Induced Seismicity Monitoring Project (ISMP): October 2017-March 2018 Report

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Contents

Executive Summary

With the addition of seismographic stations in recent years, our ability to monitor induced seismicity in northeast British Columbia (NE BC) has improved significantly. Moreover, through collaboration with universities, energy companies, and regulatory bodies from other jurisdictions recorded waveforms at near field has enabled detailed analysis of ground-motion amplitudes and their potential seismic hazard to structures in the vicinity of operations. In this report, I provide an update on seismic monitoring in northeast British Columbia for the period October 2017 to April 2018. In the previous report (Babaie Mahani, 2018), seismic activity in NE BC for the period January 2016 to October 2017 were shown. In this paper, I provide the earthquake catalog since October 2017 to April 2018 and give explanations on distribution of the events in the area. Moreover, analysis of near field ground-motion amplitudes is then presented followed by the list of presentations and publications by the members of the BC Seismic Research Consortium. Finally, a brief explanation of the current research related to induced seismicity is given.

Update on Seismic Monitoring in Northeast BC

Currently the seismographic station NAB1 (Figure 1) of the enhanced monitoring network is out of service. Field analysis by the service provider (Nanometrics Inc.) indicated that 1) one solar panel needs replacement due to corrosion 2) the 15-amp breaker needs replacement 3) the battery bank will require replacement 4) a new solar controller should be installed to have the station back in service.

In order to have a better control on the process of earthquake detection in northeast British Columbia (NE BC), a new system (SeisComp3; Figure 2) for data acquisition, processing, and automatic location has been configured at the Pacific Geoscience Center in Sidney, BC. SeisComp3 has been an essential part of earthquake monitoring in Europe in the past decade and proven to be a vital tool in applications such as early warning systems and rapid identification of earthquakes. Moreover, we are in the process of configuring a system for NE BC which provides maps of shaking parameters such as peak ground acceleration across the area following relatively larger events. The automated system will use waveforms to generate ground motion maps within ~5 minutes of receiving the earthquake information.

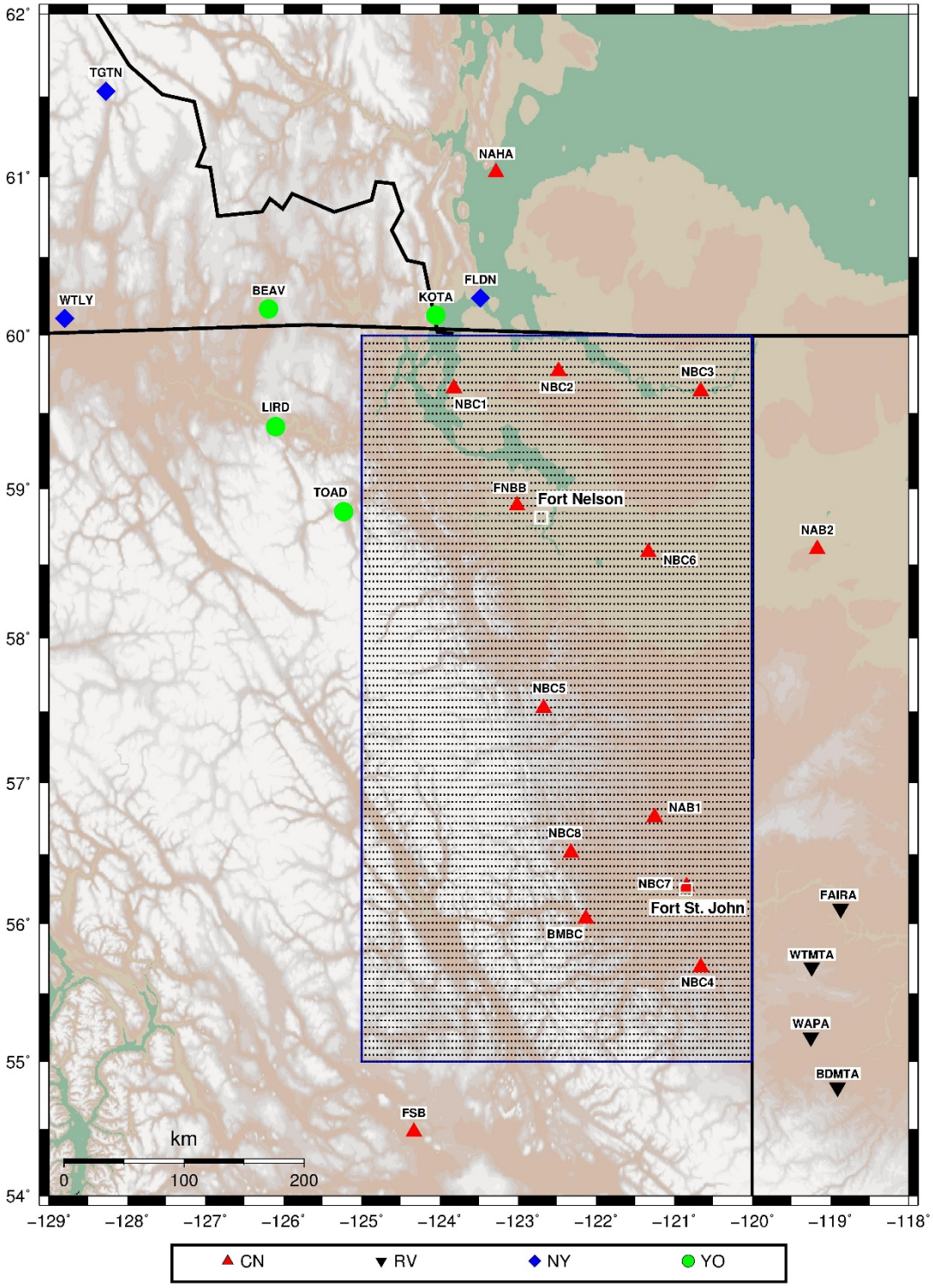

Figure 1. Distribution of seismographic stations. The gridded area marks northeast BC. CN is the Canadian National Seismic Network, RV is the Regional Alberta Observatory for Earthquake Studies Network, NY is the Yukon Northwest Seismic Network, YO is the Yukon Geological Survey Seismic Network.

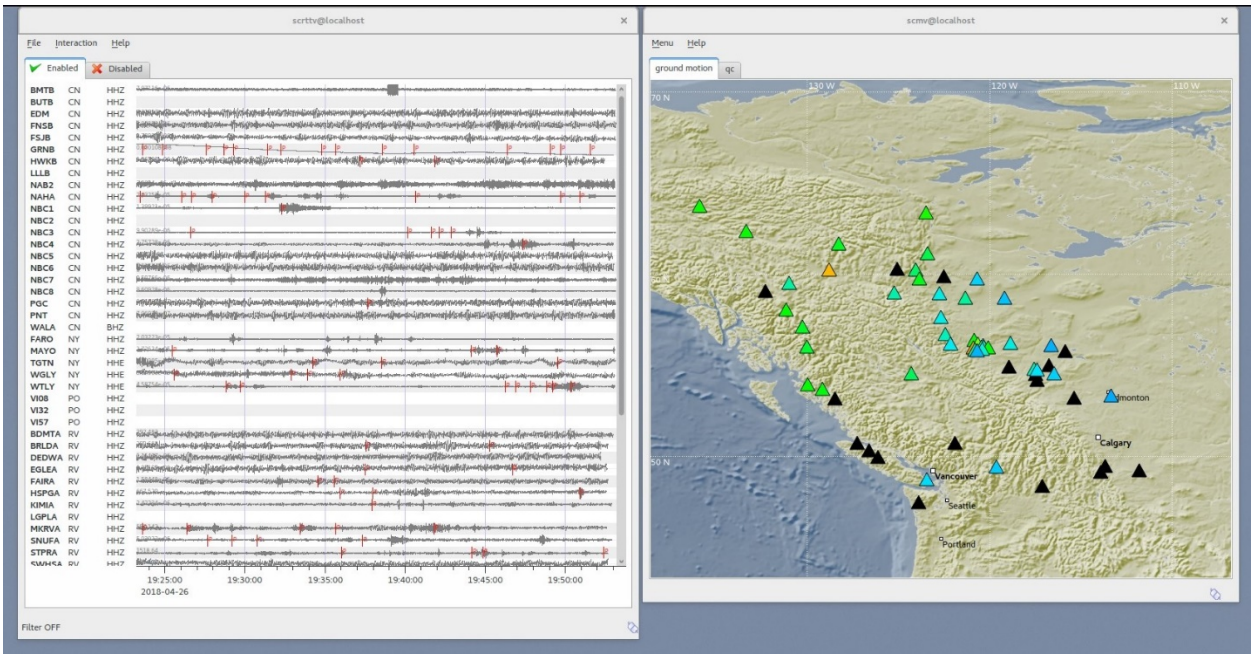

Figure 2. SeisComp3 components. (left) real-time data acquisition from various seismographic networks in western Canada. (right) distribution of seismographic stations.

Seismicity between October 2017 and April 2018

Figure 3 shows the events occurred in NE BC. The map on the left shows the events between January 2016 and October 2017 (355 earthquakes) while the map on the right plots the events from October 2017 to April 2018. Total of 84 events were reported in the Natural Resource Canada (NRCan) earthquake catalogue since October 2017 with local magnitude of 1.4 to 3.7.

Distribution of the events is similar between the two time periods shown in Figure 3 with some exceptions. There are some events north of Fort St. John that occurred during the second period while the area marked as cluster 5 in the first period has been quiet since then. Similar to the first period, most of the events occurred in the Montney Play (51 events, orange circle) and clustered in areas of Doe-Dawson, Fort St. John, Altares, Graham, Town, and Caribou (Figure 3, right). As with the first period, There are also other clusters to the south and southwest of the Montney Play; 26 events occurred in clusters to the south of the Montney Play (blue circle) and 6 events occurred in a cluster to the southwest of the Montney Play (green circle). As mentioned in the 2016-2017 report (Babaie Mahani, 2018), the source of earthquakes to the south and southwest of the Montney Play can be either related to quarry blasts or natural.

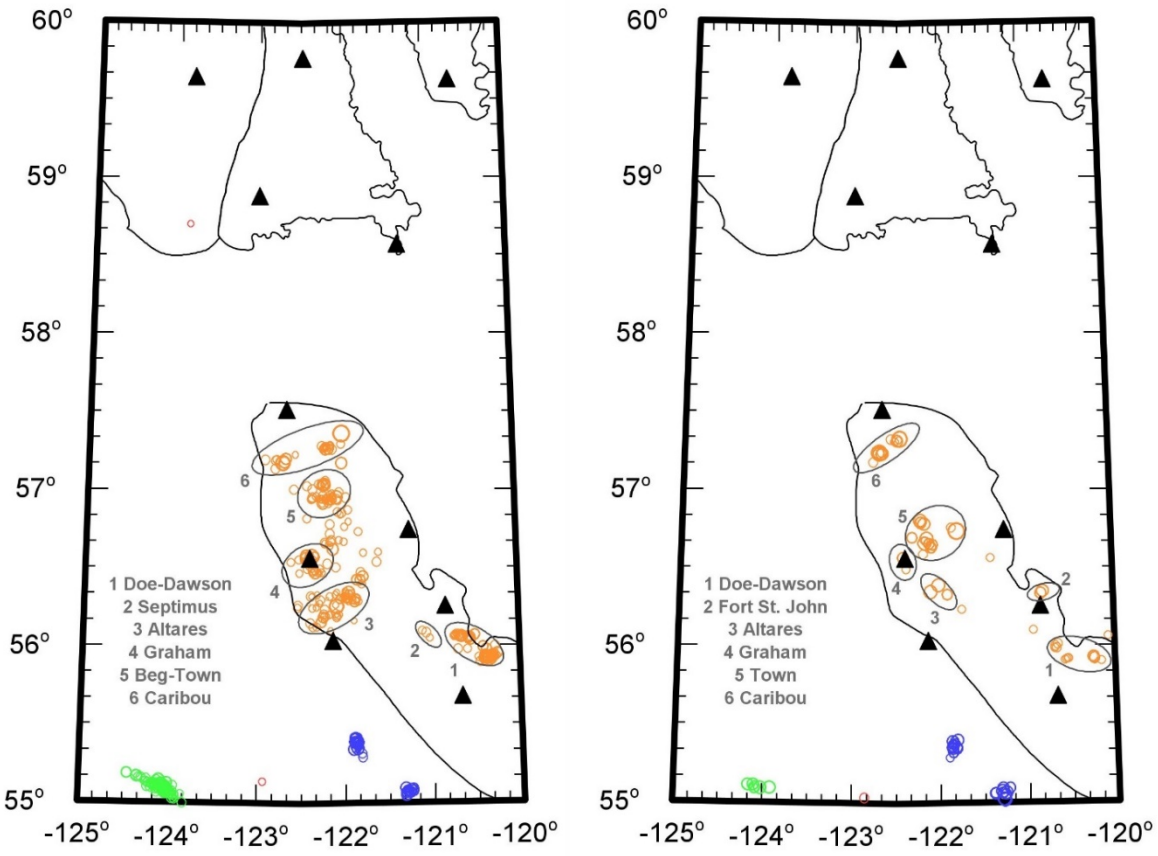

Figure 3. Events reported in the Natural Resources Canada earthquake catalogue in northeast British Columbia between January 2016 and October 2017 (left) and October 2017 to April 2018 (right).

Figure 4 shows the magnitude distribution of the events shown in Figure 3 (right). Events in the Montney Play follow a normal distribution with an average magnitude of ~2.4, while the two other clusters slightly skew towards higher magnitudes although this can be due to the higher magnitude of completeness for areas outside of the well-covered seismographic network in NE BC (Babaie Mahani, 2018).

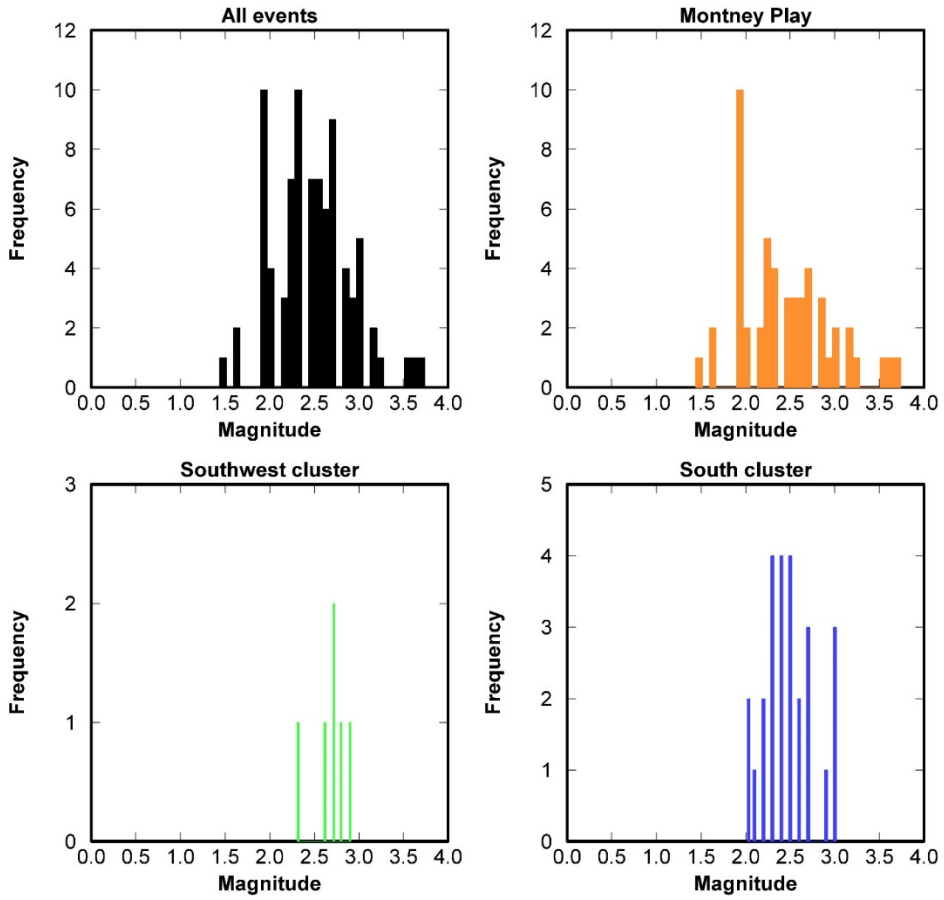

Figure 4. Histogram of the magnitude distribution of the clusters shown in Figure 15 (right). Black shows all the events in northeast British Columbia between October 2017 and April 2018 while orange, green, and blue represent the events in the Montney Play, the cluster to the southwest, and the cluster to the south of the Montney Play, respectively.

Near Field Ground Motion Analysis

Although there has been extensive research to analyze the relationship between fluid injection and induced seismicity, an exact cause-and-effect relation is still missing. This is important for infrastructure with long life times that are initially designed and built in areas with low natural seismicity rates. With the increase in development of unconventional hydrocarbon resources in the past decade, areas such as Oklahoma are now experiencing a high level of seismicity with several relatively large earthquakes. Large ground-motion amplitudes recorded at near field from induced earthquakes show that ground motions from events with magnitudes in the range of 4 to 5 can be damaging. Examples of these large ground motions in central U.S. are the October 2, 2014 Kansas earthquake with moment magnitude (**M**) 4.3 with the maximum horizontal peak ground acceleration (PGA) of 720 cm/sec2 at epicentral distance of 1.1 km and the October 10, 2015 Cushing earthquake (**M** 4.5) with the maximum horizontal PGA of 587 cm/sec2 at epicentral distance of 4.7 km (Huang et al., 2017). In the northern Montney Play of NE BC, Babaie Mahani et al. (2017) estimated the PGA of the August 17, 2015, **M** 4.6 event to be ~170 cm/sec2 at epicentral distance of ~5 km.

Figure 5 shows the response spectral acceleration (PSA) from events recorded in the hypocentral distance ranges of 0-5 (Figure 5a and b) and 5-10 km (Figure 5c and d) in NE BC. Although geometric mean of the two horizontal measurements has widely been used in ground motion analysis and prediction equations, the median orientation-independent, non-geometric mean measure of horizontal motion (RotD50; Boore, 2010) has been utilized in the Next Generation Attenuation models (e.g. Ancheta et al, 2014). For detailed structural analysis, however, it has been suggested that the maximum value or RotD100 to be used (Shahi and Baker, 2014). In Figure 5, the RotD100 values are plotted. Also shown are the ground motions associated with modified mercalli intensity (MMI) of VI, which can be indicative of the start of damage (Worden et al., 2012; Atkinson, 2017). It is clear in Figure 5 that ground-motion amplitudes from small earthquakes in NE BC are below the MMI threshold for damage at the hypocentral distance of 5 to 10 km. At shorter hypocentral distances, ground motions may reach the MMI VI at high frequencies (e.g. PGA). As mentioned in Atkinson (2017), it seems that seismic hazard from small magnitude induced earthquakes may only be a high-frequency hazard. This is also consistent with the findings of Babaie Mahani and Kao (2018) who calculated the strong motion duration for induced events in NE BC and found that the duration of relatively large ground-motion amplitudes (e.g. above 50 cm/sec2) is only a fraction of a second.

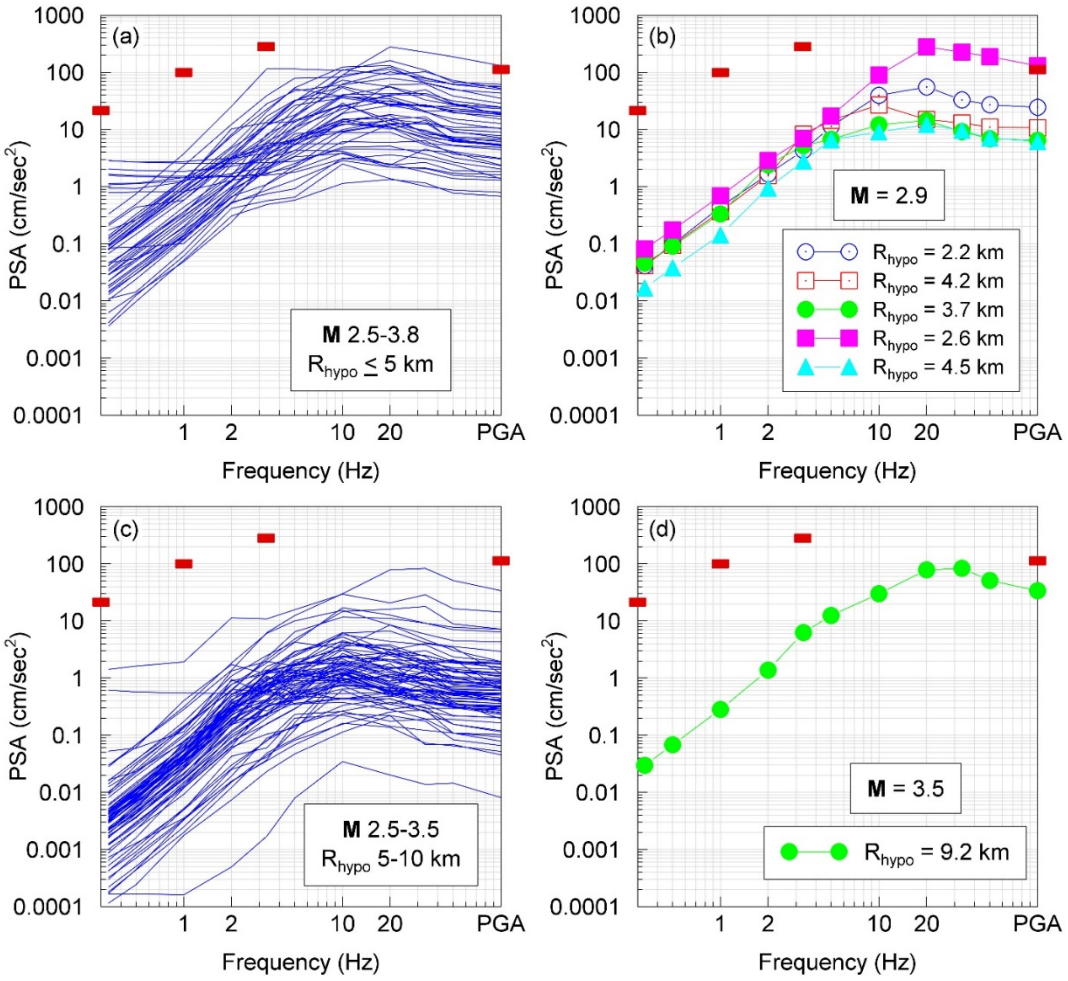

Figure 5. Response spectral acceleration (PSA) for the maximum orientation-independent, non-geometric mean measure of horizontal components (RotD100; Boore, 2010) versus frequency. Peak ground acceleration (PGA) was obtained at the highest frequency depending on the sampling rate at each station. (a) PSA values from events with moment magnitude (M) 2.5-3.8 recorded at hypocentral distance (Rhypo) < 5 km. (b) PSA values for an M 2.9 event recorded at Rhypo < 5 km. (c) PSA values from events with M 2.5-3.5 recorded at Rhypo between 5 and 10 km. (d) PSA values for an M 3.5 event recorded at Rhypo between 5 and 10 km. Solid rectangles show the ground-motion amplitudes associated with the modified mercalli intensity of VI based on relations provided by Worden et al. (2012).

Communication and Extension Plan

The members of the BC Seismic Research Consortium have presented the following papers or presentations throughout October 2017 and April 2018.

Presentations:

- Analysis of Near Field Ground Motion Amplitudes in Northeast British Columbia, 11th BC Unconventional Gas Technical Forum, Victoria, BC, April 24, 2018 (Ali Mahani, Project Seismologist)

Technical Papers:

- Babaie Mahani, A. (2018). Analysis of Near-Field Ground Motion Amplitudes in Northeast British Columbia, Canada, submitted to Pure and Applied Geophysics.
- Babaie Mahani, A. and H. Kao (2018). Attenuation of Ground-Motion Amplitudes from Small-Magnitude Earthquakes in the Montney Play, Northeastern British Columbia; in Geoscience BC Summary of Activities 2017, Energy, Geoscience BC, Report 2018-4, p. 15-22.

Current Research

Several projects are currently being performed by the members of the BC Seismic Research Consortium. These include evaluation of the process of automatic detection of earthquakes in NE BC, evaluation of the magnitude discrepancies between NRCan's routine earthquake catalog and corrections to the local magnitude scale provided by Nanometrics Inc. for events in the western Canadian Sedimentary Basin, and evaluation of the ground motion prediction equations suitable for the estimation of ground-motion amplitudes in NE BC for use in the automatic generation of ground motion maps.

Conclusions

With the addition of newly installed seismographic stations and data sharing from industry and universities, more detailed analysis of induced seismicity and ground motion parameters has become possible. In this report an update on the seismic monitoring of induced seismicity and catalogue of seismic events for the period October 2017 to April 2018 was presented. The near field analysis of ground-motion amplitudes in northeast British Columbia has revealed that while amplitudes from small magnitude events at hypocentral distance above 5 km are below the damage threshold, at shorter distances, high-frequency motions (e.g. peak ground acceleration) may reach the damage threshold from these shallow events. However, the large, high-frequency ground accelerations at short distances, are usually from very short duration pulses which means that the exceedance in the damage threshold is not sustained over a long period.

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Appendix A: Earthquakes recorded between October 2017 and April 2018

Date	Time (UTC)	Latitude	Longitude	Depth	Depth Type	Mag	Mag Type
2018/04/17	13:47:39	55.919	-120.556	4.2	Calculated	1.9	ML
2018/04/17	09:52:07	55.923	-120.537	5.0	Fixed	1.9	ML
2018/04/17	06:08:58	55.913	-120.570	5.0	Fixed	1.9	ML
2018/04/16	23:25:48	56.358	-120.814	4.7	Fixed	2.8	ML
2018/04/16	02:21:43	55.923	-120.531	3.3	Calculated	1.9	ML
2018/04/13	01:51:55	55.068	-121.302	0.0	Fixed	2.5	ML
2018/04/13	01:36:21	56.600	-122.192	5.0	Fixed	2.1	ML
2018/03/26	13:02:03	55.903	-120.156	1.0	Fixed	1.9	ML
2018/03/20	14:24:16	56.645	-122.099	5.0	Fixed	2.5	ML
2018/03/20	14:21:58	56.641	-122.085	5.0	Fixed	2.3	ML
2018/03/16	01:10:51	56.577	-122.423	0.3	Calculated	2.7	ML
2018/03/14	07:43:04	55.992	-120.685	10.0	Fixed	2.0	ML
2018/03/12	22:11:56	55.058	-121.268	0.0	Fixed	2.4	ML
2018/03/12	20:38:19	56.689	-122.175	1.0	Fixed	1.6	ML
2018/03/11	18:04:38	55.099	-121.300	10.0	Fixed	2.7	ML
2018/03/08	23:07:10	56.004	-120.678	5.4	Calculated	2.2	ML
2018/03/08	22:21:09	55.374	-121.841	0.0	Fixed	2.3	ML
2018/03/07	08:36:57	56.017	-120.649	1.0	Fixed	2.3	ML
2018/03/01	18:05:10	55.296	-121.895	10.0	Fixed	2.0	ML
2018/02/26	22:03:51	55.382	-121.863	0.0	Fixed	2.1	ML
2018/02/22	22:07:18	55.382	-121.851	0.0	Fixed	2.3	ML

Date	Time (UTC)	Latitude	Longitude	Depth	Depth Type	Mag	Mag Type
2018/02/19	23:06:38	55.408	-121.841	0.0	Fixed	2.0	ML
2018/02/14	22:17:52	55.098	-121.226	0.0	Fixed	2.5	ML
2018/02/14	20:57:35	56.246	-121.745	20.0	Fixed	1.9	ML
2018/02/12	12:55:46	56.769	-121.865	5.0	Fixed	2.1	ML
2018/02/08	22:08:32	55.363	-121.852	0.0	Fixed	2.2	ML
2018/02/03	22:07:48	55.332	-121.855	0.0	Fixed	2.5	ML
2018/02/03	18:34:14	55.078	-121.309	0.0	Fixed	3.0	ML
2018/01/31	18:09:04	55.386	-121.833	0.0	Fixed	2.3	ML
2018/01/28	18:28:40	55.072	-121.261	0.0	Fixed	2.9	ML
2018/01/27	22:57:36	55.102	-123.922	20.5	Calculated	2.8	ML
2018/01/25	02:31:53	56.749	-121.798	5.0	Fixed	3.7	ML
2018/01/24	22:08:56	55.357	-121.810	0.0	Fixed	2.5	ML
2018/01/22	17:52:15	55.023	-121.280	0.0	Fixed	3.0	ML
2018/01/21	08:03:34	57.322	-122.490	3.8	Calculated	2.6	ML
2018/01/21	06:07:51	57.331	-122.476	1.0	Fixed	1.6	ML
2018/01/21	05:48:47	57.337	-122.464	8.9	Calculated	3.5	ML
2018/01/20	22:30:22	55.098	-124.091	6.7	Calculated	2.6	ML
2018/01/18	13:39:10	56.660	-122.081	5.0	Fixed	2.4	ML
2018/01/15	05:20:10	55.931	-120.253	5.0	Fixed	2.3	ML
2018/01/15	02:16:00	56.061	-120.074	15.0	Fixed	1.9	ML
2018/01/11	22:11:00	55.361	-121.813	0.0	Fixed	2.4	ML
2018/01/08	19:00:19	55.406	-121.800	0.0	Fixed	2.6	ML

Date	Time (UTC)	Latitude	Longitude	Depth	Depth Type	Mag	Mag Type
2018/01/02	02:41:54	56.505	-122.389	1.0	Fixed	2.0	ML
2017/12/31	22:08:34	55.093	-124.093	0.4	Calculated	2.3	ML
2017/12/28	19:49:32	55.099	-124.027	0.0	Fixed	2.9	ML
2017/12/28	10:11:41	55.991	-120.664	10.0	Fixed	2.2	ML
2017/12/23	22:10:05	55.355	-121.860	0.0	Fixed	2.6	ML
2017/12/21	06:30:30	55.040	-122.858	5.0	Fixed	2.3	ML
2017/12/11	11:16:29	55.931	-120.244	5.0	Fixed	2.7	ML
2017/12/10	22:14:43	55.400	-121.862	10.0	Fixed	2.7	ML
2017/12/09	22:37:42	55.120	-124.106	0.0	Fixed	2.7	ML
2017/12/09	19:03:25	55.031	-121.292	0.0	Fixed	3.0	ML
2017/12/05	07:01:30	57.319	-122.524	5.0	Fixed	1.9	ML
2017/12/02	22:35:22	55.922	-120.238	5.5	Calculated	2.5	ML
2017/12/02	22:04:43	55.359	-121.871	0.0	Fixed	2.4	ML
2017/11/27	01:07:38	56.343	-120.837	1.0	Fixed	2.6	ML
2017/11/26	22:59:09	55.119	-124.165	4.6	Calculated	2.7	ML
2017/11/24	13:03:42	56.341	-121.912	10.2	Calculated	2.4	ML
2017/11/21	18:23:15	55.067	-121.388	0.0	Fixed	2.7	ML
2017/11/21	12:03:31	57.189	-122.774	5.0	Fixed	2.2	ML
2017/11/19	15:25:42	55.379	-121.848	5.0	Fixed	2.3	ML
2017/11/19	00:20:54	56.795	-122.177	6.7	Calculated	2.8	ML
2017/11/18	08:45:41	57.251	-122.706	7.6	Calculated	3.6	ML
2017/11/18	00:37:27	56.804	-122.218	8.3	Calculated	2.7	ML

Date	Time (UTC)	Latitude	Longitude	Depth	Depth Type	Mag	Mag Type
2017/11/16	00:59:37	56.667	-122.121	5.0	Fixed	2.5	ML
2017/11/15	19:13:19	56.812	-122.227	5.0	Fixed	3.1	ML
2017/11/14	13:26:35	56.575	-121.409	3.6	Calculated	1.9	ML
2017/11/14	10:59:37	56.810	-122.217	8.1	Calculated	2.2	ML
2017/10/30	22:10:41	55.360	-121.871	0.0	Fixed	2.2	ML
2017/10/27	04:18:03	56.357	-122.105	10.2	Calculated	3.1	ML
2017/10/26	20:32:12	57.240	-122.677	5.0	Fixed	2.7	ML
2017/10/26	08:29:29	57.245	-122.670	10.0	Fixed	2.8	ML
2017/10/26	00:09:48	57.335	-122.571	10.0	Fixed	2.2	ML
2017/10/25	22:43:28	56.400	-122.013	5.0	Fixed	3.0	ML
2017/10/25	07:03:57	57.252	-122.672	5.0	Fixed	2.3	ML
2017/10/23	01:28:27	56.698	-122.150	5.0	Fixed	3.2	ML
2017/10/22	21:26:55	56.669	-122.175	9.9	Calculated	3.0	ML
2017/10/22	15:57:52	56.704	-122.317	11.3	Calculated	2.4	ML
2017/10/12	13:39:41	57.252	-122.718	5.0	Fixed	2.9	ML
2017/10/10	18:21:54	57.243	-122.709	5.0	Fixed	2.6	ML
2017/10/10	12:48:56	56.112	-120.927	5.0	Fixed	1.9	ML
2017/10/10	10:21:55	57.257	-122.763	1.0	Fixed	1.4	ML
2017/10/02	01:55:04	55.066	-121.386	0.0	Fixed	2.4	ML