DEFLECTION CHARACTERISTICS OF CSM-LHT-T DETERMINED THROUGH STANDARD AND TRIDENT FOOTPAD STATIC PLATE TESTING.

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Introduction: As lunar exploration initiatives progress toward sustained surface operations, a reliable understanding of lunar regolith behavior under loading is essential [1]. Surface infrastructure, including landers, rovers, and construction systems, requires predictive models of soil deformation and bearing response. This study presents the results of static plate load tests performed on Colorado School of Mines-Lunar Highland Type-Testbed (CSM-LHT-T) lunar highland regolith simulant contained in the new Mines Lunar Surface Simulator (MLSS). The data collected during this testing used a standard plate geometry and the footpad from the Honeybee Robotics TRIDENT drill, focusing on the relationship between plate deflection and relative density. The findings support the development of in-situ geotechnical instrumentation and offer pathways to derive fundamental soil parameters from lunar surface loading tests.

Figure 1: Honeybee Robotics TRIDENT footpad [2].

Background: The mechanical behavior of lunar regolith under static and dynamic loads has been an ongoing research priority, particularly in preparation for Artemis-era missions. Previous missions lacked direct in-situ geotechnical tools capable of resolving elastic parameters such as modulus of subgrade reaction, strain modulus, or Poisson's ratio from surface interactions. Static plate load testing, standardized under ASTM D1195: 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 [3], is a well-established approach in terrestrial geotechnics and offers promise for lunar surface adaptation. When conducted appropriately, this test can yield not only bearing capacity indicators but also deeper insights into subgrade stiffness, settlement behavior, and soil-structure interaction [4]. Additionally, correlating standard plate geometries to that of the footpad of the TRIDENT drill provides comparable data that can be used in near future missions. Known geotechnical properties of CSM-LHT-T were recently determined through outer work at Mines, including cohesion (c), friction angle (φ), and compression index (C_c) at known density states. Thus, a known plate deflection in regolith simulant with known geotechnical values can be used to approximate geotechnical properties of the direct surface of the moon where the TRIDENT footpad is deployed.

Methodology: Testing was conducted on CSM-LHT-T simulant in the large MLSS testbed under ambient Earth conditions. The tests employed a 6-inch diameter standard circular plate in accordance with ASTM D1195, as well as the TRIDENT footpad provided by Honeybee Robotics. Four relative densities (D_r), 73%, 75%, 78%, and 85%, were prepared using controlled compaction techniques verified from standard proctor densification (ASTM D698) [5] and cone penetrometer measurements (ASTM D3441) [6]. Compaction levels inside the testbed were achieved through the preparation process indicated in Table 1.

Table 1: CMS-LHT-T compaction levels tested

Approximate D_r	Compaction Method
73%	Natural conditions of testbed
75%	Foot stamping
78%	Moderate hammer tamping
85%	Heavy hammer tamping

The loading protocol on each plate adhered to the ASTM D1195 standard regime, applying incremental static loads via hydraulic ram, recording corresponding vertical deflections, and allowing relaxation between loading increases. Each test was repeated to ensure consistency, and deflection was measured using dial gauges placed on the plates, as shown in Figure 2.

Results: The results indicate a clear correlation between relative density and plate deflection. As the relative density increased from 73% to 85%, a progressive decrease in surface deformation was observed.

Figure 2: Plate, ram, and dial gauge conditions of standard 6" plate (left) and TRIDENT footpad (right).

Figure 3 provides the resulting deflection curves plotted in relation to the pressure on the plates on the surface. The resulting deformation of the TRIDENT plate indicates more deflection is experienced than that to the standard plate.

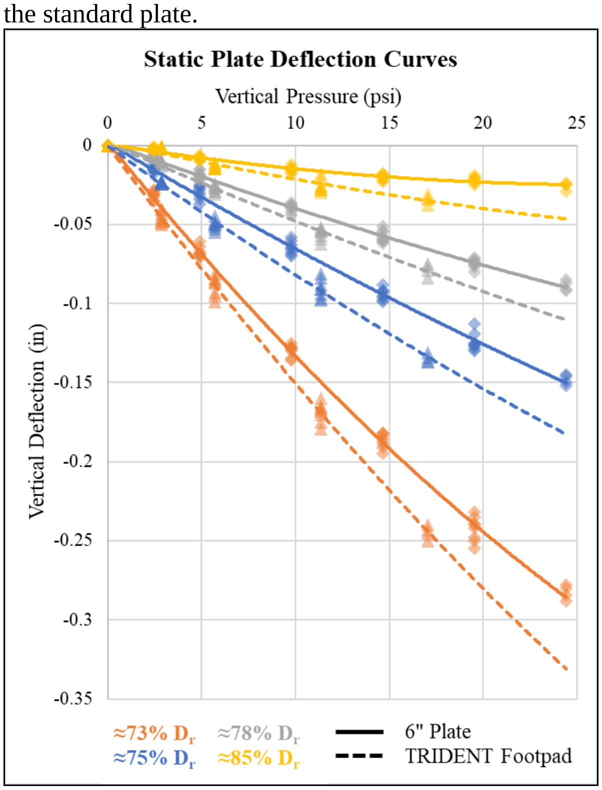

Figure 3: Static plate deflection curves for 6" plate and TRIDENT footpad at tested density conditions.

Discussion: From the deflection data, the modulus of subgrade reaction (*k*) can be estimated using the relationship [4]:

$$k = \frac{q}{\Delta}$$

where q is applied pressure and Δ is the measured plate deflection. While this method is simplistic, it offers a first-order estimate of subgrade stiffness.

ASTM D1195 specifies that the curve generated by the deflection data can be used to generate a best fit second-degree polynomial, and constants from this relationship can be used to calculate the strain modulus (E_s) using the following relationship [3]:

$$E_s = 1.5 \cdot r \cdot \frac{1}{a_1 + a_2 \cdot \sigma_{max}}$$

where r is the radius of the loading plate, a_1 and a_2 are constants of the second-degree polynomial, and σ_{max} is the maximum normal stress below the loading plate.

Using these relationships, the Poisson's ratio (v), can be calculated using the following relationship [7]:

$$k = \frac{E_s}{2 \cdot r(1 - v^2)}$$

Thus, using the known geotechnical values for CSM-LHT-T determined through other work and a correction factor applied to the TRIDENT footpad determined through the difference in dflection curves, these same geotechnical properties can potentially be approximated from measurements obtained on the lunar surface. The resulting values for CSM-LHT-T and any TRIDENT footpad correction factor will be reported at SRR.

Conclusion: Static plate load testing of CSM-LHT-T simulant shows a clear trend between increasing density and reduced surface deflection, consistent with increased stiffness, otherwise known as modulus of subgrade reaction. The results illustrate the viability of surface-based testing using the TRIDNET footpad to approximate geotechnical parameters in-situ. These findings support the progression of geotechnical in-situ static plate instruments to the lunar surface and can potentially be used to compare to data obtained in near future missions.

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