



Building a simple seismometer

Seismometers operate on the principle of **inertia**, i.e. a body at rest will tend to remain that way unless a force is applied to make it move. An ideal seismometer would be a mass floating just above the ground. When the ground moves (due to the vibrations caused by an earthquake) the mass remains stationary (since it is experiencing no force to make it move), we then directly measure the relative motion between the ground and the floating mass which will tell us precisely the motion of the ground caused by the seismic waves. In the very earliest instruments (like this chinese seismoscope) the motion of an inertial mass would cause a delicately balanced ball to drop from a dragons mouth, giving an indication that ground motion had occurred and from which direction.

However in practice masses do not float freely above the ground; they need to be held up by some mechanism which will transmit the motion from the ground to the mass and cause it to move with the ground. Seismometers are designed to ensure that this transmission of force is transmitted very weakly for the range of frequencies that we are interested in measuring.

Seismologists measure the motion of the ground in three separate directions (usually up–down, east–west and north–south) to get a complete record of how the ground has moved. However for most purposes measuring just one of these motions is usually sufficient.

A seismometer trying to detect seismic waves from large earthquakes thousands of km away needs to respond to signals with a frequency in the range 0.05 Hz (surface waves) to 2 Hz (P waves). For such small frequencies it is often easier to refer to the period of the wave (period=1/frequency) So 0.05 Hz = 20 seconds and 2 Hz = 0.5 seconds. Simple mechanical systems like pendulums or masses on springs will respond well to ground motion at frequencies at and above their natural frequency of oscillation.



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Simple seismometers

For a simple pendulum of length l the natural period of oscillation T

$$T = 2\pi\sqrt{l/g}$$

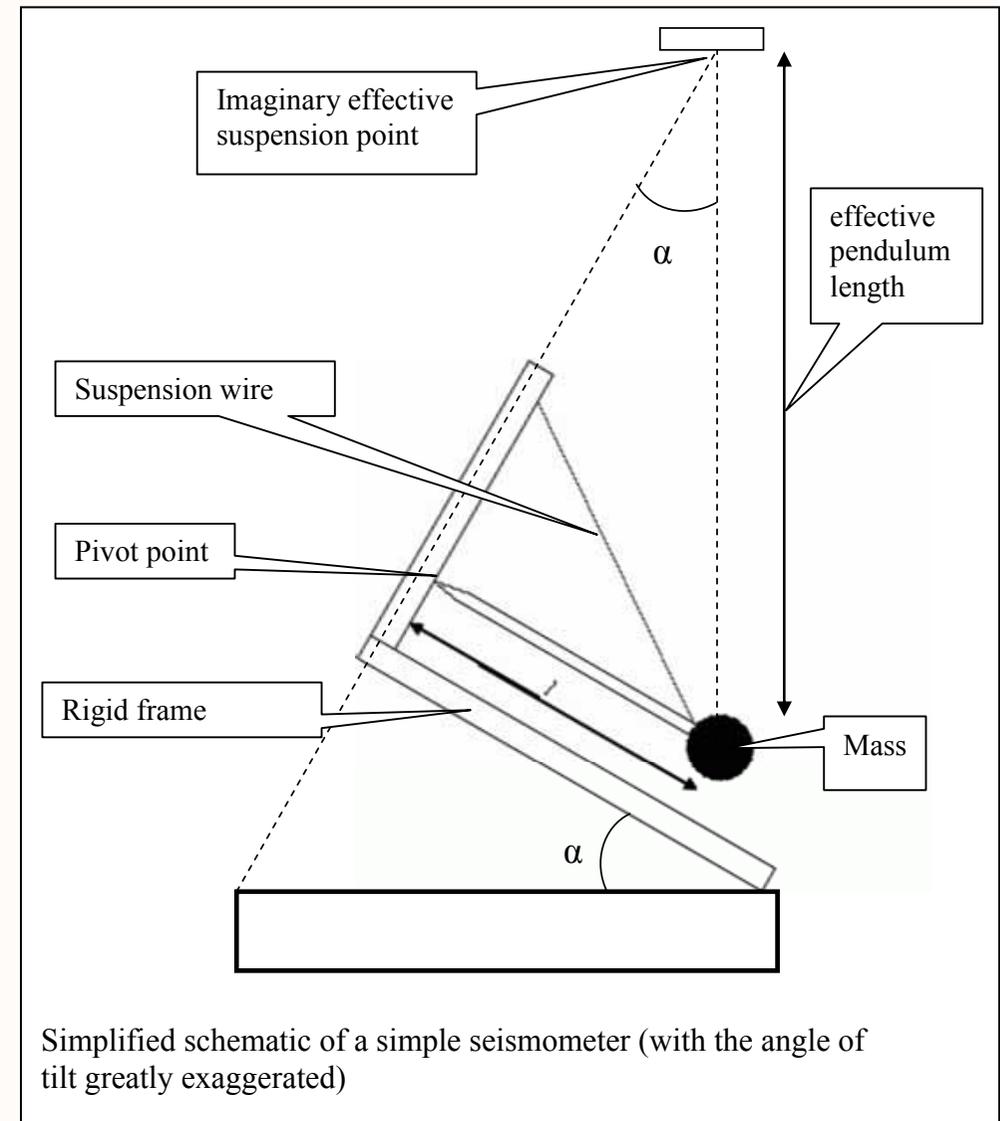
Where g is the acceleration due to gravity (9.8m/s^2)

For a pendulum of length 1m this gives $T \sim 2$ seconds (about the period of a pendulum in a grandfather clock). To design a simple pendulum with a natural period of 20 seconds we would need a pendulum length of ~ 100 m.

However if we adjust the suspension system to that of a 'garden gate' or 'Lehman pattern' where a horizontal boom rotates about a two point suspension we can adjust the effective length of the resulting system by adjusting the angle of suspension. In this case the effective length of the pendulum is $l/\sin(\alpha)$ so the natural period of the system T becomes

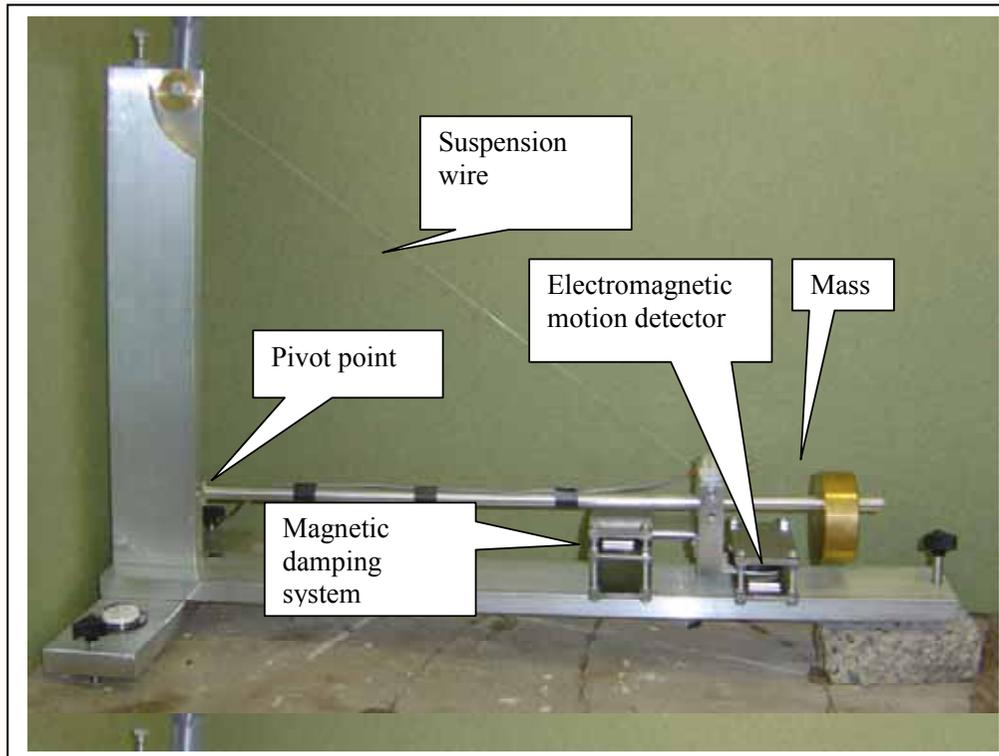
$$T = 2\pi\sqrt{l/g \sin(\alpha)}$$

In this way it is relatively easy to design a seismometer with a reasonable sized boom (0.5 m) that has a natural period of 20 seconds by slightly tilting the system with an angle of 0.3 degrees (this corresponds to tilting one end of the seismometer by ~ 2 mm)





SEP school seismometer system



The SEP seismometer system is a simple horizontal motion seismometer. It is :

- simple in principle
- open in construction so that individual components can be identified
- adjustable in natural period (10–20 seconds)
- adjustable in damping factor
- sensitive enough to detect signals from M6.5 earthquakes anywhere in the world (20–30 per year)
- cheap enough for schools to purchase.

It comes complete with an electronics box

- wideband amplifier (x 100, x 200 or x 500)
- bandpass filters between 0.0166 Hz and 5Hz
- 16-bit digitiser at 20 samples/sec

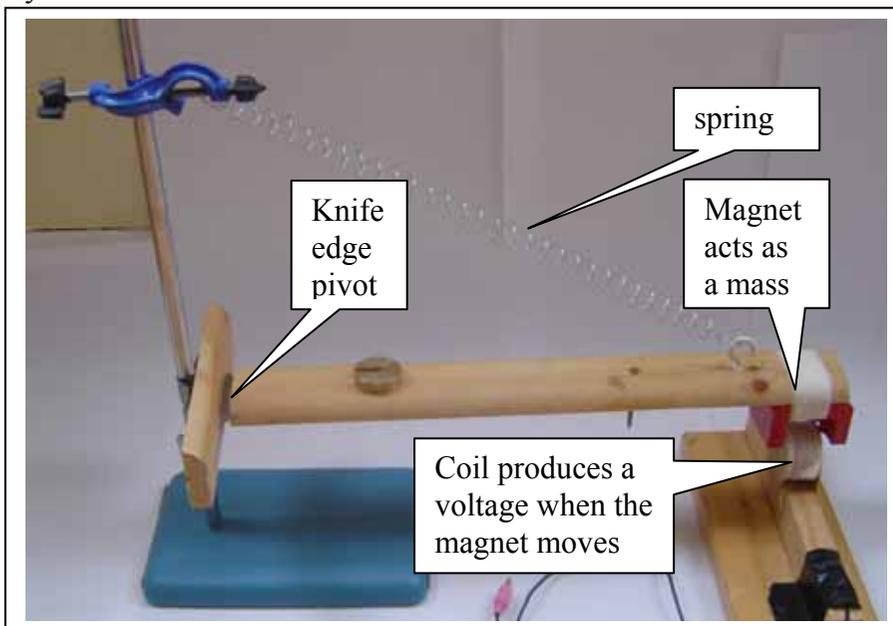
This unit can then be connected to a PC to record and analyse the data (see datasheet on Amaseis software)



Vertical seismometers

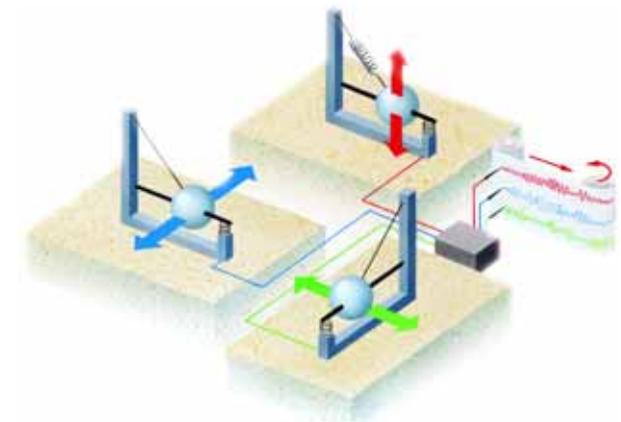
At its simplest a vertical seismometer consists of a mass suspended on a spring. The natural frequency of such a system depends on the size of the mass and the spring constant k of the spring, (where k is determined by plotting a graph of force F required to stretch the spring against the extension x produced and measuring the slope of that graph). Lower frequencies can be made by using larger masses or springs with lower spring constants.

In practice such a system is very susceptible to horizontal motion (it acts like a simple pendulum). Usually a pivot or hinge system is employed to constrain the mass to move only in the vertical plane, this then also gives the possibility of using angled spring systems to create longer period systems.



One such design is the 'Lacoste' suspension system which can easily be made to have a natural period of 2 seconds or more.

Three component data



In order to faithfully record the actual motion of the ground in 3D seismologists need to use three separate sensors each recording the vibrations in different direction. These are usually orientated:

Z component measuring up–down motion

E component measuring east–west motion

N component measuring north–out motion.

Vector addition of these data streams allows reconstruction of the motion in any direction.



Detecting the motion

Once we have a mechanical system in which the motion of an inertial mass moves relative to the ground (and hence the seismometer frame) when a seismic wave passes we need some method of detecting and recording this relative motion.



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Seismic traces being recorded onto rotating paper charts (helicorders)

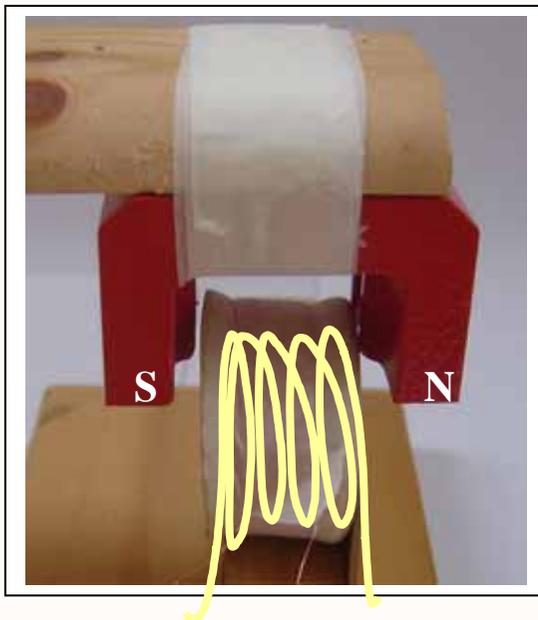
Historically this motion was recorded by pens moving against a rotating drum. There would be a simple lever system connecting the mass to a pen which would mechanically amplify the motion of the mass and the paper drum would rotate with a clockwork mechanism that would enable users to determine the time at which a seismic wave had arrived (to within a few tens of seconds).

However the sensitivity and dynamic range of these systems was very limited and they were quickly superseded by electromechanical systems in which the motion of the mass was converted to a voltage and the voltage was amplified before causing a pen to make marks on a rotating drum. This also allowed the recording system to be located away from the sensor, by using radio or telephone line links this analogue voltage signal could be transmitted hundreds or thousands of kilometres to a central laboratory where seismic data from a whole network of seismic stations could be recorded and analysed together.

Nowadays the seismic signal is digitised (usually into 16 bit or 24 bit binary code) with the data being recorded and analysed by computer. This enables seismologists to use the internet to exchange data in realtime and create vast 'virtual networks' of seismic stations that span the globe and be automatically analysed to provide near instantaneous warnings after large events.



Detecting the motion



The principle of electromagnetic induction used in a seismometer is the same as that of a loudspeaker (in reverse). The relative motion between a magnet and a coil (one of which is attached to the inertial mass and one is attached to the frame) generates a voltage in the coil that is proportional to the **velocity** of the relative motion.

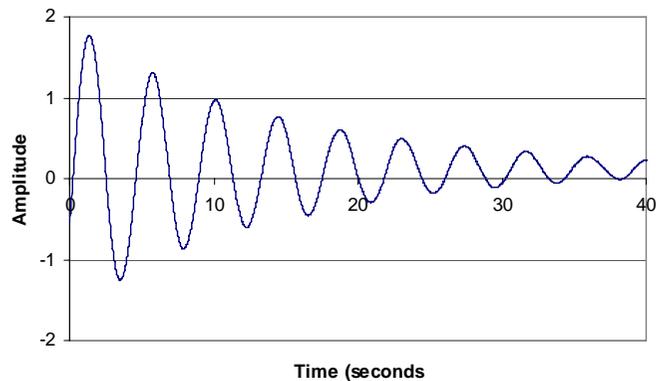
The magnitude of the voltage is also proportional to the strength of the magnet used and the number of turns in the coil.

In practice either the magnet or the coil can be attached to the inertial mass (in commercial systems the magnet is itself often used as the inertial mass)

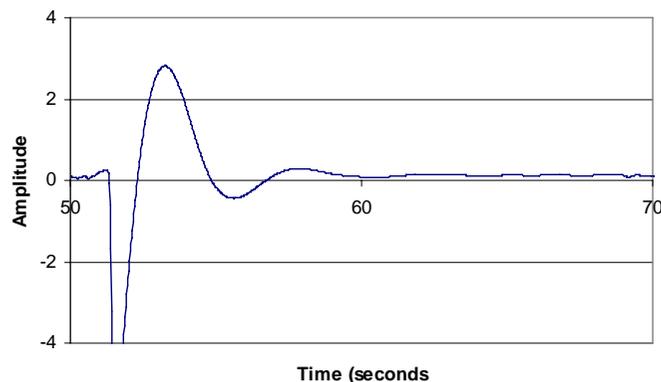


Damping

Lightly damped seismometer signal



Near critically damped signal

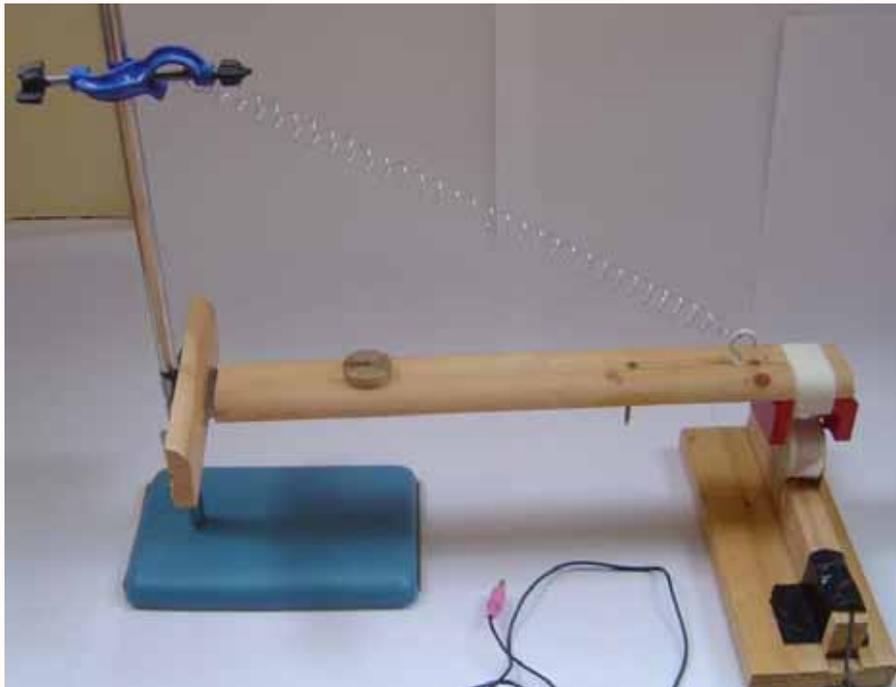


- Simple mechanical seismometers will have a natural frequency of oscillation at which they resonate.
- If we try to record a signal that contains components close to this natural frequency then the seismometer will resonate.
- We can prevent this resonance by applying a damping force to the motion of the inertial mass.
- This can be done with a simple dashpot (an oil-filled pot with a paddle in attached to the boom). This produces a force due to viscous resistance that opposes the motion and is proportional to the speed of the motion.
- We can also use a magnetic damping system where a conducting plate is attached to the moving boom which moves in a static magnetic field, this produces strong eddy currents in the conducting plate when the boom moves, these eddy currents produce their own magnetic field which opposes the static field. The end result is a force that opposes the motion and is proportional to the speed of the motion.



Weight drop test

A simple vertical seismometer was constructed using a wooden boom, a Stanley knife blade hinge, a magnet and a home wound coil. The coil is connected directly to a PC soundcard for recording. Suitable sound recording software is AUDACITY which is free and can be downloaded from <http://audacity.sourceforge.net/>



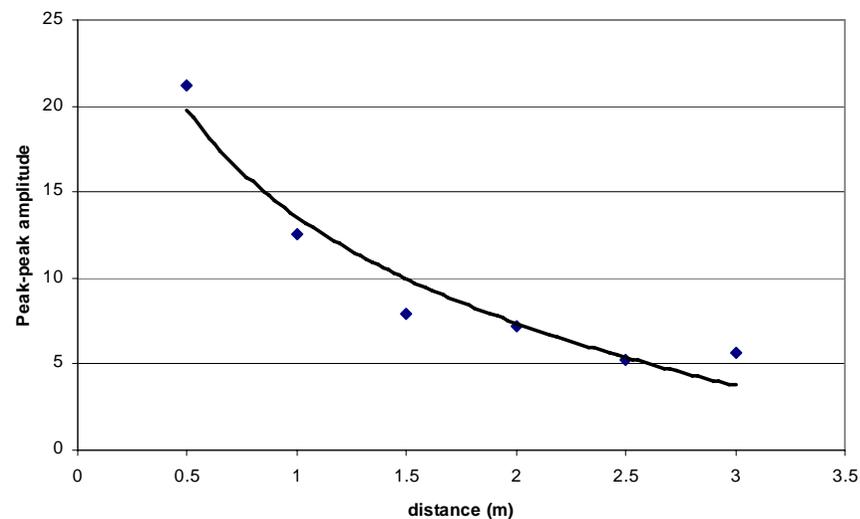
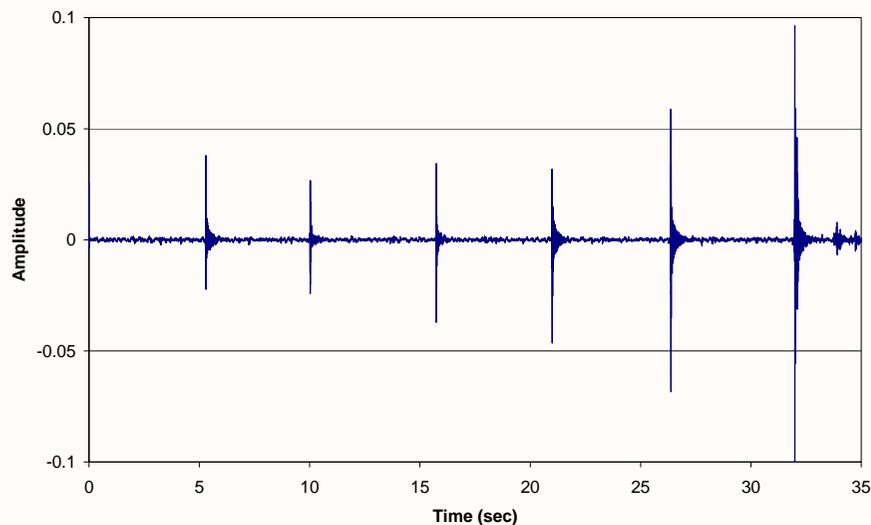
This sensor has a natural period of about 2 seconds. It is unsuitable for recording earthquake signals since the wooden boom will experience shrinkage and warping with changes in temperature and humidity.

Recording seismic signals with soundcards can be problematic, soundcards generally have a high-pass filter set at 20 Hz. Seismic signals generated by dropping a weight on the floor (try using a 4 kg bag of sand tightly bound) will have a dominant frequency of about 100 Hz. A simple seismometer like the one illustrated will respond to these high frequencies without any damping required (the 20 Hz high pass filter on the soundcard will remove any signals close to the natural period of the system at about 0.5 Hz).



Simple experiments with simple seismometers

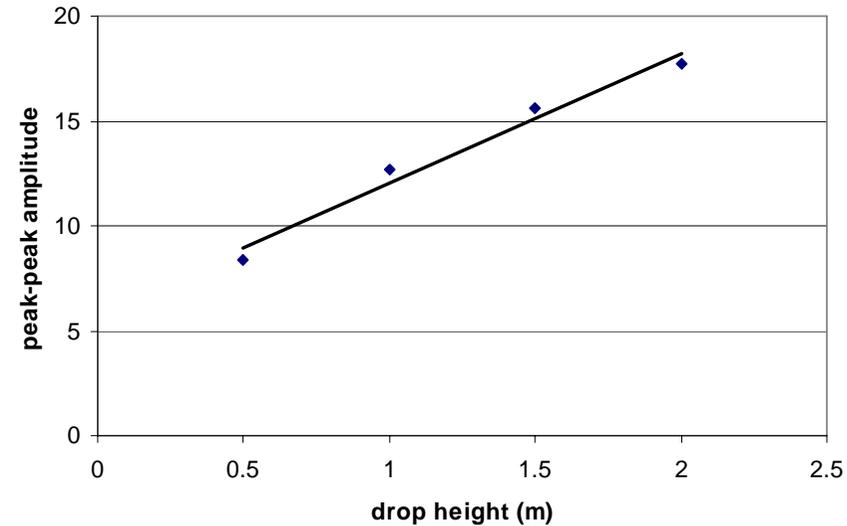
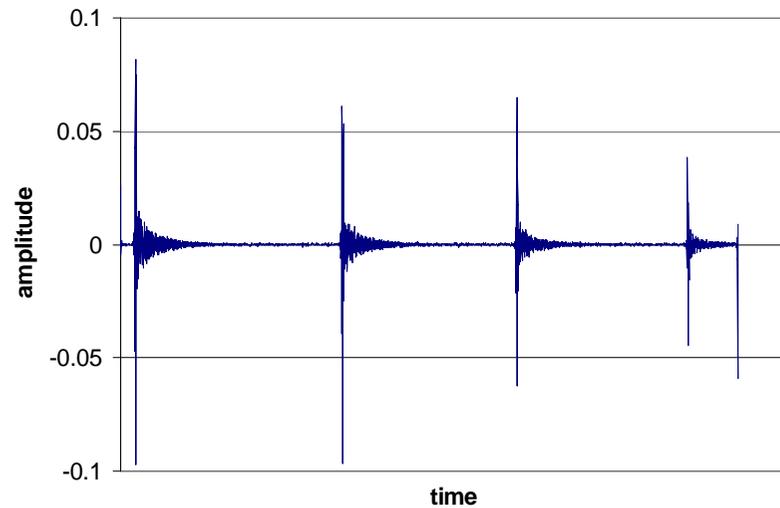
A simple homemade seismometer connected to a PC soundcard can be used to carry out a number of simple experiments to investigate how the amplitude and timing of signals recorded varies with different sources. For these experiments a standard weight (4 kg of sand tightly bound in a strong bag) was used and the data was recorded using the free Audacity sound recording software.



A weight dropped 1m at different distances from the sensor shows how the amplitude of the signal decays with distance in a non-linear way.



Another simple experiment is to keep the distance between the weight drop and the sensor fixed and to vary the height of the weight-drop (and hence the energy)



The results of this experiment indicate that the amplitude of the recorded signal is proportional to the height of the weight-drop.

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