Featured Article

2020-2021 First Place Undergraduate Student Research Grant Award Winner

Juliana South, University of Rochester. *Attenuation in Granular Materials*. Sponsor: Alice Quillen, Ph.D., Professor of Physics and Astronomy.

Abstract

To improve understanding of the transmission of energy in granular materials, we propose to carry out laboratory attenuation experiments on dry gravel through the administration of pulses and signals. With the current conflict between the jolt and seismic reverberation attenuation models in the literature we aim to differentiate between the two models in our regime by making a precise measurement of attenuation.

Additionally, by making attenuation measurements of materials with various densities and grain sizes we can better understand how seismic impacts would affect granular bodies, such as rubble-pile asteroids.

Motivation

Attenuation is an area of great interest and research in earth science, however, studies done in earth science focus on wet materials. Much less research has been conducted around attenuation in dry granular material. Additionally, there is conflict in the current literature around attenuation in granular material. The rapidly attenuated seismic pulse or `jolt' model [4, 5, 6, 10] is consistent with strong attenuation in laboratory granular materials at kHz frequencies [7] but qualitatively differs from the slowly attenuating seismic reverberation model [2, 1, 8, 9] that is supported by measurements of slow seismic attenuation rates in lunar regolith [3, 11]. This is a complex problem due to the forces between particle contacts in the material. These contacts create force networks, and interactions between the particles are influenced by packing structure [13]. Due to the complex nature of the problem and the conflicting models in the literature we believe it is important to make more precise laboratory measurements of attenuation in these materials to clarify future research using those materials.

Applications of such research are numerous and exciting. Of primary interest is the dynamics of rubble-pile asteroids, which are loosely held-together structures of granular material [12]. Research into attenuation in this material could tell us more about the structure of these asteroids. Better understanding of these asteroids could in turn inform better mission design for future sample return missions, such as Osiris-REx and Hyabusa-2. These missions are currently studying rubble-pile asteroids and rely upon an understanding of their dynamics in order to successfully land and gather samples.

Finally, DART (Double Asteroid Redirection Test) is a mission that intends to deflect asteroids that are earthbound. One of DART's purposes is to better understand how asteroids react to an impact. A better understanding of attenuation in these asteroids could benefit programs such as this, which depend on impacts. Attenuation experiments measure impact responses so our results are relevant to deflection strategies for the DART mission.

Goals

We aim to assess attenuation in granular materials of different porosities and densities. Both of these properties affect contact points in the material, and therefore the forces between them. In the future further experiments could repeat our procedures in vacuum in order to determine if our results are upheld in a setting with no air, such as space.

Procedure

Work for this project began in November 2020. Data was taken by attaching piezoelectric tabs to the inside walls of a wooden trough filled with granular material. A pulse was then administered to the material by hitting the side of the trough with a weight. One piezoelectric tab received the signal before it went through the granular material, and one received the signal after it went through the material. The tabs were connected to separate channels of an oscilloscope. Measurements were then taken for various amounts of material by varying the length of the trough and filling it in with more material (see Figure 1 on page 3). Varying the length of the trough gives much better measurements than attempting to place the receivers in the material itself and is a similar method to that used in [13].

In the future we plan to repeat these experiments with more controlled conditions. With aluminum materials we will construct a trough and scaffolding so that the setup can be maneuvered into more positions to make pulses easier to create and better defined. Utilizing a metal trough also allows us to better estimate how the pulse will travel through the trough itself and how those signals can be mitigated. In the future nondestructive testing transducers can be used to produce various types of signals, such as a sine wave, chirp, or pulse, which can be used to analyze the attenuation of many frequencies in granular materials.

(Continued on p.3)

Julianna South

(Continued from p.2)

Through these experiments we expect to find how different densities and grain sizes effect attenuation in granular materials. We also expect to make a Q measurement that is of sufficient precision to differentiate between the two attenuation models of jolt and reverberation in our regime. We expect to complete these laboratory experiments by May 2021.

Grant Funding

The grant award was used to purchase granular materials, piezoelectric vibration sensors, and materials used to construct the trough experiment.

****

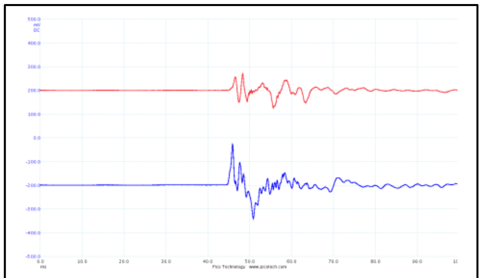

Figure 1a: 6 cm Separation

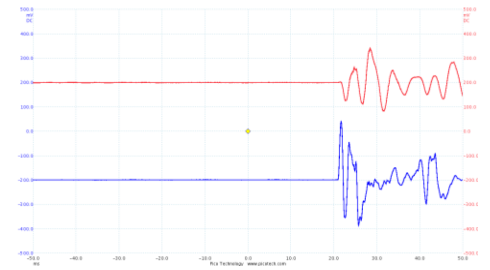

Figure 1b: 12 cm Separation

Figure 1: These graphs show a pulse measured by two piezoelectric tabs, one at the beginning of the material (blue) and one at the end (red). Figure 1a shows the measurements with a separation of 6 cm between the two tabs and figure 1b shows the measurements with a separation of 12 cm between the tabs. Both figures show a clear delay in time between the two measurements of the pulse. Both figures also show a broadening of the pulse by the time it reaches the end of the trough, indicating that the pulse has spread out through the material. Both figures also show a decrease in pulse energy by the second measurement. The second figure shows a bigger delay in measurements, as the pulse took a longer time to travel through the longer trough. These graphs indicate that we can measure attenuation using our procedures.

References:

[1] Cheng, A., Izenberg, N., Chapman, C., Zuber, M. T., "Ponded deposits on asteroid 433 Eros", *Meteoritics & Planetary Science* 37, pp. 1095-1105, 2002.

[2] Cintala, M. J., Head, J. W., Veverka, J., "Characteristics of the cratering process on small satellites and Asteroids*", Proceedings of Lunar Sci. Conf. 9*, pp. 3803-3830, 1978.

[3] Dainty, A., Toksoz, M. N., Anderson, K., Pines, P., Nakamura, Y., Latham, G., "Seismic scattering and shallow structure of the moon in Oceanus Procellarum", *Moon 9*, pp. 11-29, 1974.

[4] Nolan, M. C., Asphaug, E., Greenberg, R., "Numerical Simulation of Impacts on Small Asteroids", *AAS/Division for Planetary Sciences Meeting Abstracts 24. Vol. 24 of Bulletin of the American Astronomical Society, Jun. 1992*, p. 959. Available: http://adsabs.harvard.edu/pdf/1992DPS....24.1501N

[5] Greenberg, R., Bottke, W., M., N., Geissler, P., Petit, J., Durda, D., Asphaug, E., Head, J., "Collisional and dynamical history of Ida", *Icarus 120*, pp. 106-118, 1996.

[6] Greenberg, R., Nolan, M., Bottke, W., Kolvoord, R., Veverka, J., "Collisional history of GHaspra", *Icarus 107*, pp. 84-97, 1994.

[7] O'Donovan, J., Ibraim, E., O'Sullivan, C., Hamlin, S., Wood, D. M., Marketos, G., "Micromechanics of seismic wave propagation in granular materials", *Granular Matter 18*, p. 56, 2016.

[8] Richardson, J. E., Melosh, H. J., Greenberg, R., "Impact-induced seismic activity on asteroid 433 Eros: A surface modification process", *Science 306*, pp. 1526-1529, 2004.

[9] Richardson, J. J., Melosh, H. J., Greenberg, R. J., O'Brien, D. P., "The global effects of impact-induced seismic activity on fractured asteroid surface morphology", *Icarus 179*, pp. 325-349, 2005.

[10] Thomas, P. C., Robinson, M. S., 2005. "Seismic resurfacing by a single impact on the asteroid 433 Eros", *Nature 436*, pp. 366-369, 2005.

[11] Toksoz, M. N., Dainty, A. M., Solomon, S., Anderson, K., "Structure of the moon", *Reviews of Geophysics 12 (4)*, pp. 539-567, 1974.

[12] Walsh, K. J., "Rubble Pile Asteroids", *Annual Review of Astronomy and Astrophysics, 56(1)*, pp. 593-624, 2018.

[13] Zhai, C., Herbold, E. B., Hurley, R. C., "The influence of packing structure and interparticle forces on ultrasound transmission in granular media", *Proceedings of the National Academy of Sciences, 117(28)*, pp. 16234-16242, 2020.

***