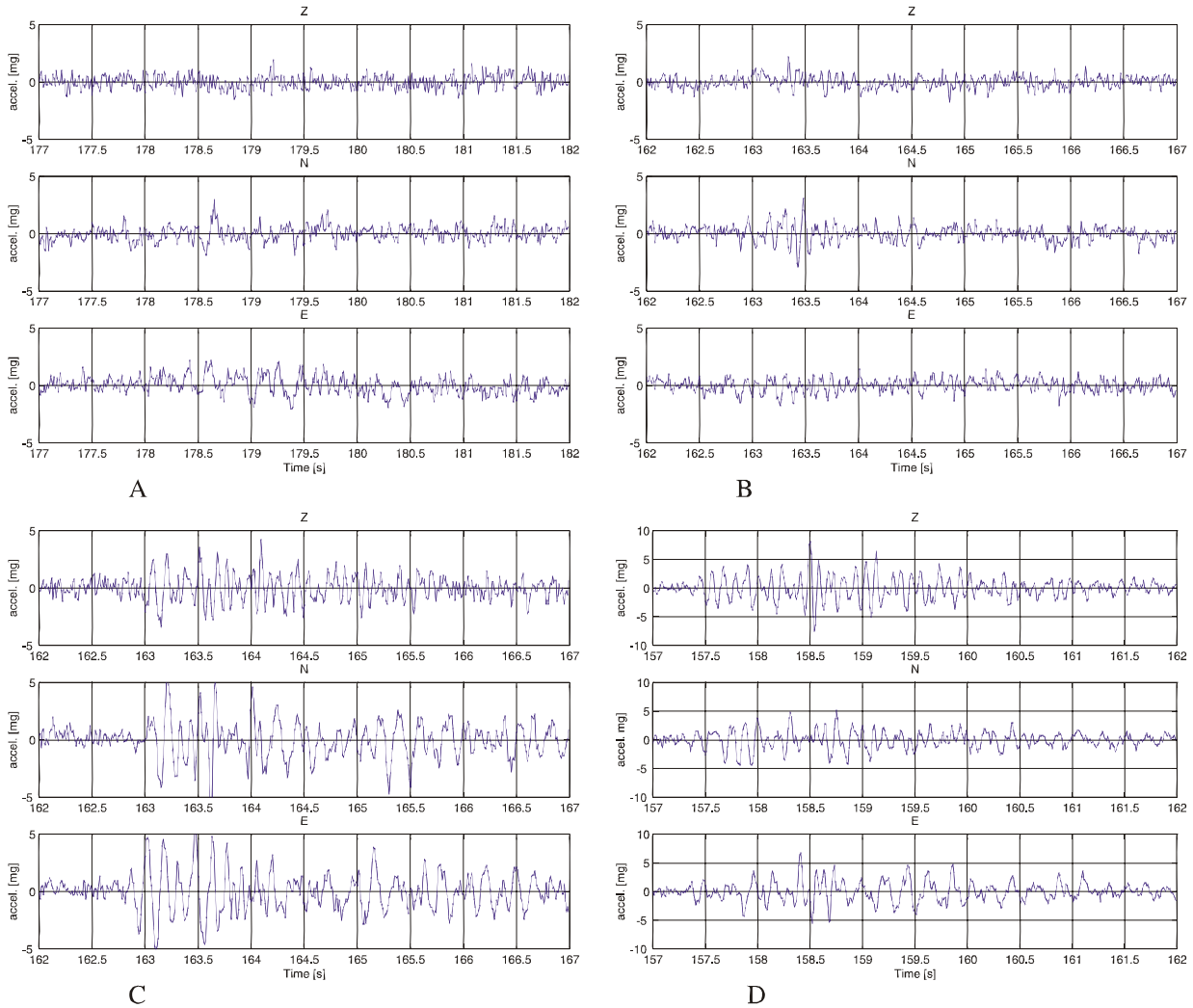

Figure 8. A) Richmond soft soil, B) Sidney bedrock, C) Sidney soft soil and D) Victoria bedrock recordings. The shear wave travelled north, the time sequence of recordings is D, C, B, and A.

VCT01NACN Fri Apr 25 10:02:28 2003, PGA 8.4965e-03, PGV 1.0559e-03, PGD 5.0582e-04
SDN01NACN Fri Apr 25 10:02:42 2003, PGA 9.4172e-03, PGV 5.3584e-04, PGD 4.4108e-04
PGC03NACN Fri Apr 25 10:02:42 2003, PGA 3.6105e-03, PGV 4.7998e-04, PGD 3.6929e-04
RMD06A9CN Fri Apr 25 10:02:58 2003, PGA 3.8241e-03, PGV 1.8625e-03, PGD 4.6670e-04

Figure 9. Parameter reports from instruments in Victoria, Sidney and Richmond. The respective recordings are shown in figure 8: D, C, B, and A.

We have recently started to automatically generate maps from reported shaking parameters (c.f. [11], [10]). As soon as more than five instruments report an event within a one minute time interval, a map is generated which depicts the respective parameter as a symbol with varying size and color at each instrument location. This will eventually evolve into a real-time information system for emergency responders and disaster mitigation teams.

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