Can you hear a landslide coming (before it's too late)?

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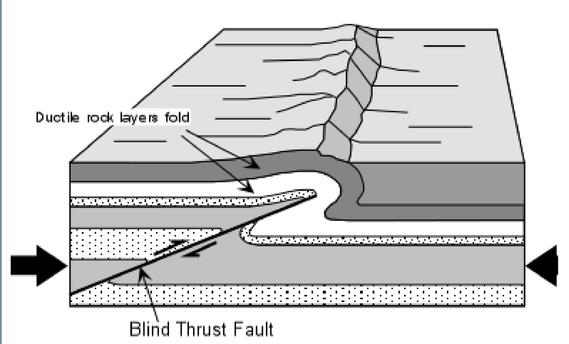
The Density of Modes (DoM)



A diagram of a seismic fault [5]

We are attempting to use the vibrational density of modes (DoM) of granular matter to forecast failure events in earth materials.

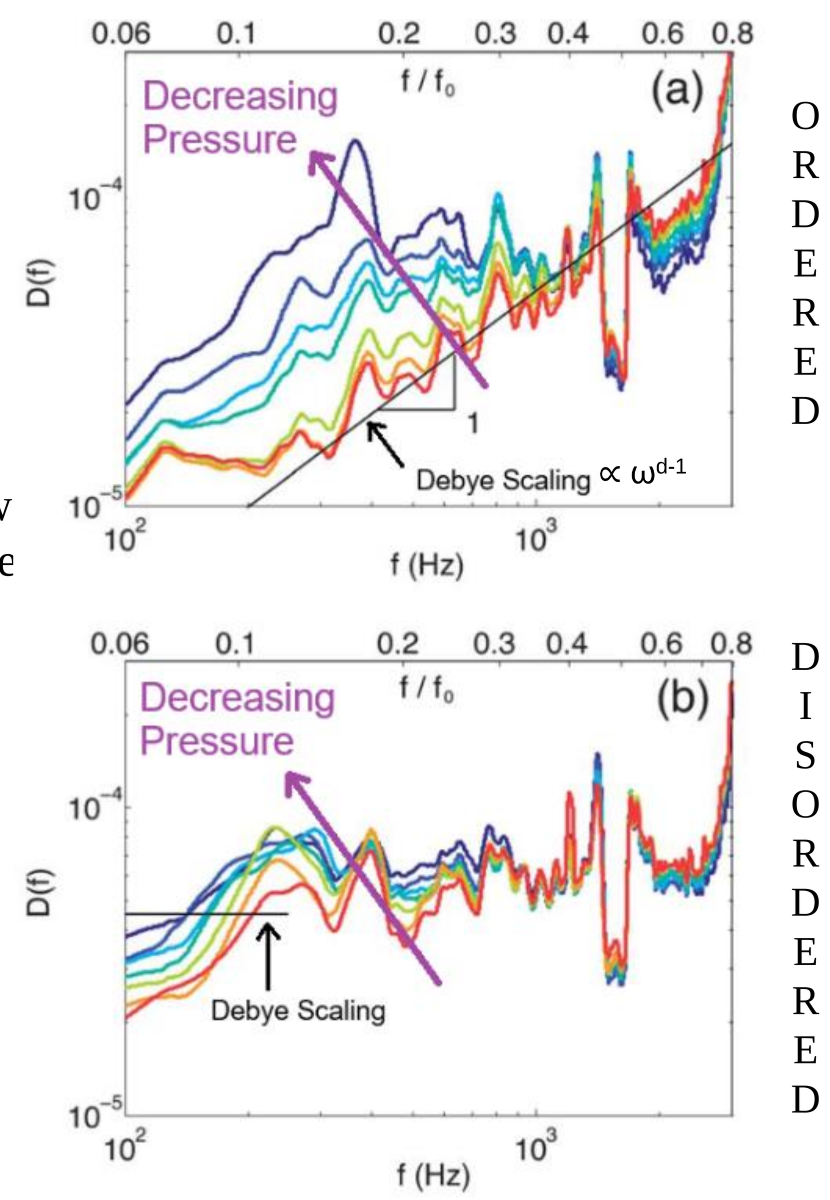
We implement a technique borrowed form thermal systems to measure the DoM using piezoelectric ceramics to measure particle accelerations.

A March 2023 Landslide in San Clemente, CA [1]

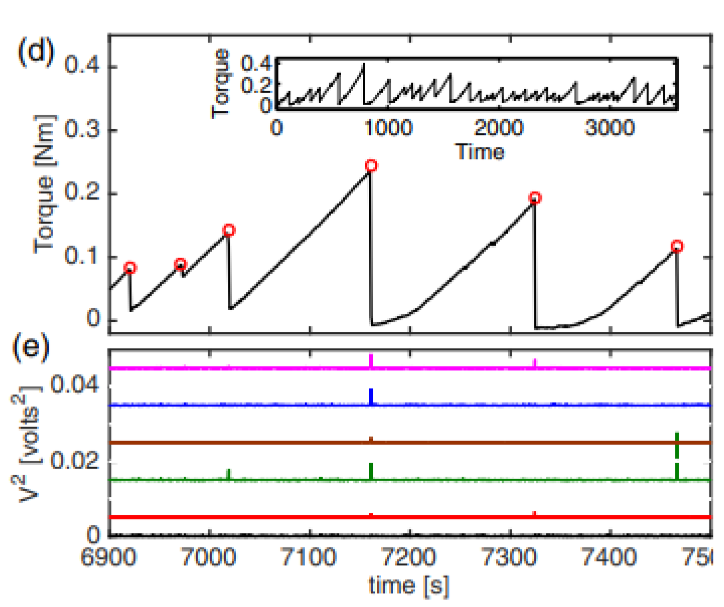
What is the Density of Modes?

The density of modes $D(\omega)$ describes the number of modes per unit frequency ω. It tells us how many possible ways the system can respond at a given frequency.

Jammed disordered system: excess low frequency modes relative to Debye-like scaling below some characteristic frequency ω^* [6] .



The DoM at 7 pressures for (a) an ordered system (b) a disordered system (Debye scaling is the black line) [2].



Piezoelectric sensors detect when a granular material fails (marked as red dots) [4].

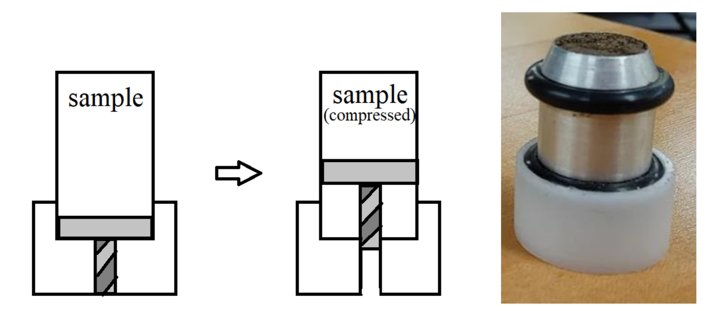
Project Goals: Using the DoM to forecast geohazards:

- An excess of low frequency modes in the DoM indicate softer material response.
- As a system approaches failure, changes in granular structure, applied stress, etc. change the shape of $D(\omega)$.
- The goal: To quantify the changes in the DoM to understand when failure is likely.

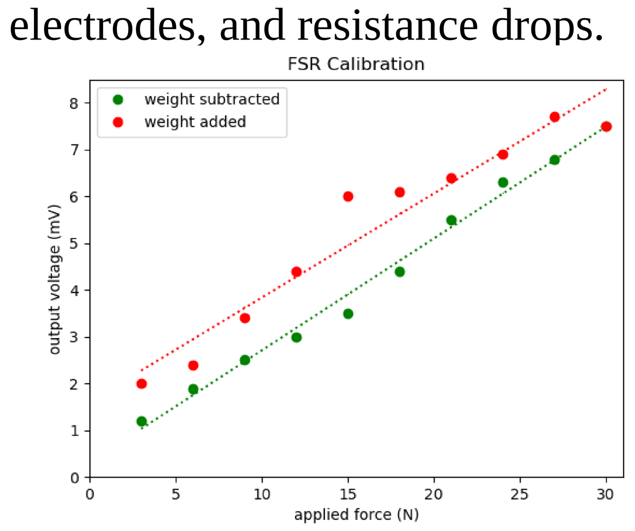
Measuring Pressure

Force Sensitive Resistors (FSRs) are semi-conductive films used to measure pressure.

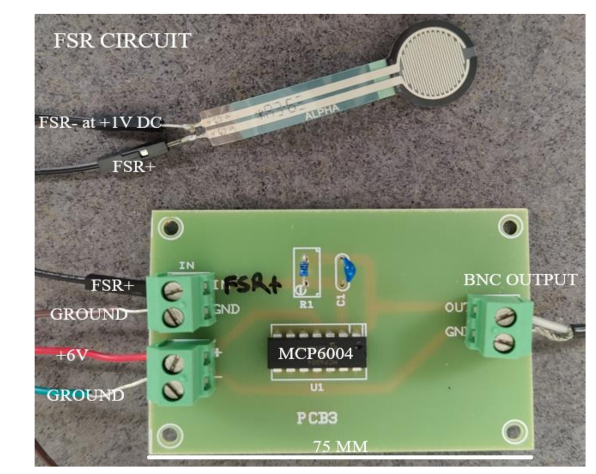
- **Without external force:** R ~20 MΩ.
- **With external force:** more conducting particles in the film are in contact with electrodes, and resistance drops.



A sample being placed under constant compressive strain using a screw.



A force response curve for the FSR

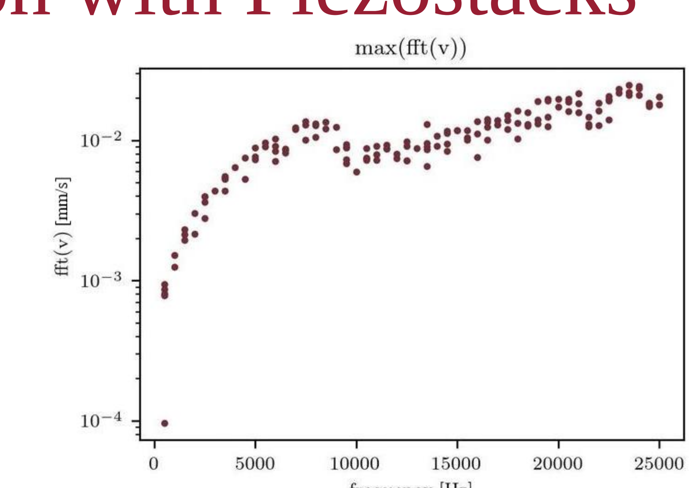


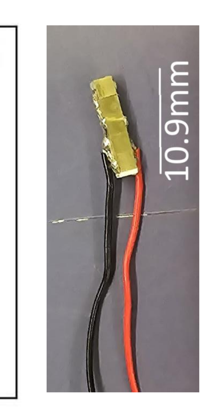
The force sensitive resistor

Acoustic Perturbation with Piezostacks

Piezoelectric stacks apply a constant acoustic perturbation to a sample of grains using a high voltage amplifier.

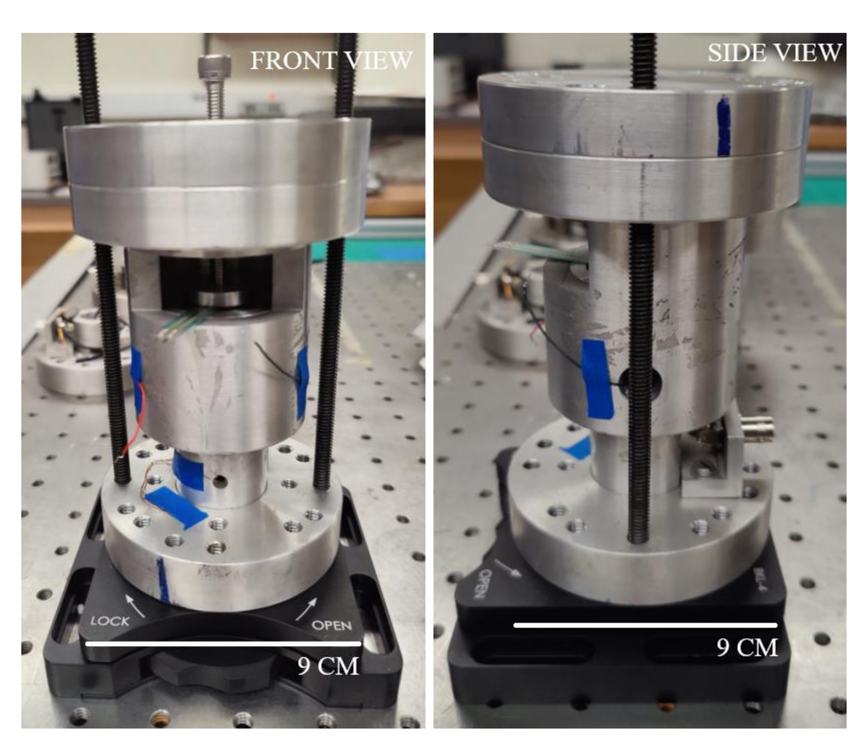
Place an aluminium disk to couple the stack and sample and ensure even distribution of force.



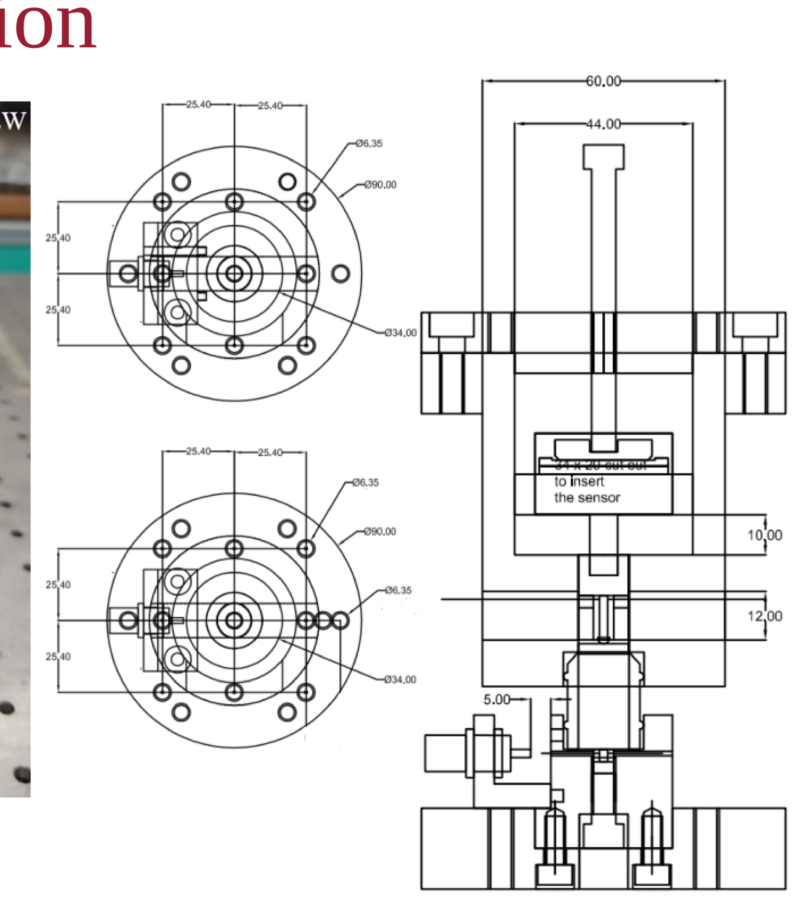


(a) A frequency response curve (b) A piezostack

Combined Instrumentation



Experimental Apparatus

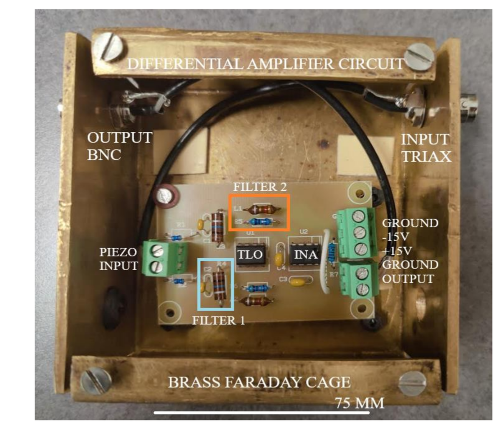


Schematics for the apparatus

Experimental Procedure:

1. Apply constant compressive strain to the sample → with an FSR
2. Applying acoustic perturbation → using a piezostack
3. Measuring the DoM → using a piezoelectric ceramic

Reading the DoM with Piezo-Ceramics



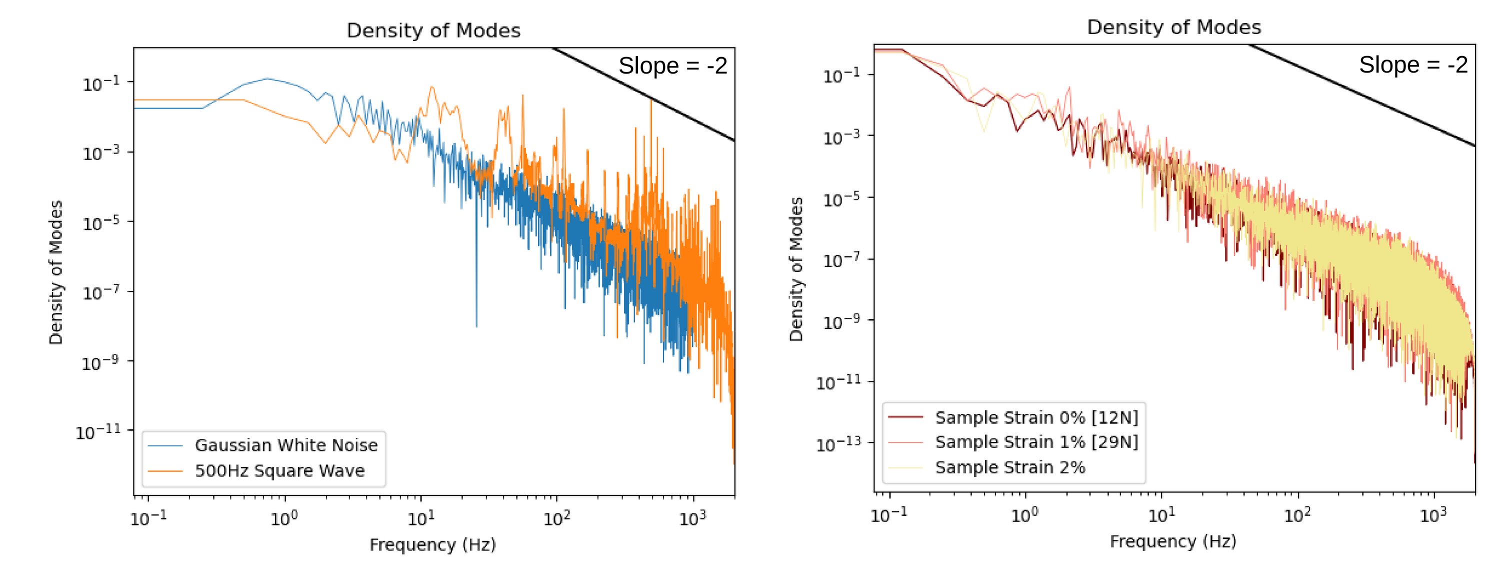
The amplification circuit

$v(t)$ is obtained by integrating piezoelectric voltage (∝ particle accelerations) v.s. time.

$$C_v(t) \equiv \frac{\sum_i \langle v_i(\tau+t)\cdot v_i(\tau)\rangle_\tau}{\sum_i \langle v_i(\tau)\cdot v_i(\tau)\rangle_\tau}$$

$$D(f) \equiv \int_0^\infty C_v(t)\cos(2\pi f t)\,dt.$$

The Velocity Autocorrelation [3,4] The DoM [3,4].

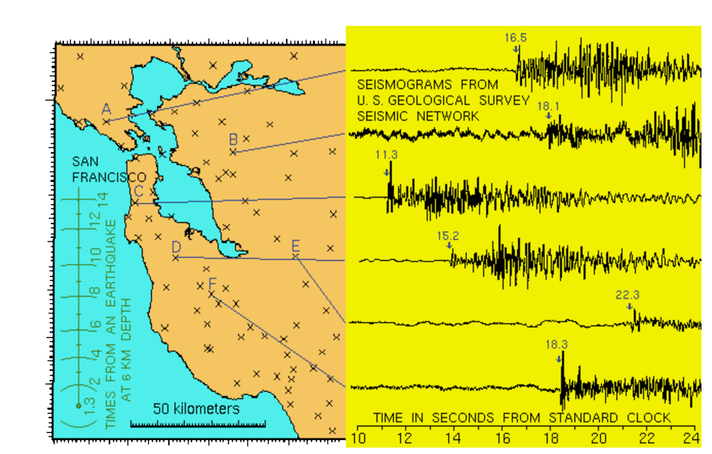


1. Demonstrating the difference between white noise driving and sine waves
2. Effects of low pressure (as a function of strain) on pluviated glass beads (1mm dia.)

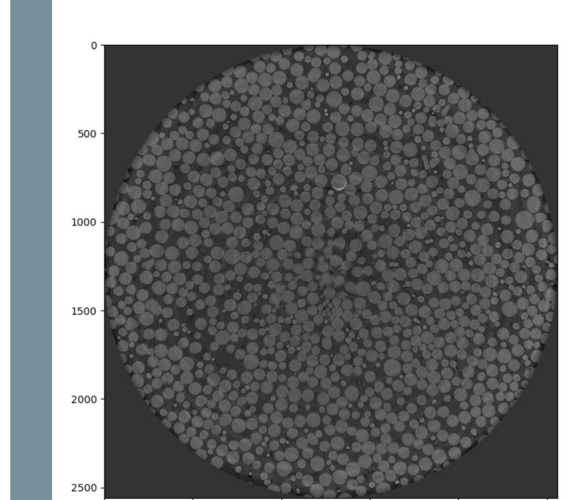
Outlook

Calibrating Geological Monitoring Instrumentation:

Soil structure and packing geometry affects the position of low frequency peaks in the DoM. This could calibrate seismographs to forecast when landscapes might fail.



Calibrating geological instrumentation [7].



An µ-CT of some glass beads.

Using tomography to understand 3D structure:

We can take a micro-tomography scan before and after DoM measurements and reconstruct 3D structure to see how changes in packings are reflected in the DoM.

Using wave pulses:

Pulses can be used in place of acoustic perturbation to measure the DoM. They are more consistent in amplitude and wavelength and can be made much stronger [8].

References

[1] J Smith, Article; San Clemente Times, 032223.
[2] Owens and Daniels, Soft Matter 9, 1214-1219.
[3] Dickey, J. M., and Arthur Paskin. Physical Review 188, 1407.
[4] Theodore A. Brzinski, III, and Karen E. Daniels. Physical Review Letters 188, 1407.
[5] Snelson, EQ Case Histories, EENS3050.
[6] N. Xu, M. Wyart, A. J. Liu, and S. R. Nagel, Physical Review Letters 98, 175502
[7] US Geological Survey, Maps of Seismic Stations.
[8] S. A. Blue, S. C. Wright, and E. T. Owens, arXiv:2403.10322.