SAMPLR – A Lunar Regolith Geophysical Evaluation Instrument and Development of an In Situ Calibration Method. C. B. Dreyer[1], B. C. Thrift[1], A. Abbud-Madrid[1], S. Doughtery[2], and The SAMPLR Team, [1]Colorado School of Mines, 1600 Illinois St., Golden Colorado, 80401, [2]Maxar Technologies, Westminster Colorado 80234 (Contact: cdreyer@mines.edu)

Introduction: SAMPLR is an instrument payload manifested on C-21, a Commercial Lunar Payload Service (CLPS) mission, that will land in the Gruithuisen Domes region on the Moon in 2028. SAMPLR consists of a robotic arm, workspace cameras, penetrometer with a 6-axis force torque sensor, and a scoop (Figure 1) [1]. SAMPLR constitutes a geotechnical measurement suite that will conduct the first regolith properties measurements on the Moon in more than 40 years.

In Situ Calibration: In-situ calibration methods are needed to enhance the collection of data on planetary materials. Typical practice on Earth is to build an understanding of geotechnical properties of soils by developing a repository of reference data and measurements collected in well-defined samples and in well understood environments. Extraterrestrial penetrometers do not have the same luxury. Reference samples are limited to sample return and regolith simulants. Terrestrial based penetrometer data can inform the general characteristics of penetrometer readings in unknown targets under less understood environmental conditions, but new references are needed for more rigorous and quantitative data.

In situ calibration methods, that is a method to interpret instrument response with respect to a geotechnical parameter using only in situ measurements, will expand the interpretation of planetary regolith. In this work we present an in situ calibration method for density using the SAMPLR penetrometer and scoop.

Methods: The density in situ calibration [2] follows these steps to produce a low-density reference measurement. Figure 2 shows an images sequence of these steps.

1. Run penetrometer test in the initial surface.

2. Scoop regolith in the area around the initial penetrometer test. Take mass measurements of the regolith used to create the pile using arm motor torque or calibrated load cells on the scoop.

3. Pour material into a loose-poured pile. Repeat steps 2 and 3 as needed to complete loose poured pile.

4. Loose-poured pile should be at least 80% of the probe length in height. Sufficient images of loose-poured pile should be taken to generate a photogrammetry model. Angle of repose can be determined for the pile from these measurements.

5. Position probe over loose-poured pile apex. Positioning over the apex of the pile helps ensure the penetrometer data are not skewed by uneven forces on the sides of the probe.

6. Conduct penetrometer test in loose-poured reference pile.

The density of the pile is determined from the mass measured in step 1 and the volume of the pile determined from the photogrammetry model produced in step 4.

Figure 1: SAMPLR Instrument.

A high density in situ reference measurement is created by excavating the surface to expose the natural high density subsurface. As with the low-density reference point, photogrammetry and arm or scoop force data can be used to produce a measurement of high the high-density reference point.

SAMPLR penetrometer measurements are analyzed by the specialized penetrometer method [3]. An example curve fit is shown in Figure 3.

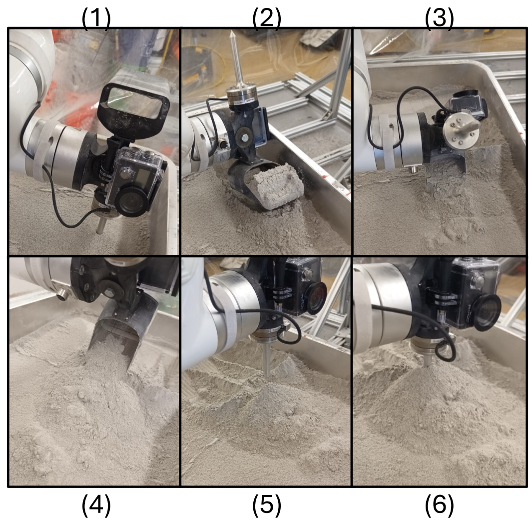

Figure 2: Production of a low-density reference pile of CSM-LHT-1 lunar highlands regolith simulant using the SAMPLR engineering model penetrometer and a 3D printed SAMPLR scoop on a 5DOF laboratory robotic arm.

In the specialized penetrometer method, the penetration force curve is fit to a second order polynomial: $F(z) = \alpha z + \beta z^2$

$F(z)$ – Force at depth

α – First-order coefficient = Slope

β – Second-order coefficient = Curvature

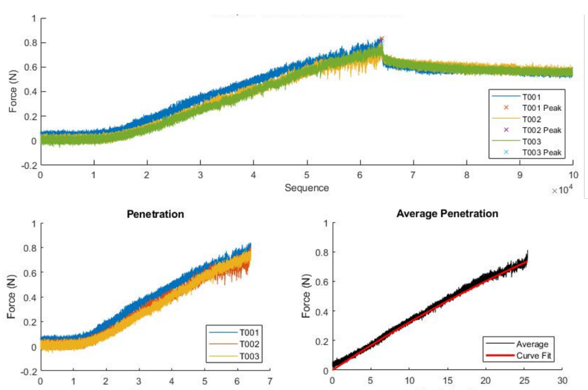

Figure 3: Example of the specialized penetrometer method.

Results: Several penetrometer tests were run on arm-generated low density reference piles and samples in reference containers where density could be well controlled. Figure 4 shows an in situ calibration of density using the methods discussed and calibration points low-density near 30% relative density and high-density reference points near 90% relative density. A power law fit was produced using linear regression that agrees well with reference data.

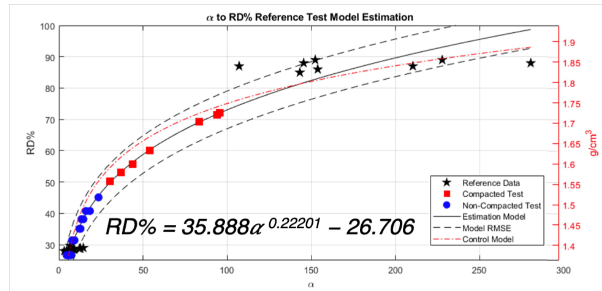

Figure 4: In situ calibration example using a low density reference pile made via a robotic arm and SAMPLR-like scoop and high density CSM-LHT-1 in sample containers at similar density as 20 cm depth on the Moon. The in situ model compares well to the control model that was produced with a power law fit to all data.

Conclusions: We have shown a method for in situ calibration of penetrometer data for density. This and other in situ calibration methods are needed to advance geotechnical measurements on planetary surfaces. In principle, calibrations are possible for friction angle, cohesion, bearing capacity and more. Additional geotechnical in situ tools can be deployed, such as shear vane, plate compaction, deflectometers, and bevameter. Planetary geotechnical measurements can be further enhanced by a Geotechnical Workbench which would deploy on the Moon the regolith test equipment in a typical research laboratory with tools for measurement of maximum and minimum density, containers for intermediate density, particle size distribution, triaxial and direct shear.

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References: [1] *Thrift, B. C., Dreyer, C. B., Seibert, M. A. et al. (2023). The Specialized Penetrometer Instrument: SAMPLR and Beyond. In Dreyer, C. B. and Little, J. (Ed.), Earth and Space 2022: Space Exploration, Utilization, Engineering, and Construction in Extreme Environments.* [2] Thrift, B., & Dreyer, C. (2025). Specialized Penetrometer Use for Extraterrestrial Surface Characterization. *Journal of Aerospace Engineering, 38*(4), 04025041. [3] *Atkinson, J. (2019). Cryogenic Penetration and Relaxation Behavior of Dry and Icy Lunar Regolith Simulants. Ph.D. thesis Colorado School of Mines Golden, CO.*