Strong Motion Seismograph Networks, Data, and Research in Canada

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ABSTRACT :

Strong motion monitoring has undergone a revolution in Canada in recent years. Most analogue, non-communicating instruments have been replaced with modern digital instruments that provide information in real-time. Dense networks are being deployed in the urban centres of southwest British Columbia to provide shaking parameters and "shake maps" immediately after an earthquake. Monitoring of critical infrastructure, including bridges, dam sites and transmission facilities is increasing. This article documents the current state of strong motion monitoring across Canada, and summarises the data sets that are currently available. As of 2008, the Geological Survey of Canada operates 110 strong motion instruments (Internet Acclerometers or IA's) across Canada, most of which are deployed in the urban centres of high seismic hazard in southwest British Columbia. Partner organisations operate an additional 70 strong motion instruments monitoring critical infrastructure in western Canada. In eastern Canada, the GSC operates a network of 18 strong motion instruments in the active Charlevoix zone, and 6 IA's in greater Ottawa. Partner organisations operate instruments at an additional 15 sites. During the past decade, more than 700 three component accelerograms have been recorded across Canada. While some large ground motions have been recorded (peak ground acceleration (PGA) greater than 2g), most of the records represent weak motion (PGA less than 5%g). These are useful for evaluating local site response, which in turn will be valuable to engineers evaluating strong ground shaking during future earthquakes.

KEYWORDS: Earthquake hazard, site response, seismic instrumentation

1. INTRODUCTION

The purpose of this paper is to give a brief overview of the strong motion networks in Canada and datasets (as of January 2008). For details of the history of strong motion instrument deployment in Canada see Milne and Rogers, (1971), Rogers (1976), Rainer and Luctar, (1983), Weichert and Munro (1987), and Rogers et al. (1999). Over the past decade the number of strong motion instruments in Canada has nearly doubled and now the vast majority of instruments are digital with data availability in real-time. 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 based on the local site conditions. The largest networks are the "Internet Accelerometer" network (Rosenberger et al., 2007) operated by the Geological Survey of Canada (134 instruments), BC Hydro and BC Transmission Corporation (62 instruments) and Hydro-Québec (27 instruments) with most of the instruments in the earthquake prone areas of British Columbia and Quebec. A summary of instruments and owners is provided in Table 1.

2. STRONG MOTION NETWORK

2.1. Western Canada

The GSC's strong motion network in western Canada has undergone a complete upgrade since 2001. As of January, 2008, the GSC strong motion network consists entirely of internet accelerometers (IA's). These are a new, GSC-developed strong-motion instrument that is permanently connected to the internet and records data continuously, rather than in "triggered mode". IA's also continuously compute a set of parameters which characterise the intensity of shaking and actively report those values whenever ground shaking exceeds certain levels to the GSC's data centres. Waveform data can be retrieved from an instrument at any time over the internet. For more details of the IA, see the article by Rosenberger et al. (2007). The GSC network in western Canada (Figure 1-3) consists of 97 IA's. 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 schools, surface vaults or small buildings (for internet access) to be as close to free field conditions as possible. There are currently no strong motion instruments operating in the Queen Charlotte Island region, or in the seismically active regions of northern Canada.

BC Hydro (BCH) and BC Transmission Corporation (BCTC) are Provincial Crown Corporations responsible for producing and delivering electricity to most of British Columbia. BCH operates 39 strong motion instruments (SMA's) at 17 dam sites around the province (Figures 1-3). These instruments were installed as part of the permanent monitoring of important dams, to verify design assumptions about the dynamic behaviour of structures and foundations subjected to earthquakes, and to contribute to improving the strong motion data base for Western Canada. Twenty-eight of the BCH instruments are old analogue SMA-1s (1-g full scale, and all with a trigger threshold of 1.0 %g) which are essentially obsolete and non-maintainable. Most of the other instruments are ETNAs (2-g full scale, with trigger thresholds of about 0.5 %g). The analogue instruments are scheduled to be replaced by digital instruments within 2 to 3 years.

BCTC owns 23 SMAs, (SSA-2s and ETNAs), in southwestern BC. All of these 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. Instruments are installed at major substations and terminal stations and have recorded a number of earthquakes (described in more detail later in this article) including the 2001 M_W 6.8 Nisqually Washington and 2006 M_W 3.7 Strait of Juan de Fuca earthquakes. The original purpose for installing these instruments was primarily for post-earthquake back-analysis of station performance, but in the future, reliable real-time warning capability could be of value to system operators. BCH and BCTC continue to share any records obtained with the scientific and engineering communities in order to maximize the value of the records. The GSC has copies of all records obtained to date.

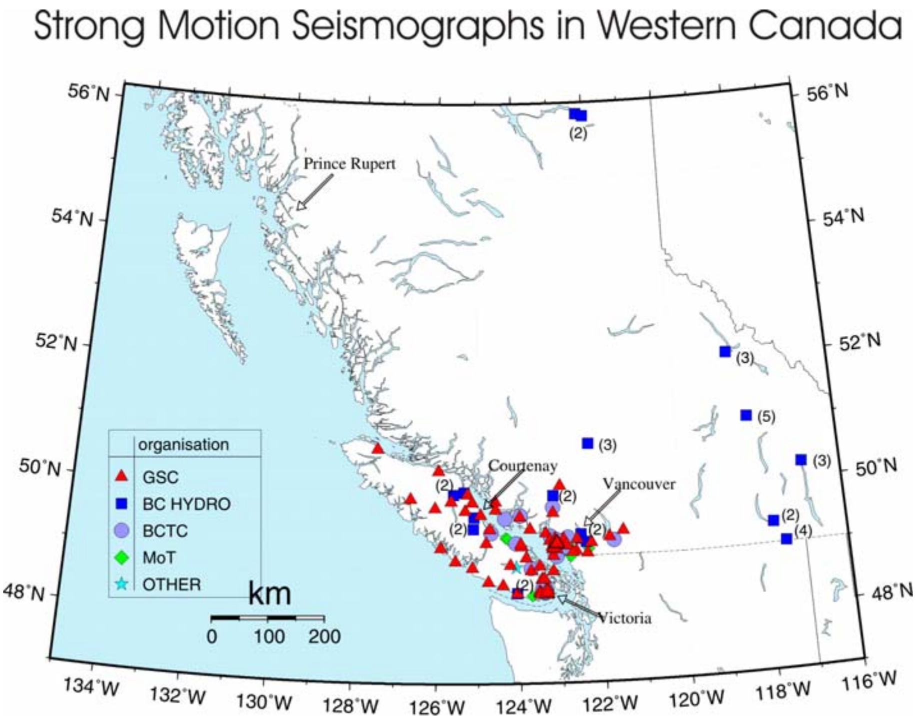

Figure 1. Strong motion seismographs in western Canada. Numbers in parantheses indicate the total number of strong motion seismographs at a site.

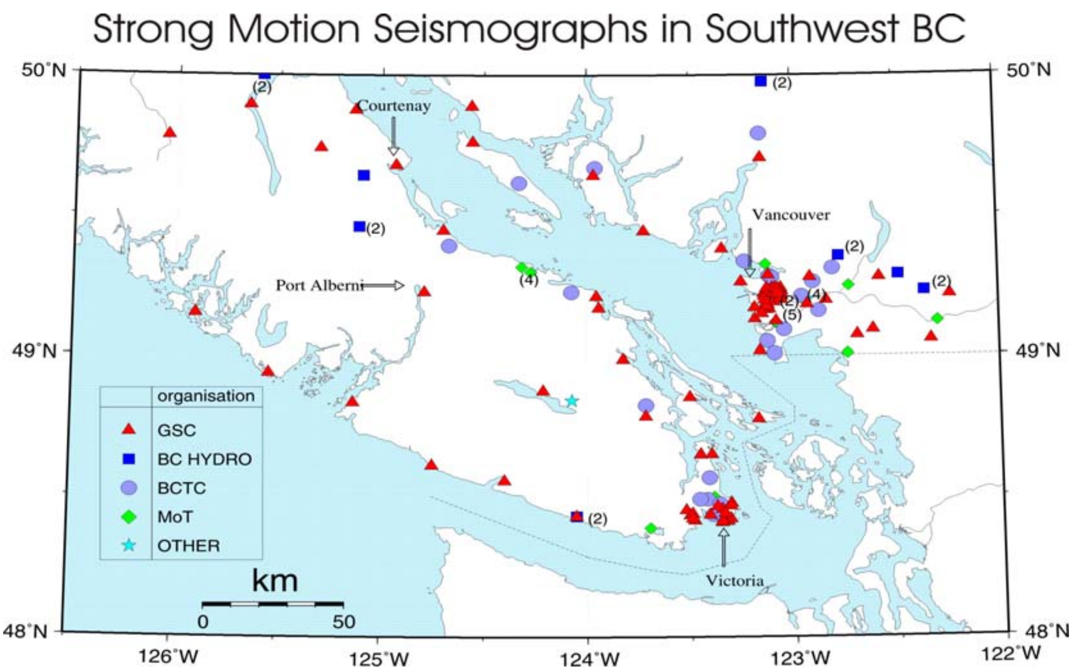

Figure 2. Strong motion seismographs in southwest BC. Numbers in parantheses indicate the total number of strong motion seismographs at a site.

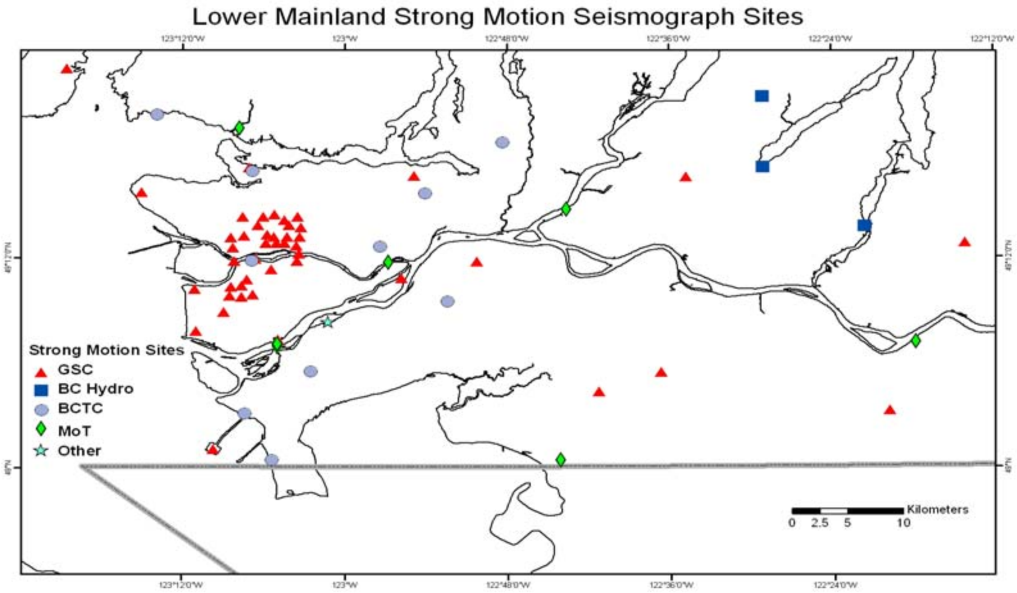

Figure 3 . Strong motion seismographs in greater Vancouver.

The B.C. Ministry of Transportation (BC MoT), in collaboration with the University of British Columbia Department of Civil Engineering, and the GSC, operates 17 strong motion instruments at locations (including some key bridges and the Massey Tunnel beneath the Fraser river) in southwestern British Columbia. Six of these instruments are IA's (see: http://earthquakescanada.nrcan.gc.ca/stnsdata/cnsn/sm/sm_motbc_e.php) with data archived with GSC data (described above). An additional ten IA's have been purchased and will be deployed along the Sea-to-Sky Highway north of Vancouver during 2007. Additional strong motion instruments (Geosig AH-63-DH shallow downhole instruments) will be deployed in Kelowna, BC and on the Pitt River Bridge, in the near future. 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 at the Queensborough Bridge, Massey Tunnel, and French Creek Bridge, see Latendresse and Ventura (1997). Real time IA data are combined with GSC and data from other partners in order to produce shaking maps, and near-real-time estimates of ground shaking parameters useful for earthquake response.

Other strong motion instruments in western Canada are operated by Terasen Gas (formerly BC gas) with two strong motion instruments (GeoSig GSR-18) at the Tillbury Island LNG plant, just south of Vancouver.

2.1. Eastern Canada

The GSC operates an eastern regional network of 26 instruments (many in the vicinity of the seismically-active Charlevoix region – see Figure 4) 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 and at present only one of the SMA-1 instruments remains in operation. Six of the ETNAs are co-located with the triaxial seismographs of the Charlevoix Local Telemetred Network.

Trigger thresholds vary between 1%g for the SMA-1 to 0.25%g for the ETNA's. Instruments are deployed mainly in surface bedrock vaults or in small buildings to be as close to free field conditions as possible. One (Baie St. Paul) is a soil site.

The GSC also operates a temporary prototype urban strong motion network in Ottawa. This consists of five

The instrument collocated with the Ottawa seismometer is on a pier on bedrock, while the remaining instruments are sited in basements of small buildings on a variety of soil conditions including some thick, soft soil sites. The Ottawa network has already produced some interesting earthquake records which demonstrate the nature and amount of soil amplification. The AuSable Forks earthquake (20020420) produced 18 accelerograms, 12 of the magnitude M_W 5.0 mainshock and 6 of a M4.1 aftershock (Al-Khoubbi and Adams, 2004). The M_W 4.7 Rivière-du-Loup (Grand-Portage) earthquake (20050306) produced 9 accelerograms, and the M_W 4.0 Thurso earthquake (20060225) produced 21 accelerograms (Adams 2007, this volume).

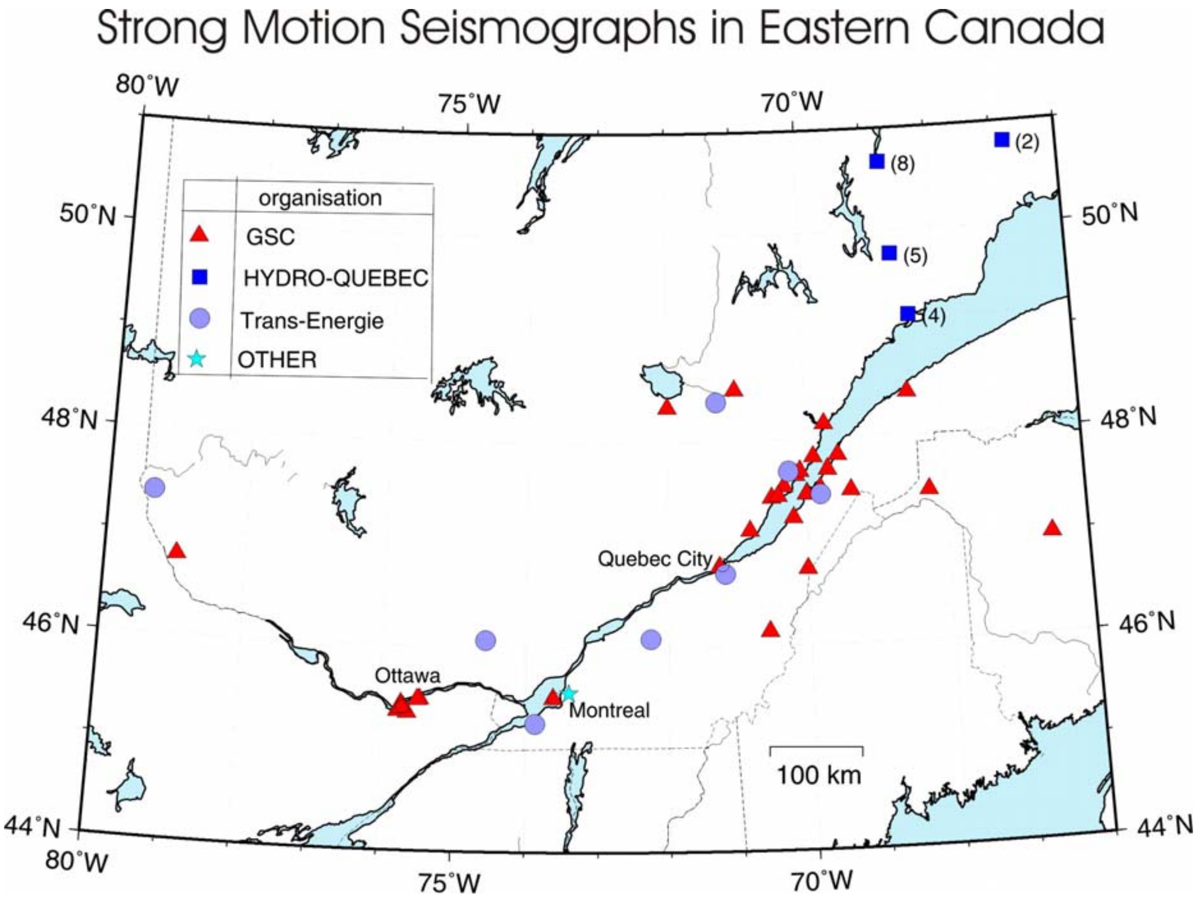

Figure 4. Strong motion seismographs in eastern Canada. Numbers in parenthesis indicate the total number of instruments at the site.

Strong motion instruments are also operated by Hydro-Québec and Trans-Energie. Their instruments are installed at key hydroelectric dams and 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. The 8 Trans-Energie (Hydro-Québec) instruments have trigger levels ranging from 0.05%g to 0.2%g.

Ontario Power Generation and New Brunswick Power operate strong motion instruments near their nuclear power plants in Ontario and New Brunswick, respectively, and Gaz Metropolitian Inc. has a free field digital accelerograph installed at their LNG plant in Montreal.

Table 1. Strong motion instruments deployed in Canada (as of Jan. 2007).

Owner	Analogue	Digital	Total
GSC West	-	97	97
BC Hydro	28	11	39
BCTransmission Corp.	-	23	23
BC MoT	-	17	17
Other West*	-	2	2
GSC East	1	36	37
Hydro-Québec	8	19	27
Other East*	-	13	13

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

2. RECENT ACCELEROGRAMS AND RESEARCH

Since the last review of strong motion networks in Canada by Rogers et al. in 1999, 12 earthquakes have triggered strong motion instruments providing significant data sets in both western and eastern Canada (see Table 2). The deployment of 97 IA stations in southwest BC by the GSC since 2002, is now resulting in much larger datasets than in the past. Most of the higher amplitude accelerograms have been processed by the Geological Survey of Canada following U.S. Geological Survey procedures (e.g. Converse, 1995) and released as Open Files. Here, we briefly summarize the more significant data sets, and some analysis results.

In western Canada there have been 9 earthquakes recorded on the strong motion network since 1999 (Table 2). In all cases, the “strong motion” recordings are at shaking levels less than 6%g. The Mw=6.8 Nisqually earthquake of 28 February, 2001 produced 96 strong motion records in southwest BC (distances of 150-300 km and shaking levels of up to 3.5%g). For details of this combined GSC, BC Hydro dataset, see Cassidy et al. (2003). A thorough analysis of these data, including comparisons with local geology and felt effects, is provided in Molnar et al. (2004a) and Molnar et al. (2004b). A study comparing the Nisqually earthquake recordings with ambient noise measurements to estimate seismic site response (Molnar and Cassidy, 2006) showed excellent agreement between these two datasets in the Victoria, BC region.
The largest strong motion data sets were obtained for the offshore Vancouver Island earthquakes of July 15, 2004 and July 19, 2004. A total of 108, and 132 records (respectively) were obtained at distances of 90-300 km. A peak horizontal acceleration of 0.6%g was recorded for the Mw=5.9 event of July 15, and a peak acceleration of 1.4%g was recorded for the Mw=6.4 event of July 19. This data set, comprised of GSC IA data as well as BC Hydro and BCTC data, is described in Molnar et al. (2006a).
Recordings of the 29 November 2002 M=3.9 Georgia Strait earthquake (18 records, with peak acceleration of 0.4%g) and the 25 April 2003 M=4.2 Olympic Peninsula, Washington State, earthquake (78 records, peak acceleration of 0.8%g) are documented in Molnar et al. (2006b).

During 2006, two widely felt earthquakes near Victoria BC produced significant data sets (Cassidy et al., in preparation). The ML=3.6 earthquake of 15 January 2006 produced 102 records, with a peak acceleration of 1.5%g, and the 4 July 2006 Mw=4.0 event produced 72 records with a maximum peak acceleration of 3.9%g. These events were recorded to distances of 83 km and 42 km, respectively. Two other earthquakes near Victoria, recorded only on BCH and BCTC instruments (they occurred prior to the GSC IA network deployment) are the 11 December 1999 Mw=4.9 event and the 20 September 2002 M=4.3 event. The 1999 event yielded a total of 12 accelerograms with a peak acceleration of 5.4%g, and the 2002 event yielded 18 records with a peak acceleration of 3.4%g.

In eastern Canada 3 earthquakes have been recorded on the strong motion networks (Table 2). The Au Sable Forks, New York earthquake of 20 April 2002 produced 18 accelerograms in Ottawa, 12 of the magnitude M_W 5.0 mainshock and 6 of a M4.1 aftershock (Al-Khoubbi and Adams, 2004). The M_W 4.7 Rivière-du-Loup (Grand-Portage) earthquake of 6 March 2005 produced 9 GSC accelerograms, as well as recordings on the Hydro-Quebec network. Two of the latter recordings at epicentral distances of 20-25 km were as large as 15%g.

The M_W 4.0 Thurso earthquake of 25 February 2006 produced 21 accelerograms (Adams, 2007) with soil-amplified peak accelerations up to 3%g. Analysis of these data will provide new information on site response effects in the Ottawa and St. Lawrence Valley regions.

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

Earthquake	Date	Location (Lat, Lon)	Magnitude	No. Records
Victoria	99/12/11	48.52N, 123.27W	M_W 4.9	12
Nisqually, WA	01/02/28	47.15N, 122.71W	M_W 6.8	96
Au Sable, NY	02/04/20	44.53N, 73.73W	M_W 5.0	24*
Victoria	02/09/20	48.49N, 123.15W	M_W 4.3	18
Georgia Strait	02/11/29	48.92N, 123.06W	M_L 3.4	18
Olympic Peninsula, WA.	03/04/25	47.67N, 123.25W	M_W 4.6	78
Offshore Vancouver Isle.	04/07/15	49.52N, 127.24W	M_W 5.8	108
Offshore Vancouver Isle.	04/07/19	49.47N, 127.25W	M_W 6.4	132
Rivière-du-Loup	05/03/06	47.75N, 69.73W	M_W 4.7	15
Victoria	06/01/15	48.57N, 123.53W	M_L 3.6	102
Thurso	06/02/25	45.66N, 75.24W	M_W 4.0	21
Victoria	06/07/04	48.33N, 123.20W	M_W 4.0	72

*Includes recordings of an aftershock

3. DISCUSSION

During the past seven years the number of strong motion seismographs in Canada has nearly doubled to approximately 250. 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, British Columbia Transmission Corporation, Hydro-Québec, and the British Columbia Ministry of Transportation and Highways. In contrast to just 7 years ago, the vast majority of instruments are now digital (85%) and about half have real-time communication capabilities. 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, BC Transmission Corporation, and Hydro-Québec have deployed instruments on and near major dams and at strategic electrical substations in southwestern British Columbia and Québec.

During the period 1999-2006, nearly 700 accelerograms have been recorded across Canada, most in southwest BC, and most by the new real-time IA network. Almost all of these records 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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