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Engineering Characteristics of Ground Motion Records of the Val-des-Bois, Quebec, Earthquake of June 23, 2010

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Abstract: The magnitude (Mw) 5.0 Val-des-Bois earthquake that occurred in Quebec on June 23, 2010, was the biggest recent earthquake in Eastern Canada. It produced the strongest shaking ever felt in Ottawa. The ground shaking was widely felt in Ontario and Quebec, and it was also felt into the US as far as Kentucky. A number of ground motion records from this event were obtained through the ground-motion monitoring network operated by the Geological Survey of Canada. These records are very useful for understanding the characteristics of earthquake ground motions in Eastern Canada. This paper presents results from the analysis of the records obtained at epicentral distances less than 200 km. The engineering parameters considered in this study include peak ground motions (acceleration, velocity, and displacement) and response spectra of the recorded motions. The response spectra of the records are compared with the design spectra for different soil conditions prescribed by the 2010 edition of the National Building Code of Canada (NRCC 2010) for Ottawa. In addition, the attenuation of the recorded peak ground acceleration and spectral accelerations at periods of 0.2 s and 1.0 s, are compared with the relationships used for NBCC2010 in Eastern Canada.

1. Introduction

The epicentre of the Val-des-Bois earthquake was at latitude of 45.90 and longitude of 75.50 with its hypocentre at depth of 22.4 km. The ground motions were widely felt in Ontario and Quebec, and it was also felt into the US as far as Kentucky. It was about 60 km from Ottawa, where it caused damage to building 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 shaking was probably stronger than that from the 1944 Mw 5.8 Cornwall earthquake (which was recorded only by an analog seismometer in Ottawa) and thus produced the strongest shaking ever felt in Ottawa.

This paper describes the engineering characteristics of the ground motion records obtained during the earthquake. The records were obtained by instruments operated by the Geological Survey of Canada (GSC) which were accelerometers (Etna and Internet-accelerometer (IA) instruments) and seismometers. Ground motions were recorded by 4 Etnas, 9 IAs, and a number of seismometers, some of which are 3-component like the accelerometers, while others only record the vertical component. Only records within 200 km of the epicentre are considered in this paper. Most are considered to be free-field motions. The ground motion data are available in Lin and Adams (2010a, 2010b). In addition to the records discussed here, there are also records made within the buildings of Parliament (Lin et al., 2011) which reach structurally-amplified values of 0.49 g; while those records made at ground level have similar PGA amplitudes to the free-field records, but they are likely to include Soil-Structure Interaction (SSI) effects.

2. Station Information

The locations of the stations which recorded the ground motions considered in this paper are shown in Figure 1. Tables 1, 2 and 3 list the basic information (station code, coordinates of stations, epicentral distances, and soil conditions) for the Etna stations, the IA stations, and the seismometer stations respectively. The soil class given in each of the tables is adjusted from Assatourians and Atkinson (2010) but needs to be confirmed in the future. As shown in the tables, most of the stations are on NEHRP soil class A (hard rock with shear wave velocity Vs>1500 m/s), and only two stations are on NEHRP soil class E (soft soil, clay, Vs<180 m/s).

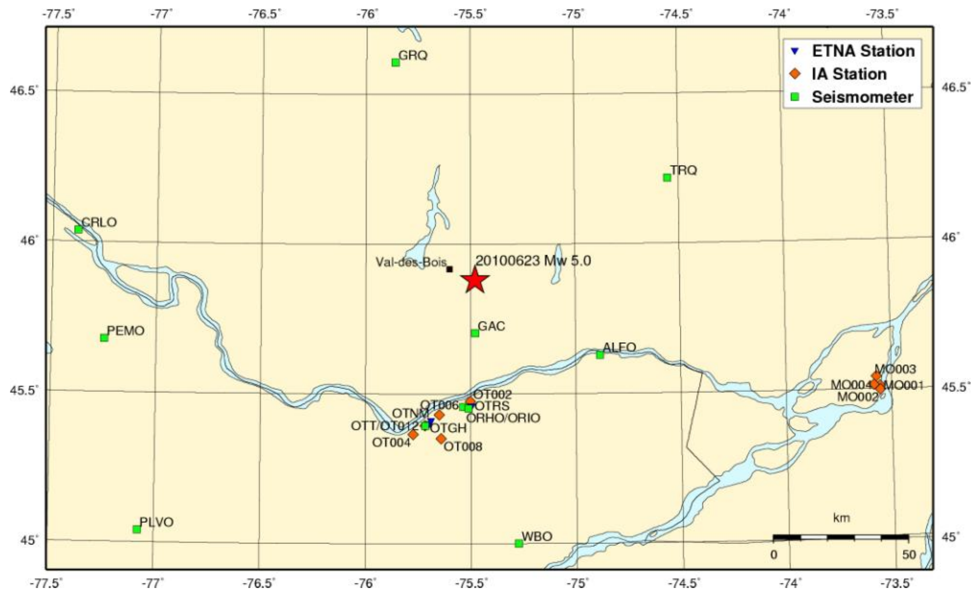

Figure 1: Locations of stations.

Table 1: List of Etna stations.

No.	Station Code	Station Name	Coordinates		Elevation (m)	Soil Condition	Soil Class (NEHRP classification)
1	OTT	Ottawa, Ontario	45.3942 N	75.7167 W	77	Rock	A
2	OTGH	Ottawa, Ontario	45.4014 N	75.6969 W	74	Thin soil	A
3	OTNM	Ottawa, Ontario	45.4121 N	75.6891 W	72	Soil	C
4	OTRS	Orleans, Ontario	45.4603 N	75.4962 W	90	Soil	E

Table 2: List of IA stations.

No.	Station Code	Station Name	Coordinates		Elevation(m)	Soil Condition	Soil Class (NEHRP classification)
1	OT002	Ottawa, Ontario	45.4742 N	75.5019 W	84	Clay	D
2	OT004	Ottawa, Ontario	45.3644 N	75.7746 W	78	Clay or Till	B
3	OT006	Ottawa, Ontario	45.4292 N	75.6500 W	68		B
4	OT008	Ottawa, Ontario	45.3496 N	75.6418 W	80	Sand	C
5	OT012	Ottawa, Ontario	45.3942 N	75.7167 W	77	Rock	A
6	MO001	Montreal, Québec	45.5099 N	73.5534 W	61	Clay	D
7	MO002	Montreal, Québec	45.4962 N	73.5533 W	26	Sand	D
8	MO003	Montreal, Québec	45.5430 N	73.5714 W	52	Remblais	D
9	MO004	Montreal, Québec	45.5125 N	73.5841 W	84		D

Table 3: List of Seismometer stations.

No.	Station Code	Station Name	Coordinates		Elevation (m)	Soil Condition	Soil Class (NEHRP classification)
1	GAC	Glen Almond, Québec	45.7033 N	75.4783 W	62	Rock	A
2	ORHO	Orleans, Ottawa, Ontario	45.4563 N	75.5367 W	51	Soil	E
3	ORIO	Orleans, Ottawa, Ontario	45.4515 N	75.5111 W	74	Rock	A
4	ALFO	Alfred, Ontario	45.6283 N	74.8842 W		Till ?	B
5	OTT	Ottawa, Ontario	45.3942 N	75.7167 W	77	Rock	A
6	TRQ	Mont-Tremblant, Québec	46.2175 N	74.5514 W	864	Rock	A
7	GRQ	Grand-Remous, Québec	46.6067 N	75.8600 W	290	Rock	A
8	WBO	Williamsburg, Ontario	45.0003 N	75.2750 W	85	Rock	A
9	PEMO	Pembroke, Ontario	45.6773 N	77.2466 W	180	Soil	C
10	CRLO	Chalk River, Ontario	46.0375 N	77.3801 W	168	Rock	A
11	PLVO	Plevna, Ontario	45.0396 N	77.0754 W		Rock	A

2. Instrument Characteristics

For the purpose of the data processing it is important to know the characteristics of the instruments, so the characteristics of the Etna, IA, and Seismometer instruments used at the time of the Val-des-Bois earthquake are summarized below.

2.1 Etna Instruments

- Data type: acceleration.
- Number of components recorded: two orthogonal horizontal components and one vertical (designated V) component. The horizontal components of all Etnas are oriented North-South (N-S) and East-West (E-W).
- Sampling rate: 200 samples per second, i.e., the time interval of the recorded data is 0.005 s.
- Units: the data recorded by Etna are in units of Volts; note that 1.25 Volt=1 g.

2.2 IA Instruments

- Data type: acceleration.
- Number of components recorded: two orthogonal horizontal components (N-S and E-W) and one vertical component (V).
- Sampling rate: 100 samples per second, i.e., the time interval of the recorded data is 0.01 s.
- Units: the data recorded by IA are in the units of Counts. The conversion factor from Counts to acceleration in g is different for different components and different stations.

2.3 Seismometers

- Data type: velocity.
- Number of components recorded: Each record consists of the single vertical component (V) for the short period instruments using S-13 seismometers or three components, i.e., two orthogonal horizontal components (N-S and E-W) and one vertical component (V) for the instruments using Guralp CMG-3 seismometers.
- Sampling rate: 100 samples per second, i.e., the time interval of the recorded data is 0.01 s.
- Units: the data recorded by Seismometer are in units of Counts. The calibration factor to convert Counts to m/s^2 differs for different stations.

3. Data Processing

The recorded data are normally called "raw" or "uncorrected" data and they 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 procedure for the data processing depends on the type of instrument. The two main phases of the data processing are baseline correction and filtering.

The baseline correction is necessary to remove the offset of the record, i.e., any initial shift of the record from the zero line that might be present is removed from the record. This shift can be easily quantified based on the pre-event segment of the record.

The filtering 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 are available that can be used in the filtering of records. In this paper, a band-pass Butterworth filter of the order of 4, with high-pass frequency of 0.1 Hz, and low-pass frequency of 40 Hz was used.

4. Discussion of Results

4.1 Peak Ground Motions

The peak ground accelerations (PGA), the peak ground velocities (PGV), and the peak ground displacements (PGD) of the recorded components considered in this paper are given in Tables 4, 5 and 6 respectively. It is seen in Table 4 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). The maximum PGA value of the records in Ottawa is 0.089 g. Tables 5 and 6 show that the PGV values of the records are between 0.07 and 4.8 cm/s, while the PGD values are between 0.004 and 0.43 cm. 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 amplifications of the PGA, PGV and PGD values on soft soil relative to those on hard rock of about 2.0 (Tables 4 to 6). It is necessary to mention that PGV and PGD values are very sensitive to the integration process, and may be unreliable when the ground motion amplitudes are very small and/or when the signals have high noise levels. For example past experience with the IA sensors suggests that the PGD values from IA station OT012 are less reliable than those from the co-located OTT Etna and seismometer.

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) employed by the Geological Survey of Canada (GSC) for modelling probabilistic seismic hazard analysis (PSHA) in Eastern Canada. Figure 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) 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 quite well the adopted attenuation curve. Note that a similar comparison is not possible for other types of soil conditions and other peak ground motions (PGV, PGD).

Table 4: 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

Table 5: Peak ground velocities (PGV) of the records.

Record ID	Station Code	Recording Instrument	Epicentral Distance (km)	Hypocentral Distance (km)	PGV (cm/s)			Soil Class (NEHRP classification)
					N-S component	V component	E-W component	
Re1	OTT	Etna	58.7	62.8	0.94	1.08	1.37	A
Re2	OTGH	Etna	57.5	61.7	0.75	0.74	1.12	A
Re3	OTNM	Etna	56.2	60.5	1.80	1.79	4.80	C
Re4	OTRS	Etna	48.9	53.8	2.19	1.10	1.79	E
Re5	OT002	IA	47.3	52.3	1.26	0.70	1.77	D
Re6	OT004	IA	63.3	67.1	2.02	1.93	2.43	B
Re7	OT006	IA	53.6	58.1	0.87	0.75	1.46	B
Re8	OT008	IA	62.2	66.1	1.37	1.36	2.75	C
Re9	OT012	IA	58.7	62.8	1.06	1.00	1.45	A
Re10	MO001	IA	157.2	158.8	0.28	0.33	0.32	D
Re11	MO002	IA	157.7	159.3	0.33	0.20	0.25	D
Re12	MO003	IA	154.9	156.5	0.29	0.25	0.22	D
Re13	MO004	IA	154.9	156.5	0.27	0.24	0.24	D
Re14	GAC	Seismometer	21.9	31.3	--*	--*	--**	A
Re15	ORHO	Seismometer	49.4	54.2	--**	--**	--**	E
Re16	ORIO	Seismometer	49.9	54.7	0.35	0.37	0.81	A
Re17	ALFO	Seismometer	56.5	60.8	0.45	0.32	0.43	B
Re18	OTT	Seismometer	58.7	62.8	0.47	--**	--**	A
Re19	TRQ	Seismometer	81.3	84.3	--*	0.13	--*	A
Re20	GRQ	Seismometer	83.3	86.3	--*	--*	wrong recording	A
Re21	WBO	Seismometer	100.1	102.6	--*	0.07	--*	A
Re22	PEMO	Seismometer	137.7	139.5	0.35	0.22	0.18	C
Re23	CRLO	Seismometer	146.1	147.8	--*	0.16	--*	A
Re24	PLVO	Seismometer	155.7	157.3	0.17	0.15	0.16	A

*: the instrument does not record corresponding component.

**:record clipped.

Table 6: Peak ground displacements (PGD) of the records.

Record ID	Station Code	Recording Instrument	Epicentral Distance (km)	Hypocentral Distance (km)	PGD (cm) N-S component	V component	E-W component	Soil Class (NEHRP classification)
Re1	OTT	Etna	58.7	62.8	0.06	0.10	0.12	A
Re2	OTGH	Etna	57.5	61.7	0.06	0.08	0.11	A
Re3	OTNM	Etna	56.2	60.5	0.18	0.10	0.43	C
Re4	OTRS	Etna	48.9	53.8	0.23	0.05	0.21	E
Re5	OT002	IA	47.3	52.3	0.27	0.21	0.24	D
Re6	OT004	IA	63.3	67.1	0.25	0.27	0.18	B
Re7	OT006	IA	53.6	58.1	0.27	0.22	0.24	B
Re8	OT008	IA	62.2	66.1	0.36	0.35	0.28	C
Re9	OT012	IA	58.7	62.8	0.24	0.20	0.16	A
Re10	MO001	IA	157.2	158.8	0.17	0.28	0.20	D
Re11	MO002	IA	157.7	159.3	0.23	0.17	0.19	D
Re12	MO003	IA	154.9	156.5	0.30	0.16	0.17	D
Re13	MO004	IA	154.9	156.5	0.22	0.18	0.19	D
Re14	GAC	Seismometer	21.9	31.3	--*	--*	--**	A
Re15	ORHO	Seismometer	49.4	54.2	--**	--**	--**	E
Re16	ORIO	Seismometer	49.9	54.7	0.02	0.03	0.07	A
Re17	ALFO	Seismometer	56.5	60.8	0.05	0.02	0.04	B
Re18	OTT	Seismometer	58.7	62.8	0.04	--**	--**	A
Re19	TRQ	Seismometer	81.3	84.3	--*	0.005	--*	A
Re20	GRQ	Seismometer	83.3	86.3	--*	--*	wrong recording	A
Re21	WBO	Seismometer	100.1	102.6	--*	0.004	--*	A
Re22	PEMO	Seismometer	137.7	139.5	0.03	0.03	0.02	C
Re23	CRLO	Seismometer	146.1	147.8	--*	0.01	--*	A
Re24	PLVO	Seismometer	155.7	157.3	0.02	0.02	0.02	A

*: the instrument does not record corresponding component.

**: record clipped.

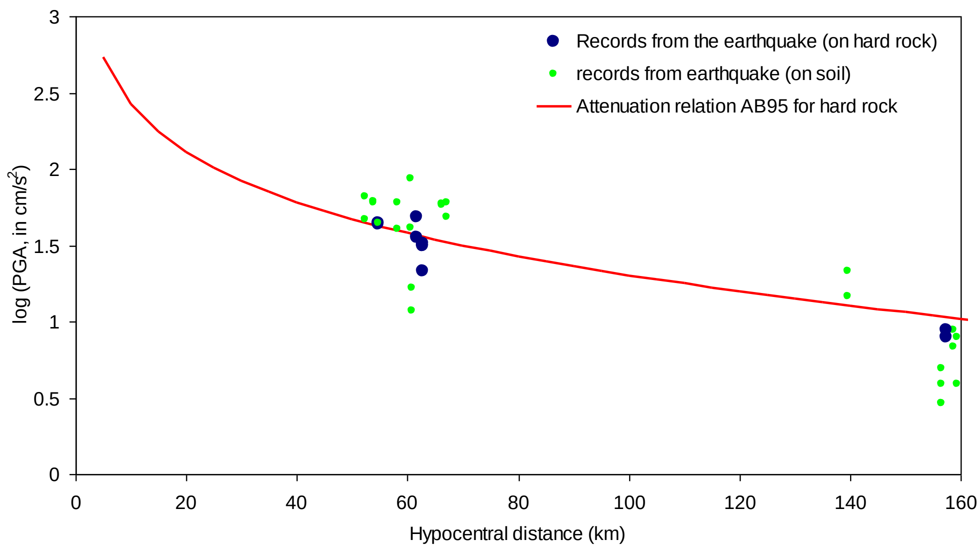

Figure 2: Attenuation relation for PGA for hard rock (NEHRP soil class A) used for Eastern Canada together with PGA values of horizontal components recorded at hard rock and soil sites.

4.2 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 7 and 8 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 7: 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 8: 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. The comparisons for Sa(0.2) and Sa(1.0) are shown in Figures 3 and 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).

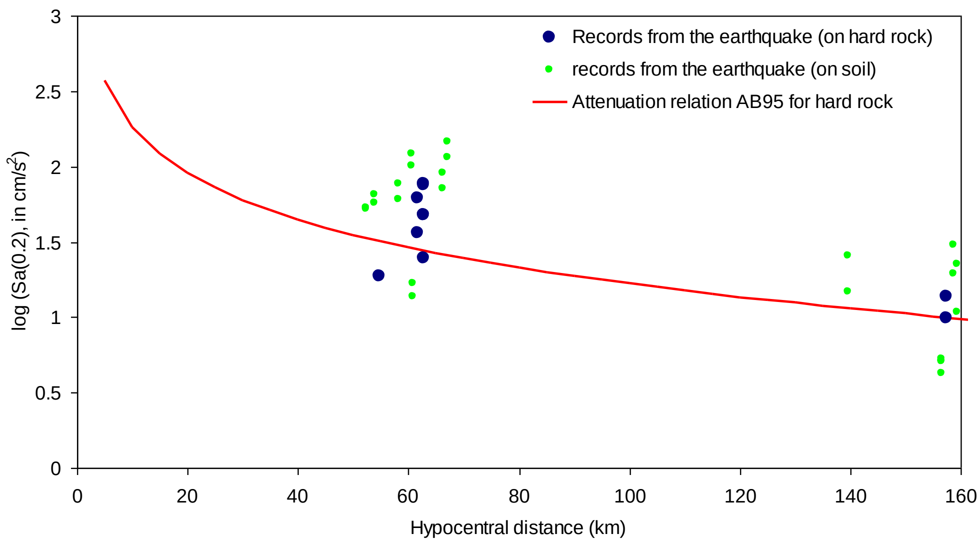

Figure 3: Attenuation relation for Sa(0.2) for hard rock (NEHRP soil class A) used for Eastern Canada together with Sa(0.2) values for horizontal components recorded at hard rock and soil sites.

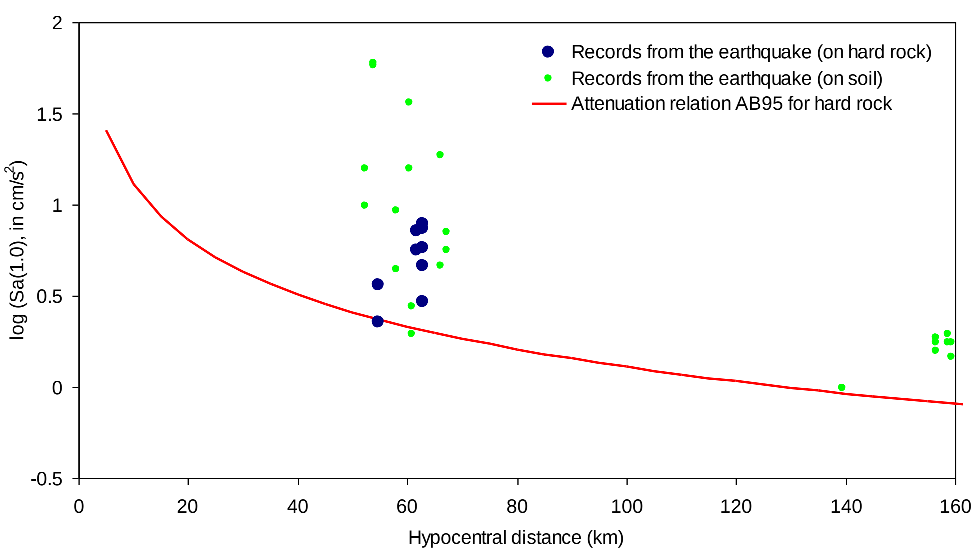

Figure 4: Attenuation relation for Sa(1.0) for hard rock (NEHRP soil class A) used for Eastern Canada together with Sa(1.0) values for horizontal components recorded at hard rock and soil sites.

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 (NBCC2010). Figure 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 7 and 8). The NBCC2010 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 by a factor of about 6.5 than the computed spectra. These factors are consistent with the observed amplitudes of the Val-des-Bois shaking (adjusted to Site Class C) being about 1/150 year shaking according to the NBCC2010 seismic hazard model (Figure. 6).

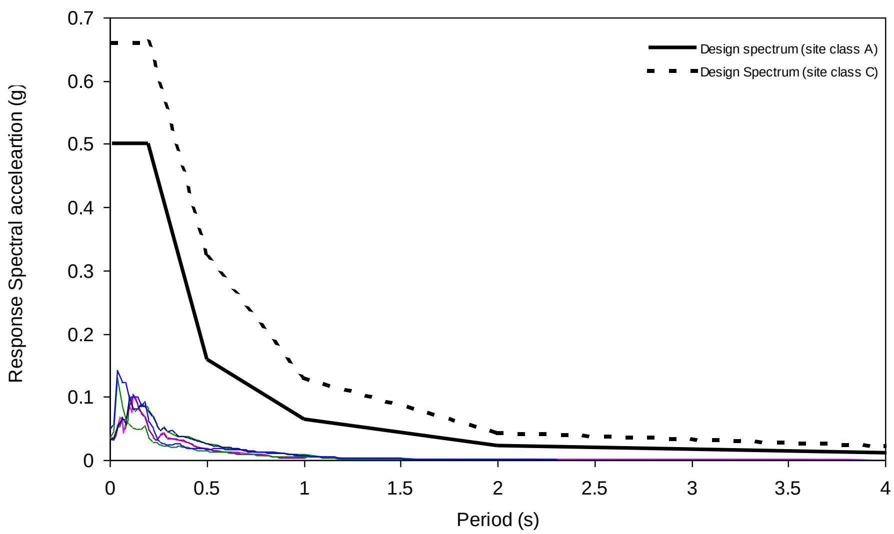

Figure 5: Comparison of the response spectra for records obtained at hard rock sites in Ottawa with the NBCC2010 design spectra for Site Class A and C.

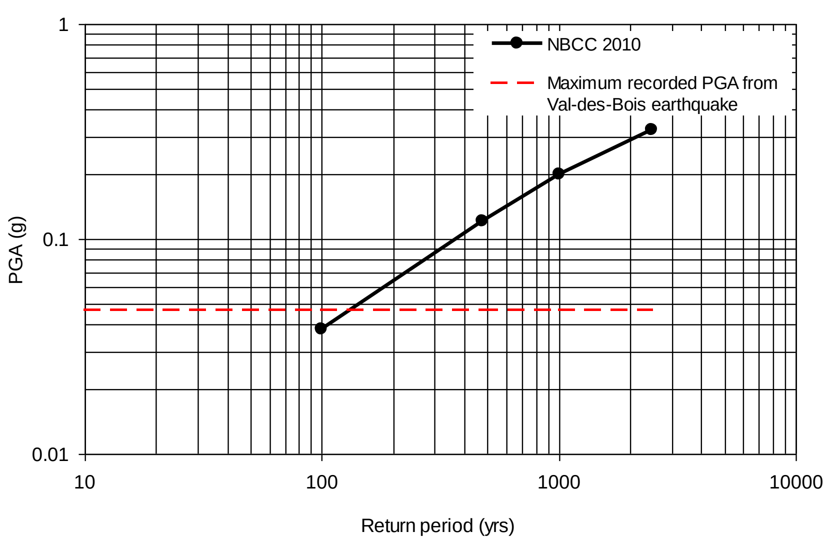

Figure 6: Hazard curve for PGA on Site Class C in Ottawa, showing that the Val-des-Bois earthquake shaking represents about the 1/150 year shaking level.

5. Summary and Conclusions

Fifty-five components of ground motion were recorded at close (<200 km) epicentral distances and on different soil conditions during the Val-des-Bois earthquake of June 23, 2010. All the records obtained were processed to determine the corrected acceleration, velocity, and displacement time histories and response spectra for the ground motions. The summary parameters include peak ground acceleration (PGA), peak ground velocity (PGV), peak ground displacement (PGD), and 5% damped spectral accelerations for periods of 0.2 s and 1.0 s. The computed PGA, Sa(0.2) and Sa(1.0) for the records obtained at hard rock sites were compared with the currently-used attenuation relations. The main findings are summarized below:

- For PGA, the maximum amplification of the horizontal motions on soft soil deposits relative to hard rock is about 2.0.
- The AB95 relations attenuation relations for peak ground accelerations at hard rock in Eastern Canada predict the Val-des-Bois earthquake peak ground accelerations reasonably well.
- However, the AB95 attenuation relations for spectral accelerations at periods of 0.2 s and 1.0 s, significantly underestimate the recorded spectral accelerations.
- The response spectra of the Val-des-Bois recorded motions are significantly lower than the design spectra specified in the National Building Code of Canada, and are consistent with the Val-des-Bois motions in Ottawa having an annual probability of about 1/150 years.

6. References

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*, Vol. 81, Number 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*, Vol. 81, Number 5, 849-860.

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

Lin, L. and Adams, J. 2010a. Strong motion records of the Val-des-Bois, Québec, Earthquake of June 23, 2010. *Canadian Hazard Information Service Internal Report 2010-1.1*, 20 pages. Available 2010/ 06/25 at http://earthquakescanada.nrcan.gc.ca/recent_eq/2010/20100623.1741/index-eng.php

Lin, L. and Adams, J. 2010b. Strong motions records from nearby seismometer records of the Val-des-Bois, Québec, Earthquake of June 23, 2010. *Canadian Hazard Information Service Internal Report 2010-2.1*, 23 pages. Available 2010/07/ 12 at http://earthquakescanada.nrcan.gc.ca/recent_eq/2010/20100623.1741/index-eng.php

Lin, L. and Adams, J. Paquette, J., Glazer, R. and Duchesne, D., 2011. Dynamic characteristics of three major towers on Parliament Hill, Ottawa, from vibrations recorded during the Val-des-Bois, Quebec, Earthquake of June 23, 2010. *2011 Annual Conference of the Canadian Society for Civil Engineering*, Ottawa, Ontario, June 14-17, 2011, paper 173, 10pp.

NRCC. 2010. National Building Code of Canada 2010. Institute for Research in Construction, *National Research Council of Canada*, Ottawa, Ontario.