UTILIZING THE SPECIALIZED PENETROMETER FOR ICE DETECTION

B.C. Thrift, PhD Candidate; C.B. Dreyer, Professor of Space Resources

COLORADO SCHOOL OF MINES
EARTH • ENERGY • ENVIRONMENT

BACKGROUND

Penetrometers are useful geotechnical tools that are widely used both on Earth and off. In general, only the penetration response is evaluated, however, the viscoelastic response after motion has stopped can also reveal information about the surface being tested. Atkinson, et al. [1] showed that this relaxation response was sensitive to various parameters including ice content. By enabling the detection of ice and the characterization of surfaces, a specialized penetrometer is a useful resource prospecting tool.

A specialized penetrometer was developed at the Colorado School of Mines along with the ISRU Experimental Probe (IEP) as a part of the Institute for Modeling Plasma, Atmospheres, and Cosmic Dust (IMPACT) of NASA's Solar System Exploration Research Virtual Institute (SSERVI) [2]. The IEP consists of a zero backlash three-axis translation stage, a highly sensitive force-torque sensor, and a probe. The IEP is used to conduct specialized penetrometer operations in the lab. The Commercial Lunar Payload Service (CLPS) Masten Mission One will carry a specialized penetrometer as part of the Sample Acquisition, Morphology filtering, and Probing of Lunar Regolith payload. The mission is set to fly to the South Pole region of the Moon in late 2023 and will serve as a technology demonstration of the specialized penetrometer and other instruments.

DATA COLLECTION

Specialized penetrometer tests consist of conducting a slow (0.25 mm/s) penetration. The low speed effectively eliminates any dynamic responses during penetration. Once the test depth has been reached, the penetration motion is stopped, and the probe is held steady to collect the relaxation data. The relaxation occurs in the first seconds after motion has stopped. The character of the relaxation curve changes depending on the properties of the target regolith.

PROCESS

Measurement

- Note System Parameters
- Collect Penetrometer Data

Algorithm & Database

- Split Penetrometer Data into Penetration and Relaxation
- Average and Perform Fits
- Compare Fit Coefficients to Catalog

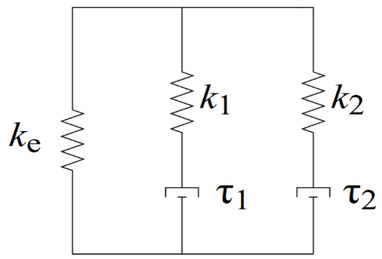
Regolith Type

- Density
- Ice Content
- Cohesion
- Etc…

DATA ANALYSIS

The specialized penetrometer data are split into penetration and relaxation responses. Curves are fit to the penetration and relaxation data, and the curve fitting coefficients from different test conditions are examined. Penetration data is modeled as a second-order polynomial. Relaxation is modeled as a Maxwell Rheostatic Model consisting of an external Hookean spring in parallel with two Maxwell Arms that are made up of a Hookean spring in series with a viscous dashpot [1].

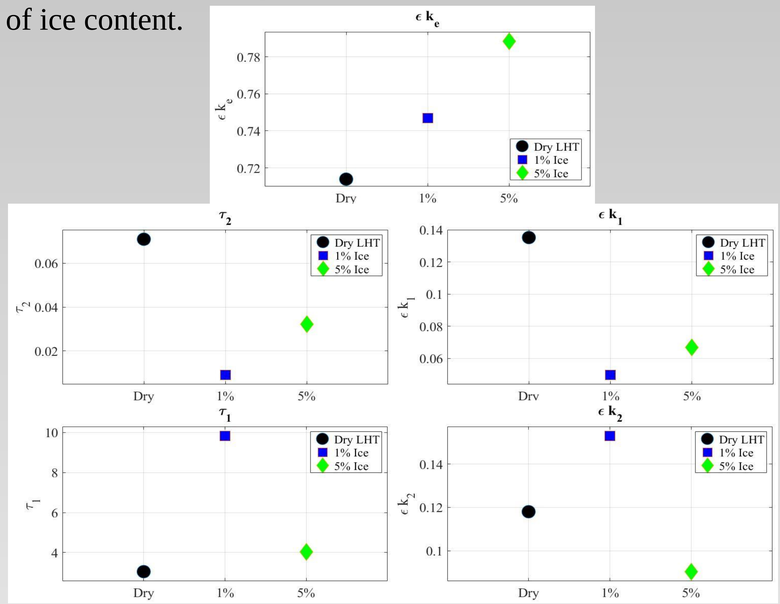
Relaxation Model



$$\frac{\sigma(t)}{\sigma_{max}} = \varepsilon\left(k_e + k_1 e^{\frac{-t}{\tau_1}} + k_2 e^{\frac{-t}{\tau_2}}\right)$$

RESULTS

The relaxation coefficients are sensitive to ice content. Combined with penetration data and some knowledge of the target, relaxation data can provide a first approximation of ice content in the target. k_e, k_1, and τ_1 represent the initial relaxation response, and are more reliable indicators of ice content.



CONCLUSION

Specialized penetrometer data can be useful in resource prospecting, not just through ice detection, but by providing geotechnical information about a surface to aid in excavation and transport across the surface. By examining both penetration and relaxation data acquired during a penetrometer operation, information about the geotechnical properties of a surface and the potential ice content of the test surface can be gathered. A specialized penetrometer is a low-cost, low-complexity, and low-mass geotechnical tool that can provide useful geotechnical information and initial indications of the presence of ice.

REFERENCES

[1] Atkinson, J., et al. (2020) *Icarus, 346*, 113812.
[2] Dreyer C., et al. (2018) *Review of Scientific Instruments, 89, 6*, 064502.