Seismometer

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Some history

“instrument for measuring the seasonal winds and the movements of the Earth”

Zhang Heng, China
132 AD
1755 – the Great Lisbon earthquake

- Subsequent fires and a tsunami destroyed the city
- Probably Mw 8.5 to 9.0
- Between 10,000 and 100,000 death
- First systematic analysis of earthquake damages with questionnaires
Some history

First “modern” seismograph (1880-1885)

Horizontal pendulum

Pioniers: John Milne, Sir James Alfred Ewing and Thomas Gray

John Milne with Boris Galitzin and his wife, 1914

https://www.e-education.psu.edu/earth520/node/1784
Some history

**Emil Wiechert** (1861-1928)

- Converted or astatic pendulum
- 1st seismograph with viscous damping → useful recordings for the entire duration of ground motion
- Founder of the 1st global seismic network
- One of the co-founder of the Association Internationale de Seismologie; today: International Association of Seismology and Physics of the Earth’s Interior (IASPEI)

**Quelle:** http://musee-sismologieunistra.fr/english/the-collection-seismology

mass 1.000g
period 10s

**Moxa**
Instruments
We want to measure ...

Ground motion!

Caused by ...

+ Earthquakes
  Surface waves
  Body waves
  Free oscillations
  Large & small
+ Cultural noise
+ Ocean noise
+ Tides
+ ...
We want to measure ...

“... the Earth motion at a point with respect to this same point undisturbed.”

Problems:

- measurement is done in a moving reference frame
  → displacement cannot be measured directly, can only observe the motion if it has an acceleration

- amplitude and frequency range of seismic signals is very large
  → need several instruments to cover the full range in amplitudes and frequencies

(Instrumentation in earthquake seismology, Havskov & Alguacil, 2002)
A seismometer is a mechanical pendulum.
The motion of the seismometer mass as a function of the ground displacement is given through a differential equation resulting from the equilibrium of forces:

\[ F_{spring} + F_{friction} + F_{gravity} = 0 \]

- \( F_{spring} = -k \dot{x} \)  \( k \) – spring constant
- \( F_{friction} = -D \dot{x} \)  \( D \) – friction coefficient
- \( F_{gravity} = -mu \)  \( m \) – seismometer mass
The equation of motion for the mass is then:

\[ \ddot{x}_r(t) + 2\epsilon \dot{x}_r(t) + \omega_0^2 x_r(t) = -\ddot{u}_g(t) \]

\[ \epsilon = \frac{D}{2m} = h\omega_0 \]

\[ \omega_0^2 = \frac{k}{m} \]

damping constant

eigenfrequency

What do we learn from the equation?
Mechanical pendulum

\[
\ddot{x}_r(t) + 2 \epsilon \dot{x}_r(t) + \omega_0^2 x_r(t) = -\ddot{u}_g(t)
\]

- For slow movements (low frequency)

\[x_r(t) \gg \dot{x}_r(t), \ddot{x}_r(t)\]

\[\omega_0^2 x_r(t) \approx -\ddot{u}_g\]

**movement of mass ~ ground acceleration**

→ measure ground acceleration
Mechanical pendulum

\[ \ddot{x}_r(t) + 2\varepsilon \dot{x}_r(t) + \omega_0^2 x_r(t) = -\ddot{u}_g(t) \]

- For fast movements (high frequency)

\[ \ddot{x}_r(t) \gg \dot{x}_r(t), x_r(t) \quad \Rightarrow \quad \ddot{x}_r(t) \approx -\ddot{u}_g \]

movement of mass ~ ground displacement

→ measure ground displacement
Mechanical pendulum

Natural frequency

new push at exact the „right time“, i.e. when mass is at extreme position

\[
\ddot{x}_r(t) + 2\varepsilon \dot{x}_r(t) + \omega_0^2 x_r(t) = -\ddot{u}_g(t)
\]

movement of mass >> ground displacement

→ amplitudes get larger and larger (gain > 1)
Modern, electromagnetic seismometers always measure **ground velocity**.

- Damping through a coil moving in a permanent magnetic field
- Movement induces voltage
- Voltage ~ velocity

*seismometer by Boris B. Golizyn (1862-1916)*

- **H**: mass 7 kg, period 12 s
- **V**: mass 10 kg, period 24 s
Problem: Nonlinearity

- Instruments are **non**linear when:
  + mass moves out of measurement range (or coil)
  + clipping
  + spring changes/ages
  + large spring extension

Solution:
force feedback seismometer

Don’t let the mass move!
We want to measure ...

Frequency range:
10 – 10e-4 Hz

Amplitude or
dynamic range:
10e-1 – 10e-10 m
~ 180 dB

(adapted from Davis, IGPP)
The type of construction defines which frequency range can be discovered

→ scientific question defines the choice of instrument
Recording seismic data

... several influencing factors alter the seismogram ...

Source → Path → Near-Field → Instrument → Seismogram

Figure 6.6-12: Diagram showing the analog-to-digital (ADC) process.

Seismometer → Amplifier → AAA filter → DAA filter

Sampling → Decimation

Analog system → Digital system
Seismometers act as a filter on the recorded data.
Filter-effect needs to be corrected by restitution (removing instrument response)