A NOVEL METHOD OF MEASURING SEISMIC VELOCITY IN OFF-EARTH CONDITIONS: IMPLICATIONS FOR FUTURE RESEARCH.

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Introduction**:** Understanding the strength of regolith on airless planetary bodies (e.g. moon and asteroids) is expected to be highly important for planning future exploration, mining, colonization and asteroid deflection missions. For example, asteroids of differing composition/structural type may react differently to various deflection methods [1, 2], and understanding the strength and composition of regolith is needed for the selection of in-situ anchoring devices [3] and mining techniques. One proposed method for determining the strength of the regolith and the internal composition on these bodies is to place seismic sensors on its surface. However, interpreting the data from these sensors may be difficult.

To date, little is known about the geomechanical properties of the regoliths of these airless planetary bodies, especially asteroids [4]. On Earth, relationships exist between seismic properties and the strength of consolidated and unconsolidated materials found [5]. In order to understand the geomechanical properties of airless bodies, there needs to be an understanding of how seismic sensors work when placed on these low-gravity bodies.

Limited work has been performed to test seismic sensors on Earth for use on other planetary bodies [6, 7]; however no data have been published for testing seismic sensors in simulated near-vacuum, weightless conditions as expected on asteroids.

Here, we outline a new approach for the purposes of measuring the seismic velocity of regolith on airless bodies and discuss its usefulness for future planetary missions. Our designed approach is to set up a ‘seismic in a box’ experiment to correlate the seismic properties and strength of a variety of regolith simulants under environmental conditions. To date, the only planetary seismic data acquired other than the Earth is the Moon during the Apollo missions. Here, we present preliminary results for determining the P-wave velocity of the Australian Lunar Regolith Simulant 1 (ALRS-1).

Regolith simulant: ALRS-1 was created by Garnock and Bernold [8] at UNSW Australia based on the geochemistry and geomechanics of Lunar regolith identified from the Apollo landers. The material was created using basaltic soils from northern Sydney, NSW, Australia, and was prepared by sieving to achieve the desired particle size distribution.

While the geochemistry of ALRS-1 has been measured, and is comparable to the Lunar regolith [9], the geomechanical (and in particular seismic) properties remain untested. Determining the accuracy of these properties is critical to ensure that previous experiments performed using the material [9] can be accurately applied to Lunar environments, and to open the way for future experiments.

Seismic**:** Small scale, ‘seismic in a box’ testing of regolith is relatively uncovered in the literature. Buddensiek [10] and Sherlock and Evans [11] used small, high frequency seismic receivers in a relatively confined sandbox to measure seismic velocities. However, these studies focus primarily on imaging small scale versions of regional geological features; they did not focus on measuring seismic velocity. Seismic waves experience strong attenuation when travelling through unconsolidated sand, which has been a major issue for imaging sandbox models with seismic [12]. This is largely due to friction between individual grains and uneven pore space distribution. Additionally, the wavelengths typically generated by sandbox seismic sources are approximately the same length as the width of individual grains, which results in additional reflection and scattering.

The seismic velocity of consolidated rocks is primarily influenced by density, which is a function of mineralogy, fluid type/saturation and porosity, degree of cementation, pressure and temperature. In unconsolidated sediments, the influence of these parameters is significantly weaker. In particular, density, porosity and type of material are less important and may even have no effect [13, 14], while sediment frame rigidity becomes more important [11]. Sediment frame rigidity, and therefore velocity, are strongly affected by grain shape and sorting. However, grain size and permeability do not appear to strongly influence velocity.

Methodology**:** The Pundit PL-200 system was used to collect seismic data, which has interchangeable piezoelectric sources and receivers of different frequencies. The source and receiver used for this test were rated at 54 kHz. We constructed a stainless steel container for containment of the regolith (200 x 300 x 300 mm, with 1.2 mm thick steel walls). It has a free-floating lid with a Perspex window and 6 latches to hold it closed for work in dynamic environments. This container was designed to allow for portable use of the entire system. The full set-up is displayed in Figure 1.

The container is filled with loose ALRS-1 (no compaction applied) to approximately 5-10 cm high, and the source and receiver are placed inside and buried under the regolith. The distance between the closest edges of the source and receiver is measured, and the Pundit is used to determine the delay time of a 54 kHz seismic wave transmitted through the regolith, using the first arrival of the received seismic wave. The recordable delay time ranges from 0.1 – 7930 μs, with a resolution of 0.1 μs (for < 793 μs) and 1 μs (for > 793 μs).

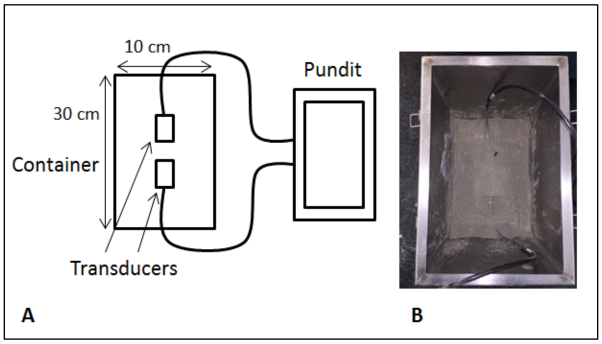

Figure 1 – A, sketch of experimental set-up, and b, image of piezoelectric transducers buried in ALRS-1.

***Preliminary Results*:** Velocity measurements were made by measuring the separation distance of the source and receiver and using the range of delay times read by the Pundit for that distance. 23 measurements were taken at a range of separation distances from 0.5 cm to 3.5 cm. The measured velocities ranged from 38.6 m/s to 286.7 m/s with an average of 98.6 m/s.

***Discussion*:** The average measured velocity for ALRS-1 is compared to the *in-situ* measurements of Lunar regolith during the Apollo 14 and Apollo 16 missions, which are 104 m/s and 114 m/s respectively [15]. While preliminary, this is an encouraging result for the geomechanical and seismic accuracy of the ALRS-1. It is hoped that further refinement of this methodology will improve the accuracy of this measurement. Some differences in velocity between lab and in-situ conditions are expected, as this experiment assumes zero compaction, and due to the differing measurement environment.

***Future work*:** We will refine the accuracy of the methodology and ensure its validity. This will be done by testing a regolith or sediment of known velocity (e.g. a pure sand) to ensure the results are accurate for unconsolidated material. A method will be devised to ensure that the source-receiver separation is accurate and repeatable. This can be achieved by developing foam molds that the source and receiver can be placed into with a known separation distance, and then buried in the regolith. Finally, the repeatability problem relating to the deposition of sediment in the lab should be addressed. We will also examine taking measurements for a given regolith sample in different atmospheric and gravitational conditions (e.g. by using a vacuum chamber or a parabolic/free-fall jet). This will determine whether varying atmospheric conditions and gravitational strength, as found on other planetary bodies, will impact the seismic velocity of a given sample. This is critical to understand for any future space mission intending on using seismic for the purposes of determining regolith strength, as relationships between velocity and strength may only be valid for Earth-like conditions.

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