**Experimental Study of Large-Scale Bearing Force Mechanics in Highlands Lunar Regolith Simulant.**

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**Introduction:** With the Artemis missions planning a sustained presence on the moon, the importance of various forms of infrastructure is an apparent need for supported long-term operation. Landing pads, habitats, power generation and ISRU plants, and roads will all benefit from surface preparation efforts, including compaction. Terrestrially these compacted surfaces can be tested using standard testing procedures like ASTM D1195, which assume known properties about stress dispersion through a granular medium. In lunar regolith, the actual stress bulb generated by such tests can be assumed but hasn't been quantified.

Analysis of surface bearing capacity has been carried out in regolith before, but not at the scale demanded by terrestrial foundation testing standards (Board 1972 p. 16; Dotson et al. 2024; Jaffe 1971; Mueller et al. 2025). The Planetary Surface Technology Development Lab (PSTDL) conducted a series of bearing capacity tests according to ASTM D1195, Standard Test Method for Repetitive Static Plate Load Tests of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements (ASTM D1195 2021).

These tests were conducted with upwards of one ton of lunar highland simulant MTU-LHT-1A (Carey and Van Susante 2022) in both atmospheric and vacuum conditions, at a variety of bulk densities. The atmospheric tests featured the use of a buried Tek Scan pressure sensing blanket to measure the stress distribution in the simulant with respect to depth. These tests aimed to quantify not only the pressure sinkage curve of the simulant in atmospheric and vacuum conditions, but also to quantify the resulting stress bulb created in the soil.

**Methods:** First, a load frame capable of handling the anticipated loading forces and heavy regolith loads, while still able fit inside the PSTDL Dusty Thermal VAcuum Chamber (DTVAC) was built. ASTM Standard D1195 calls for a 2.54 cm thick circular plate with a minimum diameter of 15.2 cm. Additionally, the Bossinesq equation for round footings indicates that pressures in the soil euivalent to 0.05 * the initial applied pressure may be present up to 3 diameters away from the plate edge of the soil surface (Figure 1). The final element to the design was estimating the forces the system would experience to size the linear actuatora. Previous testing suggested that bearing capacity ranging from 100kPa-160kPa could be expected (Heiken et al. 1991; Jaffe 1971).

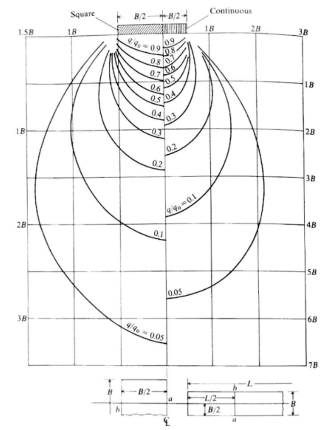


*Figure 1: Soil stress distribution* (Bowles 1996)

Given these size constraints, a steel load frame called officially called the High-strength Experimental Rig for Construction and Uniaxial Lunar Engineering Studies (HERCULES) was developed. The bin of the test frame holds 0.5m^3 of regolith (0.6m x 0.6m x 1.2m), and is marked in 10cm intervals for ease of following fill and compaction procedures. Due to the bin size, the maximum load plate used had a radius of 18cm.

For the electrical system, a A 100mm 16kN 48 Vdc linear actuator was selected to apply the load to the plate, paired with an inline A 22,241 N (5000 LBF) load cell. The displacement was measured by 2 linear voltage transducers attached to the load plate via magnets, on an external frame isolated from any strain on HERCULES' upper frame (figure 2).

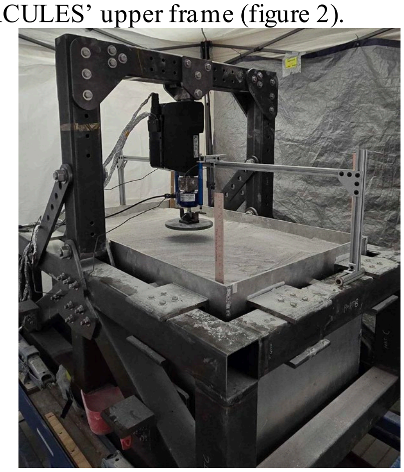

*Figure 2: HERCULES Load Frame in tent in PSTDL.*

Three bulk initial densities were selected for this test campaign: 1.4 g/cm^3 ("fluffy"), 1.6 g/cm^3 ("average"), and 1.8 g/cm^3 ("dense"). Each bulk density was tested three times in atmospheric and vacuum conditions leading to a total of 18 bearing capacity tests. The 1.4 g/cm^3 and 1.6 g/cm^3 tests used the 18 cm diameter plate. However, due to the required force exceeding the actuator push force, a 10 cm diameter plate was used for the 1.8 g/cm^3 tests. Each test measured the force applied to the plate using the load cell, and plotted against the average displacement measured by the two transducers. A plot of all collected data can be found in Figure 3.

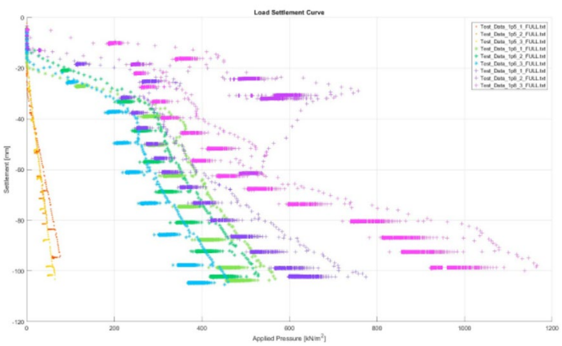


*Figure 3: Load Settlement Curves from All Tests*

For the vacuum tests, the chamber pressure and temperature were also logged throughout the testing process. A Tek Scan pressure sensing blanket was used in the middle and bottom of the 1.6 g/cm^3 and 1.8 g/cm^3 atmospheric tests, leaving one test bed for each bulk density undisturbed. Additionally, for at least 1 test bed of each bulk desnity in atmospheric conditions, a handheld 3d LiDAR scanner was used to characterize changes in the bed surface elevation surrounding the area where load was applied.

**Preliminary Results:** Initial results indicate that the presence of the estimated pressure bulb can be measured from the pressure blanket placed in the center of the test bed (Figure 4). The pressure blanket placed in the bottom of the test bed tended to capture when the forces propogated to the bottom but not the distinct bullseye shape from the center. The test data also suggests that the presence of the pressure blanket and sensor in the regolith bed did not change the overall results of the atmospheric loaded plate testing.

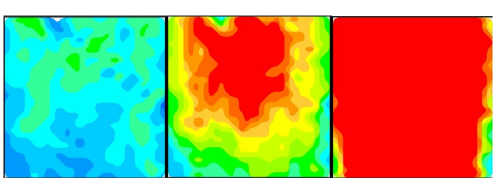

*Figure 4: Pressure blanket 1.6 g/cm^3 middle of the bin, beginning, middle, and end of test.*

Test results were found to varry between vacuum and atmosphere. Overall force was greater in vacuum for 1.4 and 1.6 beds and weaker for 1.8 g/cm^3. This was thought to be becase less air could remain trapped in lower bulk density regolith beds after pumpdown. Higher density tests could better trap air in the subsurface. These observations were supported by pressure transducer data from the DTVAC.

**Future Work:** Going forward, the point cloud data from the LiDAR surface scans will be converted into .stl files and comapred in CAD software before and after each test to quanitfy any observed changes in the surface profile. This will further support the presence and quantification of subsurface stress distribution. Further analysis of the pressure blanket data will be conducted to visualize the distribution of pressure throughout testing with respect to the depth of the loaded plate.

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