Lecture 5

Instruments

History of instrument development

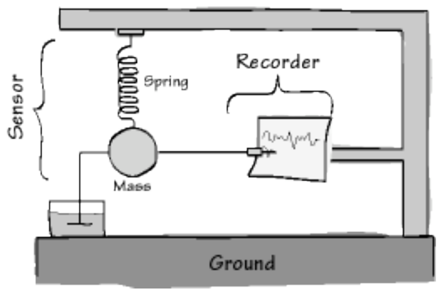
132 AD	The first seismoscope was made in China, a vessel with dragons heads and frogs.
Early 18th C	Italian seismoscopes.
1784	First attempt to record time of shaking.
1851	The speed of seismic waves moving across the surface was first measured.
1875	The first true seismography was invented in Italy. The relative motion between a pendulum and the Earth was recorded as a function of time.
1887	The oldest known seismogram. Instrumentation rapidly developed from there, with mechanical or optical amplification of mass motion, with friction providing damping.
1900	The first global array of 40 photographically recording horizontal-component seismographs.
1914	Electromagnetic seismometers were developed, where the mass is a magnet moving in an electric coil.

The earliest seismometer, 132 AD

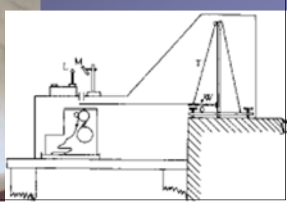
213

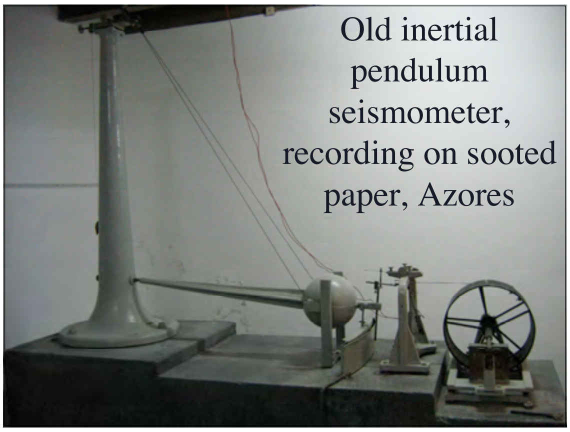
Inertial pendulum systems

Schematic inertial pendulum seismometer



Milne seismograph, 1902





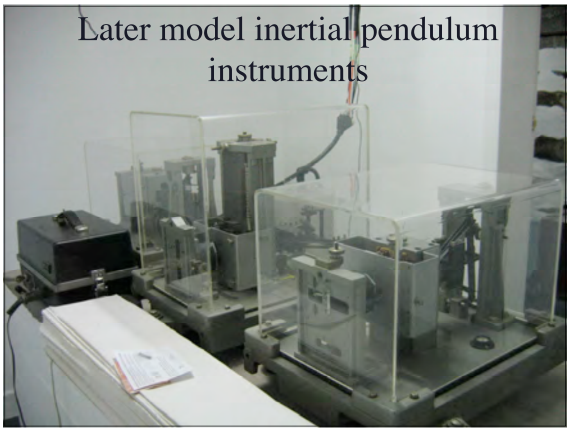
Old inertial pendulum seismometer, recording on sooted paper, Azores

Inertial pendulum, Azores

218

Sooting the drum, Azores


Recording drum
encasement,
Azores


Later model inertial pendulum
instruments


The final
frontier: A
broadband
seismometer

Initial development of field-portable instruments

Single-component 1 Hz seismometer

Teledyne Geotech S13

224

Kinemetrics FBA 23 3-component seismometer

225

Ocean-bottom seismometers

226

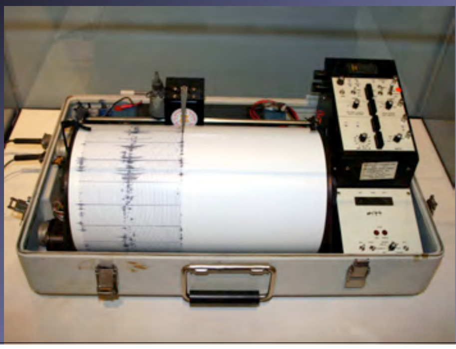
Strong motion seismometer

227

Wilmore Mk II seismometer

228

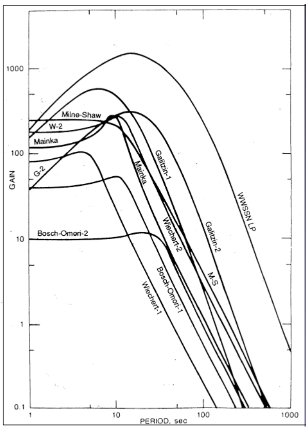
Paper drum recorder



229

Geophone

230



Frequency responses of long-period seismometers

231

Instrument calibration

The response function of a seismometer may always be expressed as the ratio of two polynomials:

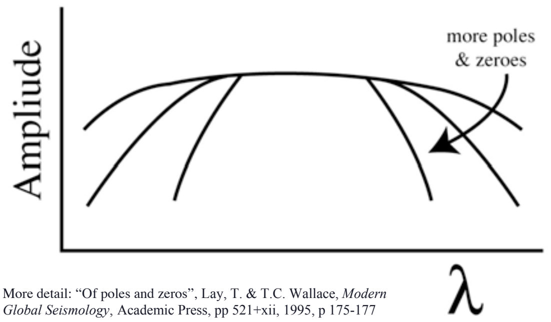
$$\frac{x(s)}{u(s)} = \frac{b_0 + b_1 s + b_2 s^2 \ldots}{a_0 + a_1 s + a_2 s^2 \ldots}$$

where *x(s)/u(s)* is the ratio of the output to the input in the frequency domain. These polynomials may be expanded and the equation written:

$$\frac{x(s)}{u(s)} = \frac{A(s - z_1)(s - z_2)(s - z_3)\ldots(s - z_n)}{(s - p_1)(s - p_2)(s - p_3)\ldots(s - p_n)}$$

The z_{1-n} are called the zeroes because if one of them equals *s* then $x(s)/u(s) = 0$. The p_{1-n} are called the poles because if one of them equals *s* then $x(s)/u(s) = \infty$.

Poles & zeroes



More detail: "Of poles and zeros", Lay, T. & T.C. Wallace, *Modern Global Seismology*, Academic Press, pp 521+xii, 1995, p 175-177

Instrument response

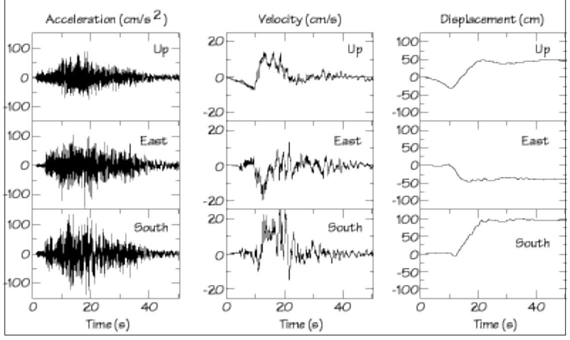
Frequency of ground motion	**Output proportional to**
high	displacement
low	acceleration

Long-period instruments–could be very large

Modern seismometers–sensitive to velocity

235

Acceleration, velocity & displacement



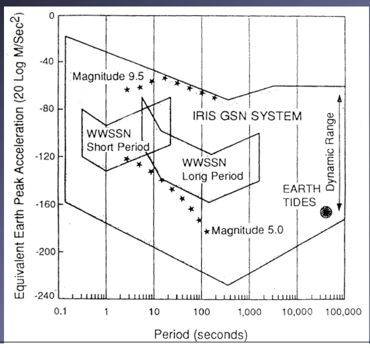
Broadband seismometers

Broadband seismometer characteristics

- Flat response over broad range, *e.g.*, 50 Hz to 100 s
- High dynamic range because forced feedback system prevents mass from making large excursions = enables instrument to be smaller
- Electronic and thus must be powered
- Digital output
- Examples: Guralp 40T, 3ESP, 3T

238

Comparison with traditional seismometers



239

Broadband seismometers

CMG 3T

STS 2

240

Inside a broadband seismometer

241

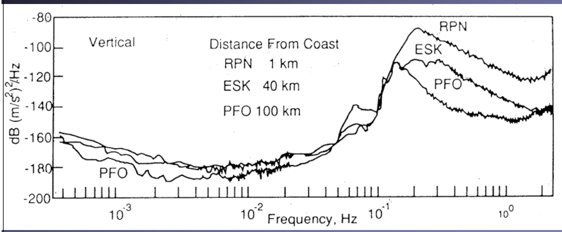
Then & now

Sensors	Inertial sensors	Broadband sensors
Data type	Analogue	digital
Time-keeping	Clocks, or radio time signals	GPS
Data transmission	Recorded on paper or tape at the site, or analogue radio transmitted	Recorded digitally at the site, or transmitted digitally via radio transmitters or the internet
Data storage	At individual institutes	Central storage, (almost) and free access to (almost) everyone
Cost	Cheap	expensive

242

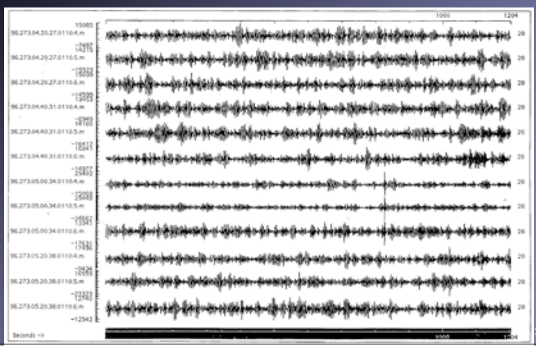
A visit to the WWSSN station at Akureyri, Iceland

Why two sets of instruments?

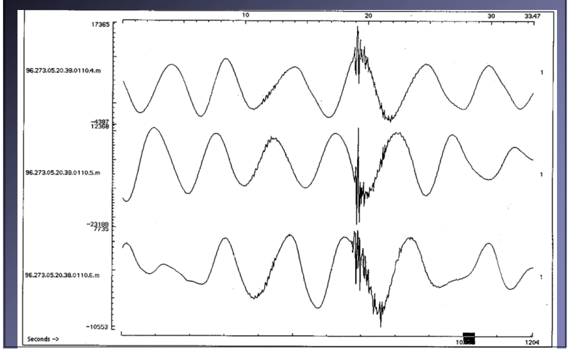


244

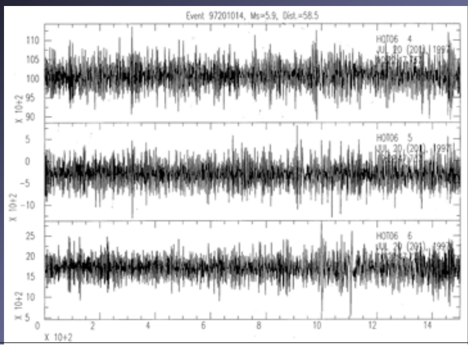
Broadband records



Broadband records expanded

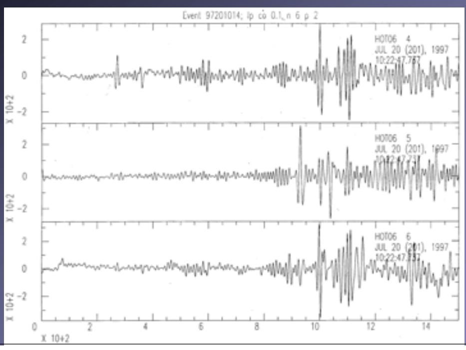


Broadband recording of a teleseism



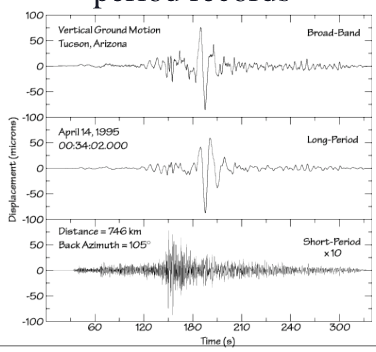
247

Filtered



248

Broadband, long-period & short-period records

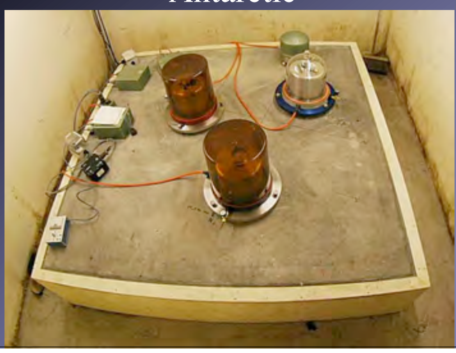


Permanent global network stations

Global Network Station, Kyrgyzstan

251

GSN station CASY, Australian Antarctic

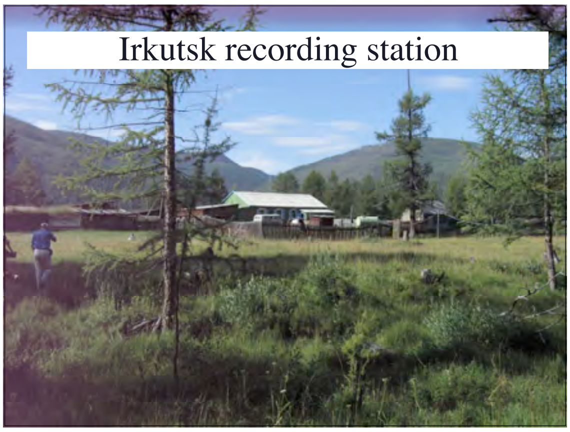


252


GSN station, Borg, Iceland
253

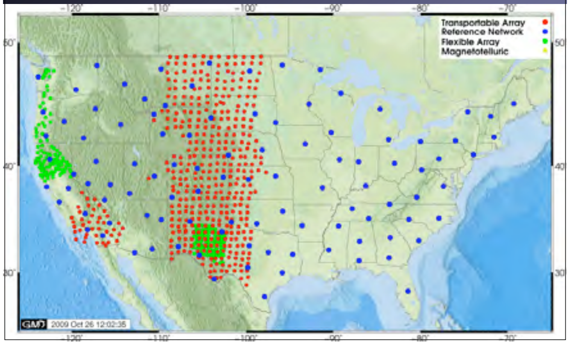

Russian network: Irkutsk, Siberia


Russian network: Irkutsk, Siberia
255



A modern mega-experiment:
US Array

USArray Stations, 26 Oct 2009



Installing a sensor

260

Instrument installation

261

The completed vault

262

Solar panels

263

Hmmm, wonder why my station isn't working…

264

Data Management Center servers: 143 Tbyte

265

Smaller-scale experiments

Coso geothermal area, Ca


Coso geothermal


Coso geothermal area, California


Coso geothermal area, California


Coso geothermal area, California


Coso geothermal area, California


GPS clock at Desert Peak, NV