Introduction to Seismology: Lecture Notes
11 May 2005

SEISMOMETERS, SEISMIC STATIONS, AND SEISMIC NETWORKS

DEFINITIONS

Seismometer: The apparatus that actually detects ground motion (displacements, velocities, or accelerations).

Seismograph station: The complete set of equipment necessary to detect, record, and possibly transmit seismic data at a single observation location. A modern seismograph station incorporates the following:

- Seismometer – Detects ground motion
- **DAS** (Data Acquisition System) – Records signals detected by the seismometer
- **GPS** – Provides accurate, globally synchronized time for onboard clock
- Power – Frequently heavy-duty car batteries augmented with solar chargers
- Other stuff – Cables, etc.

SEISMOMETERS

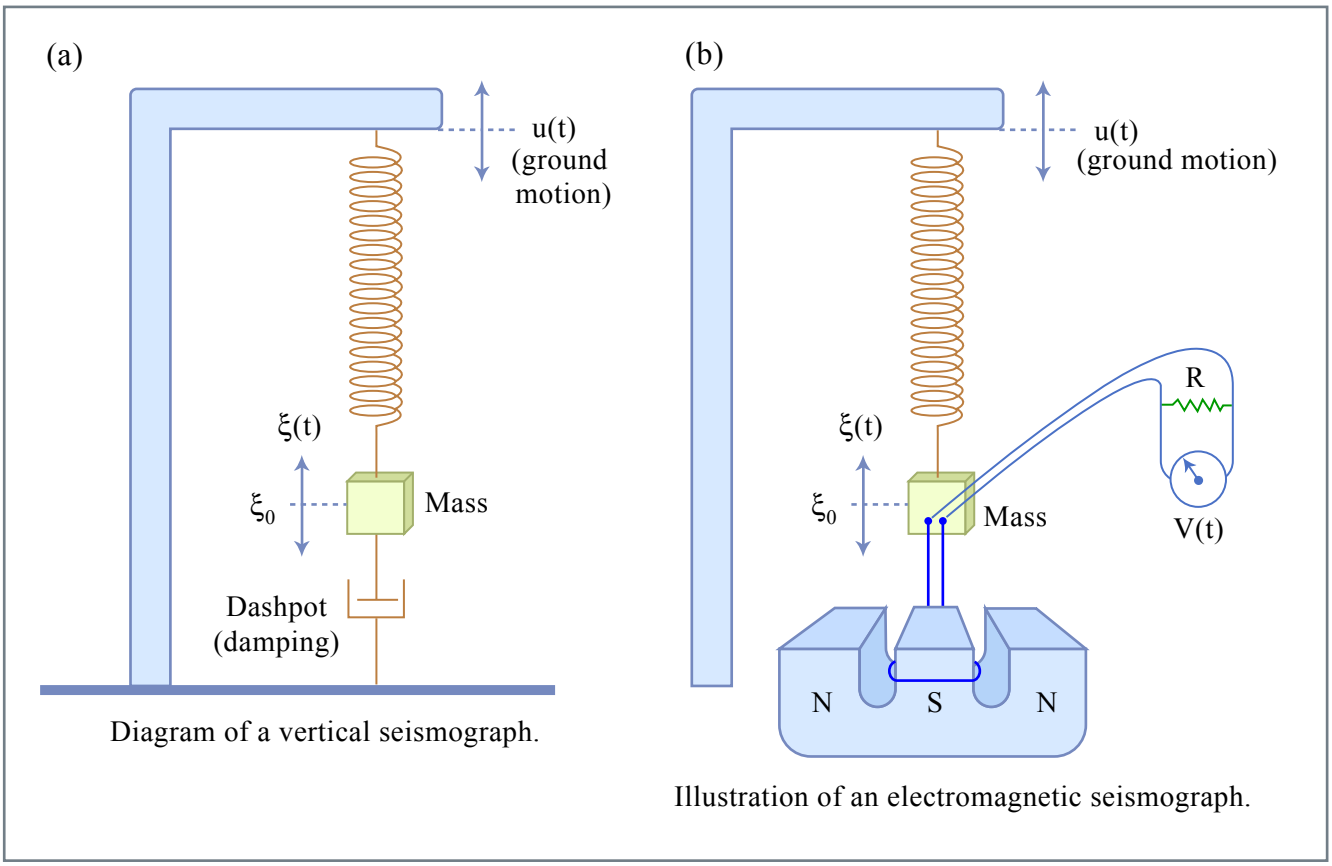


Diagram of a vertical seismograph.

Illustration of an electromagnetic seismograph.

Figure by MIT OCW.
(Adapted from Stein, and Wysession textbook)

Seismometers can be categorized as either passive or powered.

- Figure 1a (Stein and Wysession, 2003) is a schematic of a traditional *passive* seismometer. During a seismic event, the mass attached to the spring remains stationary under its own inertia, so the seismometer chassis (coupled with the ground) moves

relative to the mass, producing a signal. Mechanical damping must be introduced so the spring won't tend to oscillate endlessly, or ring, at its resonant frequency once the event has terminated.

- Figure 1b (S&W, 2003) is a schematic of a *powered* electromagnetic seismometer. Like a passive seismometer, a mass is attached to a spring, but the mass couples with an electromagnet so that ground motion induces an electric current in a wire attached to the mass. A voltage is therefore also induced, and this voltage is the output signal of the seismometer. Note that the electromagnet automatically damps oscillation, so no mechanical damping is required.

Like most geophysical sensors, seismometers respond differently according to the frequency content of the incoming signal. This fact necessitates knowledge of a seismometer's *transfer* or *response function*. We can analyze a seismometer's response by considering the PDE arising from the equation of motion for the coupled mass/chassis system. Two quantities that arise in this PDE are:

$k\{\xi_0 - \xi(t)\}$ → Concerning the spring constant and relative motion of the mass/chassis system

$d\dot{\xi}$ → Concerning the damping factor and the velocity of the relative mass/chassis system

These quantities are plugged into the equation of motion, yielding the following PDE:

$$m\frac{\partial^2}{\partial t^2}\{\xi(t)+u(t)\}+d\frac{\partial \xi}{\partial t}+k\{\xi(t)-\xi_0\}=0,$$

which is alternately written as

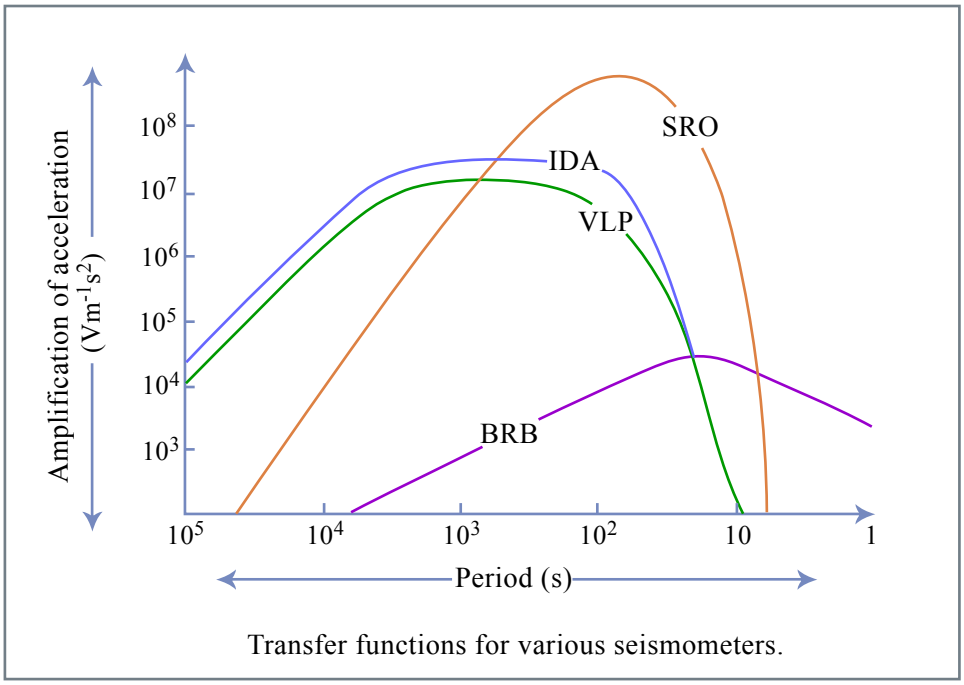
$$\ddot{\xi}+2\varepsilon\dot{\xi}+\omega_0^2\xi=-\ddot{u} \qquad (1)$$

where $\varepsilon \equiv d/2m$ and $\omega_0 \equiv \sqrt{k/m}$, the eigenfrequency of the spring/mass system. Equation 1 provides an instructive framework for understanding the design of seismometers. Consider the following two cases:

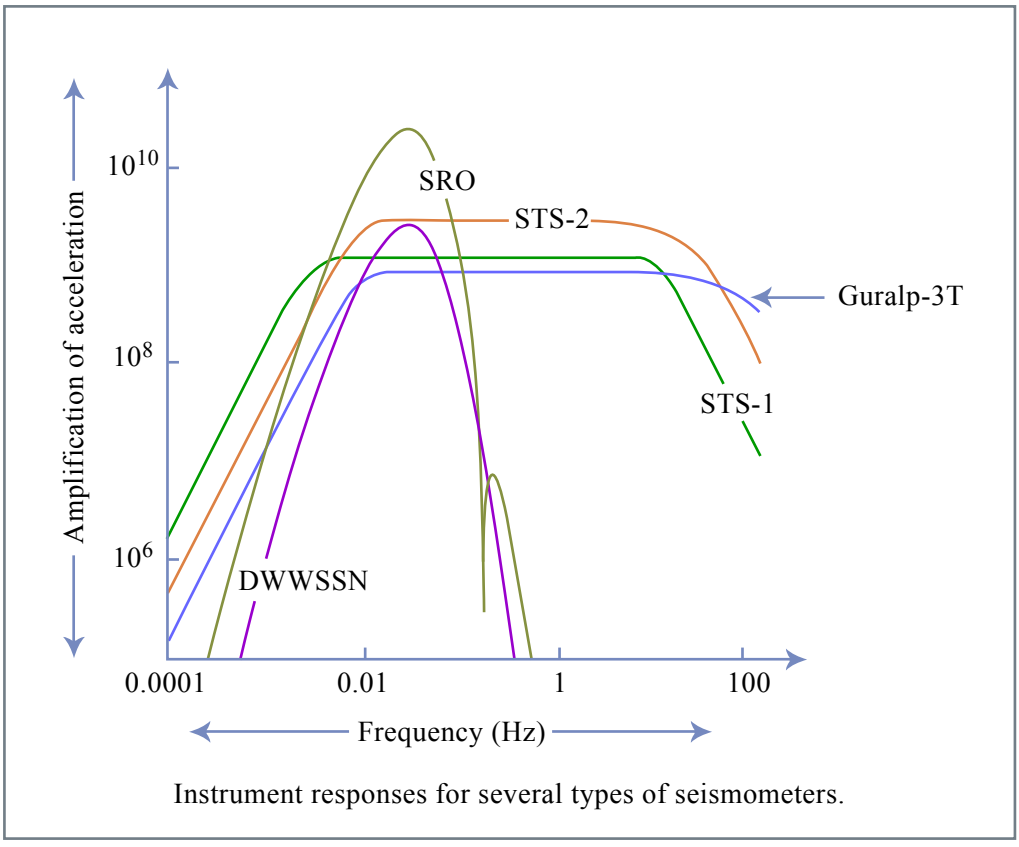
- $\omega << \omega_0$: The frequency content of the incoming signal is far smaller than the eigenfrequency of the spring/mass system → the ω_0 term in (1) dominates, allowing us to disregard the two time derivatives and making ξ proportional to ground acceleration.
- $\omega >> \omega_0$: The frequency content of the incoming signal is far larger than the eigenfrequency of the spring/mass system → the $\ddot{\xi}$ term dominates and allows us to equate ξ with u.

In general, low frequencies are measured by acceleration and high frequencies are measured by displacement. To have a small ω_0, which offers one the convenience of directly equating ξ with u, one can simply make the mass very large. But this makes a seismometer very heavy! Newer electromagnetic seismometers have circumvented this problem by applying a voltage to a small mass in order to keep it *stationary*, rather than letting the mass move with respect to the chassis, and this has revolutionized the portability of seismic instruments.

Seismometers are designed to be sensitive to certain frequency ranges, ideally with their resonant frequency being within the bandwidth over which data are to be collected. However, the frequency band and range of displacements over which seismology operates spans six or seven orders of magnitude. The question naturally arises: Is it possible to design a seismometer that is sensitive over this range of frequency and spatial scales? Practically, the answer appears to be 'no', but researchers and engineers are coming ever closer to designing such ideal instruments.



Transfer functions for various seismometers.



Instrument responses for several types of seismometers.

Figures by MIT OCW.
(Adapted from Stein, and Wysession textbook)

Figure 2

Two examples of instrument responses are given in Figure 2 (S&W, 2003). Ideally, the instrument response should be flat over the frequency band of interest. One also needs to account for amplification factors if displacement amplitudes are to be analyzed.

NOISE

Pre-event signal gives us some idea of the background noise at a seismic station. Figure 3a (S&W, 2003) shows an example and demonstrates that interseismic noise often contains coherent features. The amplitude spectrum in this example shows a pronounced frequency band between 0.1 and 1Hz. Oceanic processes such as waves interacting with the shore, tides, etc often explain such coherent signals. In fact, there is worldwide ~6s-period signal in ambient seismic data that is attributed to oceanic processes.

To contend with such noise, practitioners often low- or high-pass filter data sets, depending on the analysis at hand. Figure 3b (S&W, 2003) shows two examples of data filtering. In the top two panels, a low-pass filter was applied to isolate arrivals of interest. In the bottom panel, a high-pass filter was applied to filter out the local event that appears as a 'chirp' in the third panel.

NETWORKS

Seismic networks are responsible for collecting, archiving, and distributing seismic data worldwide. There are a number of national and international networks, including:

- International Seismological Centre (ISC)
- National Earthquake Information Center (NEIC)
- WWSSN (1962) – A cold-war inspired network geared toward detecting subterranean nuclear explosions
- DWWSSN – the digital version of the preceding
- Global Seismograph Network (GSN) – operated by IRIS
- Geoscope (France)
- Federation of Digital Seismograph Networks – Set data formats, standards, etc.
- USARRAY

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Please see:
Stein, S., and M. Wysession. Figures. 6.6-3 and 6.6-11 in *An Introduction to Seismology, Earthquakes, and Earth Structure*. 1st ed. Malden, MA: Blackwell, September 2002. ISBN: 0865420785.