Acoustics of Earth Materials- Geohazard Forecasting

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The Density of Modes (DoM)- Background

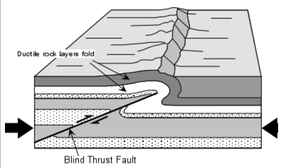

Figure 1: A diagram of a seismic fault [5]

Earthquakes and Landslides cause enormous devastation but are poorly understood compared to other natural disasters.

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

Figure 2: 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.

In Debye Solids (like ordered systems) $D(\omega) \propto \omega^{d-1}$ (the black line in 3a & 3b).

In a jammed disordered system (3b) we have excess low frequency modes relative to Debye-like scaling below some characteristic frequency ω^* [6] .

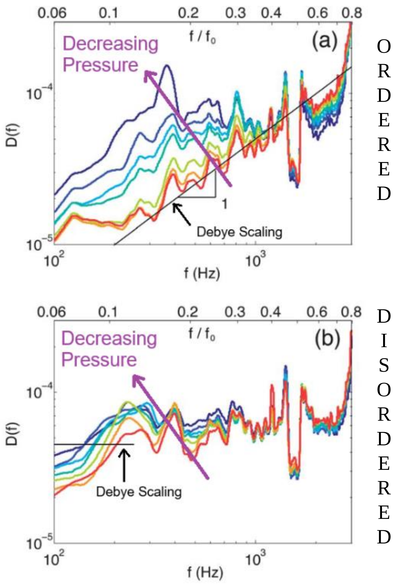

Figure 3.a and 3.b: The DoM at 7 pressures for (a) an ordered system (b) a disordered system (Debye scaling is the black line) [2].

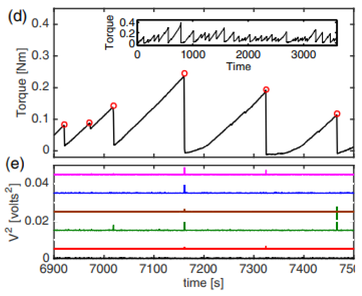

Figure 4: Piezoelectric sensors detect when a granular material fails (marked as red dots) [4].

Project Goals: Using the DoM to forecast geohazards:

- Low frequency peaks in the DoM indicate an abundance of high wavelength modes.
- As a system approaches failure, changes in granular structure, applied stress, etc. change the frequencies of these peaks.
- The goal: To quantify the change in positions of the peaks to understand when failure is likely.

Experimental Details

Measuring Pressure with FSRs

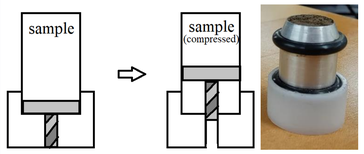

Figure 5: A sample being placed under constant compressive strain using a screw.

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.

Pressing an FSR:

Interactive Element

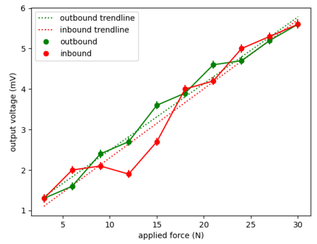

Figure 6: A force response curve for the FSR

Acoustic Perturbation with Piezostacks

Piezoelectric stacks apply a constant acoustic perturbation using a high voltage amplifier.

Coupling the stack and the sample:

1. Use an acoustic couplant (molasses)
2. Place a disk to ensure even distribution of forces into the sample.

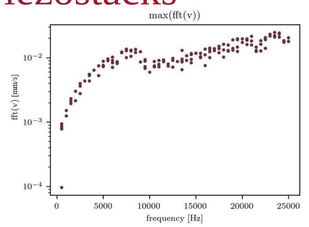

Figure 7: A frequency response curve for the piezostack

Reading the DoM with Piezo-Ceramics

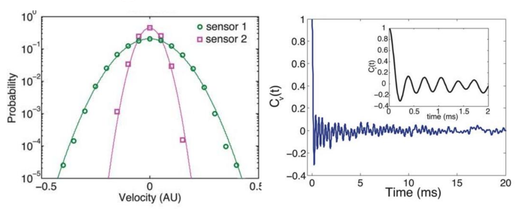

Figure 8: a) An example velocity distribution; b) a velocity auto-correlation function [2].

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

$$D(f) \equiv \int_0^\infty C_v(t) \cos(2\pi f t) \mathrm{d}t.$$

Equation 1 and 2: The Velocity Autocorrelation. and The DoM [3,4].

1. Collect the particle velocities
2. Do a velocity auto-correlation (Eq1).
3. Take an FFT
4. The real part of the FFT is the DoM (Eq2) .

Pressing a ceramic:

Interactive Element

Combined Instrumentation

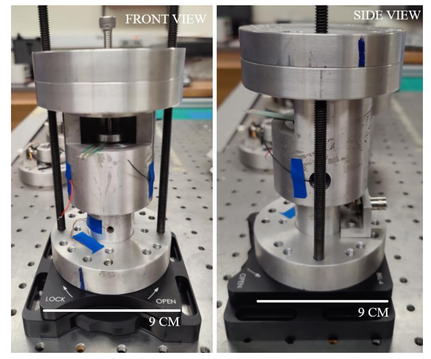

Figure 9: Experimental Apparatus

Experimental Procedure:

1. Apply constant compressive strain to the sample
2. Applying acoustic perturbation
3. Measuring the DoM with piezoelectric ceramics

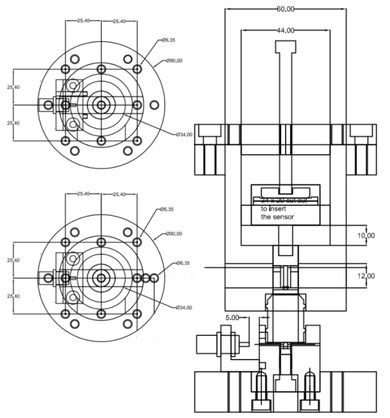

Figure 10: Schematics for the apparatus

Outlook + Future Work

Calibrating Geological Monitoring Instrumentation:

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

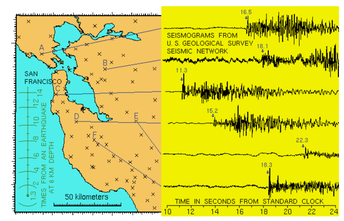

Figure 11: Calibrating geological instrumentation [7].

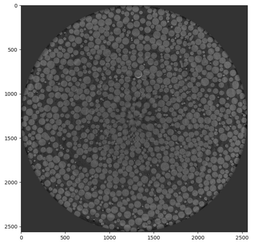

Figure 12: An μ-CT of some glass beads.

Using tomography to understand 3D structure:

We can take a μ-CT sample scan before and after DoM measurements and reconstruct 3D structure to see how changes in granular structure 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] "Landslide Leaves Evacuated Residents' Futures in Limbo." San Clemente Times, 22 Mar. 2023.
[2] Owens and Daniels, "Acoustic measurement of a granular density of modes", Soft Matter, 1214-1219, 2013
[3] Dickey, J. M., and Arthur Paskin. "Computer Simulation of Lattice Dynamics of Solids." Physical Review Journals Archive, American Physical Society, 15 Dec. 1969.
[4] Theodore A. Brzinski, III, and Karen E. Daniels. "Sounds of Failure: Passive Acoustic Measurements of Excited Vibrational Modes." Physical Review Letters, American Physical Society, 25 May 2018.
[5]] Nelson, Stephen. "Natural Disasters." EQ Case Histories.
[6] Xu, Ning, et al. "Excess Vibrational Modes and the Boson Peak in Model Glasses." Physical Review Letters, vol. 98, no. 17, 24 Apr. 2007.
[7] USGS- "Locating Earthquakes in San Francisco", 1997.
[8] Blue, Wright, and Owens, "Experimental Measurements of the Granular Density of Modes via Impact", 2024