Strong Motion Seismograph Networks in Canada

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ABSTRACT

More than 150 strong motion seismographs have been deployed in Canada, mainly in earthquake prone regions in British Columbia and Quebec. Most are deployed in networks operated by the Geological Survey of Canada (GSC), BC Hydro and Hydro-Québec. The trend in the past decade has been to install digital instruments which now account for about one half of the units deployed. Most of the Geological Survey of Canada sites are in small buildings or surface vaults in order to be as close to free field conditions as possible. Both BC Hydro and Hydro-Québec have deployed instruments on or near major dams, but about one half of BC Hydro instruments are at electrical substations in greater Vancouver and on southern Vancouver Island in sites selected to be as close to free field conditions as possible. The GSC networks focus on determining near-field strong motions on rock sites to check and improve the ground motion attenuation relations being used to calculate seismic hazard. Another focus of the western networks is to gather ground motion information on the soft soils of the Fraser River delta. This has been accomplished using digital recordings of two recent earthquakes. Thus far, over 200 three component accelerograms have been obtained from both eastern and western Canada and from a temporary network deployed in the epicentral area of a large earthquake in the Nahanni region of the Northwest Territories. While some large ground motions have been recorded (peak ground acceleration greater than 2g), most of the records produced from strong motion instruments so far represent weak motion (peak ground acceleration less than about 5%g).

INTRODUCTION

The purpose of this paper is to give a brief overview of the strong motion networks in Canada as they were at the beginning of 1999. For details of the history of strong motion instrument deployment in Canada see Milne and Rogers, (1971), Rogers (1976), Rainer and Luctar, (1983), and Weichert and Munro (1987). Since the last review by Weichert and Munro (1987) the number of instruments deployed has almost doubled and about one half of the instruments are now digital. These modern digital instruments provide high data quality even near their limit of resolution and have adjustable triggers, which means the trigger levels can be optimized to the local site conditions. The largest networks are currently operated by the Geological Survey of Canada (54 instruments), BC Hydro (58 instruments) and Hydro-Québec (27 instruments) with most of the instruments in the earthquake prone areas (e.g. see Basham et al., 1997) of British Columbia and Quebec.

WESTERN CANADA

Geological Survey of Canada

The Geological Survey of Canada (GSC) operates a network of 36 strong motion seismographs in western Canada (Figures 1-3). The purpose is to acquire strong ground motion records in and near urban areas and to define strong ground motion attenuation relationships for western Canada. There is also a focus on acquiring ground motion on the deep soft soils of the Fraser River delta just south of Vancouver. Instruments are deployed mostly in surface vaults or small buildings to be as close to free field conditions as possible. Most of the GSC stations in the greater Vancouver area use Kinemetrics SSA-2 accelerographs, all 1g full-scale sensors, with trigger thresholds ranging from 0.2%g to 1%g. Thresholds of 0.2%g are used for most bedrock sites, and a threshold of 0.4%g is used for many soil sites. On Vancouver Island and in the Queen Charlotte Islands most accelerographs are Kinemetrics SMA-1 1g instruments with trigger thresholds of 1%g. Replacement of these SMA-1's with digital instruments is underway; 3 Kinemetrics 2g ETNA's were deployed on Vancouver Island in the autumn of 1998, more will be deployed during 1999.

BC Hydro

B.C. Hydro (BCH) operates strong motion instruments at key hydroelectric projects and electrical substations across British Columbia (Figures 1-3). These instruments have been installed as part of the permanent monitoring of important dams, to verify design assumptions about the dynamic behaviour of structures and foundations when they are subjected to earthquakes, and to contribute to the strong motion data base for Western Canada. The BCH network includes 1g SMA-1's (all with a trigger threshold of 1.0 %g), and SSA-2 instruments and ETNA's. The older SMA-1's are installed at 13 hydroelectric dam sites in British Columbia. Since 1991, digital instruments have been installed, mostly at electrical substation sites in greater Vancouver and on Vancouver Island. All of the SSA-2's and ETNA's are 2-g full scale, and are set to trigger at thresholds of either 0.4%g or 0.6%g. Trigger thresholds are set as low as possible to allow recording of low-level ground motions, while avoiding false triggers due to traffic or other cultural vibrations. One downhole instrument is installed at a depth of 20 m at a substation on the soft soils of the Fraser River delta. Currently, BCH is completing installation of modems on all digital instruments outside of the greater Vancouver area, to allow rapid retrieval of data following an earthquake.

Other

The B.C. Ministry of Transportation and Highways, in collaboration with the University of British Columbia Department of Civil Engineering, operates 11 strong motion instruments at three locations (two bridges and one tunnel beneath the Fraser river) in southwestern British Columbia. The main goal of this program is to obtain information about ground motions and structural responses of critical transportation links in southwestern British Columbia, for use in seismic design and the retrofit of highway structures. For details on the instrumentation see Latendresse and Ventura (1997).

BC Gas has deployed 2 digital instruments at their LNG plant, just south of Vancouver, and Teleglobe Canada has an SMA-1 instument deployed at their earth station at Cowichan Lake on Vancouver Island.

EASTERN CANADA

Geological Survey of Canada

The GSC operates a network of eighteen instruments (Figure 4) radiating out from the seismically active Charlevoix region to gather near-field strong motion and to define strong ground motion attenuation relations for eastern Canada. Replacement of the 1g SMA-1 instruments by 2g ETNA accelerographs was started in the fall of 1998 with the installation of four units. Similar units have been purchased to be colocated with the 6 triaxial seismographs of the Charlevoix Local Telemetred Network. Trigger thresholds vary between 0.6%g and 1%g for the SMA-1's while the ETNA's are set to 0.25%g. Instruments are deployed mainly in surface bedrock vaults or in small buildings to be as close to free field conditions as possible.

Hydro-Québec

Hydro-Québec has instruments installed at 4 hydroelectric dams and 8 transformer sub-stations (Figure 4) as a part of their overall permanent seismic monitoring program that includes a network of 12 seismographs telemetered to Ottawa in real-time. The former provide free field and structural response for the generating systems along the Manicouagan River, while the response of the overburden at transformer stations, one of which was seriously damaged during the 1988 Saguenay earthquake, is covered by the latter. Most of the 27 sites are fitted with Kinemetrics SSA-1's (1 or 2g) or 2g ETNA's, while one dam remains instrumented with 8 analogue SMA-1 1g units.

Other

Gaz Metropolitian Inc. and New Brunswick Power both have one free field digital accelerograph installed at their respective facilities (LNG plant in Montreal and the Point Lepreau nuclear generating station).

RECENT ACCELEROGRAMS

Since the last review by Weichert and Munro in 1987, six earthquakes have triggered strong motion instruments providing significant data sets in both western and eastern Canada (see Table 2). In addition, five other small earthquakes have triggered a single instrument each, close to the epicentre. Most of the higher amplitude accelerograms have been processed by the Geological Survey of Canada following U.S. Geological Survey procedures (eg Converse, 1995) and released as Open Files. Here, we briefly summarize the more significant data sets, and some analysis results.

The Nahanni Northwest Territories earthquake sequence produced the most records to date, and the strongest levels of ground shaking. Strong motion instruments were deployed in the epicentral region shortly after the sequence began with a Ms=6.6 event on October 5, 1985. On December 23 1985 a Ms=6.9 earthquake occurred at nearly the same location. Accelerations recorded from this earthquake at distances of 8 to 30 km have a level of 10%g to 30%g for 10-12 s. One record exhibits a peak horizontal acceleration of 60%g to 120%g, and a vertical acceleration in excess of 2g (Weichert et al., 1986). These records clearly revealed the potential for extreme, short-duration accelerations in the near-field that maybe attributed to earthquake source and rupture characteristics. In total, 157 accelerograms were recorded from 105 earthquakes in this sequence (between 14 October 1985 and 18 February 1989) before the instruments were removed (Weichert et. al. 1991).

The 1988 M_W=5.9 Saguenay earthquake was the most significant in eastern Canada in more than 50 years. Twenty-seven accelerographs were triggered at epicentral distances of 43 to over 300 km and produced 37 accelerograms (Munro and Weichert, 1989; Rainer and Dascal, 1991). Peak horizontal accelerations ranged from less than 1%g to 17.4%g. The Saguenay records, being the first, and so far only, records of a strong eastern earthquake, challenged previous assumptions, as close instruments recorded lower ground motions than distant instruments and all records contained high frequency levels up to an order of magnitude higher than predicted by pre-1988 ground motion relations. These data were modelled by Haddon (1995) who concluded that apparent anomalies were due to an asymmetric rupture with strong directivity effects, and were not atypical for eastern earthquakes. The 1997 Cap-Rouge earthquake located 22 km under the western suburbs of Quebec City produced an analogue record at Laval University 11 km from the epicentre and a digital record at a distance of 57 km.

In western Canada, the M_W=5.1 1996 Duvall earthquake (Weichert et al., 1996) and the M_W=4.3 1997 Strait of Georgia earthquake (Cassidy et al.,1998) were the most significant earthquakes of the past decade recorded on strong motion instruments. The ground motions were relatively weak motions (0.5%g to 1.5%g at epicentral distances of 155 to 186 km for the Duvall earthquake, and 0.2%g to 2.4%g at epicentral distances of 37 to 87 km for the Georgia Strait earthquake). However, these data sets are significant because of the number of recordings on the deep soils of the Fraser River delta, which gives some insight into the nature and variability of the seismic response (Cassidy et al., 1996; Rogers et al., 1998; Cassidy and Rogers, 1999a; Cassidy and Rogers, 1999b).

SUMMARY

During the past decade the number of strong motion seismographs in Canada has nearly doubled to more than 150. Most of these instruments are located in the earthquake prone regions of British Columbia and Quebec, and almost all are in networks operated by the Geological Survey of Canada, British Columbia Hydro, and Hydro-Québec. The trend during the 1990's has been to install digital instruments, and about one half of those installed are now digital. Most of the GSC instruments are in small buildings or surface huts in order to be as close to free-field conditions as possible. BC Hydro and Hydro-Québec have deployed instruments on and near major dams. BC Hydro also has instruments at electrical substations in southwestern British Columbia, and is installing modems on all digital instruments outside of the greater Vancouver area for rapid retrieval of data after an earthquake. Thus far, more than 200 three-component accelerograms have been obtained across Canada. While some ground motions have been large (>2g for the Nananni mainshock), most represent weak motion (<5%g). These data sets have been used to better estimate ground motion attenuation and earthquake source characteristics and frequency content. The low-level recordings in southwest British Columbia have provided important new information on the variability of the seismic response on the soft soils of the Fraser River Delta.

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Table 1: Strong motion instruments deployed in networks in Canada

Owner	Analogue	Digital	Total
GSC West	22	14	36
BC Hydro	29	29	58
Other West*	1	13	14
GSC East	16	2	18
Hydro-Québec	8	19	27
Other East*	-	2	2

*This number may not be complete as we have not surveyed all potential owners

Table 2: Recent significant data sets from strong motion seismographs in Canada

Earthquake	Date	Location		Magnitude	Records
Nahanni*	85/12/23	62.19N	124.24W	6.9	157
Saguenay	88/11/25	48.12N	71.18W	5.9	37
Duvall	96/05/03	47.76N	121.88W	5.1	9
Georgia Str.	97/06/24	49.62N	123.62W	4.3	19
Charlevoix	97/10/28	47.67N	69.92W	4.7	3
Cap-Rouge	97/11/06	46.79N	71.40W	5.1	2

* Contains records triggered on aftershocks

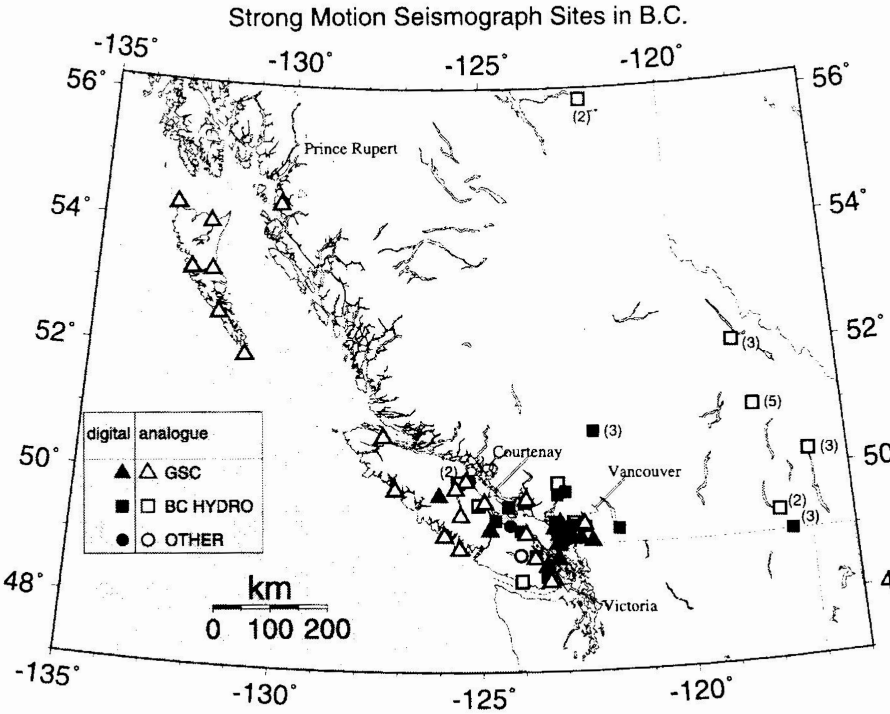

Figure 1. Strong motion seismographs in western Canada. Numbers in parantheses indicate the total number of strong motion instruments at a site.

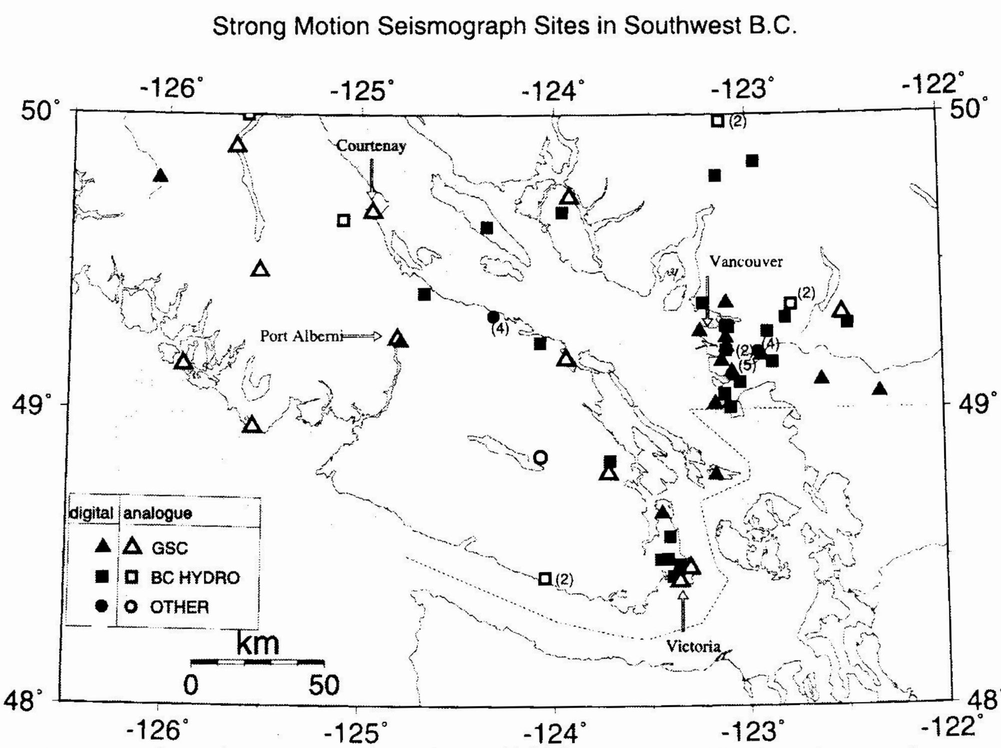

Figure 2. Strong motion seismographs in southwest British Columbia. Numbers in parantheses indicate the total number of strong motion seismographs at a site.

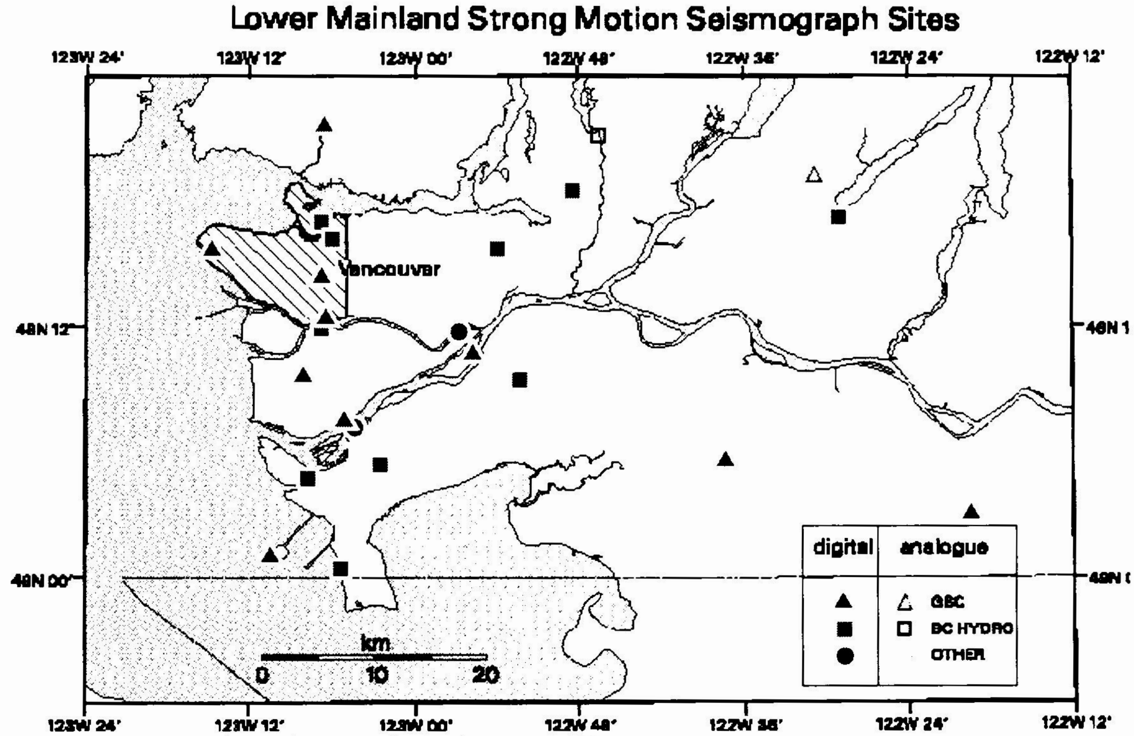

Figure 3. Strong motion seismographs in the greater Vancouver area.

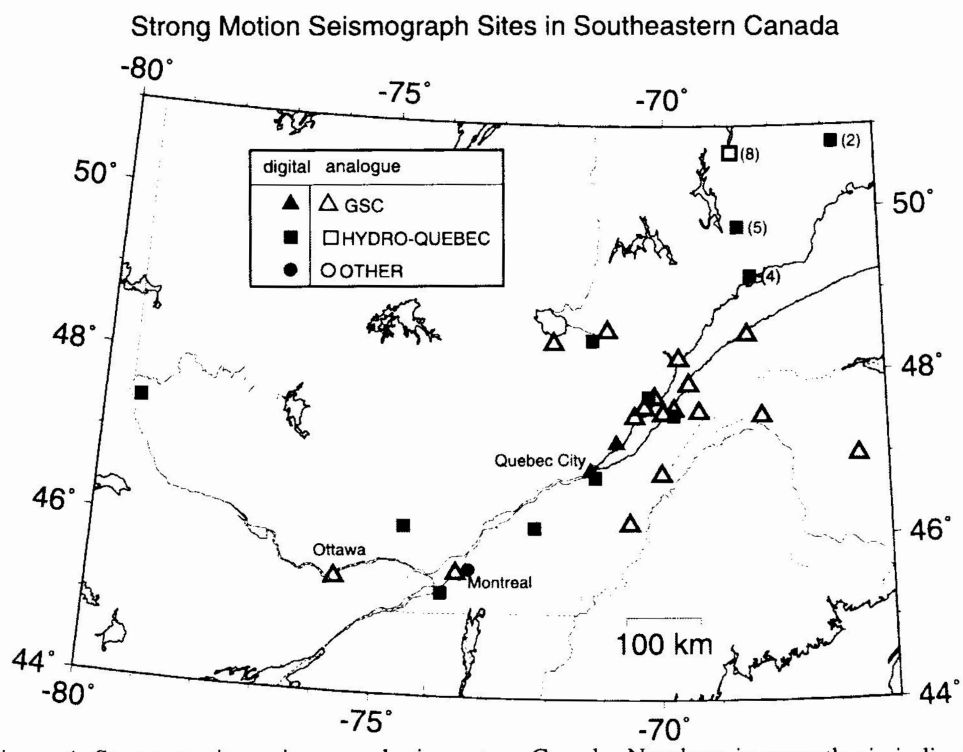

Figure 4. Strong motion seismographs in eastern Canada. Numbers in parenthesis indicate the total number of strong motion seismographs at the site.

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