

Guideline for Extraction of Ground Motion Parameters

for Scientific Hydraulic Fracturing Review Panel

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Executive Summary

The Scientific Review of Hydraulic Fracturing in British Columbia (2019) provides the key findings of a scientific panel on the topic of hydraulic fracturing in British Columbia and the associated environmental risks. As indicated in the report, the panel recommends preparation of guidelines for standard calculation of earthquake magnitude and ground motion parameters. Since Babaie Mahani and Kao (2019 and 2020) have addressed the methodology for calculation of local magnitude in two publications, this report deals with standard methodologies for extraction of ground motion parameters from recorded earthquake waveforms. The guidelines include data from both types of seismic sensors that are used for induced seismicity monitoring; seismometers that record ground motion velocities and accelerometers that are designed to record strong ground accelerations at short distances. Waveforms from the November 30, 2018 induced earthquake with moment magnitude (M_w) of 4.6 that occurred in northeast British Columbia within the Montney unconventional resource play are presented for better understanding of the processing steps.

Data Formats

The standard format that is used to archive earthquake data is called the SEED format (Standard for the Exchange of Earthquake Data; <https://ds.iris.edu/ds/nodes/dmc/data/formats/seed/>). When both the time series data and metadata are archived in one file, the name full-SEED is also used. miniSEED is the stripped down version of SEED that only includes waveform data (<https://ds.iris.edu/ds/nodes/dmc/data/formats/miniseed/>). Note that SEED volumes are not designed for data processing and, therefore, users need to convert the SEED volumes to other formats to extract ground motion parameters. A standard software for data conversion from full-SEED volumes is rdseed (<https://ds.iris.edu/ds/nodes/dmc/software/downloads/rdseed/>). Similarly, mseed2sac (<https://seiscode.iris.washington.edu/projects/mseed2sac>) is a standard software for data conversion from miniSEED volumes. After data conversion to a format suitable for processing, several steps are involved to extract the desired ground motion parameters. A

standard software that is widely used by seismologists for data processing is the Seismic Analysis Code (SAC; https://ds.iris.edu/files/sac-manual/manual/file_format.html).

Guideline for Extraction of Ground Motion Parameters

Figure 1 shows ground motion from the Mw 4.6 November 30, 2018 induced earthquake in northeast British Columbia recorded at station MONT1 (vertical component) at epicentral distance of ~16 km (Babaie Mahani et al., 2019). This station is equipped with a seismometer and an accelerometer. Visual inspection of the waveforms show that the recorded motion at the accelerometer needs to be adjusted so that ground motion starts at zero on the y-axis. Therefore, the first step would be to subtract the mean from the signal. The de-meanned signals are shown in Figure 2. As can be seen in Figures 1 and 2, ground motion amplitudes at this stage do not show the physical units such as velocity or acceleration. In order to obtain the ground motion in physical units, one must remove the instrument response from the recorded motion.

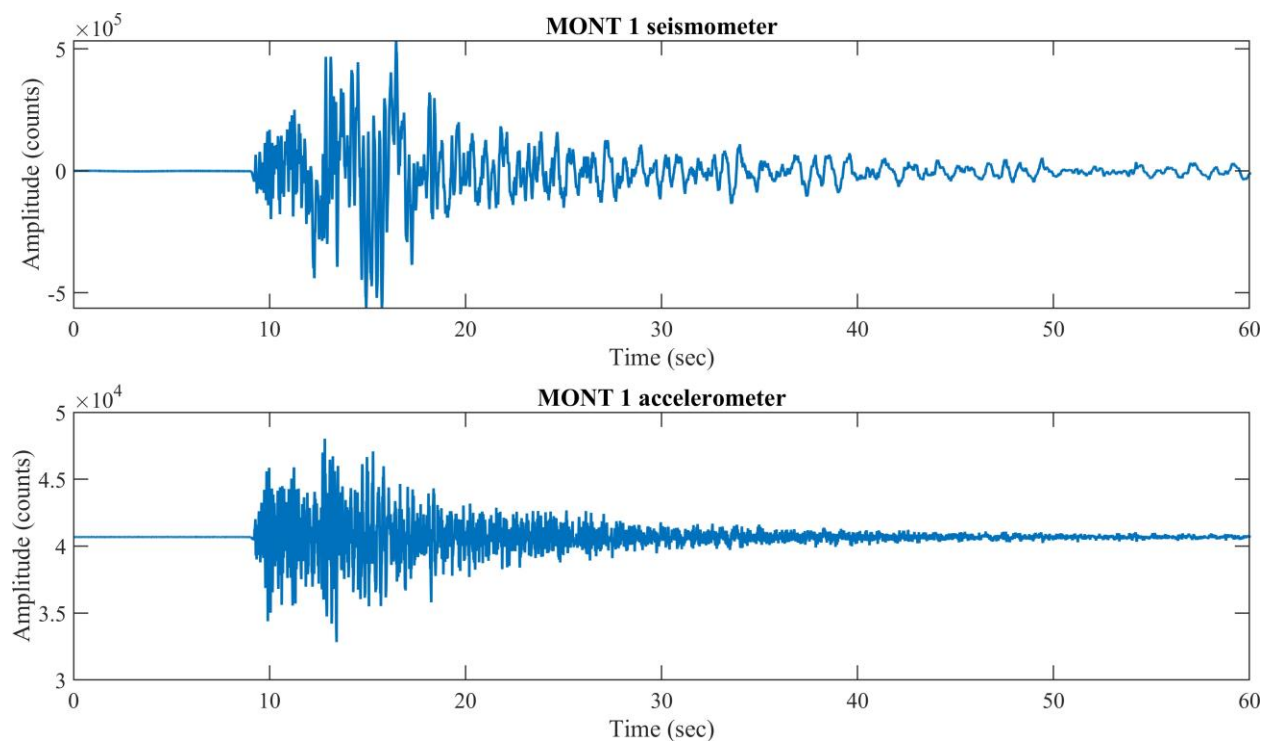


Figure 1. Ground motion from the November 30, 2018 induced earthquake with Mw of 4.6 in northeast British Columbia recorded at station MONT1 at epicentral distance of ~16 km.

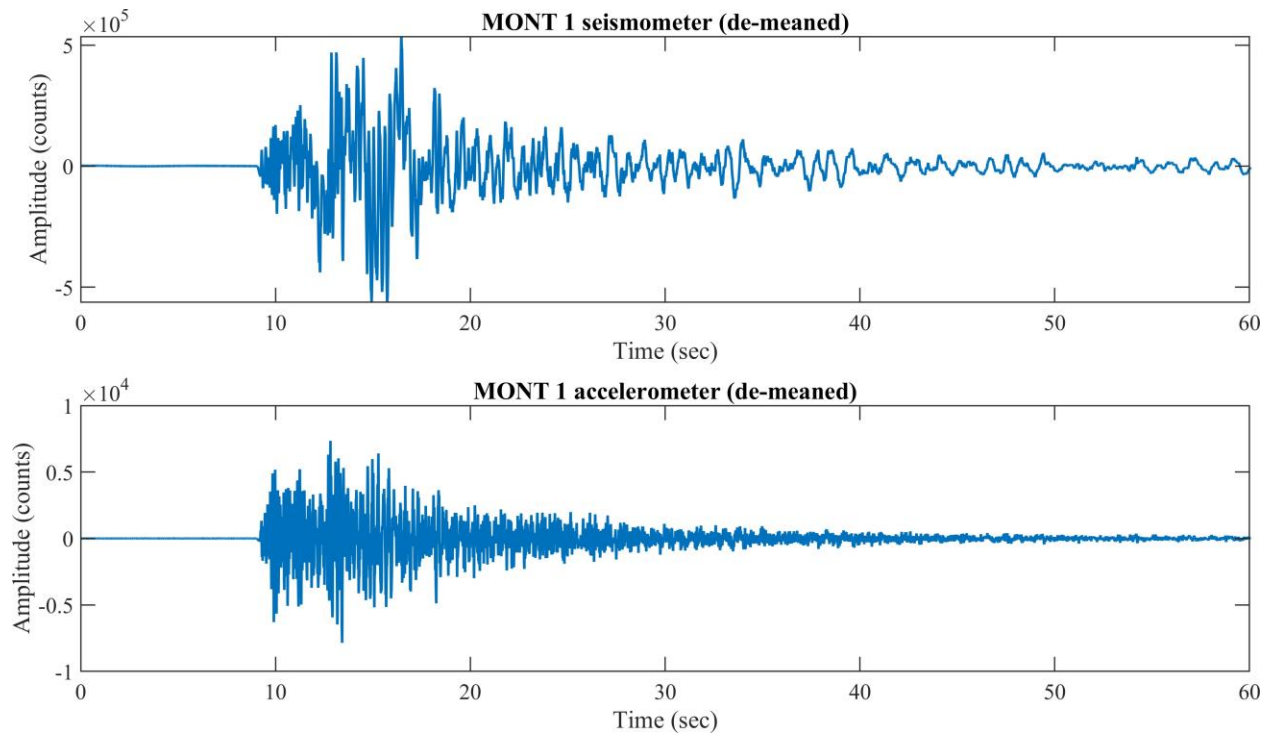


Figure 2. De-meaned waveforms.

Note that the instrument response has two major components; sensor response and digitizer (data logger) response. When ground motion receives at a seismic station, it is first registered by the sensor, which turns the motion into voltages. At this stage, a gain is introduced that has the unit of V/(ground motion unit). The voltage output of the seismic sensor is then digitized by the digitizer through another gain with unit of counts/V. Therefore, the final output is a waveform with unit of counts. For example, for the input ground motion unit of m/sec the following process occurs

$$\frac{m}{sec} \times \frac{V}{\frac{m}{sec}} \rightarrow V \times \frac{counts}{V} \rightarrow counts$$

For the data sample presented here, Table 1 shows the gains for the seismometer and accelerometer. As can be seen in Table 1, the sensor includes two gains at different steps. The standard procedure for instrument response removal involves deconvolution in the frequency domain. The topic of instrument response correction has been covered in many papers. As an example, I use the method and MATLAB code provided by Haney et al. (2012) to correct the waveforms for instrument response through deconvolution in the frequency domain, which is shown in Figure 3.

Table 1. Sensor and digitizer gains for the seismometer and accelerometer of MONT1 station.

	Sensor gain	Sensor gain	Digitizer gain	Total gain
Seismometer	1.2025×10^3 (V/m/sec)	9.92542×10^{-1} (V/V)	4×10^5 (counts/V)	4.77412702×10^8 (counts/m/sec)
Accelerometer	5.1×10^{-1} (V/m/sec ²)	9.950156×10^{-1} (V/V)	4×10^5 (counts/V)	2.02983182×10^5 (counts/m/sec ²)

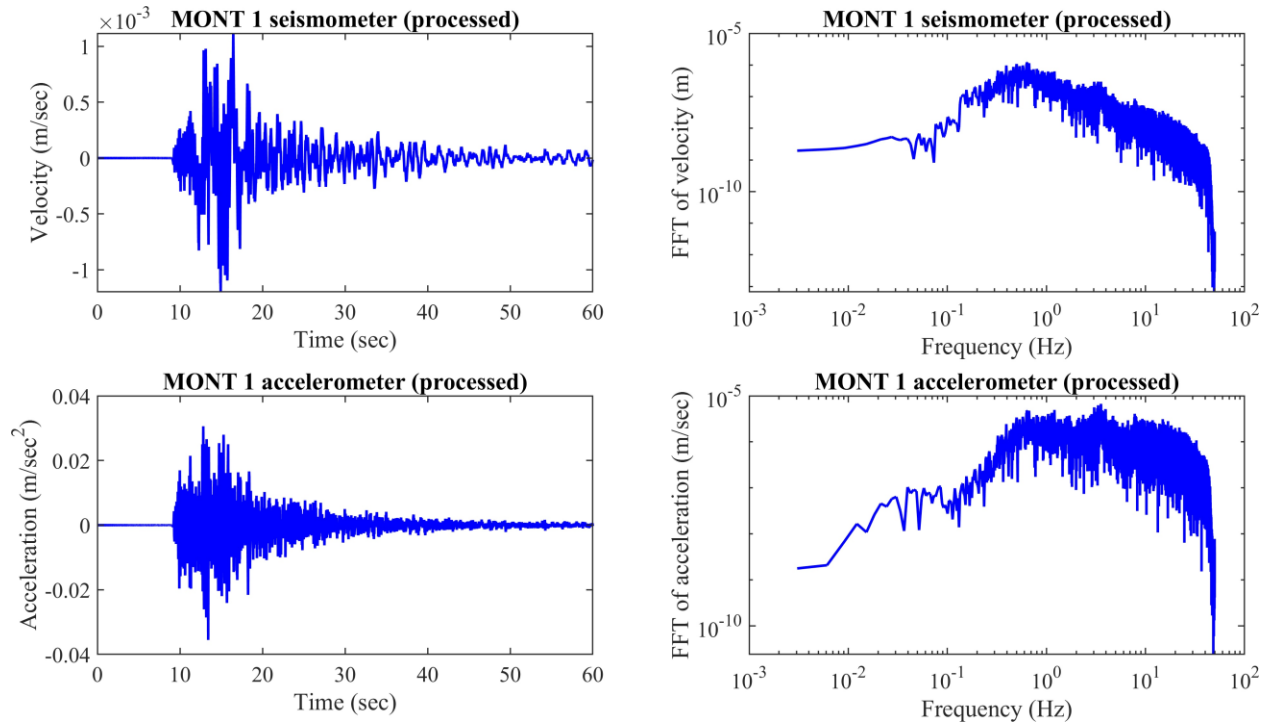


Figure 3. Instrumentally corrected waveforms from deconvolution in the frequency domain.

The last step of data processing is filtering out the unwanted noise. In Figure 4 filtered waveforms using a 4th order, high-pass Butterworth filter with corner frequency of 0.07 Hz is shown.

Various ground motion parameters can be extracted at this stage from the de-meaned, instrumentally corrected, and filtered waveforms. Peak amplitudes are common ground motion parameters, which includes peak ground acceleration (PGA), peak ground velocity (PGV), and peak ground displacement (PGD). The pseudo-response spectral acceleration (PSA) for different frequencies are also usually reported. Note that all these parameters can be obtained from each waveform type (seismometer or accelerometer) through differentiation or integration of the signal. The peak amplitudes (PGA, PGV, and PGD) are usually the zero-to-peak amplitude that can be directly extracted from the signal time series. PSA values represent the response of various structures with different natural frequency and they are essential ground motion parameters in the ShakeMap systems and seismic hazard and risk assessments. Methodology for

calculation of PSA values can be found in most geotechnical and earthquake engineering textbooks (e.g. Kramer, 1996). Here, I calculate PGA, PGV, and PSA values using the seismometer and accelerometer data that are instrumentally corrected using deconvolution in the frequency domain (also de-meanned and filtered). For PSA calculation, I use a MATLAB code provided by Tazarv (2020). Table 2 shows the PGA and PGV values and Figure 5 shows the PSA values. Results obtained from the seismometer and accelerometer data are similar.

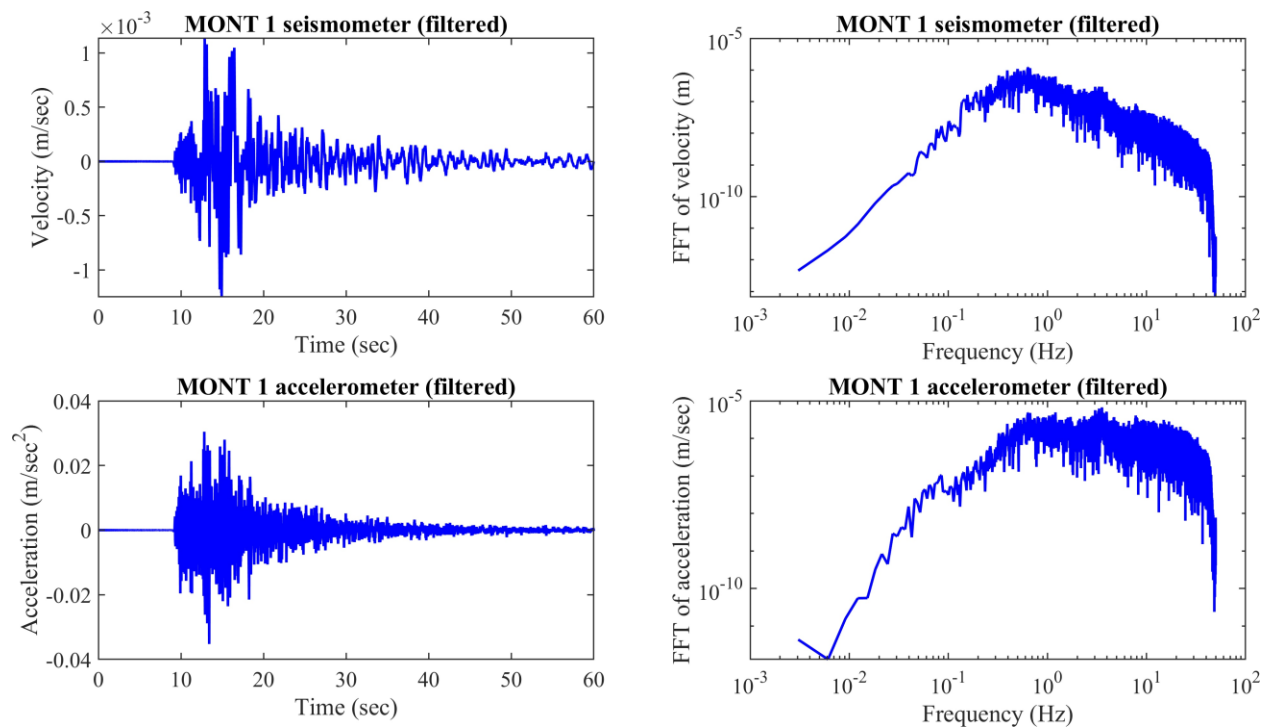


Figure 4. Filtered waveforms.

Table 2. PGA and PGV values.

	Seismometer	Accelerometer
PGA (m/sec ²)	0.0341	0.0352
PGV (m/sec)	0.0012	0.0013

Conclusion

The routine to extract ground motion parameters for the purpose of ground motion reporting for regulatory purposes, includes the following steps:

1. Signal de-meaning
2. Instrument response correction through deconvolution in the frequency domain

3. High-pass filtering
4. Differentiation or integration of signals
5. Calculation of peak amplitudes (zero-to-peak)
6. Calculation of PSA values

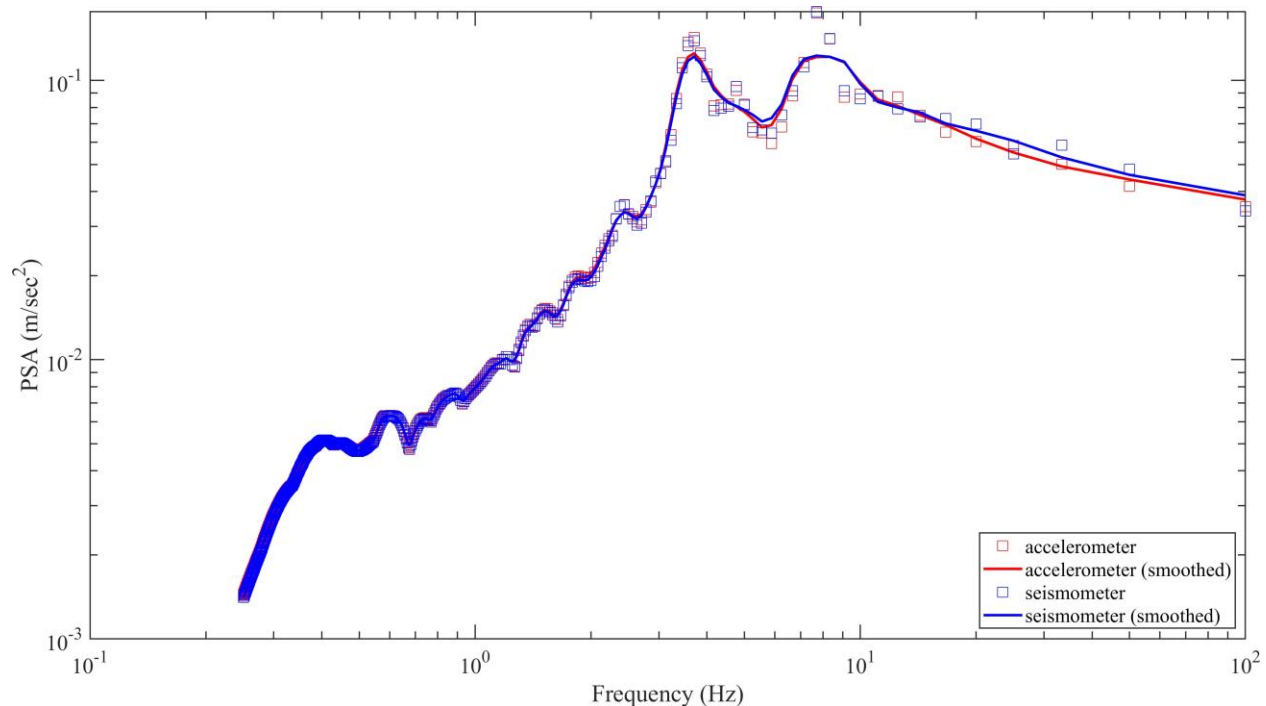


Figure 5. PSA values from the seismometer and accelerometer waveforms.

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