

Using Micro-ElectroMechanical Systems (MEMS) accelerometers for earthquake monitoring

Adam Pascale, June 2009

Accelerometers have been used for earthquake monitoring for many years, and are most often coupled with velocity seismometers to extend the range of recordable ground motion. A velocity sensor alone is useful for recording small and/or distant earthquakes, but they will saturate if a moderate to large earthquake occurs nearby. This is where the accelerometer takes over.

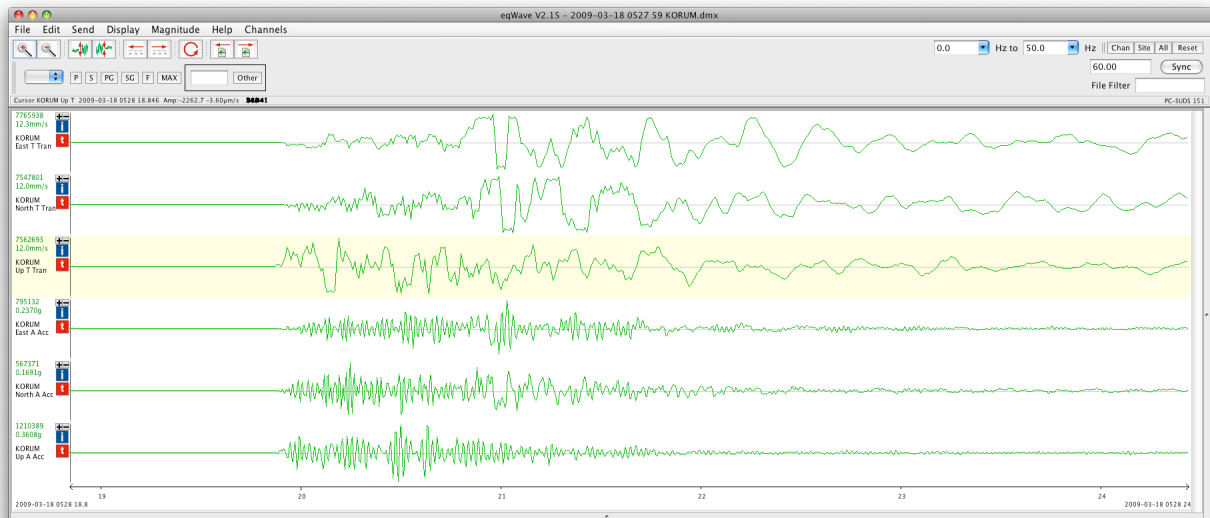
Very high accelerations from earthquakes are not often recorded. Earthquakes frequently generate accelerations of more than 1g, but the ability to record these accelerations requires the accelerograph be located very near the epicentre, which is often only possible in on-shore aftershock monitoring situations where the source location is known beforehand.

In blast monitoring, where accelerometers can be less than a hundred metres away from a known source of ground motion, accelerations of 10g or more can be recorded, albeit at high frequencies, so the frequency response of the accelerometer also needs to be considered when looking at strong motion sensors and recorders.

The limitations of accelerometers lies not in their ability to record high levels of ground motion (1g, 2g and 4g sensors are commonly available for earthquake monitoring) but in their sensitivity at the other end of the ground motion scale. The noise level of the accelerometer determines the smallest level of ground motion visible when using the sensor, which is usually measured in micro-g.

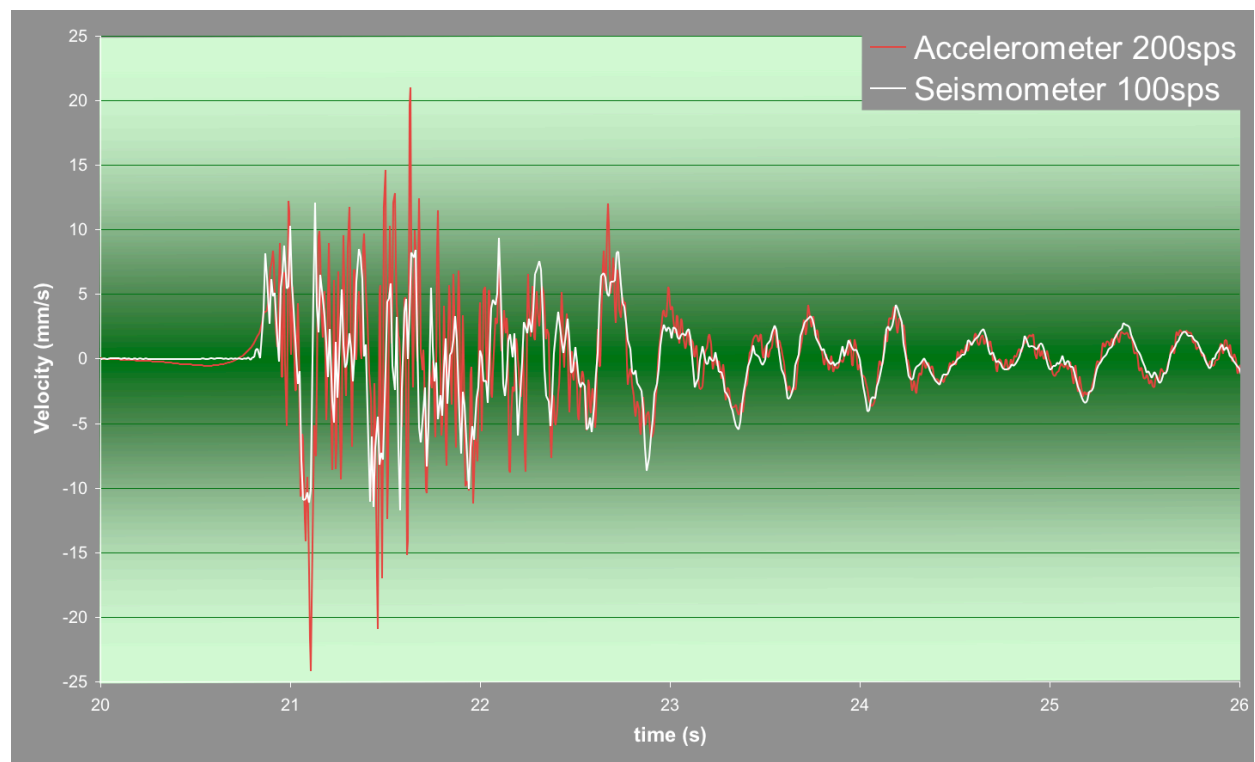
As technology has advanced, accelerometers have become less noisy, but is this of any advantage when using an accelerometer with a seismometer? How much overlap is there between the point at which a seismometer approaches saturation and the point where the signal is visible on an accelerometer?

The seismograms presented in the following pages demonstrate that even using the noisiest of modern accelerometers, there is significant overlap between a seismometer and accelerometer. So is there a place for low noise accelerometers? Yes, but not when combined with a seismometer.

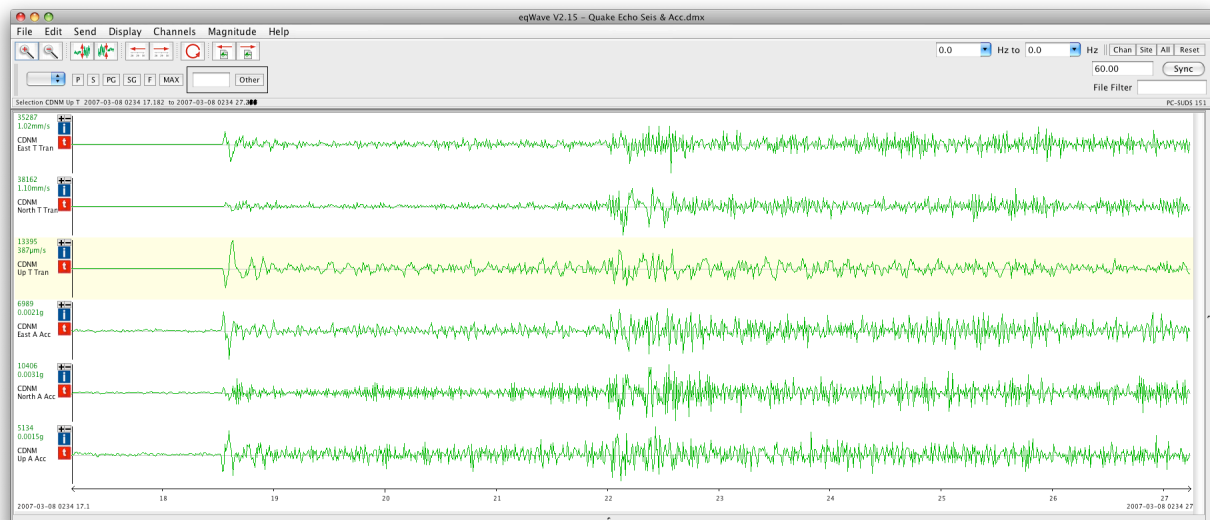


The first recording (above) is of an ML 4.7 earthquake where the seismic recorder was at a hypocentral distance of about 8km. The top three channels (from top: east-west, north-south and vertical) are velocity recordings from a modern short period sensor, which has obviously clipped due to the high level of ground motion. The lower three channels (again E-W, N-S and vertical) are from a MEMS accelerometer that has a full scale range of $\pm 2g$. The velocity sensor saturated at about 12mm/s, but the accelerometer still has a great deal of recording range left, with the ground motion peaking at 0.36g in the vertical axis.

By converting the vertical acceleration channel into velocity (red trace below) and overlaying the original vertical velocity channel (white trace below) we can see that the peak vertical velocity was actually around 24 mm/s. The accelerometer was sampled at 200 samples per second (sps), which reveals a number of velocity peaks not visible on the 100sps seismometer channels.



This demonstrates the usefulness of accelerometers to record large ground motion, but how much overlap is there between the seismometer and accelerometer?



The above recording is of an ML 3.7 earthquake at a hypocentral distance of about 30km. The full scale range of the recorder is about ± 8 million counts. The vertical seismometer channel recorded a peak of about 13,000 counts – only about 0.2% of full scale. The seismometer used at this site was an old sensor that has a sensitivity about 10 times lower than modern sensors. A modern seismometer would have produced a signal peaking at about 2% of full scale.

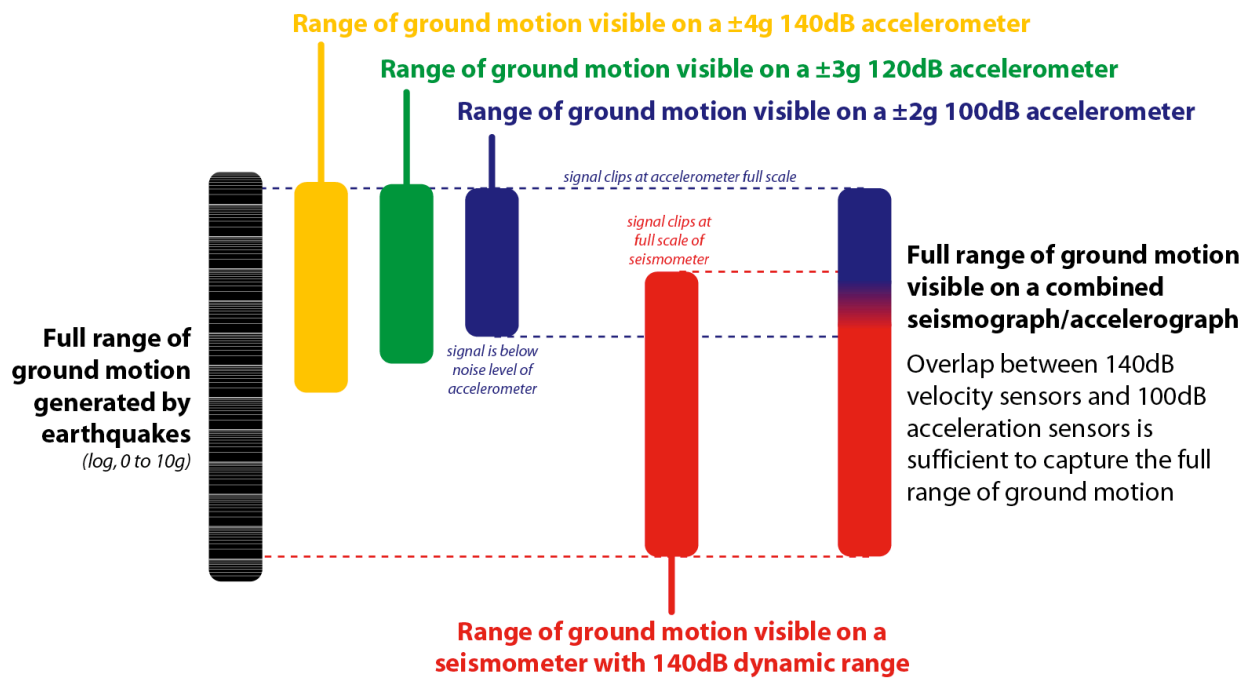
As you can see, the vertical channel of the accelerometer (bottom trace) shows the earthquake quite obviously above the background noise level, by about a factor of 10:1.

It is obvious that there is a massive degree of overlap between a typical seismometer and a low-end accelerometer. Well before a seismometer achieves 5% of its full scale range, even the most basic of accelerometers becomes effective.

Given these results were achieved using a low-cost MEMS accelerometer with a relatively high real-world noise level of $150\mu\text{g}$, what is the advantage of using more advanced accelerometers with noise levels that go down to $10\mu\text{g}$ or less? The conclusion is that there is no practical benefit – when an accelerometer is used in conjunction with a seismometer.

The diagram below illustrates the practical result of combining a seismometer and accelerometer. The black bar represents the full range of ground motion generated by earthquakes (logarithmically scaled to from zero to 10g for illustrative purposes). Seismometers can record down to the smallest of levels of vibrations (the red bar) but have a limited range at the top end of ground motion. Accelerometers (yellow, green and blue bars) can easily handle strong motion but have limited sensitivity at the bottom end.

What you want to achieve is the maximum recording range possible (the rightmost bar) by combining a seismometer and accelerometer. All of the common earthquake-oriented accelerometers, including the $\pm 2g$ 100dB MEMS accelerometer, have a sufficient overlap with the seismometer to achieve the desired result.



It is not currently possible to record the full range of potential ground motion from earthquakes using a single sensor, and even if you could there is no recorder that can currently achieve this level of dynamic range. A good quality seismometer will have a dynamic range of 140dB, and accelerometers are available with dynamic ranges from 100dB to 140dB. The full range of ground motion equates to about 200dB, so the recording of this full range will, for the foreseeable future, be only achievable with two sensors and a multi-channel recorder with up to 140dB dynamic range per sensor input.

Using Low-Noise Accelerometers

So, when are low-noise accelerometers useful? If you are primarily interested in recording strong motion (in structural monitoring, for example), but also wish to be able to see the smallest events possible without going to the expense of adding a seismometer, then a low-noise accelerometer may be of advantage, but only if your site noise is below the sensitivity level of the accelerometer.

It is important to remember to not get caught up in the dynamic range specifications of an accelerometer when the application cannot justify the extra cost for no practical advantage. For example, when using an accelerograph to monitor a structure such as a dam for earthquake response, is a $\pm 2g$ 140dB accelerometer that can detect ground movements of less than $1\mu g$ required, or would a $\pm 2g$ 100dB accelerometer that can measure down to around $60\mu g$ (and costs significantly less to purchase) suffice? Would $60\mu g$, or even $200\mu g$, be an issue for the structure? Is the background noise level at the structure above the lower threshold of the sensor? Appropriate technology for the application should always be considered.

Advantages of MEMS accelerometers

Apart from the significant cost saving over traditional force-balance accelerometers, due to the nature of their design micro-electromechanical systems sensors have a much better high frequency response. Where most earthquake accelerometers are specified as having a frequency response of DC to 50Hz, 100Hz or in some cases 200Hz, the seismic-oriented MEMS sensors have a much higher frequency range. For example, the Silicon Designs units used in the ESS-1221 sensor have a frequency response of DC to 400Hz, and the Colibrys SF3000L MEMS sensors extend to 1000Hz.

Frequency response is important when recording strong motion, particularly for events at close range where high frequencies have not been attenuated with distance. In blast monitoring, where the source can be only dozens of metres away from the sensor, frequencies of 5000Hz or more can be recorded, so it is possible that large, nearby earthquakes could achieve their peak accelerations in frequencies above 200Hz.

Earthquake recorders typically record data at 100sps and 200sps, meaning that frequencies above 50Hz or 100Hz are not recorded. More can be learnt about earthquakes by using MEMS accelerometers and recorders capable of sampling at up to 2000sps.

Acknowledgements and References

Earthquake recordings courtesy Victorian Water Industry Seismic Network

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Trevor Allen – Geoscience Australia

Assistance in production of velocity waveform from acceleration recording

Silicon Designs 1221-002 Data Sheet

<http://www.silicondesigns.com/pdfs/1221.pdf>

Colibrys SF3000L Data Sheet

<http://www.colibrys.com/files/pdf/products/DS%20SF3000L%2030S.SF3000L.D.03.09.pdf>

Guralp CMG-3ESP Compact Data Sheet

<http://www.guralp.com/documents/DAS-C3E-0001.pdf>

Guralp CMG-5T Data Sheet

<http://www.guralp.com/documents/DAS-050-0001.pdf>