A Method of Measuring Bulk Density of Regolith Simulants In-Situ

Development of the methodology for in-situ measurement of surface layer bulk density for granular regolith simulants.

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Motivation

This work developed correlation curves to relate pocket penetrometer readings to bulk density as a way of determining regolith simulant densities in-situ without the need for other largely destructive measurement methods such as core sampling.

The density (ρ) of a soil greatly affects essential properties such as the shear strength (τ_f), internal friction angle (ϕ), or Poisson's ratio (ν) which are used to determine the soils Mohr-Columb failure envelope, bearing capacity, and settlement [1].

For lunar construction technologies being tested terrestrially, a proper starting regolith simulant density and, in some cases, measurement of the final regolith density post technology testing are needed to verify operation. Preparation and measurement of regolith simulant bins can be difficult work depending on their volume and mass. Verifying the density is challenging without affecting the density of the bin through sample collection itself.

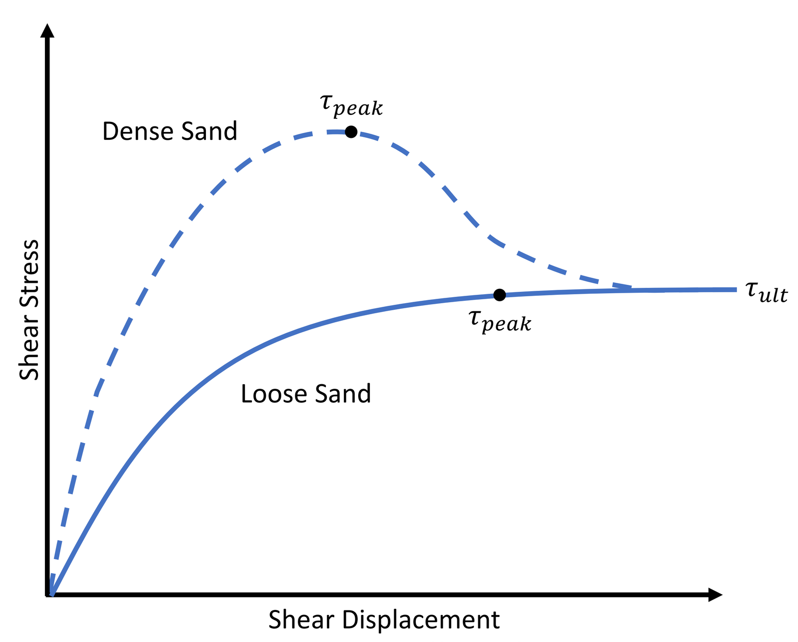

Figure 1 – Chart highlighting effects of density on results of a direct shear test

[1] Braja M. Das Principles of Geotechnical Engineering, 7th Edition; Cengage Learning (2006).

Procedure

A Humbolt Split Compaction mold (H-4159) and a Humbolt Aggregate Tamper (fig 1) were used as a regolith container and impact weight to prepare each sample tested. The mold has a height of 203.2 mm (8in) and a diameter of 152.4 mm (6in). The drop mass on the aggregate tamper weighs 4.2 kg with the total mass of the tamper, including the drop mass, weighing 8.3 kg.

To prepare densities roughly less than 1.5 g/cc the regolith was carefully poured into the sample container through a 6.3 mm sieve plate. Once the desired mass was reached the sieve plate was removed and the surface was carefully leveled. Three equidistant height measurements were then taken along the edge of the sample container, and a penetrometer reading was taken from the center of the sample. For densities greater than 1.5 g/cc the sample was prepared in the same way, however after gently leveling the surface a thick aluminum plate was then placed on top of the sample. Depending on the desired density to be tested, a number of impacts from the Humbolt Aggregate Tamper were imparted on the surface of the lid on top of the prepared sample. Then a penetrometer reading was taken after the lid was removed.

A Humbolt H-4205 pocket penetrometer was used to record the applied pressure with a standard 20 mm diameter foot and a custom 60 mm diameter adaptor (Figure 2). Low density samples required a larger diameter foot to read a measurable force on the gauge. A custom 60 mm foot was designed by Swamp Works for these lower density samples to be properly measured. The penetrometer provides a reading in kg force imparted by the user to press the cylindrical foot 15 mm into the soil, so that the soil surface is flush with the top of the foot. This force can be converted to a pressure applied to the surface based on the area of the foot used in the test.

Table 1 – Sample data collection test matrix

Goal Density (g/cc)	Penetrometer foot	# of hits	Calculated Density (g/cc)	Penetrometer Reading
1.6	20mm	Static load only	-	-
1.65	20mm	2	-	-
1.7	20mm	4	-	-
1.5	60mm	0	-	-
1.55	60mm	lid	-	-
1.6	60mm	Static load only	-	-

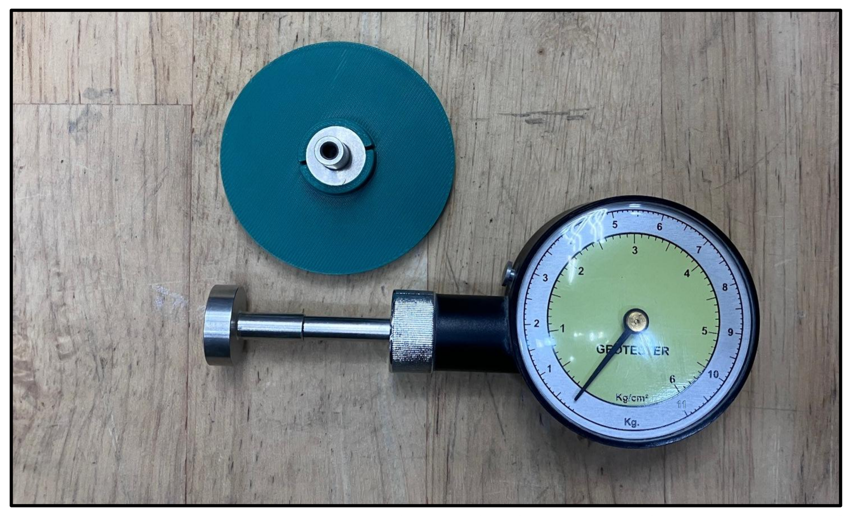

Figure 2 – H-4205 Penetrometer with standard 20mm and custom 60mm foot

Figure 3 - Test Procedure Tools

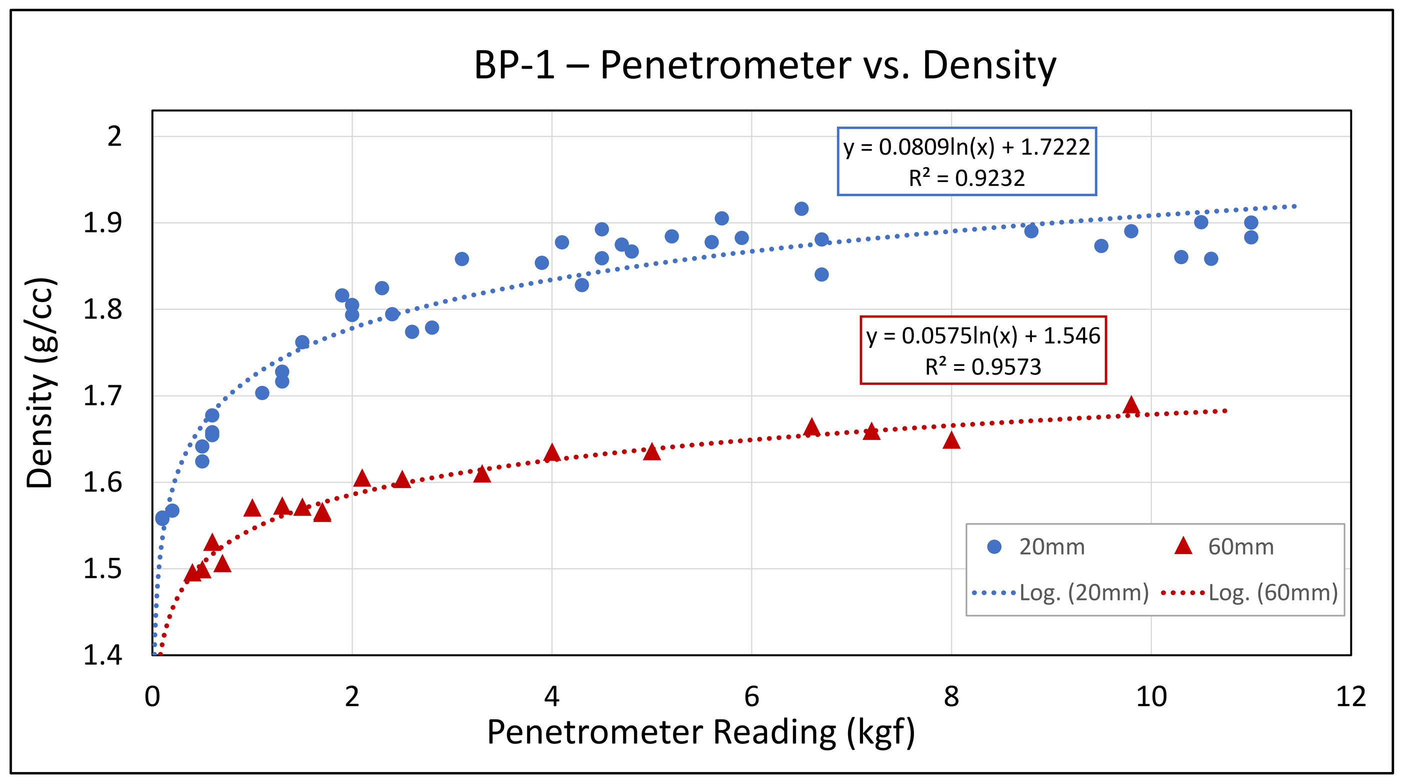

Figure 4 – Penetrometer Reading vs. Calculated Density

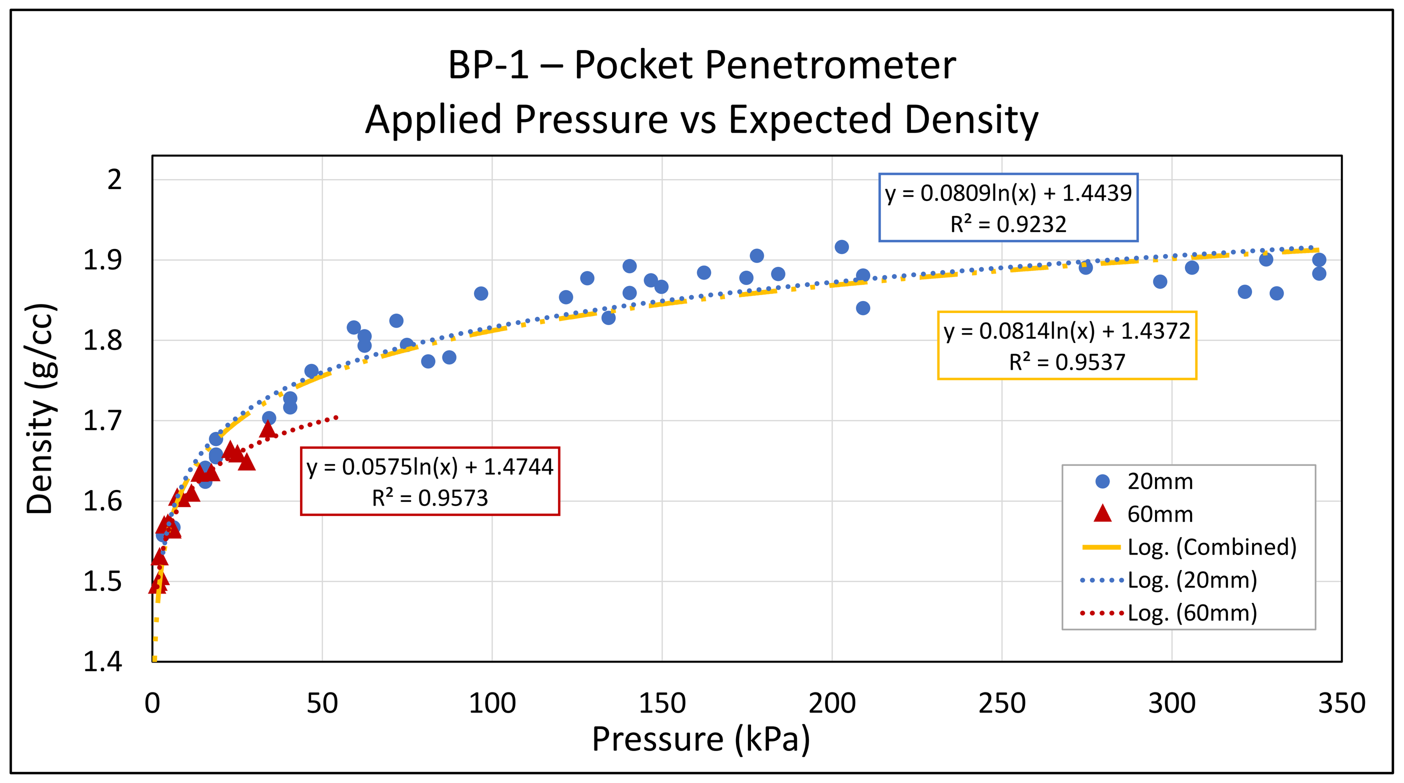

Figure 5 – Calculated Pressure vs. Calculated Density

Discussion

To properly interpret these recorded values, curves are generated to correlate the penetrometer readings and the applied pressure to the goal density. Using the calculation of pressure applied allows for comparison of multiple different diameter feet to be overlayed with each other. These correlation curves can then be used to get an estimation of density of a sample that is measured with a H-4205 penetrometer. Figure 4 shows the results of testing in the form of penetrometer reading vs. the calculated density of the sample. The resulting curve of pressure vs. density is seen in Figure 5.

ASTM standards were consulted when developing the procedure, however they were not used in their full scope. Standards such as the standard proctor (D968) or modified proctor test (D1557) were determined to be unfit for the purposes of creating the desired density range. These standards use a method of compaction that layers soil within a mold like the one used. A layer of soil is placed within the mold and then compacted, then the next layer is placed on top of and compacted on top of the previous layers. This method is acceptable for terrestrial soils with higher moisture contents and desired densities, but makes achieving a range of medium (roughly 1.5-1.7 g/cc) densities within dry regolith simulants challenging due to potential over compaction of lower layers during preparation of higher layers. For this work compaction was performed without layering. While this may reduce homogeneity throughout the sample, it allowed for a broader range of densities to be achieved in regolith simulants tested initially. Other standards such as ASTM D5195, D2937, D4564 can potentially enable a better understanding of a desired density range, however they were found to either require extensive complex equipment, are not suited for easily molded granular media, or require previous soil specific calibration

Future Work

Throughout the duration of data collection and process development, locations for improvement and development were identified. Future testing will include efforts to develop of the procedure to further increase the reliability, accuracy, and usefulness of the discussed procedure. Items that are desired to be addressed are as listed:

- Assess and reduce density gradients within the prepared samples
- Complete analysis of margin of error and accuracy of measurements
- Develop methods for multilayer compaction that allows for medium density range samples
- X-ray Computed Tomography scanning to measure density homogeneity throughout a prepared sample
- Effective zone of measurement determination
- Quantify the effect of density gradients on the results
- Adaptation of procedure and sample preparation for in vacuum testing for further understanding of atmosphere on density
- Predictive model based on methodology for development of granular media modeling