BRITISH COLUMBIA EARTHQUAKE EARLY WARNING SYSTEM

C. E. Ventura(1), M. Turek(2), K. Johansen(3),Y. Kaya(4), F. Yao(5) , B. Southby(6)

(1) *Professor, University of British Columbia, ventura@civil.ubc.ca*
(2) *Research Associate, University of British Columbia, meturek@mail.ubc.ca*
(3) *Chief Technical Officer, TCLA Safety Ltd., kent@extrasensory.ca*
(4) *Research Associate, University of British Columbia, kayaya@mail.ubc.ca*
(5) *Research Engineer, University of British Columbia, yao@civil.ubc.ca*
(6) *Principal Consultant, Quicklink Consultants Inc., brian@quickl.ca*

Abstract

An earthquake early warning system has been developed and implemented in the Province of British Columbia in Western Canada. The system was developed in collaboration between UBC, The Roman Catholic Archdiocese of Vancouver and the BC Ministry of Education. The system was originally developed for BC Schools, and has since been expanded to other government institutions, at Municipal, Regional and Provincial levels. The system is based on development of a new, low cost seismic sensor that operates over a network. This provides both local warning at the sensor site and a regional warning over the network. The system is made up of both sensor sites (with two early warning sensors installed) and alarm sites. The alarm sites connect back to the central server over the internet, and once an early warning message is received the alarm is triggered either through sirens or the local public address system. Currently the system includes more than 30 sensor sites and 50 alarm sites. The system includes the capability to provide the messages over the internet and cell networks. This paper describes details of the system, and an example from a Mw 4.7 Earthquake that triggered this system in December 2015.

Keywords: earthquake monitoring, earthquake early warning, sensors

1. Introduction

The University of British Columbia has developed a network-based Earthquake Early Warning System (EEWS) for schools in British Columbia. The system was initially developed with the Roman Catholic Archdiocese of Vancouver (RCAV) for use in Catholic Schools throughout the Southwest Coast of BC (see Figure 1) which is a region of high seismic hazard. The concept of the system was to 1) develop a low-cost, easy to deploy sensor for the purpose of early warning to be installed at selected schools throughout the hazard area and 2) develop a network-based system of alarms that would trigger at every one of the schools and provide additional warning across the region.

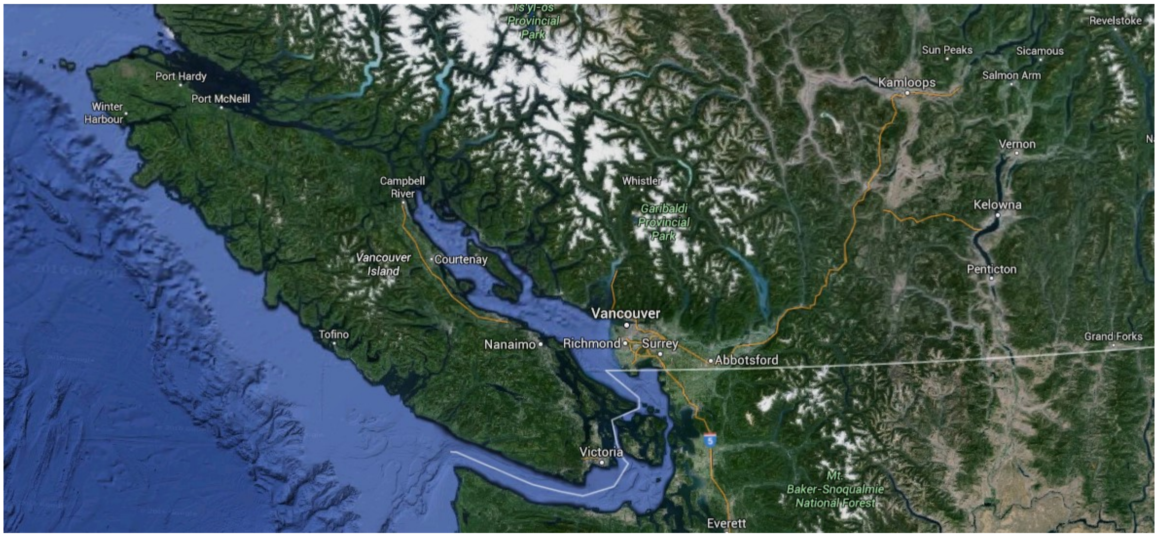

Figure 1: Southwest Coast of British Columbia

The original system had 20 sensor sites and an additional 30 alarm only sites. Subsequently the system has been expanded to include public schools, and other sites as well. There are more than 1000 schools within the seismic hazard region in the Southwest Coast of BC. The system has been in operation since 2014, and was subjected to a Mw 4.7 Earthquake in December of 2015 which triggered the alarms in every site. At the trigger site on Vancouver Island 6 seconds of warning was achieved, for schools on the mainland as much as 16 seconds of warning was achieved and for the most distant sites with alarms more than 25 seconds of warning was achieved.

2. Practical Implementation of EEWS

The concept of earthquake early warning is based on measurement of a rupture and relating this information to a population in the quickest and most efficient way. If the faults are known, then sensors can be placed between them and the at-risk population in what is referred to as ‘front-line’ early warning, as in the Romanian system [1].

Typically early warning is achieved by exploiting the concept of the P-wave; which relies on the fact that the P-wave will travel faster and arrive several seconds before the damaging S-wave. There are many proprietary standalone early warning devices, which are intended to provide warning to a specific site or to provide a specific function (such as shutting off gas valve). A significant effort is made on reducing the risk of false alarms by attempting to distinguish between other environmental noise and vibration and a true seismic event. Typically this is done by examining multiple components of motion and attempting to distinguish the presence of a P-wave [2].

When the hazard is not explicitly know or many faults exist, the best solution is to utilize a network of sensors. The benefit of a network system is that more warning can be given, as well as more information (such as time to shaking and expected Magnitude. The first example of a networked EEW system was with the Japan Railways Company in 1965 that started operation in the following year. In particular, the systems developed at the National Research Institute for Earth Science and Disaster Prevention (NIED) and the Japan Meteorological Agency (JMA) were integrated in June, 2005 [3]. The system has been successfully activated during several earthquakes since 2007, and provided accurate information regarding the source location, magnitude and intensity at about 3.8s after the arrival of P wave at nearby stations.

In the past decade, progress has been made towards implementation of earthquake early warning in China, Taiwan, Mexico, Italy, and Romania, among others**.** The system for the west coast of the United States is being developed by the United States Geological Survey (USGS) as a coordination of three existing systems run by the California Institute of Technology, University of California at Berkeley, and University of Washington. The ShakeAlert application a combination of “ElarmS” [4], “Virtual Seismologist” [5] and “On-Site” [6] algorithms, and,is intended to report to the user the distance from your position to the epicentre; the time for the shaking to reach your location and the estimated magnitude of shaking at your site. Each of the three networks along the west coast employ their own detection method, referred to as Virtual Seismologist, ElarmS and PreSEIS. Each of the methods offers a trigger, localization and event magnitude calculation. The ShakeAlert system is effectively a uniform notification system that utilizes the existing EEWS technology.

In 2009, the Chinese government announced that a nation-wide earthquake early warning platform had been planned and will be deployed in near future. The prototype system deployed in the Beijing Capital Region (BCR) is described in [7]. The authors make use of the regional EEWS concept in order to implement their methodology. Following this endeavor, other provincial authorities are pursuing EEWS.

The primary challenge with implementing and maintaining an early warning network is cost; they require a significant investment in hardware and installation, and ongoing maintenance. This is more pronounced for large systems such as in Japan and the US. In many cases the early warning systems share the infrastructure with strong motion networks. While the scientific challenges persist and much research is ongoing, the fundamental concepts of earthquake early warning are well established and proven.

3. Methodology and System Details

The methodology employed for the BC-EEWS is to 1) use a smart sensor which can be programmed to use various algorithms to detect ground shaking 2) use a pair of sensors at each site to provide redundancy and 3) use a network of sensors which allows for ‘jumping of the P-wave’ (send warnings over the internet which arrive faster than the P-wave) and provides alarms to sites that don’t have sensors. A conceptual overview of the network is shown in Figure 2. A prime benefit of this design is that costs can be controlled by minimizing the number of sensor sites while still providing alarms to all schools.

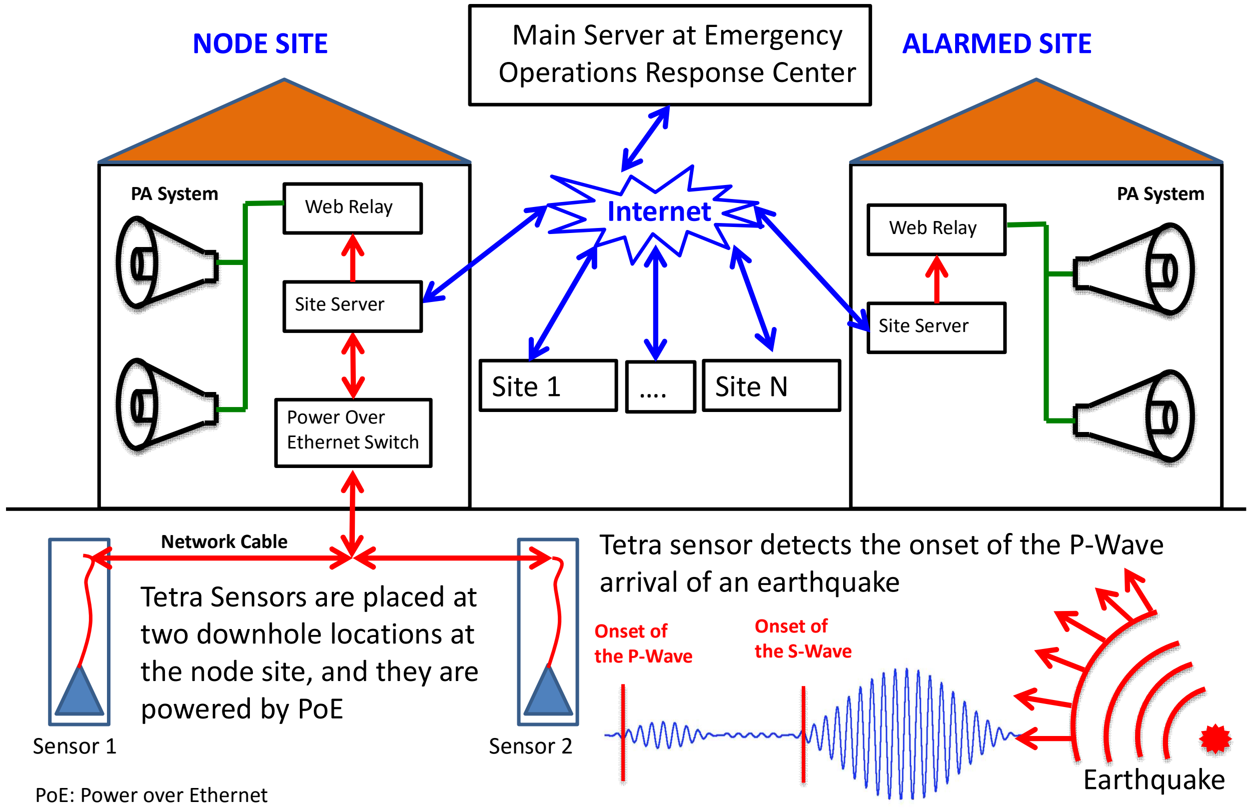

Figure 2. Concept of BC EEWS

The network is comprised of sensors (Tetras, Fig 3) installed at selected sites (Node Sites), a server to monitor all of the earthquake activity in the region, the necessary software for earthquake detection suitable for the seismicity of the region, and the software to issue and distribute alarms and notifications to the stakeholders selected to receive the alarms notifications (Alarm Sites). Each Node Station features an EEW controller and a pair of sensors. Ideally, each of the two sensors will be installed in a free-field downhole, and the two sensors will be at least 30 m apart. If this is not possible, at least one sensor will be installed in a free-field at least 30 m away from any major construction and the other sensor will be installed inside the building where the controller will be installed (Figure 4a). The two sensors are connected directly to the controller through trenched cables back into the school (Figure 4b), where they are connected to the controller and then the internet. Additionally the use of two sensors installed at a sufficient distance apart aids in distinguishing seismic activity from other background noise, which is not likely to excite both sensors simultaneously. These EEW systems will operate in standalone mode, and will be also part of the EEW network.

For any warning system, reliability is always important and it is desirable to have redundancy built in the system. This system has the capability to use several early warning methods suitable to the geological and seismicity conditions of the region selected for the pilot project in order to increase the speed and reliability of early warning. In these methods, the information from the initial part (up to a few seconds) of P wave is used to estimate the magnitude and the strength of the impending ground motion at the same site.

Figure 3. Tetra sensor in downhole configuration

Figure 4a. System control and alarm box

Figure 4b. Surface junction box and trench

4. Strong Motion Network

Currently there is a Strong Motion Network (SMN) in operation within British Columbia; it was developed by Natural Resources Canada (NRCan) in collaboration with the BC Ministry of Transportation and Infrastructure (BC MoTI) and UBC [7]. There are approximately 100 active strong motion stations throughout the province (Figure 5). The network is based on a concept developed by NRCan called the Internet Accelerometer. Data from the SMN is available from the BC Smart Infrastructure Monitoring System (www.BCSIMS.ca).

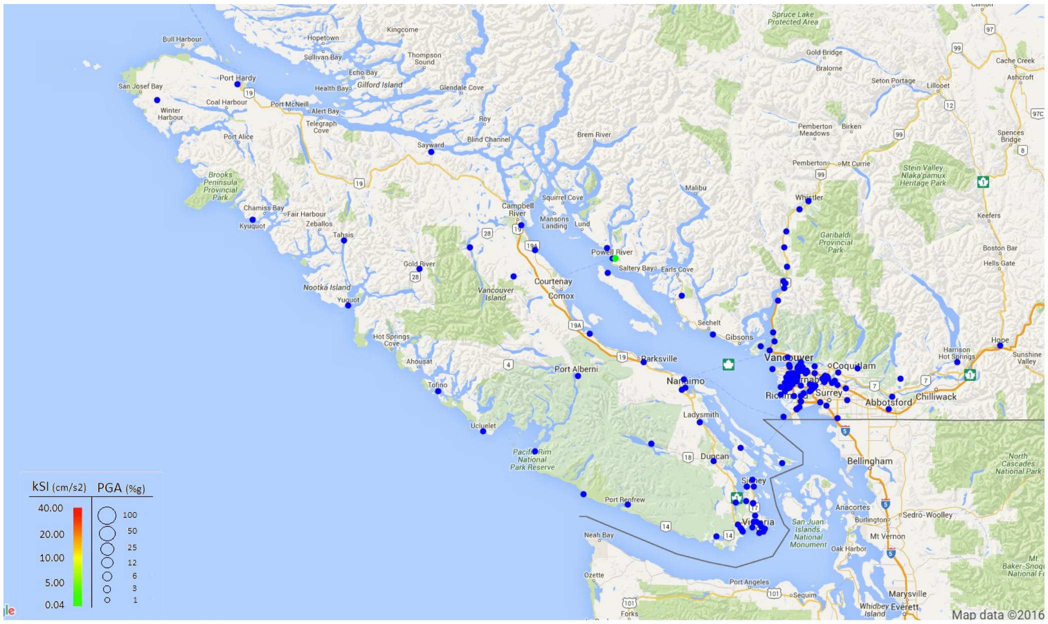

Figure 5: British Columbia Strong Motion Network (via www.bcsims.ca)

The Tetra sensor for the EEWS is capable of measuring accelerations up to 5g and the firmware includes tools to generate information for the creation of Shake Maps in just a few minutes after the earthquake. This permits an integration of the EEWS with the existing SMN, thus enhancing the capability of the SMN to generate more detailed shake maps and collect information about the level of strong motion shaking in the region.

5. Tetra Sensor

At the heart of the developed EEWS is the Tetra sensor. It has been developed specifically for EEWS, focusing on cost of the unit and of installation, robustness, reliability, speed and the optimal level of sensitivity. Urban EEWS need to operate with no false alarms in an environment with a certain constant level of man-made noise. In the British Columbia network, which spans from rural, suburban to central downtown Vancouver, constant noise peaks of 100-120µg (DC-12Hz) are typical; this establishes the urban background noise level.

The sensitivity needed to warn for a potentially (light) damaging earthquake is given by the peak ground acceleration of a Mercalli (Instrument Scale) IV, which is known to produce PGA of about 40mg (40000µg). An earthquake of this size would be expected to produce a P wave about 10-100 times weaker (400-4000µg). All practical P wave based warning systems around the World use thresholds of 2000-5000µg. Presently, a threshold of 2000μg is used for Vancouver, and in the current time of operation the urban noise has not exceeded 1000μg.

While a force balance instrument is much more sensitive, it rarely provides any additional, useful information in an EEWS setting. Comparing the specifications of such an instrument to the Tetra, we found that the Force Balance seismometers can measure the urban noise with great accuracy, but the information is of no use in the context.

6. Performance of the BC EEWS during the December 29, 2015 Sidney Island Earthquake

The system was put to the test during the Mw 4.7 Earthquake which occurred on December 29, 2015, approximately 10km from Sidney, BC and is referred to as the Sidney Island earthquake. Although it was a small event, it was felt by any over a large region across Vancouver Island and through the Mainland. The earthquake occurred at 1130pm local time, and was first detected by St. Patrick's school on the southern tip of Vancouver Island (approximately 40km from the epicenter). At the trigger site, the P-wave arrived 6 seconds before the S-wave. Upon triggering the system alerted the server at UBC, which in turn triggered all of the alarms across the network. Schools on the mainland received as much as 16 seconds of warning while the most distant schools received more than 25 seconds.

7. Summary and Future Developments

A network based earthquake early warning system has been implemented in schools in the Province of British Columbia. The system is comprised of node (sensor) sites and alarm only sites. Each node site connects back to a central server, which then relays potential alarm messages to each connected alarm site. Each node site features two downhole sensors installed a minimum of 30m apart. Currently there are more than 30 node sites and 50 alarm sites. The system is being expanded to more schools and other sites as well. More development of the early warning software is being done, and new integrated sensor and alarm devices are being developed to help further expand the network. In the two years of operation, there have been no false alarms. The system was successfully triggered in December 2015 by a Mw 4.7 Earthquake that was felt throughout the region. Typically warning time was between 6 and 16 seconds across the network.

8. Acknowledgements

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