Testing of a Rover-Mounted Instrumented Percussive Cone Penetrometer in Icy Layered Lunar Regolith Simulant

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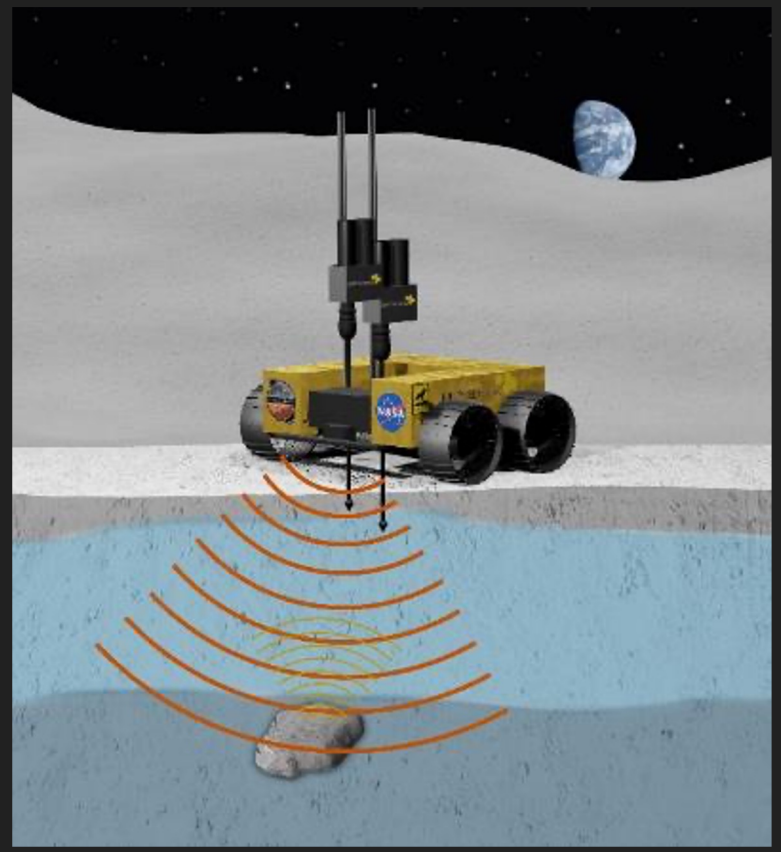
SPACE RESOURCES ROUNDTABLE

Project Introduction

- Find and Identify Volatiles below the Lunar Surface and Estimate Retrieval Viability
- Solution: Percussive Hot Cone Penetrometer (PHCP) and Ground Penetrating Radar (GPR)
  - GPR
    - Location of larger ice deposits and rocks
  - Hot Cone Thermal Data
    - Vertical and lateral quantification of volatiles
    - Properties of desiccated regolith
  - Percussive Cone Penetrometer Geotechnical Data
    - Impact forces on cone used for friction angle and cohesion
    - Displacement per impact for California Bearing Ratio (CBR)



Percussive Action for Regolith Penetration

SPACE RESOURCES ROUNDTABLE

- Terrestrial Cone Penetration Testing
  - Large Vehicle Mass to counteract Penetration Forces
  - Hydraulically driven constant velocity Cone Penetrometer
  - Energy Intensive

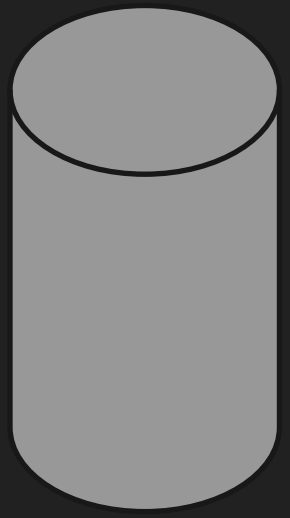
https://en.wikipedia.org/wiki/Cone_penetration_test#/media/File:Cpttruck.jpg

- Lunar Cone Penetration Testing
  - Small Vehicle Mass due to launch constraints
  - Electromechanically driven Percussive Cone Penetrometer
  - Energy Conservative

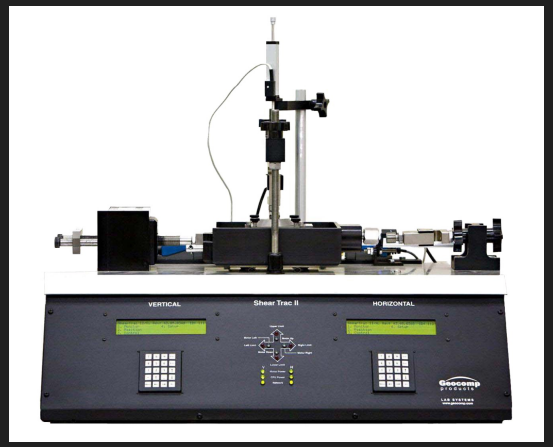
In-Situ Geotechnical Properties

Space Resources Roundtable

Lunar Regolith Sample



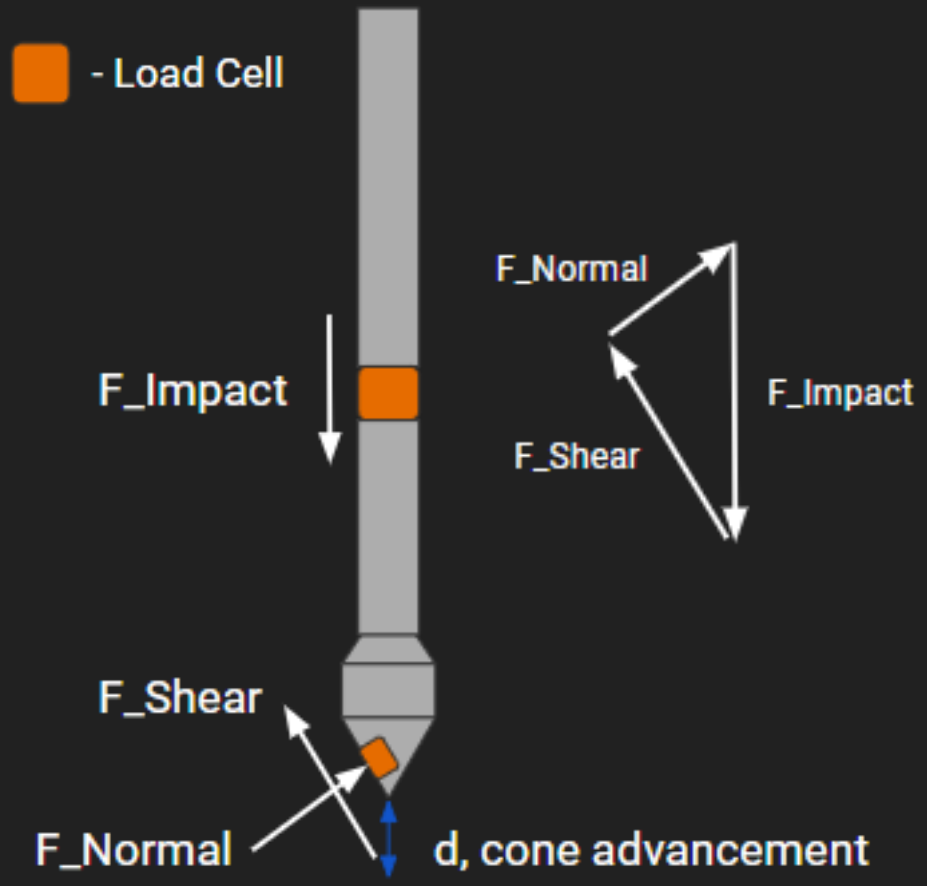
Geotech Lab On Earth



In-Situ Geotech Device

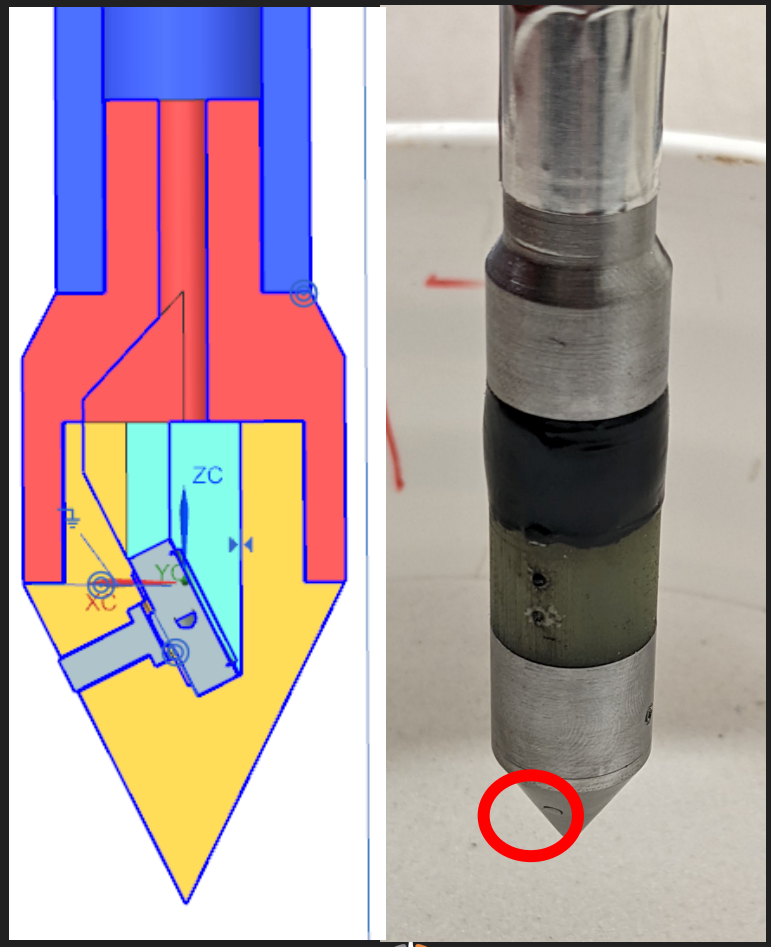
Friction Angle
Cohesion

Instrumented Cone Penetrometer Hardware

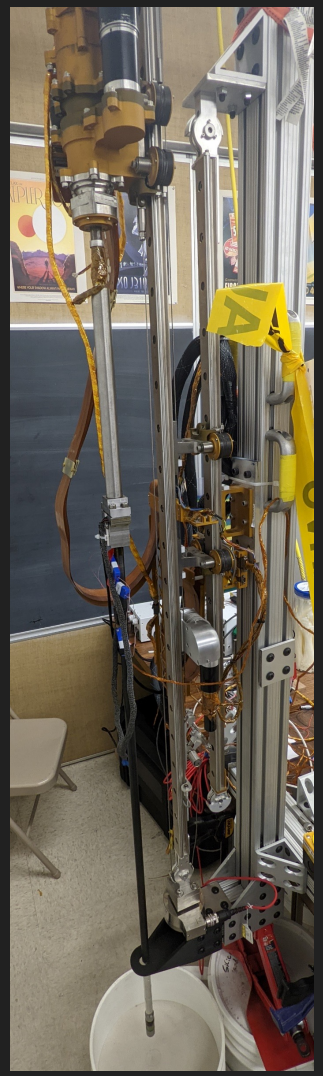


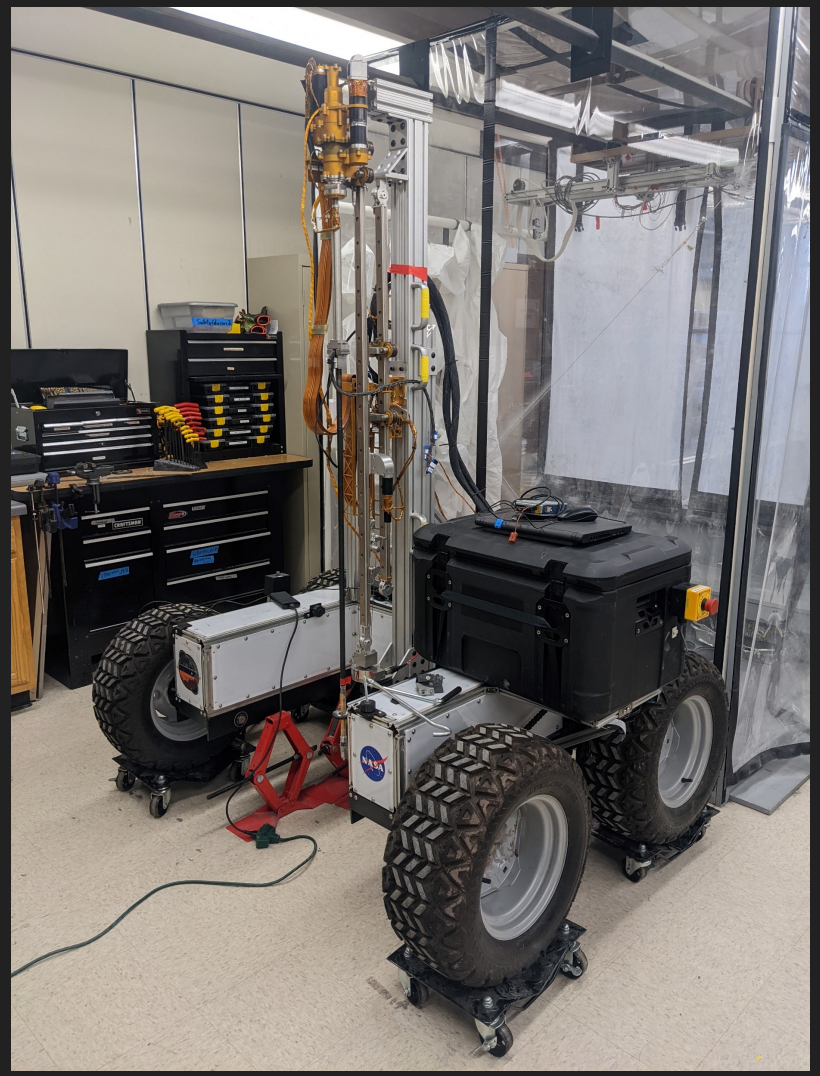
Impact Force Load Cell

Normal Force Load Cell



Integration With Honeybee TRIDENT



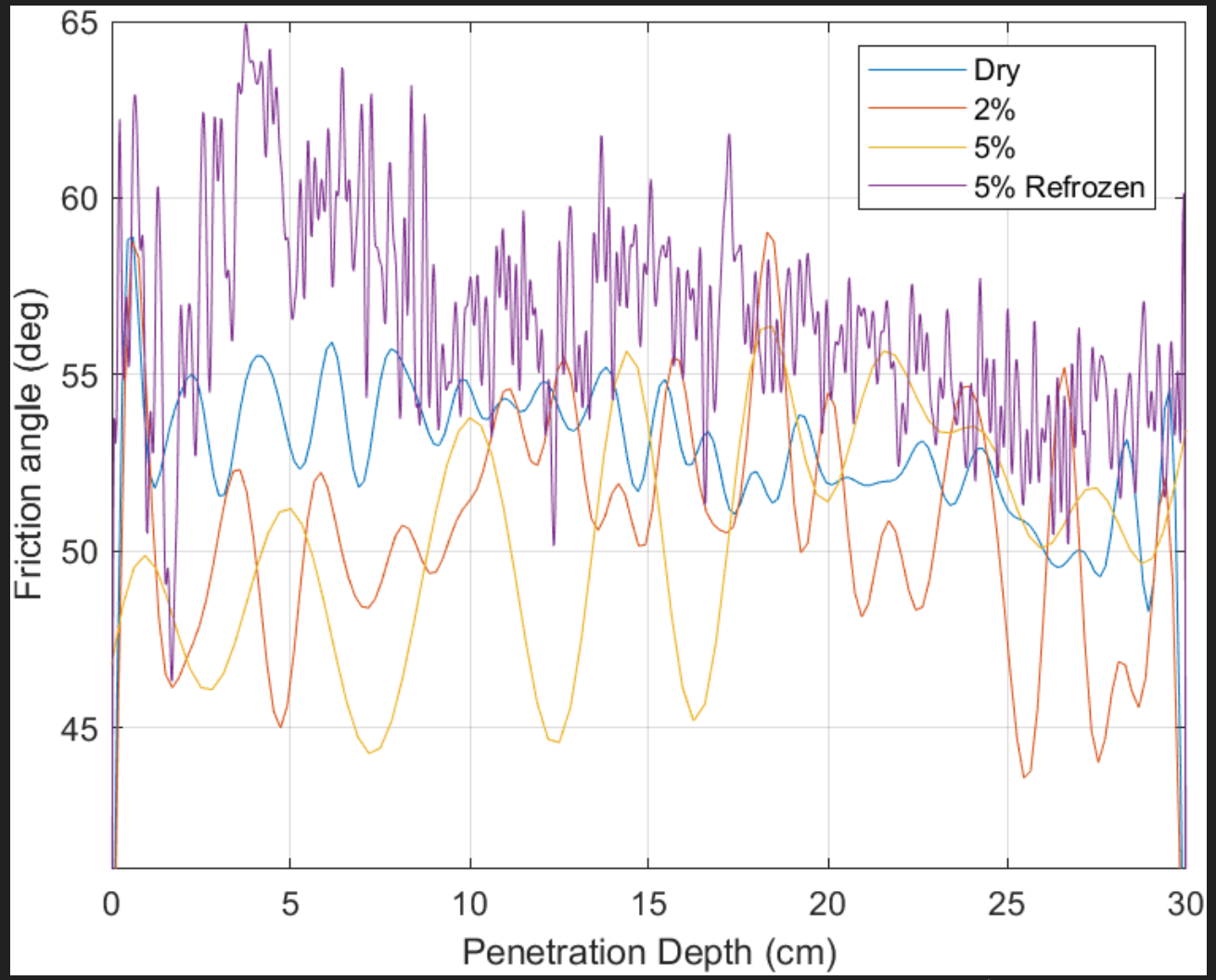


Icy Regolith Test Beds Preparation

- Three Tests Conducted with Icy Regolith
  - 2%, 5%, and 5% ice by mass
  - 2% and 5% with shaved ice mixed with regolith at freezing temps
  - 5% shaved ice mixed with regolith, melted, and refrozen
- Samples prepared in cylinders
  - Diameter of 47.5 cm
  - Depth of 30 cm
- All Densities similar, near 1.5 g/cc

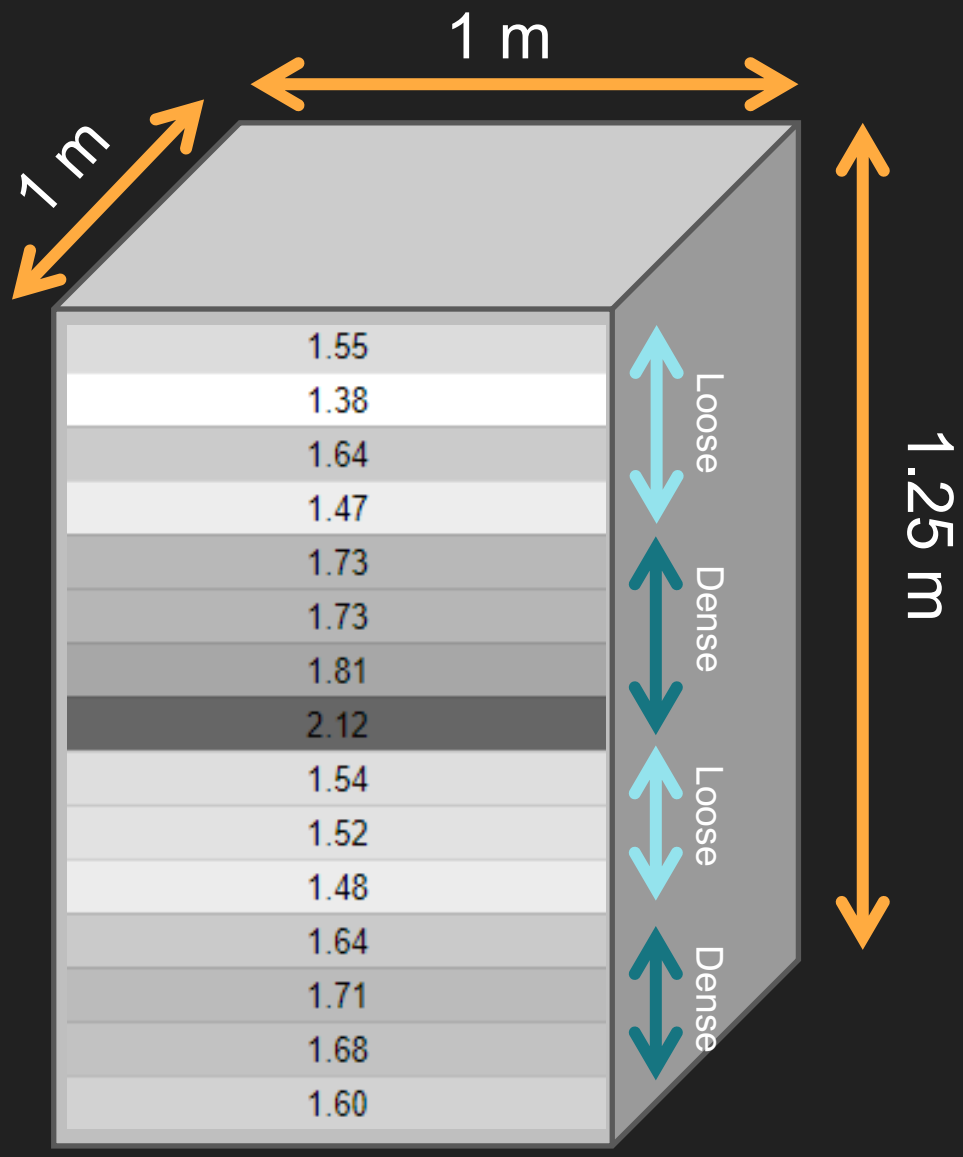
Icy Regolith Test Results

- Dry Regolith has lower variance than icy regolith
  - possibly from less layering effects during preparation
- 5% Refrozen consistently higher
  - More data points because took more blows to penetrate
  - Consistent with reasoning that regolith bound with ice has higher strength
- Cohesion Found to be 3116 Pa
- External Triaxial Testing yielded MTU-LHT-1A fiction angle of 53 degrees and Cohesion of 1640 Pa



Varied Density Big Bin Preparation for full 1m test

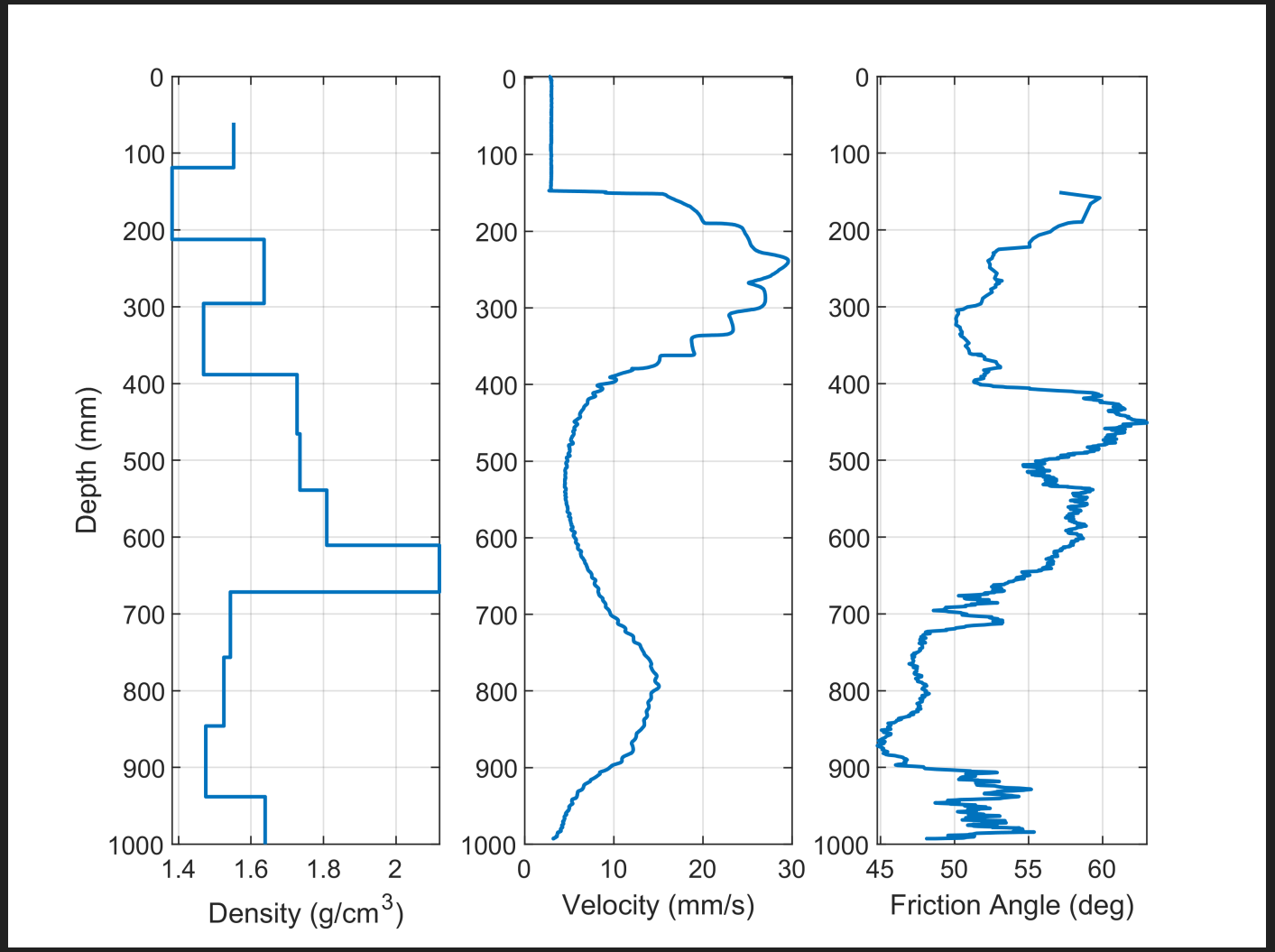
- 1x1x1.25 m Bin filled with Lunar Simulant
- Varied density from loose (1.4 g/cc) to dense (2.12 g/cc)
- Note: First layer of dense zone is above max density due to compaction of lower loose layers
- Layer Heights approximately 10 cm



Varied Density Big Bin Testing

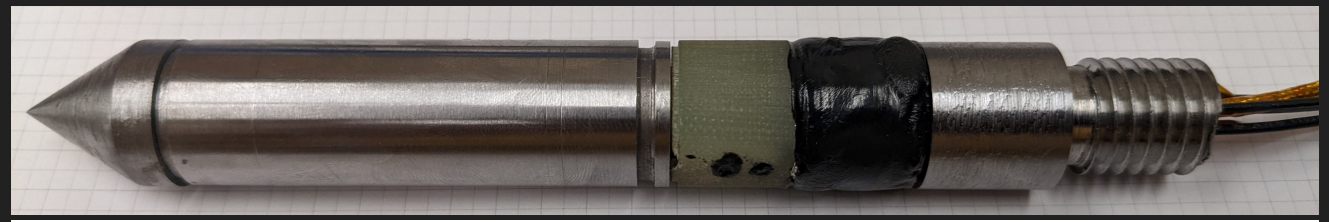
Varied Density Big Bin Results

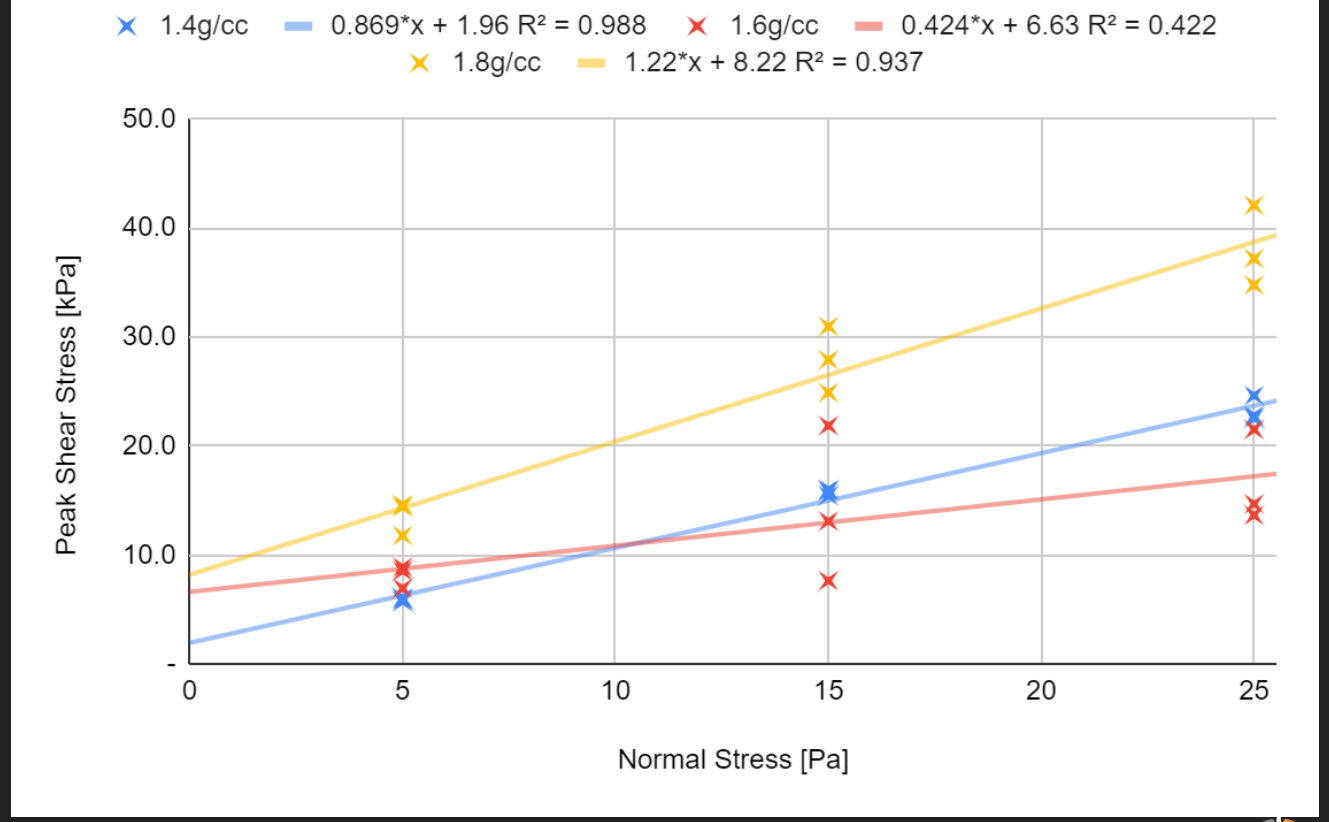
- Plot of density, Penetrometer Velocity, and Friction angle as a function of depth
- TRIDENT pushed through first 15 cm of loose regolith
- Velocity low in dense regolith, high in loose
- Friction angle High in dense regolith, low in loose



Future Work

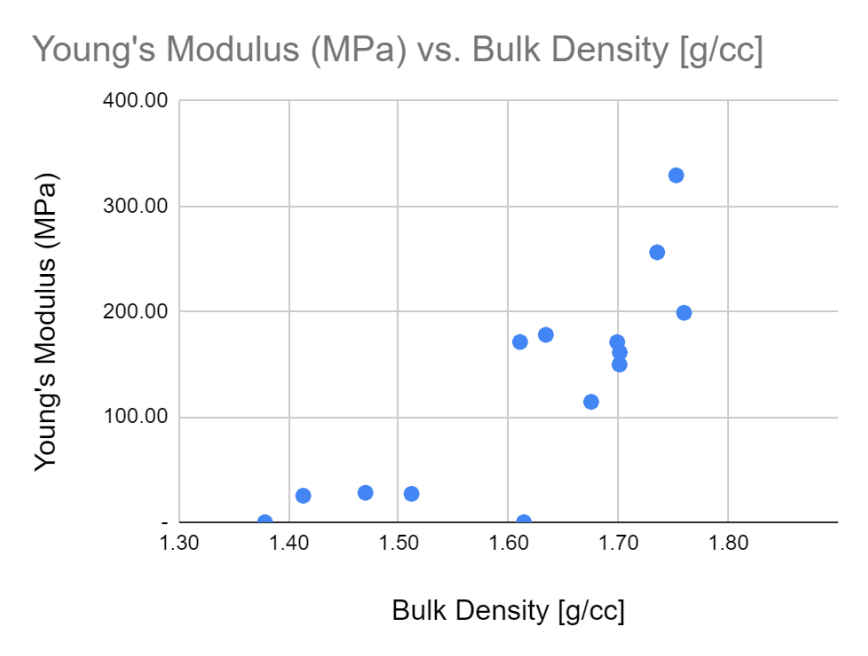
- Development of a new cone design that will allow for better cohesion measurements
- Direct shear tests of MTU-LHT-1A at different densities, compressive stresses, and ice contents
- Perform CBR tests on MTU-LHT-1A for different densities





Future Work

- Bearing Capacity Tests of MTU-LHT-1A at different densities to build CBR database
- Large Scale outdoor Trench Test in winter 2023/2024



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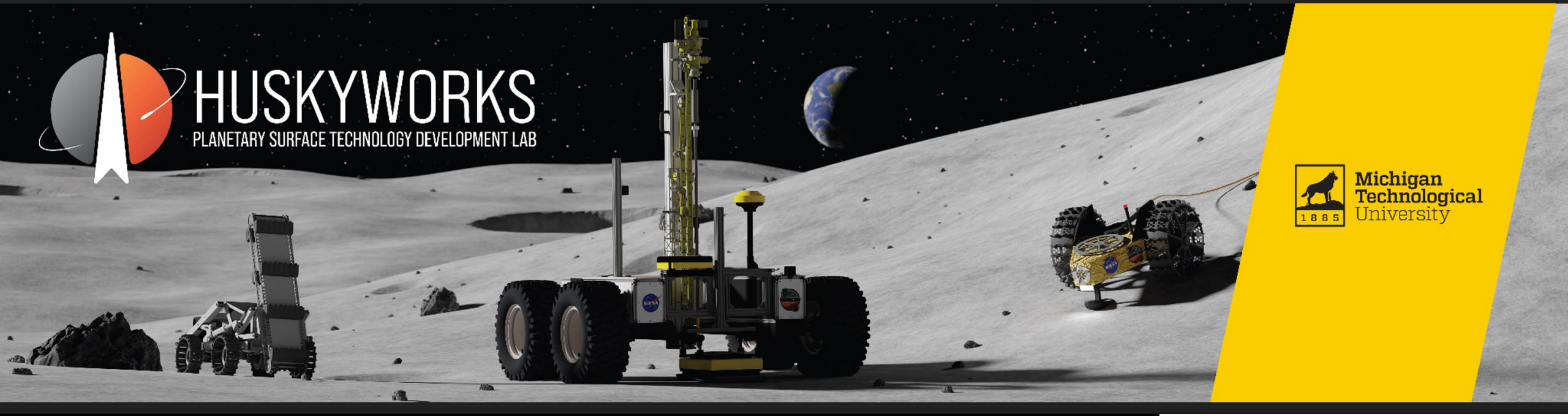
Thank You!!!



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