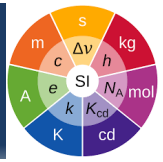
SnT 2025
8 SEPTEMBER ONLINE DAY
9 TO 12 SEPTEMBER AT HOFBURG PALACE, VIENNA & ONLINE
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE



Side event on metrology SE01-O2

The Challenges of Measuring Ground Motion

Precision, Uncertainties and Calibration

Horst Rademacher

Berkeley Seismology Laboratory
University of California, Berkeley
(retired)

Berkeley University of California
Seismological Laboratory

Vienna, 10 Sep 2025

Disclaimer:

In this contribution mentioning manufacturer's names, instrument models or showing photos or drawings is purely for informational purposes and **does not imply any value judgement.**

SnT 2025 8 SEPTEMBER ONLINE DAY 9 TO 12 SEPTEMBER AT HOFBURG PALACE, VIENNA & ONLINE
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

University of California Berkeley Seismological Laboratory

The Challenges of Measuring Ground Motion

Motivation for this session:

Calibration of instrumentation for the three technologies used in the IMS

traceability to SI standards

Motivation for this contribution:

Explore complexities and difficulties in operation of seismic stations

I want to show that calibration is not enough,

its necessary but not nearly sufficient

We want to measure ground motion with

- highest precision,
- least uncertainties
- lowest noise possible
- in real units (m/sec, m/sec^2)

This is easier said than done

We need a complex measuring system

complete measuring system - commonly called a seismic station

Consists of many elements:

- seismometer
- digitizer
- clock
- data management and storage
- telemetry

instrumental elements

- thermal and other insulation
- geologic conditions (i.e. tilt)

environmental elements

We need to understand all of them and how they are working together.

What does this mean for ground motion measurements?

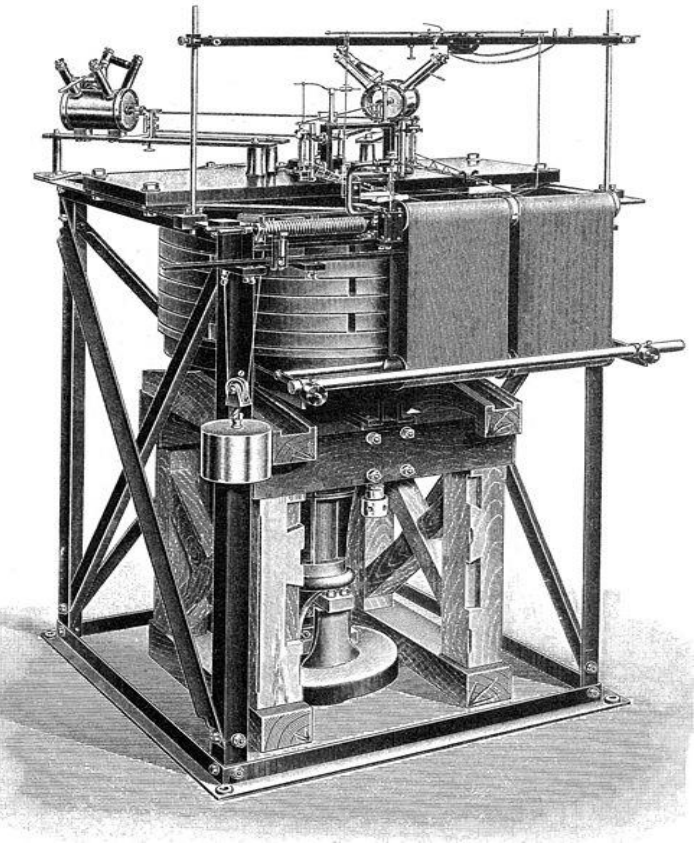
each element of the measuring system
has its own precision and its specific uncertainties.

each element needs its own calibration

Just calibrating a seismometer gives us only limited information about the overall health of a seismic station (SOH)

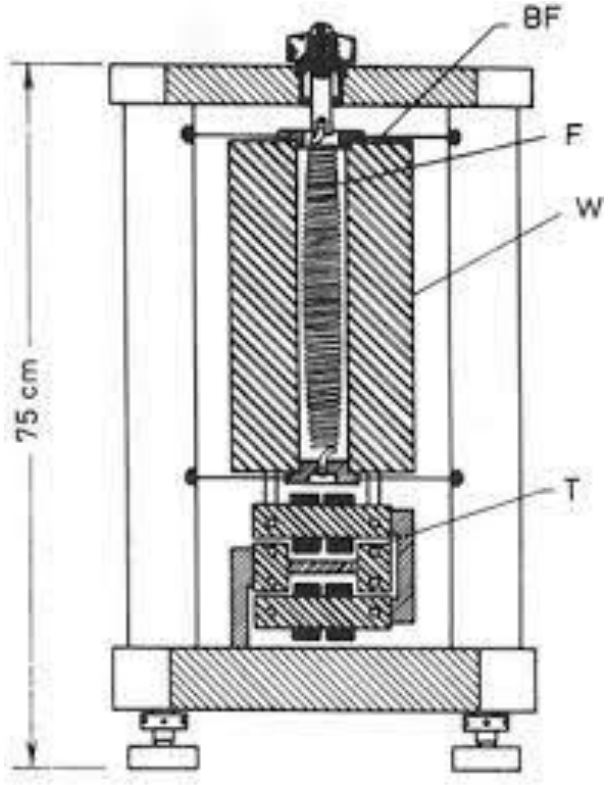
It is necessary **but it is not sufficient**

What does this mean for seismometer calibration?



In the old days we had mechanical instruments

Put a penny of the inertial mass
Tuning fork (old Benioff sensors)



We measured the magnification of the ground motion:
seismometer plus system of mechanical levers with styluses to scratch on soot paper.

What does this mean for seismometer calibration?

In modern era: All seismometers are

- **three components in one housing**
- **different internal layout of the seismic components** *(classic orthogonal vs. Galperin)*
- **controlled by feedback systems of different design**

two methods of seismometer calibration in the lab

1. **mechanical via precision shake table**
2. **electrical, by injecting a signal into the feedback system**

What does this mean for seismometer calibration?

both methods are valid, but yield different insights

#1: mechanical:

we get a voltage proportional to the mechanical excitation

but we treat seismometer as a black box.

we don't know at all what the internal components are doing

#2: electrical:

inject voltage into the feedback system, measure response of inertial mass

depending on component layout, we can test each component separately

gives somewhat more insight

get information about behavior of the inertial mass and the feedback system

more in Thomas Bruns' talk (SE01-O5) later in this session

What about the other elements of the seismic system?

- digitizer	needs separate calibration
- clock	needs separate calibration
- data management	functionality test
- telemetry	functionality test
- thermal and other insulation	inspection necessary
- geologic conditions (tilt)	inspection necessary

Only when we know all these parameters can we judge the State of Health (SOH)
of a seismic station and can perform ground motion measurements with high precision

Is that complex enough?
What about field calibration - I

Simple: Huddle test

Many seismometers of same type operated simultaneously and collocated yields comparison amongst the seismometer, easy to find outliers.

More complex:

take a lab calibrated seismometer (reference) into the field
set-up next to existing seismometer under test
compare their respective measurements

What about field calibration - II

sounds straight forward but several pitfalls:

- What happens to the reference seismometer during transport?
  mechanical vibrations, different environmental conditions
  (temperature, pressure)
- Interruption of the continuous real time measurements by
  opening the vault and insulation, generating mechanical vibrations
- reference seismometer will be connected to separate periphery (digitizer, data collection system) compared to seismometer under test. Does that introduce any additional errors and uncertainties?

more in John Mechant's talk later in this session

Conclusion

For precision measurements of ground motion

we need a stable State of Health

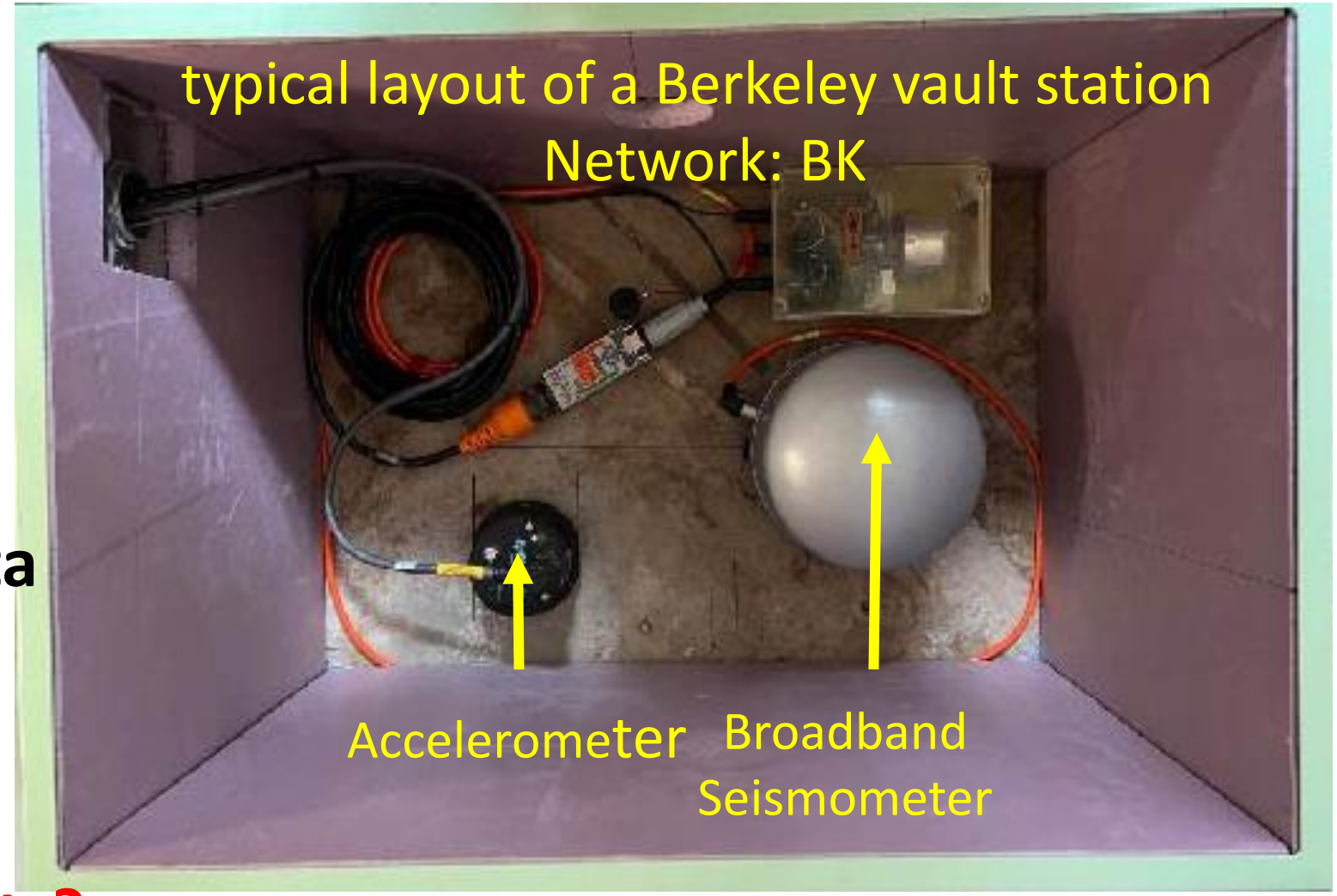
Calibration of seismometer is one element of establishing SOH of a seismic station

necessary but not nearly sufficient

Seismometer calibration shall be viewed as important element of troubleshooting process

Possible Alternate Approach:

Non-invasive health check and alternative "calibration" of a complete seismic station



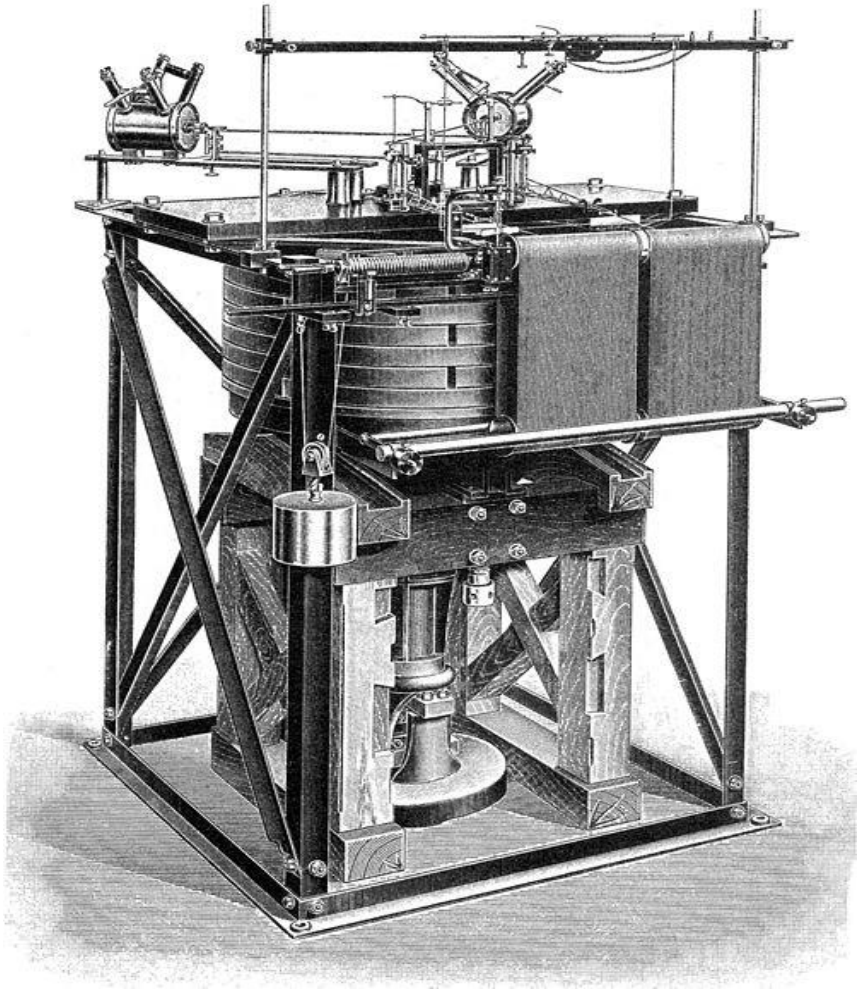
Wait for EQ,
compare Accelerometer data to BB Seismometer data
Integrate/Differentiate

Do they give the same results?

If yes, station in good health

SnT 2025
8 SEPTEMBER ONLINE DAY
9 TO 12 SEPTEMBER AT HOFBURG PALACE, VIENNA & ONLINE
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

University of California Berkeley Seismological Laboratory



Thank You