Simulating Lunar Highland Regolith Profiles on Earth to Inform Infrastructure Development on the Moon
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Motivation: Upcoming robotic and human missions to the Moon (e.g., NASA’s VIPER and Artemis) will begin the process of establishing infrastructure for a long-term lunar presence, as plans are underway [1] to achieve this at highland [2] landing sites at the south pole. The logistical requirements for a sustained presence on the lunar surface necessitate a thorough understanding of the geotechnical properties and density profile of the near-surface regolith column. However, regolith samples brought back from Apollo missions are much too precious for large-scale engineering tests, thus the need to use lunar regolith simulants.

Introduction: Shortly after the Apollo 11 mission, NASA JSC technicians had Buzz Aldrin walk on a simulated lunar surface (sand ~15 cm deep) with 5/6 of his weight supported in a marionette rig. When asked how the test track compared to walking on the actual lunar surface, Aldrin replied that the test track sand was too yielding, while walking on the Moon he noticed that although the lunar regolith was soft at the surface, there was a firmer stratum underneath [3]. This straightforward observation emphasizes the overall objective of this study; i.e., to understand how the regolith will withstand construction activities, it will be critical to replicate the geotechnical properties and density profile of the near-surface lunar regolith while performing Earth-based testing (i.e., pack simulant in layers of specific densities, rather than just dumping it into the test bed). Engineering tests that consider these characteristics will be fundamental to inform future infrastructure development (e.g., launch/landing pad - LLP), and other mission logistics, such as vehicle trafficability and ISRU activities. Here, we use Exolith Lab’s LHS-1 Lunar Highlands Simulant (https://exolithsimulants.com; see [4] for LHS-1 geotechnical properties), to replicate the geotechnical characteristics of the highlands regolith column, as measured in situ with cone penetrometer testing (CPT) during the Apollo 16 mission.

CPT Measurements: We used a Rimik CP40II cone penetrometer to obtain Cone Index (CI) penetration resistance values (i.e., stress in kPa) versus depth for LHS-1 simulant packed at various densities in clear, acrylic test bins (~30 x 30 x 80 cm). The American Society of Agricultural Engineers (ASAE) standard cone area of 1.3 cm² matches that used for six CPT measurements (three each at Stations 4 and 10) during the Apollo 16 mission. We measured CI values of LHS-1 at 10 mm intervals to nominal depths of ~200–350 mm in order to derive slope parameters (Fig. 1; G = slope of stress vs. depth measured from the surface to 100 mm) and to simulate in situ Apollo 16 regolith density profiles as measured with CPT during the mission (Fig. 2).

Figure 1. Slope parameter (G; log scale) of stress penetration curves vs. relative density (ρr) for LHS-1. Data (black circles) from 50 CPT measurements (five G determinations each at 10 different ρr) yield an exponential relationship.

Figure 2. Penetration depth vs. stress for a simulated ~35 cm deep two-layer regolith column (see inset photo; 12” ruler for scale) using LHS-1 (blue curve) compared to Apollo 16 CPT data (gray curves). Black curve represents LHS-1 data with a reduction factor of x0.30 applied to adjust for lunar conditions and is consistent with density profiles measured in situ during Apollo 16 [5].

Summary: CPT measurements show a strong correlation between G and ρr for LHS-1 simulant (Fig. 1). Furthermore, LHS-1 can be used to replicate the near-surface regolith column at the Apollo 16 highland landing site (Fig. 2). Removal of the less dense upper layer of lunar regolith via rocket exhaust would leave the denser, lower layer at ~15-20 cm depth exposed, which could then be stabilized to form roadways and LLPs.