Strong Motion Records from Earthquakes in Eastern Canada

L. Lin
Concordia University, Canada

J. Adams
Geological Survey of Canada, Canada

SUMMARY:
Geological Survey of Canada (GSC) has been recording earthquake ground motions in eastern Canada since 1970. Two recording networks are deployed: a strong-motion network and a weak-motion network. This paper discusses the compilation of 282 ground motion records obtained from the GSC strong-motion network. The records are obtained from 28 earthquakes in eastern Canada including the 2011 Val-des-Bois earthquake, which is the most significant recent earthquake in eastern Canada. The earthquakes have magnitudes from 2.5 to 5.5, and depths between 5 km and 20 km. For completeness, the records from the 1982 Miramichi earthquake and the 1988 Saguenay earthquake in eastern Canada, which were recorded with SMA-1 accelerographs, are also discussed in the paper. It is believed that the compiled records are important for understanding the seismic hazard in eastern Canada and for the improvement of the seismic provisions of the National Building Code of Canada.

Keywords: strong motion records, eastern Canada, earthquakes, attenuation relations, NBCC

1. INTRODUCTION

Records of ground motions due to earthquakes are very important for seismologists and structural engineers. They are essential for understanding the regional seismicity, the development of attenuation relations for earthquake ground motions, and for investigation of the behaviour of structures subjected to ground motions.

In the past decades, significant changes have been made to the instruments for collecting ground motion data in Canada. The older type of instruments (i.e., the analogue SMA-1 instruments and paper seismographs) have been replaced by modern digital instruments, such as IA (i.e., internet-accelerometer), Etna, and digital seismometers.

Geological Survey of Canada (GSC) is in charge of monitoring the ground motions in eastern Canada. Two networks have been created, i.e., a strong-motion network and a weak-motion network. In terms of the instruments, Etna and IA instruments are currently used in the strong-motion network, while short-period and broad-band seismometers are used in the weak-motion network. A recent description of the national strong-motion network is given by Cassidy et al. (2007), in which can be found reference to earlier descriptions. The IA network has recently been described by Rosenberger et al. (2007).

This paper describes the compilation of strong motion data from eastern Canada recorded by Etnas and IAs. In addition, the earlier strong motion records obtained by SMA-1 instruments from the Miramichi earthquake and the Saguenay earthquake are discussed. As an example, the results from the investigation of the characteristics of the records from the 2010 Val-des-Bois earthquake are also presented.

2. STRONG MOTION NETWORK IN EASTERN CANADA

2.1 Station Information

Currently, there are 33 strong motion stations with Etna instruments and 9 strong motion stations with IA instruments in eastern Canada. All these stations are operated by Geological Survey of Canada (GSC). Figure 2.1 shows the current GSC Etna stations, while the locations of IA stations are described in Section 3. As seen in Fig. 2.1, most of the Etna stations are located in the Charlevoix region of Québec, and were installed to capture the next strong earthquake in this seismically-active region including ground motions propagating into New Brunswick. Seven stations (i.e., OTBB, OT001, OTGH, OTNM, OTRS, OTT, and OTWM) are located in Ottawa, Ontario to assess ground motion amplification on soft soil (Adams 2007).

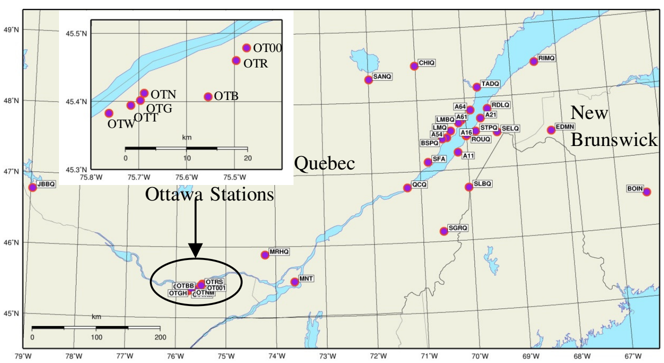

Figure 2.1. GSC Strong-motion stations in eastern Canada, 2009.

Tables 2.1 and 2.2 present detailed information for the GSC's strong-motion stations equipped with Etna and IA instruments respectively in eastern Canada, such as station code, coordinates, elevation and approximate soil condition at the stations. As seen in the tables, most of the Etna stations are on bedrock while all the IA stations are on soft soil except station OT012.

Table 2.1. List of GSC strong-motion Etna stations

No.	Station Code	Station Name	Coordinates		Elevation (m)	Soil Condition
1	A11	St-Roch des Aulnaies, Québec	47.2431 N	70.1968 W	76	Bedrock
2	A16	Rivière Ouelle, Québec	47.4680 N	70.0096 W	72	Bedrock
3	A21	St-André, Québec	47.7045 N	69.6891 W	66	Bedrock
4	A54	Misere, Québec	47.4568 N	70.4134 W	414	Bedrock
5	A61	Sainte-Mathilde, Québec	47.6936 N	70.0914 W	372	Bedrock
6	A64	Saint-Siméon, Québec	47.8274 N	69.8914 W	184	Bedrock
7	BOIN	Boiestown, New Brunswick	46.4628 N	66.4067 W	86	Bedrock
8	BSPQ	Baie St-Paul, Québec	47.4418 N	70.5057 W	23	Alluvium
9	CHIQ	Chicoutimi-Nord, Québec	48.4902 N	71.0123 W	133	Bedrock
10	EDMN	Edmundston, New Brunswick	47.4607 N	68.2398 W	186	Bedrock
11	JBBQ	Temiscaming, Québec	46.7751 N	78.9632 W	278	Bedrock
12	LMBQ	La Malbaie, Québec	47.6555 N	70.1526 W	42	Bedrock
13	LMQ	Les Eboulements, Québec	47.5485 N	70.3258 W	429	Bedrock
14	MNT	Montréal, Québec	45.5025 N	73.6231 W		Bedrock
15	MRHQ	Morin Heights, Québec	45.8870 N	74.2127 W	422	Bedrock
16	OT001	Orleans, Ontario	45.4788 N	75.4745 W	88	Clay, Silt, Silt-clay
17	OTBB	Ottawa, Ontario	45.4068 N	75.5548 W	76	Alluvium
18	OTGH	Ottawa, Ontario	45.4014 N	75.6969 W	74	Thin alluvium
19	OTNM	Ottawa, Ontario	45.4121 N	75.6891 W	72	Alluvium
20	OTRS	Orleans, Ontario	45.4603 N	75.4962 W	90	Alluvium
21	OTT	Ottawa, Ontario	45.3942 N	75.7167 W	77	Bedrock
22	OTWM	Ottawa, Ontario	45.3824 N	75.7628 W	69	Alluvium
23	QCQ	Québec, Québec	46.7791 N	71.2760 W	111	Bedrock
24	RDLQ	Rivière du Loup, Québec	47.8352 N	69.5376 W	55	Bedrock
25	RIMQ	Rimouski, Québec	48.4449 N	68.4820 W	124	Bedrock
26	ROUQ	Rivière Ouelle, Québec	47.4753 N	69.9966 W	32	Bedrock
27	SANQ	St-André du lac St-Jean, Québec	48.3249 N	71.9886 W	296	Bedrock
28	SELQ	St-Éleuthère, Québec	47.4958 N	69.3620 W	463	Bedrock
29	SFA	St-Férréole les Neiges, Québec	47.1244 N	70.8266 W	230	Bedrock
30	SGRQ	St-Georges, Québec	46.1399 N	70.5788 W	332	Bedrock
31	SLBQ	St-Lucie de Beauregard, Québec	46.7418 N	70.0160 W	410	Bedrock
32	STPQ	St-Pascal, Québec	47.5262 N	69.8049 W	62	Bedrock
33	TADQ	Tadoussac, Québec	48.1437 N	69.7184 W	46	Bedrock

Table 2.2. List of GSC strong-motion IA stations

No.	Station Code	Station Name	Coordinates	Elevation(m)	Soil Condition
1	OT002	Ottawa, Ontario	45.4742 N 75.5019 W	84	Clay
2	OT004	Ottawa, Ontario	45.3644 N 75.7746 W	78	Clay or Till
3	OT006	Ottawa, Ontario	45.4292 N 75.6500 W	68	
4	OT008	Ottawa, Ontario	45.3496 N 75.6418 W	80	Sand
5	OT012	Ottawa, Ontario	45.3942 N 75.7167 W	77	Bedrock
6	MO001	Montreal, Québec	45.5099 N 73.5534 W	61	Clay
7	MO002	Montreal, Québec	45.4962 N 73.5533 W	26	Sand
8	MO003	Montreal, Québec	45.5403 N 73.5714 W	52	Remblais
9	MO004	Montreal, Québec	45.5125 N 73.5841W	84	Bedrock ?

2.2 Characteristics of Instruments

The basic characteristics of the Etna and the IA instruments are the same for all the instruments of the eastern strong-motion network. Those which are needed for data processing are as follows:

- Data type: the data recorded by both the Etna and the IA instruments are accelerations.
- Number of components recorded: Each record obtained by Etna and IA instruments consists of three components of ground motions, i.e., one vertical component (V) and two orthogonal horizontal components, usually oriented in North-South (N-S) and in East-West (E-W) directions.
- Sampling rate: the sampling rate of the Etna instruments is 200 samples per second (i.e., the time interval of the recorded data is 0.005 s), while that of the IA instruments is 100 samples per second (i.e., time interval of the data is 0.01 s).

It is useful to mention that there are certain differences between the Etna and the IA instruments used in the eastern Canadian strong-motion network, the more significant of which are:

- The maximum peak ground acceleration (PGA) that can be recorded by the IA instruments is 4g, while the maximum PGA that can be recorded by Etna instruments is 2g.
- The timing accuracy of IA instruments is around ±0.01s since the timing system of IA is controlled by Network Time Protocol over Internet. However the timing accuracy of Etna is much less than that of IA since the clock in Etna can only be adjusted manually by technicians during their on-site visit, and may drift many seconds (or several minutes) between visits.
- The Etna records triggered data (typically including 10 seconds of pre-event signal), while IA records continuous data.
- The IA instrument is linked by internet and so can provide real-time readings while Etna must be visited by a technician to recover data, and cannot provide real-time readings or instrument status.

2.3 Strong Motion Records

The eastern strong-motion network has provided a large number of records of earthquake ground motions between 1997 and 2011. For the purpose of processing of the records, a detailed review was conducted of all the saved triggered data. Based on this review, 94 records (i.e., 282 components = 94x3) were selected for processing. The selected records were obtained from 28 earthquakes that occurred in eastern Canada and adjacent U.S. as summarized in Table 2.3. The Nuttli magnitude (m_N) of the events is between 2.5 and 5.5, and the moment magnitude (M_w) is between 2.1 and 5.0. The numbers of records from each earthquake are also included in the table. Note that 13 records (i.e., 39 components) are from the M_w 5.0 Val-des-Bois earthquake of June 23, 2011 and 22 records (i.e., 66 components) are from the M_w 4.7 Rivière-du-Loup earthquake of March 6, 2005. These two earthquakes are the most significant recent earthquakes in eastern Canada.

Table 2.3. List of earthquakes recorded by Etna and IA instruments

No.	Event	Location	Date	Magnitude		Depth (km)	Number of Records	Closest Record (km)
				m_N	M_w			
1	Val-des-Bois	45.90 N 75.50 W	20100623	5.2	5.0	22.4	39	52
2	Rivière-du-Loup	47.75 N 69.73 W	20050306	5.4	4.7	13.3	66	15
3	Cap-Rouge	46.80 N 71.42 W	19971106	5.1	4.9	22.5	6	56
4	Au Sable Forks	44.53 N 73.73 W	20020420	5.0	4.7	5.0	15	173
5	Thurso	45.65 N 75.23 W	20060225	4.5	3.9	20.0	6	36
6	Laurentide Fauna Reserve	47.56 N 71.06 W	20000712	4.2	3.8	18.0	15	42
7	Rivière-du-Loup	47.74 N 69.74 W	20081115	4.2	3.6	13.3	9	15
8	Charlevoix	47.70 N 70.09 W	20030613	4.1	3.8	10.9	15	1
9	Charlevoix	47.38 N 70.46 W	20060407	4.1	3.8	24.5	21	8
10	Charlevoix	47.33 N 70.51 W	20020817	3.8	3.4	18.0	9	16
11	Charlevoix	47.67 N 69.80 W	20000615	3.7	3.3	11.4	9	9
12	Charlevoix	47.65 N 69.92 W	20010522	3.5	3.1	11.4	6	13
13	Charlevoix	47.37 N 70.31 W	20080103	3.4	3.1	13.5	6	16
14	Rogersville	46.60 N 66.31 W	20090308	3.4	3.1	10.0	9	17
15	Charlevoix	47.41 N 70.37 W	20070927	3.3	3.1	14.5	6	11
16	Charlevoix	47.53 N 69.86 W	20031011	3.1	2.8	23.2	3	4
17	Charlevoix	47.51 N 70.02 W	20020612	3.1	2.8	7.8	6	4
18	Charlevoix	47.65 N 69.92 W	20010522	3.1	2.8	10.9	6	20
19	Charlevoix	47.51 N 70.02 W	20020612	3.1	2.8	7.8	3	5
20	Charlevoix	47.62 N 70.18 W	20061031	3.0	2.7	14.4	3	4
21	Charlevoix	47.64 N 70.18 W	20040524	3.0	2.7	13.6	6	3
22	Charlevoix	47.47 N 70.04 W	20000927	3.0	2.7	8.1	3	2
23	Charlevoix	47.40 N 70.48 W	20011003	3.0	2.9	9.9	3	5
24	Charlevoix	47.56 N 70.28 W	19981021	2.6	2.3	9.8	3	4
25	La Malbaie	47.65 N 70.22 W	20041118	2.6	2.3	6.7	3	5
26	Charlevoix	47.56 N 70.28 W	19981021	2.6	2.3	9.8	6	20
27	Charlevoix	47.33 N 70.51 W	20020817	2.5	2.1	18.0	3	12

2.4 Processing of Strong Motion Records

The recorded data are normally called "raw" or "uncorrected" data and these need to be processed in order to be useful for seismologists and structural engineers. The objective of the processing of a recorded component of a ground motion is to determine the "corrected" acceleration data, as well as the velocity and the displacement data of the ground motion. The corrected accelerations are further used to compute the response spectra and the Fourier spectra of the ground motions.

The data processing procedure depends on the type of the instrument used to record the ground motions. Two main phases of the data processing are:

- Baseline correction which is necessary to remove the offset of the record (i.e., the initial shift of the record from the zero line) that might be present in the record. This offset can be easily recognized based on the pre-event portion of the record.

- Filtering of the record which is done to remove high frequency and low frequency noise that might be present in the record. This requires the application of a band-pass filter. In general, various numerical band-pass filters can be used in the filtering of records.

For illustration, Fig. 2.2 shows the “corrected” acceleration waveform for the N-S component obtained by processing the recorded motion at station A16 during the March 6, 2005 Rivière-du-Loup earthquake. The processing was conducted as discussed above, i.e., by applying baseline correction and filtering of the record. A band-pass Butterworth filter of the order of 4, with high-pass frequency of 0.3 Hz and low-pass frequency of 50 Hz was used in the filtering. The PGA value of this record is about 3% g.

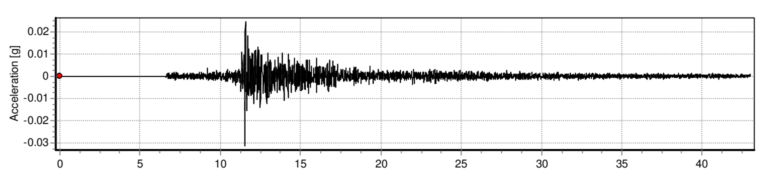

Figure 2.2. A sample of "corrected" acceleration waveform recorded at station A16 from 2005/03/06, Rivière-du-Loup earthquake

3. STRONG MOTION RECORDS – DIGITIZED SMA-1 DATA

In addition to the compilation of strong motion data recorded by Etna and IA instruments from the events that happened since 1997 as discussed above, digitized analogue data obtained by SMA-1 instruments from past earthquakes have been compiled. Such data include the records from the 1982 Miramichi earthquake (Weichert et al. 1982), the 1988 Saguenay earthquake (Munro and North 1989), and the 1997 Cap-Rouge earthquake. In total, 14 corrected records are available from the Miramichi earthquake, 33 from the Saguenay earthquake, and 3 from the Cap-Rouge earthquake. These records can be accessed through "Earthquakes Canada" website at http://earthquakescanada.nrcan.gc.ca.

4. STRONG MOTION RECORDS FROM THE VAL-DES-BOIS EARTHQUAKE

The magnitude (M_w) 5.0 Val-des-Bois earthquake that occurred in Quebec on June 23, 2010, was the largest recent earthquake in eastern Canada. Its epicentre was at 45.90 North 75.50 West with its hypocentre at depth of 22.4 km. It was about 60 km from Ottawa (population of about 1 million), where it caused damage to contents and destroyed some tens of chimneys. No significant structural damage was caused by the earthquake. However, close to the epicentre a bridge embankment collapsed and three landslides were triggered in unstable soil deposits. The ground motions were widely felt in Ontario and Quebec, and it was also felt into the U.S. as far as Kentucky. Since the Val-des-Bois earthquake was the most significant earthquake occurred in eastern Canada, the characteristics of its records will be very useful in understanding the seismicity in eastern Canada.

4.1 Earthquake records

Ground motions from the Val-des-Bois earthquake were recorded by 4 Etna instruments, 9 IA instruments, and a number of weak-motion seismometers that did not clip. Table 4.1 lists the records within 200 km of the epicentre along with the station information. The detailed information for Etna and IA stations can be found in Tables 2.1 and 2.2 respectively while the information for the seismometer stations is given in Table 4.1. It is necessary to mention that the soil class given in Table 4.1 was adjusted, based on Assatourians and Atkinson (2010), but needs to be confirmed in the future. As shown in the table, most of the stations are on NEHRP soil class A (hard rock with shear wave velocity Vs>1500 m/s), and only two stations (i.e., OTRS and ORHO) are on NEHRP soil class E (soft soil, clay, Vs<180 m/s). The locations of the stations are shown in Figure 4.1.

Table 4.1. List of records considered in the study

Record ID	Station Code	Recording Instrument	Epicentral Distance (km)	Hypocentral Distance (km)	Soil Condition	Soil Class (NEHRP Classification)
Re1	OTT	Etna	58.7	62.8	Bedrock	A
Re2	OTGH	Etna	57.5	61.7	Thin soil	A
Re3	OTNM	Etna	56.2	60.5	Soil	C
Re4	OTRS	Etna	48.9	53.8	Soil	E
Re5	OT002	IA	47.3	52.3	Clay	D
Re6	OT004	IA	63.3	67.1	Clay or Till	B
Re7	OT006	IA	53.6	58.1		B
Re8	OT008	IA	62.2	66.1	Sand	C
Re9	OT012	IA	58.7	62.8	Bedrock	A
Re10	MO001	IA	157.2	158.8		D
Re11	MO002	IA	157.7	159.3		D
Re12	MO003	IA	154.9	156.5		D
Re13	MO004	IA	154.9	156.5		D
Re14	GAC	Seismometer	21.9	31.3		A
Re15	ORHO	Seismometer	49.4	54.2		E
Re16	ORIO	Seismometer	49.9	54.7		A
Re17	ALFO	Seismometer	56.5	60.8		B
Re18	OTT	Seismometer	58.7	62.8		A
Re19	TRQ	Seismometer	81.3	84.3		A
Re20	GRQ	Seismometer	83.3	86.3		A
Re21	WBO	Seismometer	100.1	102.6		A
Re22	PEMO	Seismometer	137.7	139.5		C
Re23	CRLO	Seismometer	146.1	147.8		A
Re24	PLVO	Seismometer	155.7	157.3		A

*: the instrument does not record corresponding component.

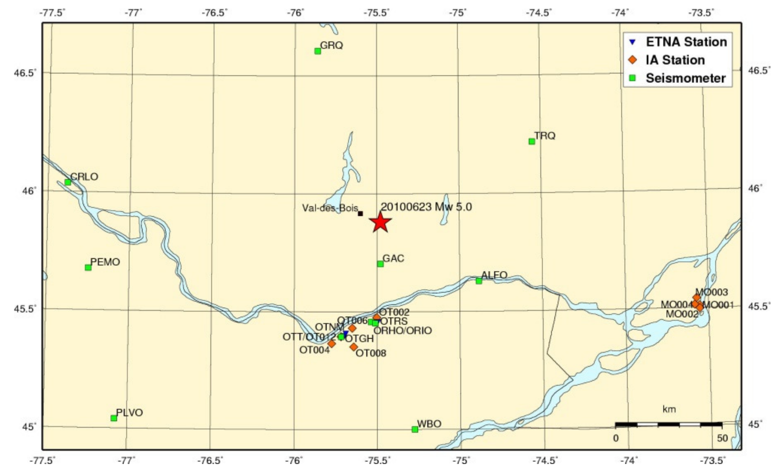

Figure 4.1. Locations of stations recording ground motions during the Val-des-Bois earthquake

4.2 Discussion of results

4.2.1 Peak ground motions

The peak ground accelerations (PGA), the peak ground velocities (PGV), and the peak ground displacements (PGD) of the processed records from the Val-des-Bois earthquake were calculated. For illustration, the PGA values of the recorded motions are given in Table 4.2. It is seen in the table that the PGA values of the ground motions in Ottawa (i.e., Re1 to Re9 in the table) are much larger than those in Montreal (i.e., Re10 to Re 13). This is because the epicentral distances of the Ottawa recording stations are about 60 km while those in Montreal are about 160 km (Table 4.2). The maximum PGA value of the records in Ottawa is 0.089 g. A review of the ratios of the horizontal peak ground motion values (N-S and E-W components) of the records in Ottawa on soft soil (Class E) to those on hard rock (Class A) shows the average amplification of the PGA, PGV and PGD values on soft soil relative to those on hard rock is about 2.0.

Table 4.2. Peak ground accelerations (PGA) of the records

Record ID	Station Code	Recording Instrument	Epicentral Distance (km)	Hypocentral Distance (km)	PGA (g)			Soil Class (NEHRP Classification)
					N-S Component	V Component	E-W Component	
Re1	OTT	Etna	58.7	62.8	0.033	0.024	0.032	A
Re2	OTGH	Etna	57.5	61.7	0.036	0.024	0.049	A
Re3	OTNM	Etna	56.2	60.5	0.042	0.065	0.089	C
Re4	OTRS	Etna	48.9	53.8	0.062	0.070	0.061	E
Re5	OT002	IA	47.3	52.3	0.048	0.053	0.067	D
Re6	OT004	IA	63.3	67.1	0.049	0.064	0.061	B
Re7	OT006	IA	53.6	58.1	0.041	0.032	0.061	B
Re8	OT008	IA	62.2	66.1	0.059	0.041	0.060	C
Re9	OT012	IA	58.7	62.8	0.033	0.025	0.032	A
Re10	MO001	IA	157.2	158.8	0.009	0.009	0.007	D
Re11	MO002	IA	157.7	159.3	0.008	0.004	0.004	D
Re12	MO003	IA	154.9	156.5	0.005	0.003	0.004	D
Re13	MO004	IA	154.9	156.5	0.003	0.003	0.003	D
Re14	GAC	Seismometer	21.9	31.3	--*	--*	--**	A
Re15	ORHO	Seismometer	49.4	54.2	--**	--**	--**	E
Re16	ORIO	Seismometer	49.9	54.7	0.044	0.015	0.045	A
Re17	ALFO	Seismometer	56.5	60.8	0.017	0.008	0.012	B
Re18	OTT	Seismometer	58.7	62.8	0.022	--**	--**	A
Re19	TRQ	Seismometer	81.3	84.3	--*	0.007	--*	A
Re20	GRQ	Seismometer	83.3	86.3	--*	wrong recording	--*	A
Re21	WBO	Seismometer	100.1	102.6	--*	0.003	--*	A
Re22	PEMO	Seismometer	137.7	139.5	0.022	0.009	0.015	C
Re23	CRLO	Seismometer	146.1	147.8	--*	0.006	--*	A
Re24	PLVO	Seismometer	155.7	157.3	0.008	0.007	0.009	A

*: the instrument does not record corresponding component.
**: record clipped.

Since the Val-des-Bois earthquake is one of the strongest recent earthquakes in eastern Canada, it is useful to compare the recorded PGA values with the values predicted by the Atkinson-Boore (1995) attenuation relations (i.e., AB 95) used by the Geological Survey of Canada (GSC) for modelling probabilistic seismic hazard analysis (PSHA) in eastern Canada for the 2005 and 2010 National Building Code values. Figure 4.2 shows the attenuation curve for horizontal PGA on hard rock (i.e., NEHRP soil class A) sites in eastern Canada given in AB95. The PGA values of the recorded horizontal motions from the Val-des-Bois earthquake at hard rock sites (as given in Table 4.2) are also shown in the figure (the scattered points in the figure) together with the values on soil sites. It can be seen that the recorded PGA values during the Val-des-Bois earthquake match the attenuation curve quite well. Note that a similar comparison is not possible for other types of soil conditions and other peak ground motions (PGV, PGD).

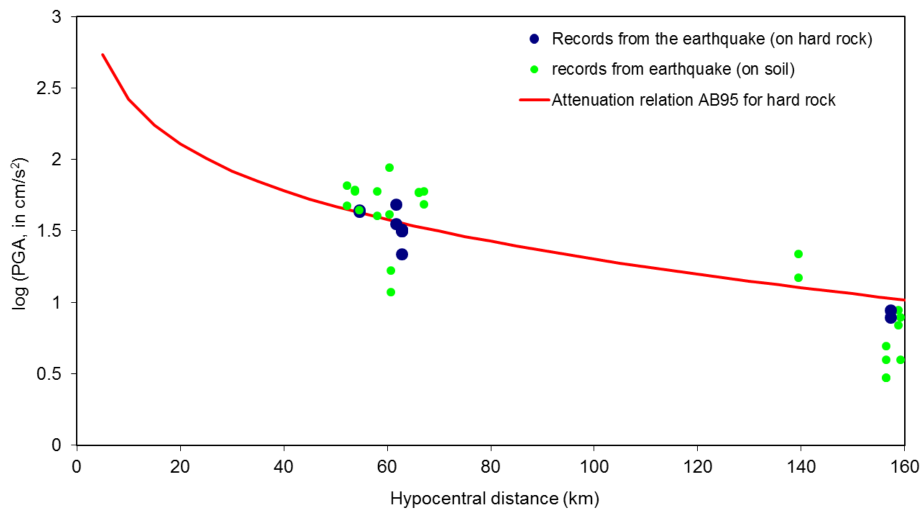

Figure 4.2. Attenuation relation for PGA for hard rock (NEHRP soil class A) used for eastern Canada and PGA values of horizontal components recorded at hard rock sites

4.2.2 Response spectra

In addition to the peak ground motions, acceleration response spectra for 5% damping were computed for the processed records. The 5% damping was selected since it is the most used value in structural engineering. Tables 4.3 and 4.4 list the spectral accelerations for periods of 0.2 second (Sa(0.2)) and 1.0 second (Sa(1.0)) for the records. Sa(0.2) and Sa(1.0) were selected as representative of the responses of short- and intermediate-period structures respectively. As expected, the Sa(1.0) values for the records are much smaller than the Sa(0.2) values.

Table 4.3. List of Sa(0.2) (g) values of the records

Record ID	Station Code	Recording Instrument	Epicentral Distance (km)	Hypocentral Distance (km)	N-S Component	V Component	E-W Component	Soil Class (NEHRP Classification)
Re1	OTT	Etna	58.7	62.8	0.049	0.043	0.077	A
Re2	OTGH	Etna	57.5	61.7	0.037	0.045	0.063	A
Re3	OTNM	Etna	56.2	60.5	0.103	0.060	0.125	C
Re4	OTRS	Etna	48.9	53.8	0.058	0.039	0.066	E
Re5	OT002	IA	47.3	52.3	0.054	0.037	0.053	D
Re6	OT004	IA	63.3	67.1	0.118	0.144	0.149	B
Re7	OT006	IA	53.6	58.1	0.062	0.037	0.079	B
Re8	OT008	IA	62.2	66.1	0.092	0.093	0.073	C
Re9	OT012	IA	58.7	62.8	0.049	0.040	0.079	A
Re10	MO001	IA	157.2	158.8	0.031	0.031	0.020	D
Re11	MO002	IA	157.7	159.3	0.023	0.006	0.011	D
Re12	MO003	IA	154.9	156.5	0.005	0.004	0.004	D
Re13	MO004	IA	154.9	156.5	0.005	0.005	0.005	D
Re14	GAC	Seismometer	21.9	31.3	--*	--*	--*	A
Re15	ORHO	Seismometer	49.4	54.2	--*	--*	--*	E
Re16	ORIO	Seismometer	49.9	54.7	0.019	0.017	0.049	A
Re17	ALFO	Seismometer	56.5	60.8	0.017	0.010	0.014	B
Re18	OTT	Seismometer	58.7	62.8	0.025	--*	--*	A
Re19	TRQ	Seismometer	81.3	84.3	--*	0.007	--*	A
Re20	GRQ	Seismometer	83.3	86.3	--*	wrong recording	--*	A
Re21	WBO	Seismometer	100.1	102.6	--*	0.005	--*	A
Re22	PEMO	Seismometer	137.7	139.5	0.026	0.018	0.015	C
Re23	CRLO	Seismometer	146.1	147.8	--*	0.013	--*	A
Re24	PLVO	Seismometer	155.7	157.3	0.014	0.008	0.010	A

*: the instrument does not record corresponding component.
**: record clipped.

Table 4.4. List of Sa(1.0) (g) values of the records

Record ID	Station Code	Recording Instrument	Epicentral Distance (km)	Hypocentral Distance (km)	N-S Component	V Component	E-W Component	Soil Condition	Soil Class (NEHRP Classification)
Re1	OTT	Etna	58.7	62.8	0.0047	0.0049	0.0075	Bedrock	A
Re2	OTGH	Etna	57.5	61.7	0.0057	0.0044	0.0073	Thin soil	A
Re3	OTNM	Etna	56.2	60.5	0.0160	0.0076	0.0370	Soil	C
Re4	OTRS	Etna	48.9	53.8	0.0610	0.0073	0.0590	Soil	E
Re5	OT002	IA	47.3	52.3	0.0100	0.0046	0.0160	Clay	D
Re6	OT004	IA	63.3	67.1	0.0057	0.0056	0.0072	Clay or Till	B
Re7	OT006	IA	53.6	58.1	0.0045	0.0043	0.0094		B
Re8	OT008	IA	62.2	66.1	0.0047	0.0043	0.0190	Sand	C
Re9	OT012	IA	58.7	62.8	0.0059	0.0056	0.0080	Bedrock	A
Re10	MO001	IA	157.2	158.8	0.0020	0.0017	0.0018		D
Re11	MO002	IA	157.7	159.3	0.0018	0.0016	0.0015		D
Re12	MO003	IA	154.9	156.5	0.0019	0.0016	0.0016		D
Re13	MO004	IA	154.9	156.5	0.0018	0.0018	0.0019		D
Re14	GAC	Seismometer	21.9	31.3	--*	--*	--**		A
Re15	ORHO	Seismometer	49.4	54.2	--**	--**	--**		E
Re16	ORIO	Seismometer	49.9	54.7	0.002	0.002	0.004		A
Re17	ALFO	Seismometer	56.5	60.8	0.002	0.001	0.003		B
Re18	OTT	Seismometer	58.7	62.8	0.003	--**	--**		A
Re19	TRQ	Seismometer	81.3	84.3	--*	0.001	--*		A
Re20	GRQ	Seismometer	83.3	86.3	--*	--*	wrong recording		A
Re21	WBO	Seismometer	100.1	102.6	--*	0.001	--*		A
Re22	PEMO	Seismometer	137.7	139.5	0.001	0.002	0.001		C
Re23	CRLO	Seismometer	146.1	147.8	--*	0.001	--*		A
Re24	PLVO	Seismometer	155.7	157.3	0.001	0.002	0.001		A

*: the instrument does not record corresponding component.

**: record clipped.

Like the PGA values, the computed Sa(0.2) and Sa(1.0) for the horizontal components recorded at hard rock sites were compared with the attenuation relations for spectral accelerations used in the GSC-model for PSHA (Figs. 4.3 and 4.4 respectively). Note that the attenuation relations presented in the figures are also for hard rock sites (NEHRP soil class A). It can be seen in the figures that the current attenuation relations for Sa(0.2) and Sa(1.0) used in the GSC-model for PSHA underestimate the ground motions, especially for Sa(1.0). This finding is consistent with the observations reported in Atkinson and Assatourians (2010).

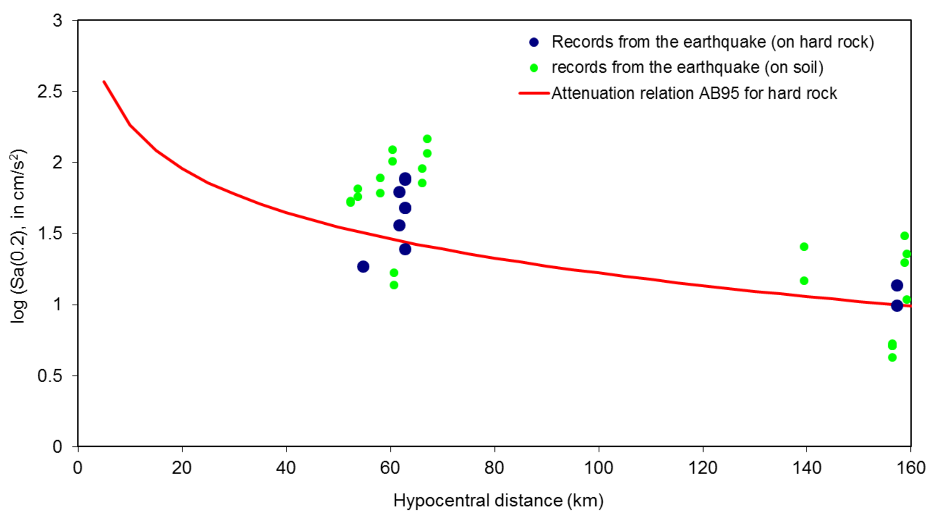

Figure 4.3. Attenuation relation for Sa(0.2) for hard rock (NEHRP soil class A) used for eastern Canada and Sa(0.2) values for horizontal components recorded on hard rock sites

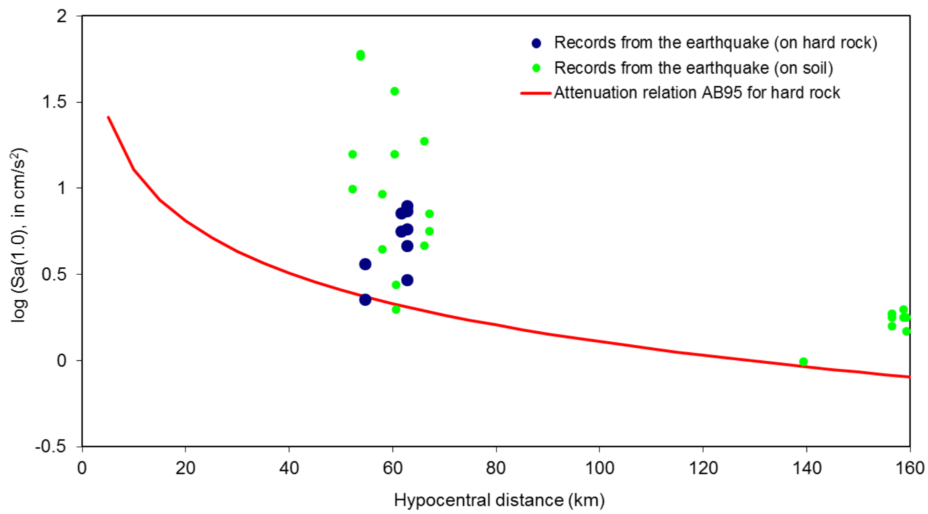

Figure 4.4. Attenuation relation for Sa(0.2) for hard rock (NEHRP soil class A) used for eastern Canada and Sa(0.2) values for horizontal components recorded on hard rock sites

In addition to the comparisons of the PGA, Sa(0.2) and Sa(1.0) of the recorded ground motions from the Val-des-Bois earthquake with those predicted by the current attenuation relations for eastern Canada, it is useful to compare the response spectra of the records with the design spectra prescribed by the 2005 edition of the National Building Code of Canada (NBCC 2005). Figure 4.5 shows the response spectra of the horizontal components recorded on hard rock sites in Ottawa (i.e., components of records Re1, Re2, and Re9 in Tables 4.3 and 4.4). The NBCC 2010 design spectra for Ottawa, for soil class A (hard rock) and soil class C (very dense soil and soft rock) are also shown in the figure. Note that the design spectra correspond to probability of exceedance of 2% in 50 years. It is seen from the figure that the design spectra are significantly higher than the computed spectra, i.e., for periods below 0.2 s, the soil class A spectrum is higher by a factor of about 5, and the soil class C spectrum higher by a factor of about 6.5 than the computed spectra.

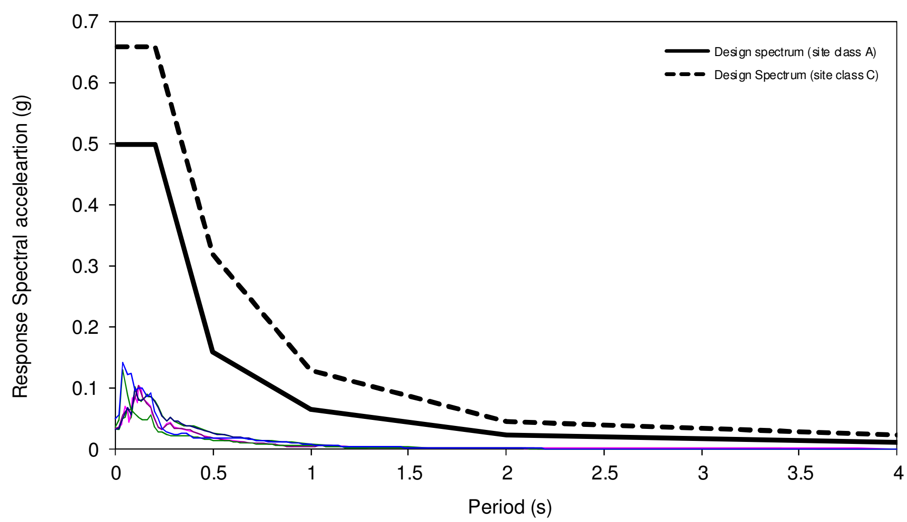

Figure 4.5. Comparison of the response spectra for records obtained on rock sites in Ottawa with the NBCC2010 design spectra for Site Class A and C

5. CONCLUSIONS

A comprehensive project was undertaken by Geological Survey of Canada (GSC) with the objective to compile and process the available records from eastern Canada obtained by the strong-motion network. This paper presents an overview of the compilation of strong-motion records that is underway in GSC. In total 94 strong motion records (i.e., 282 components) obtained during the last decades recorded by Etna and IA instruments have been processed and were selected to load in the Canadian National Waveform Archive. These include the records from the two most significant earthquakes occurred recently in eastern Canada, i.e., the 2005/03/06 Riviere-du-Loup earthquake and the 2011/06/23 Val-des-Bois earthquake. The strong motion records from the Miramichi earthquake and Saguenay earthquake obtained by the SMA-1 instruments are also available on the Earthquakes Canada Website at http://earthquakescanada.nrcan.gc.ca.

The compiled strong-motion records will be very useful for better understanding the seismicity in eastern Canada, the updating of the attenuation relations for ground motions, and in general, for the improvement of the seismic design of structures in Canada.

REFERENCES

Adams, J. (2007). Soil Amplification in Ottawa from Urban Strong Ground Motion Records. *9th Canadian Conference on Earthquake Engineering*, Paper No. 1162, 379-389, Ottawa, Ontario, Canada.

Assatourian, K., and Atkinson, G. M. (2010). Database of processed time series and response spectra data for Canada: an example application to study of 2005 Mn 5.4 Riviere du Loup, Quebec, Earthquake. *Seismological Research Letters*, **81(6):** 1013-1031.

Atkinson, G. M., and Assatourian, K. (2010). Attenuation and source characteristics of the 23 June 2010 M 5.0 Val-des-Bois, Quebec, Earthquake. *Seismological Research Letters*, **81(5):** 849-860.

Atkinson, G. M., and Boore, D. M. 1995. Ground motion relations for eastern North America. *Bulletin Seismology Society of America*, **85(1):** 17-30.

Cassidy, J.F., Rosenberger, A., Rogers, G.C., Little, T.E., Toth, J., Adams, J., Munro, P., Huffmann, S., Pierre, J.R., Asmis, H., Pernica, G. (2007). Strong Motion Seismograph Networks in Canada. *9th Canadian Conference on Earthquake Engineering*, Paper No. 1310, 459-468, Ottawa, Ontraio, Canada.

Munro, P.S., and North, R.G. (1989). The Saguenay Earthquake of November 25, 1988 Strong Motion Data, *Geological Survey of Canada Open File 1976*, Ottawa, Ontario, Canada.

NBCC. (2005). National Building Code of Canada 2005. Institute for Research in Construction, *National Research Council of Canada*, Ottawa, Ontario, Canada.

Rosenberger, A., Rogers, G.C., and Cassidy, J.F. (2007). The New Real Time Reporing Strong Motion Seismograph Network in Southwest BC: More Strong Motion Instruments for less Money, *9th Canadian Conference on Earthquake Engineering*, Ottawa, Ontario, Canada.

Weichert, D.H., Pomeroy, P.W., Munro, P.S., and Mork, P.N. (1982). Strong Motion Records from Miramichi, New Brunswick, 1982 Aftershocks, *Earth Physics Branch Open File 82-31*, Ottawa, Ontario, Canada.