ACME: Paving the Way to Planetary Basalt ISRU Construction –Lunar Launch/Landing Pad

SRR/PTMSS 2016

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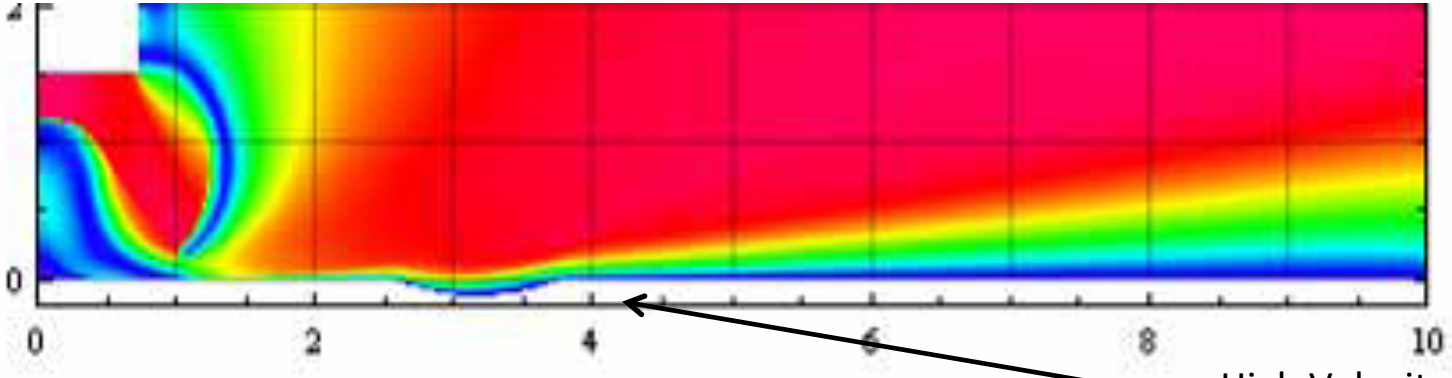
PISCES, University of Hawaii-Hilo, Kennedy Space Center, Honeybee Robotics

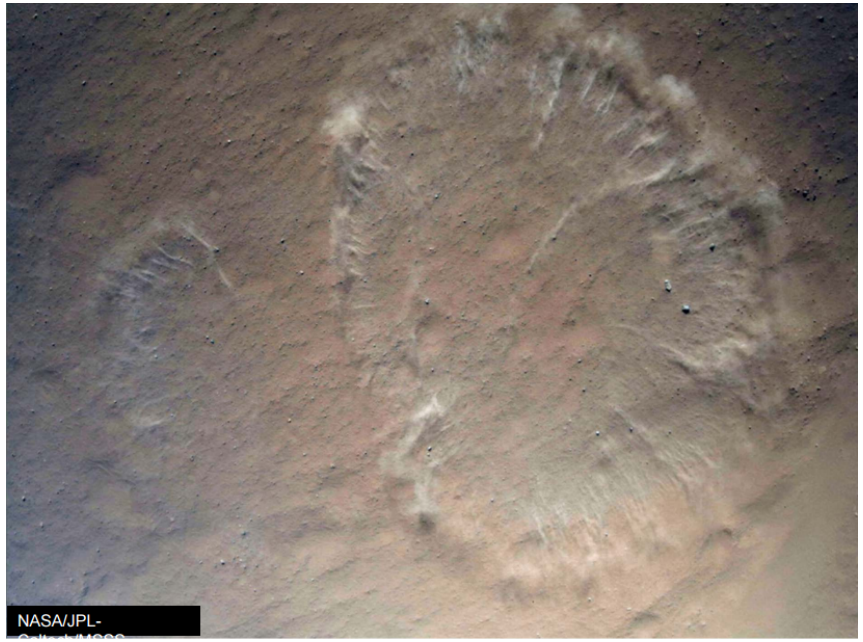
Additive Construction with Mobile Emplacement (ACME): Phase I, construction of a Vertical Take Off-Vertical Landing (VTVL) Pad

Material Science of Dust on the Lunar Surface, or Why a Landing Pad?

- Lander descent engines create high velocity / horizontal flow across surface
- Relatively flat sheet of dust (1-3 deg to surface)
  - Particles lifted by aero forces
- Dust velocities can reach as high as 2000 m/sec



High Velocity Dust Sheet



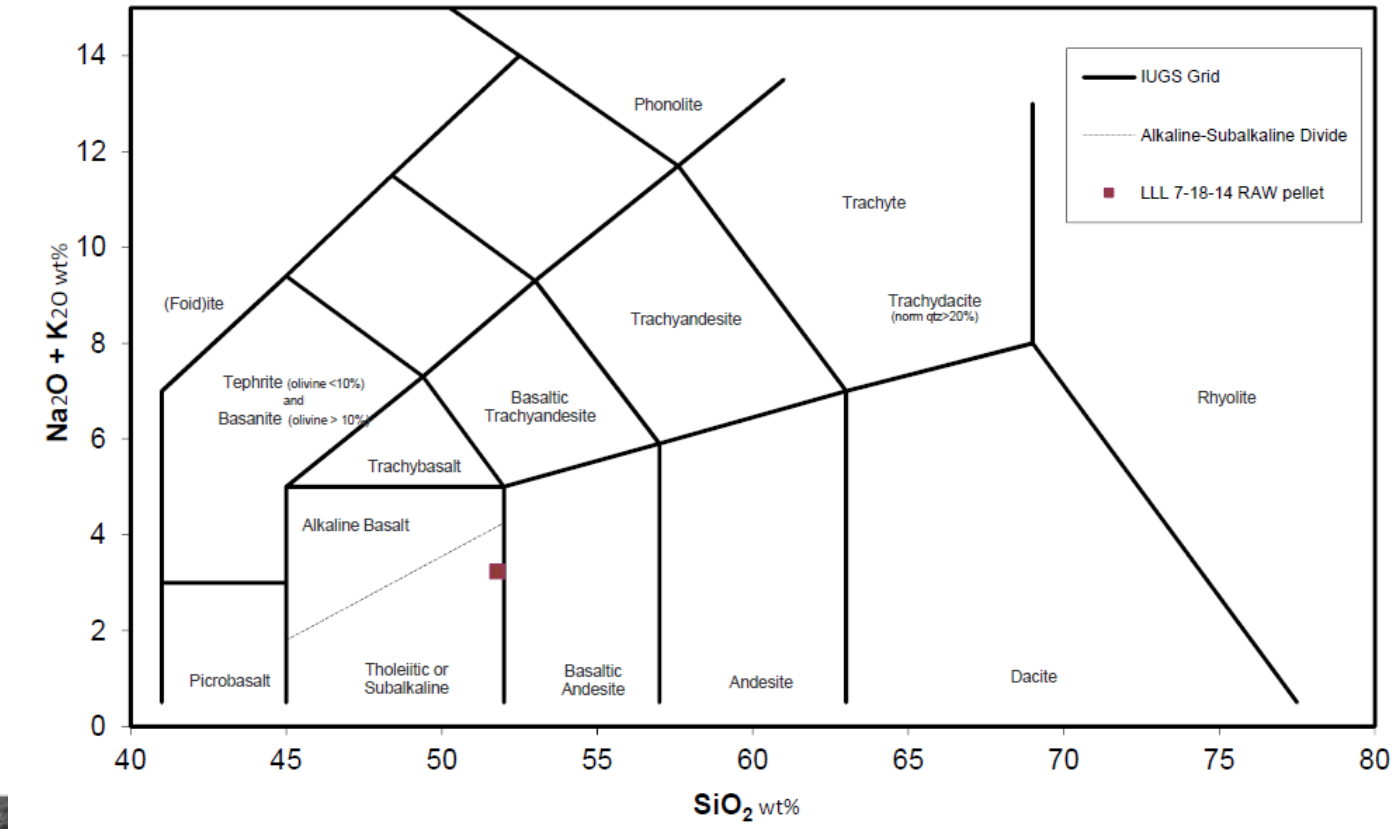
Skycrane / Curiosity Lander - Kicking up dust just prior to landing
(60 m)

ISRU: Hawai'i Crushed Basalt EDXRF Data

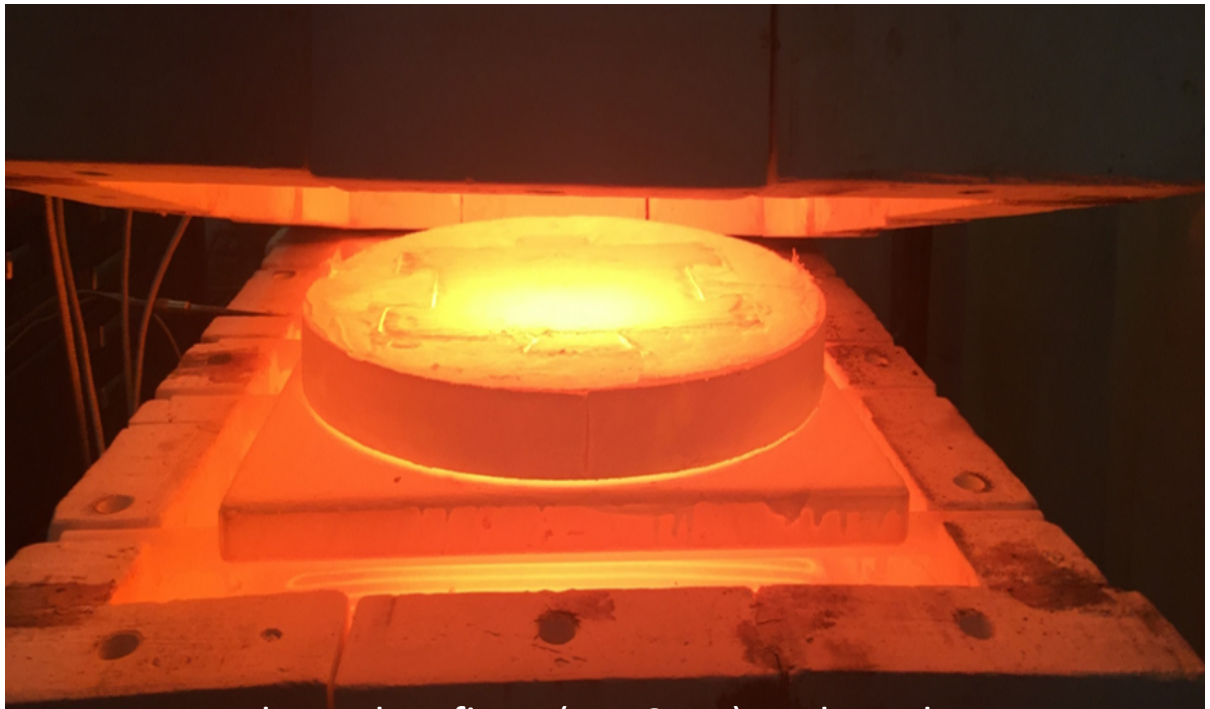
V	MnO	Fe	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb
ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
332.458	1887.956	9.071	172.395	120.679	105.953	8.078	346.408	26.997	129.704	11.516	53.586	31.549	14.181	0

s

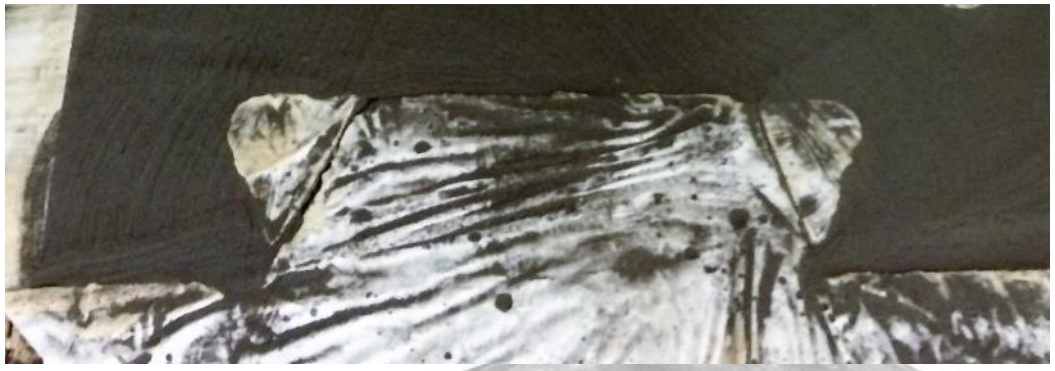
Na2O	MgO	Al2O3	SiO2	K2O	CaO	TiO2
%	%	%	%	%	%	%
2.68	7.877	14.602	51.777	0.55	10.995	2.124



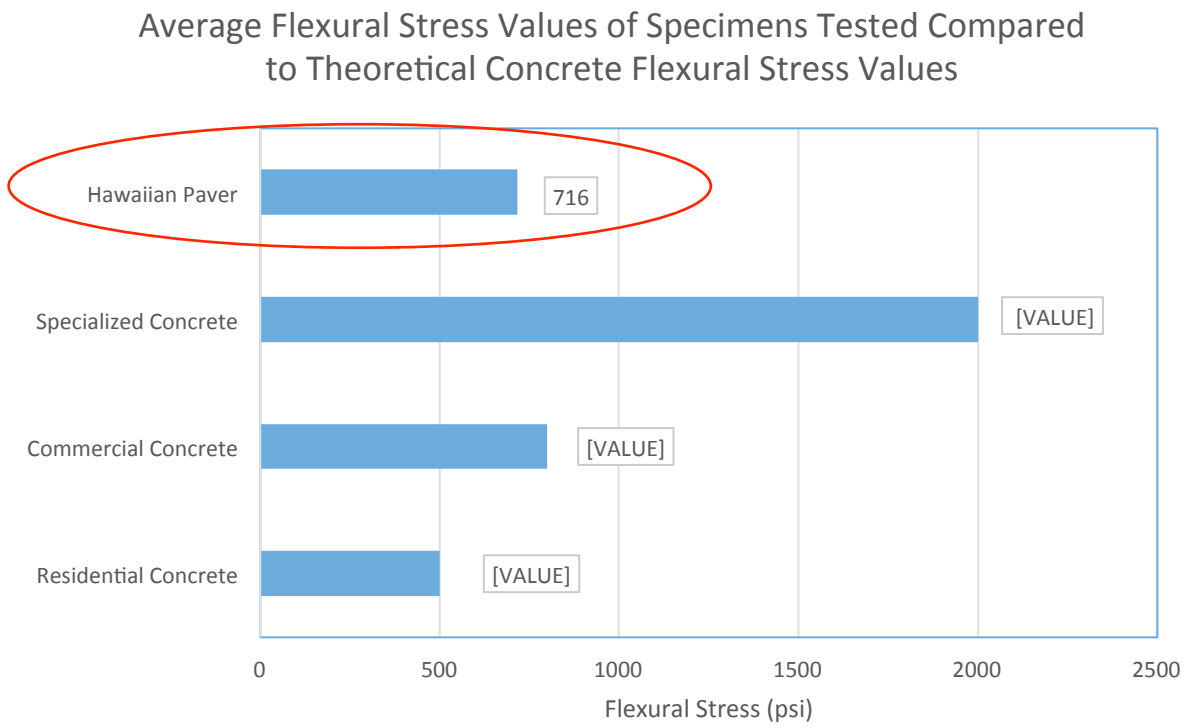
ISRU: Sintered Basalt Pavers

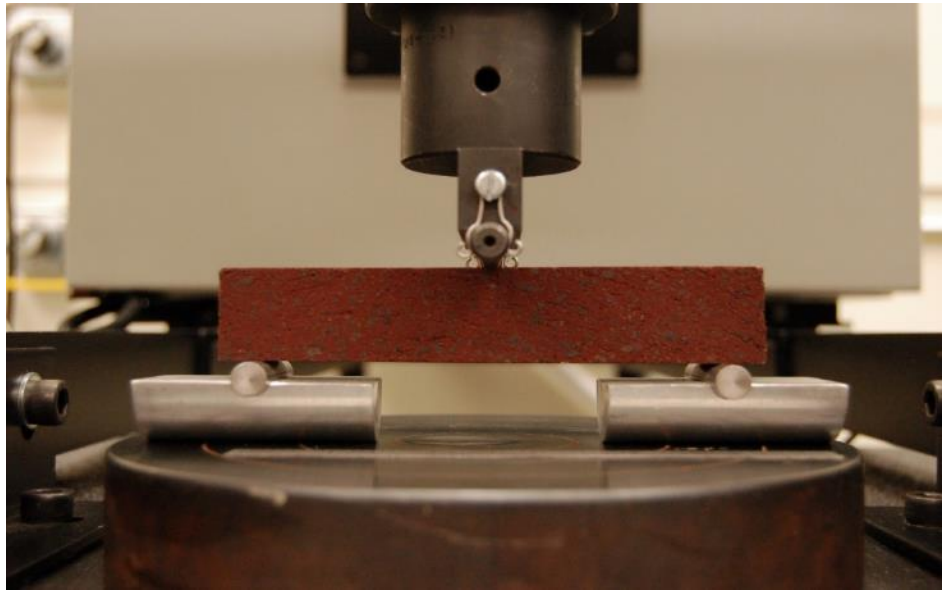


- Rock crusher fines (≤150µm) and sand (≤2mm)
- Sintered at 2100°F
- Utilized floating mold design to relieve cooling stresses



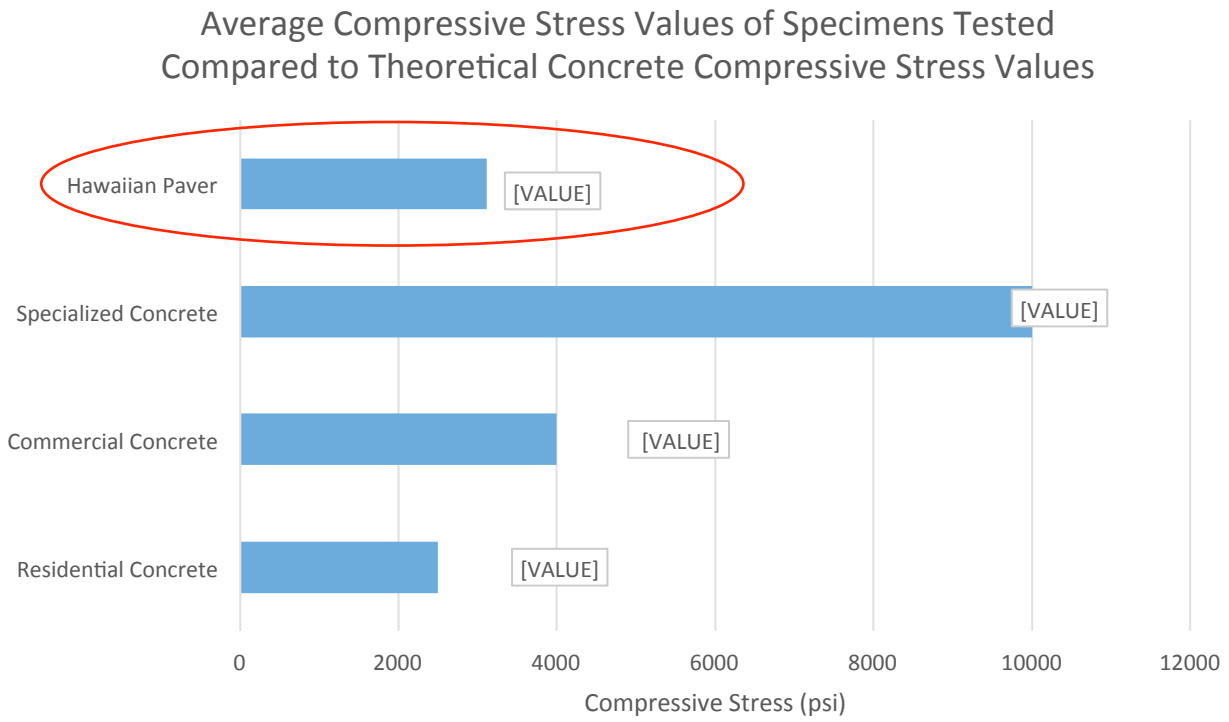
PAVERS: Physical Properties – Flexural Stress

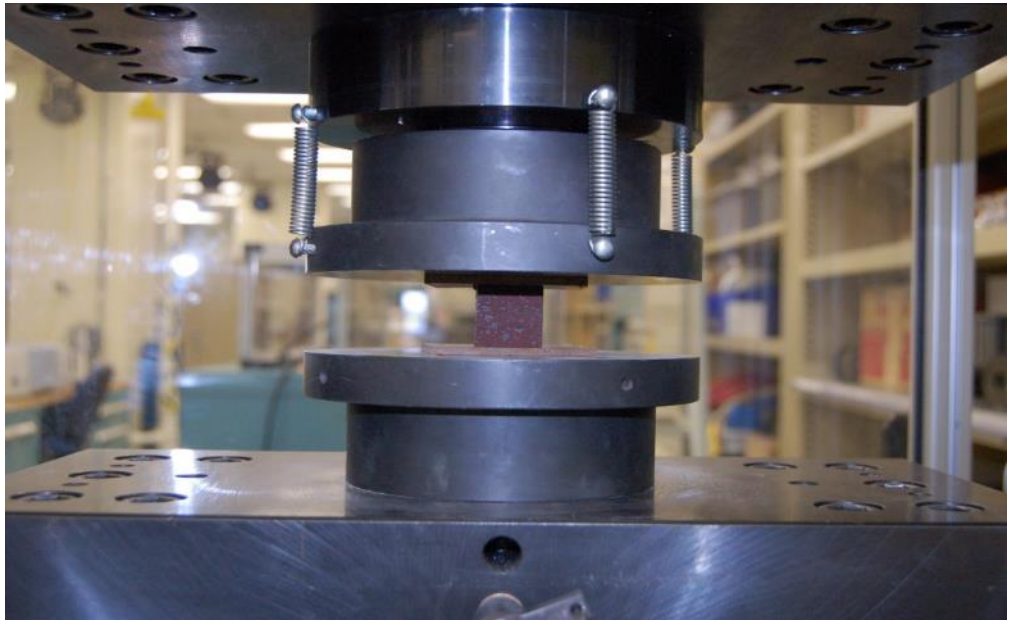




Tests done by NASA Engineering Directorate Laboratories and Test Facilities Division, Kennedy Space Center, FL. ASTM C133, Std Test Methods for Cold Crushing Strength Modulus of Rupture of Refractories.

PAVERS: Physical Properties – Compressive Stress





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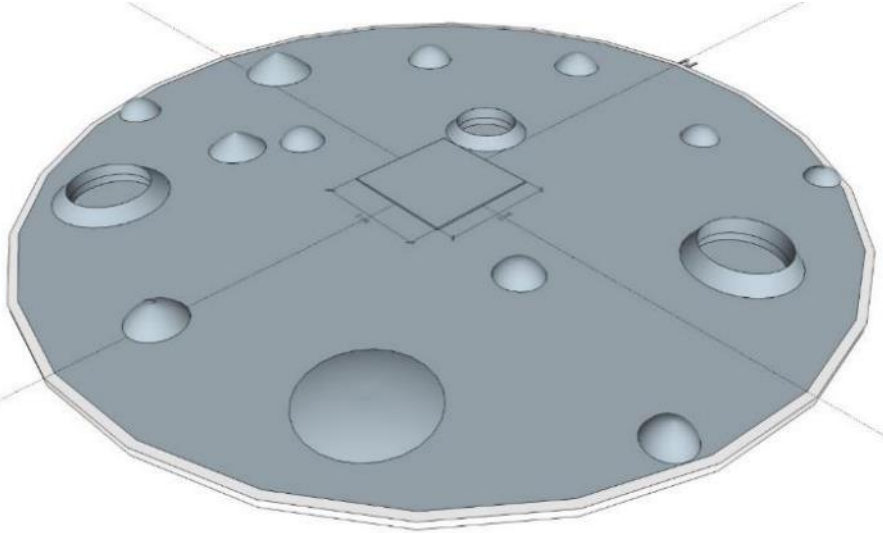
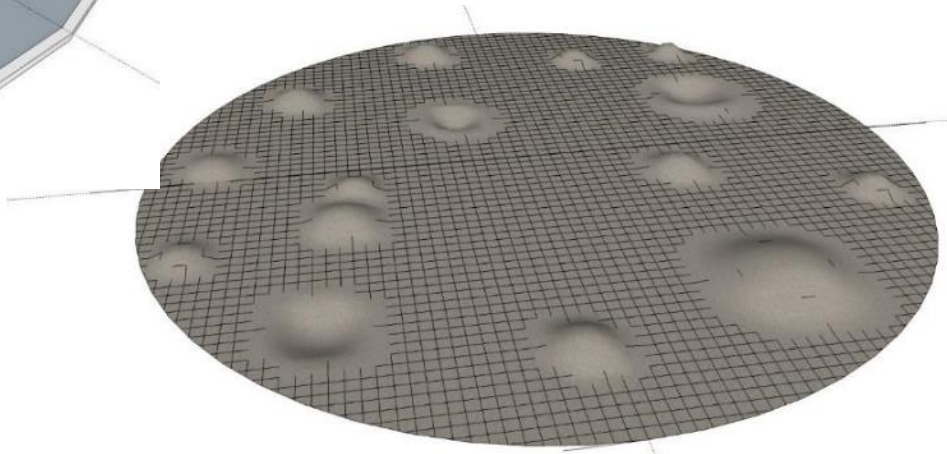
Creating a Lunar Landscape: Modeling & Building





VTVL Design, Dimensions & Specs

Dimensions

Outer Diam: 20m
Bullseye: 3m x 3m
Soil Depth: 20cm – 30 cm

Soil Type Used

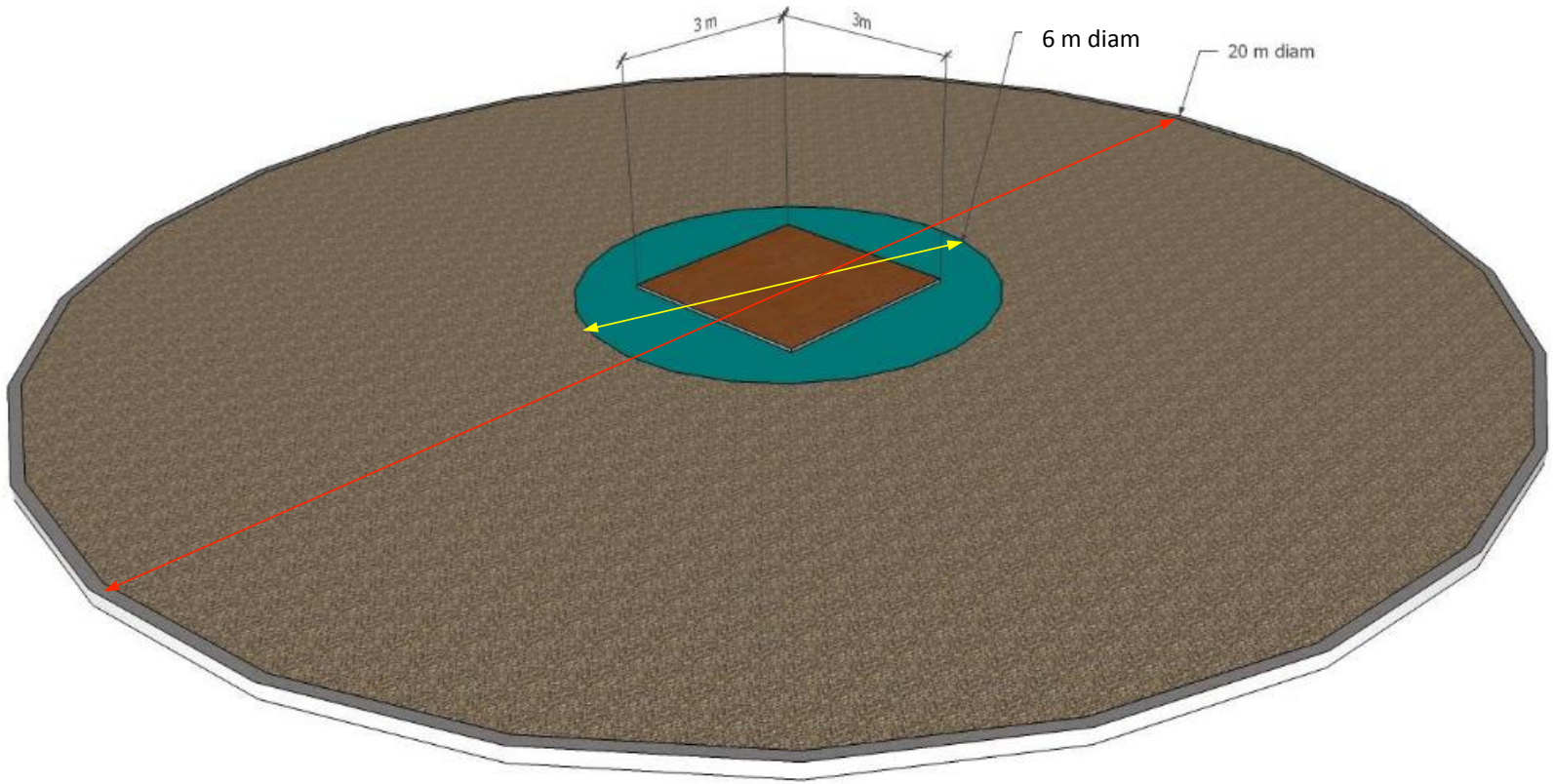
Bullseye: Crushed basalt fines < 150µ. (3m^3)
Apron: Basalt sand & gravel (90m^3)

Construction Specs

Terrain should be leveled to ± 3 degrees.
Soil Compaction: 1.8 gr/cm^3

VTVL Materials

Bullseye: 100 (30cm x 30cm) sintered basalt pavers
Apron Stabilizer: 21 m^3 of #3B Gravel (5 cm deep)



PISCES Rover, Helelani: Multi Purpose Vehicle.
Mobile Platform Base: Juno Rover (Argo, Canada)

Grading & Leveling Blade

1,270 mm x 406 mm Steel Blade

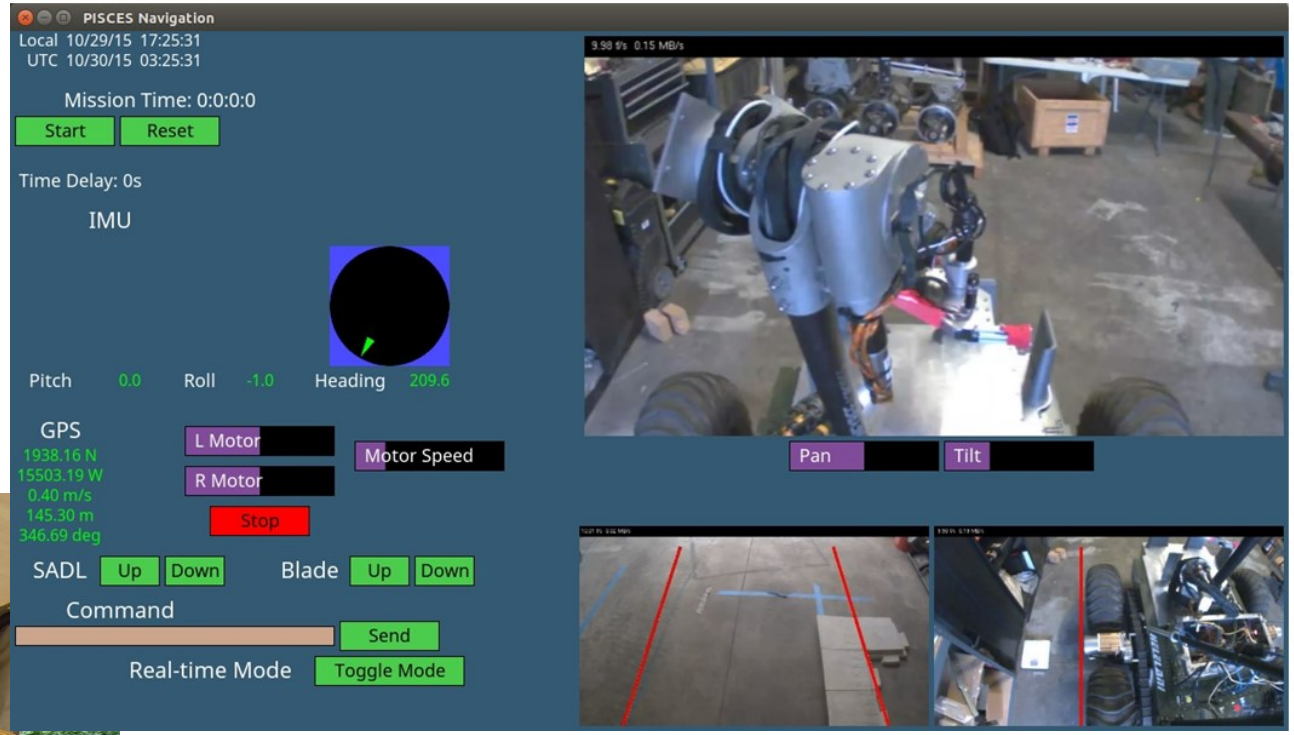
Compactor Roller

1200 mm x 450mm (diam) Roller (1.9m^3)

Paver Deployment Mechanism

Command & Control

- Wireless access through internet connection.
- SNRF Router Capability
- Command & Control through GUI station
- Telemetry GUI screen for monitoring
- Site Situational Cameras for Various Field Views



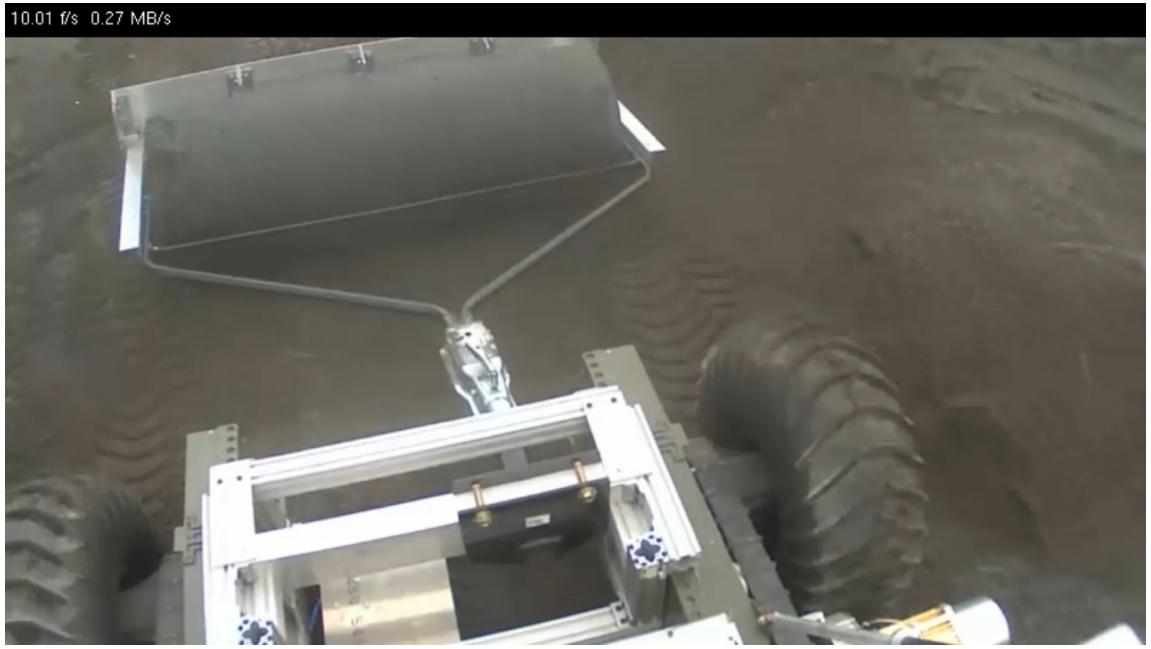
- 3 Rover Mounted Cameras + 1 on PDM gripper
- 0.49 m/s max speed, with motor speed control
- Real Time Operation Mode (keyboard or command)
- Variable Time Delay Mode with single command

Grading & Leveling

Grade to < 3° from Horizontal

Compacting Target: > 1.8 gr/cm^3

Field compaction test with nuclear gauge by ASTM D6938 Std

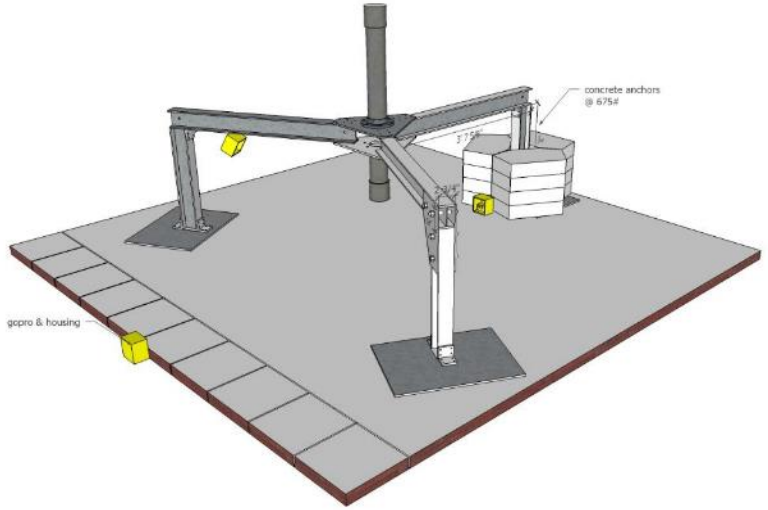


	Lab		Pre-Compaction Field Analysis				Post Compaction Field Analysis			
	Standard		smpl1	smpl2	avg		smpl1	smpl2	smpl3	avg
Moisture	0.10%		6.60%	7.40%	7.00%		7.0%	7.0%	6.40%	6.8%
Wet Density (gr/cm^3)	2.124		1.812	1.892	1.852		2.440	2.491	2.417	2.449
Dry Density (gr/cm^3)	NA		1.700	1.762	1.731		2.279	2.327	2.271	2.293
Densisty relative to Std			80%	83%	81%		107%	110%	107%	108%

Paver Deployment Operations

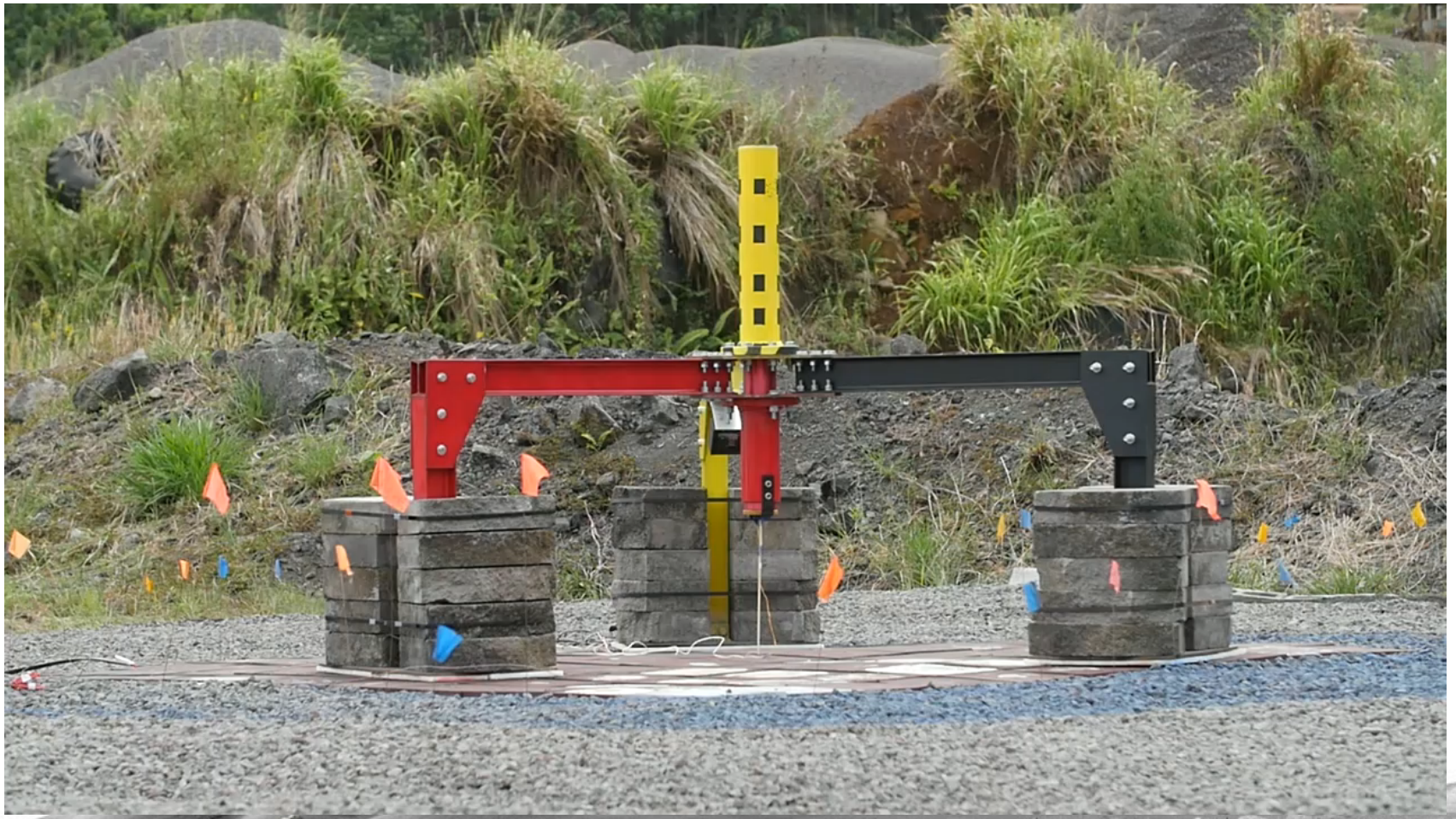
Completed VTVL

Rocket Motor Test



Rocket Motor Test Firing

- AEROTECH N3300: 960 lb (f) Class M Rocket Motor (12 kg of ammonium perchlorate propellant)
- Plume temp: 1,926°C
- Total impulse 13,410 N/s
- Static Motor Test (Not a launch)
- Gantry Designed and Built to Hold Motor
- Motor Nozzle to be placed 16” above Impact Paver.

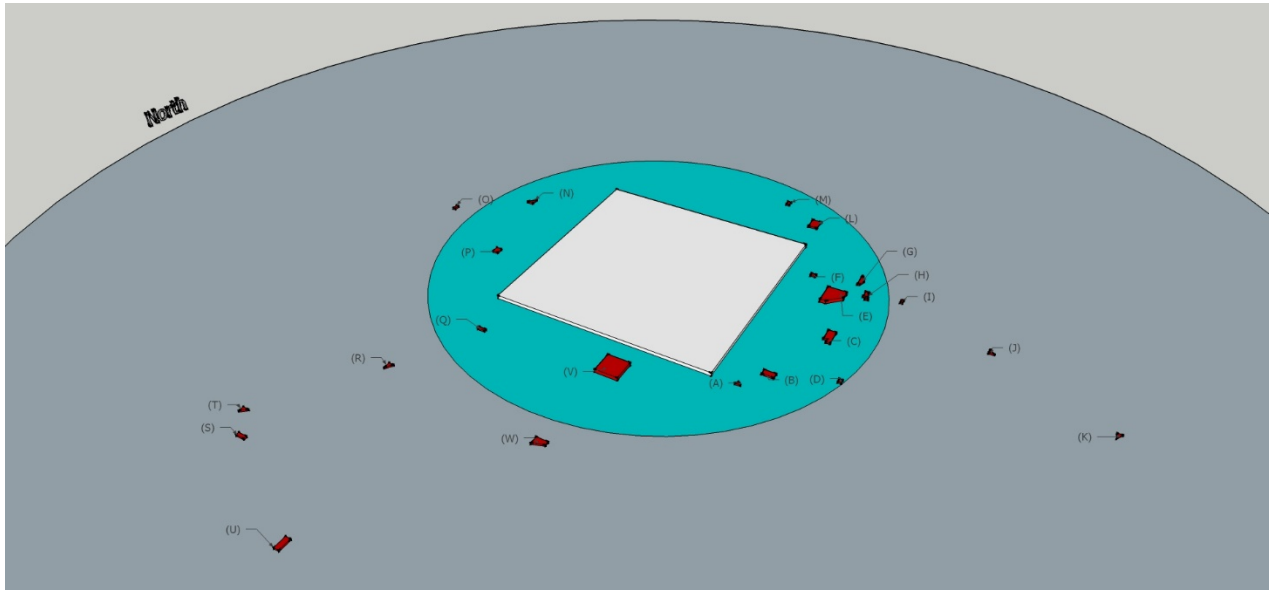


Results & Data Interpretation

Materials

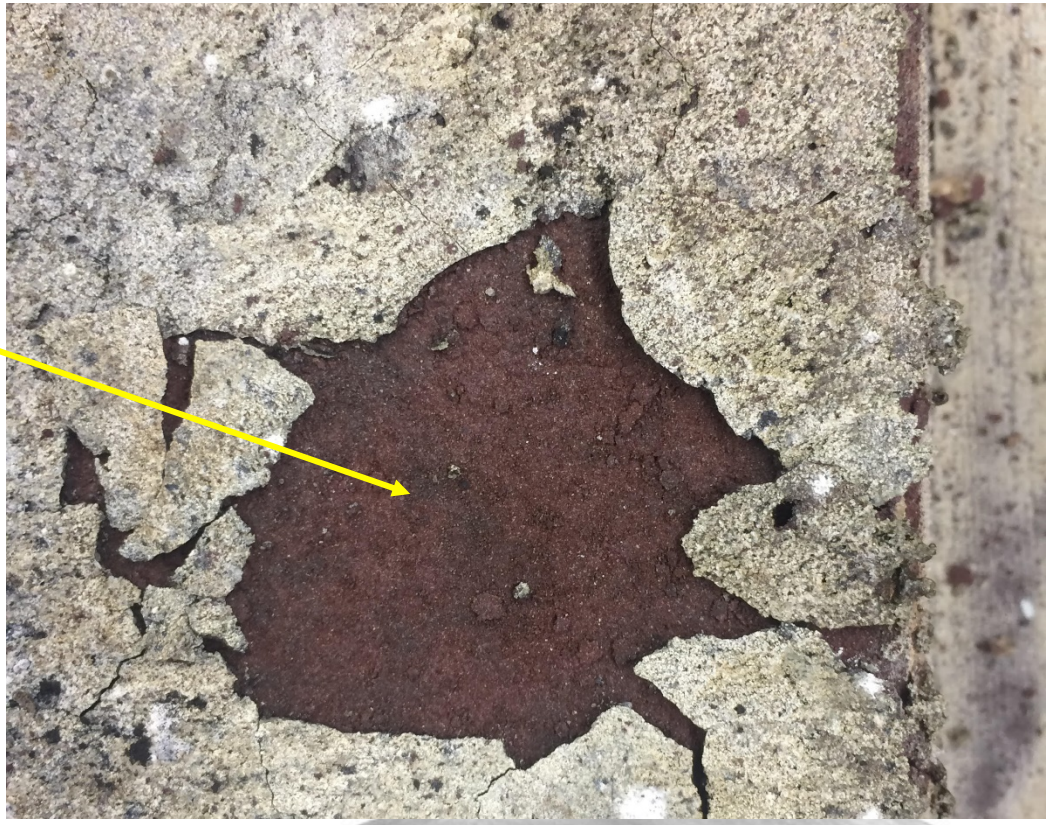
Design

Results & Data Interpretation: Design, Paver Displacement

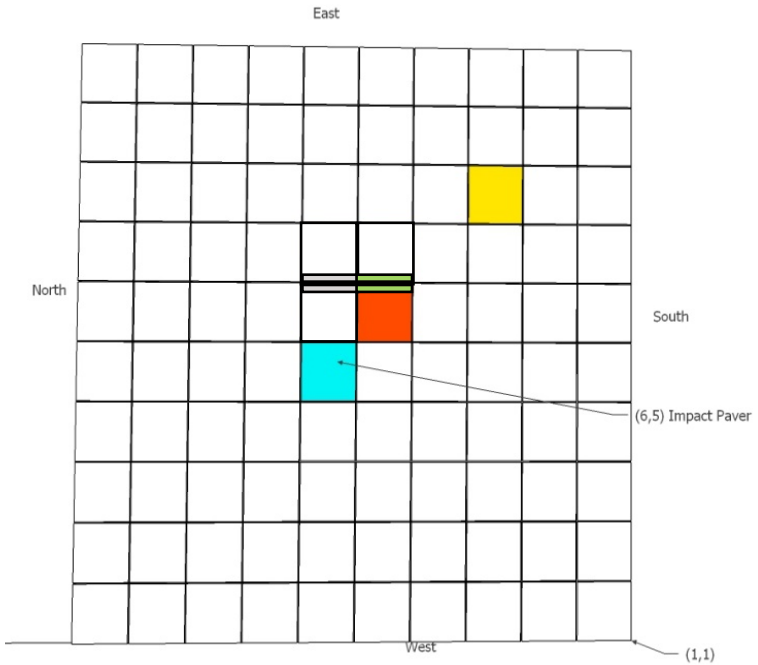


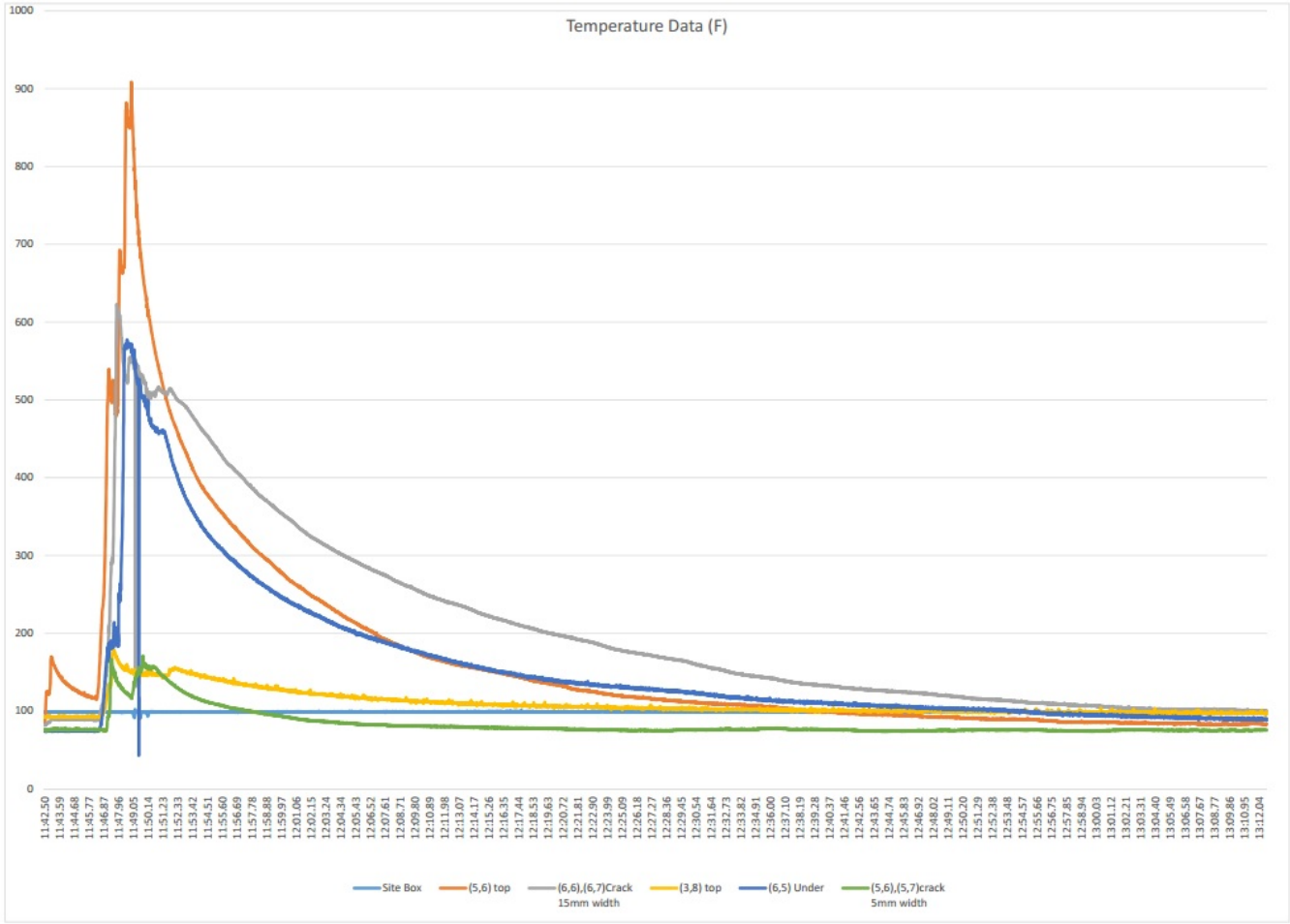
Debris Ejection Map

Results & Data Interpretation: Materials



Results & Data Interpretation: Thermocouple Data



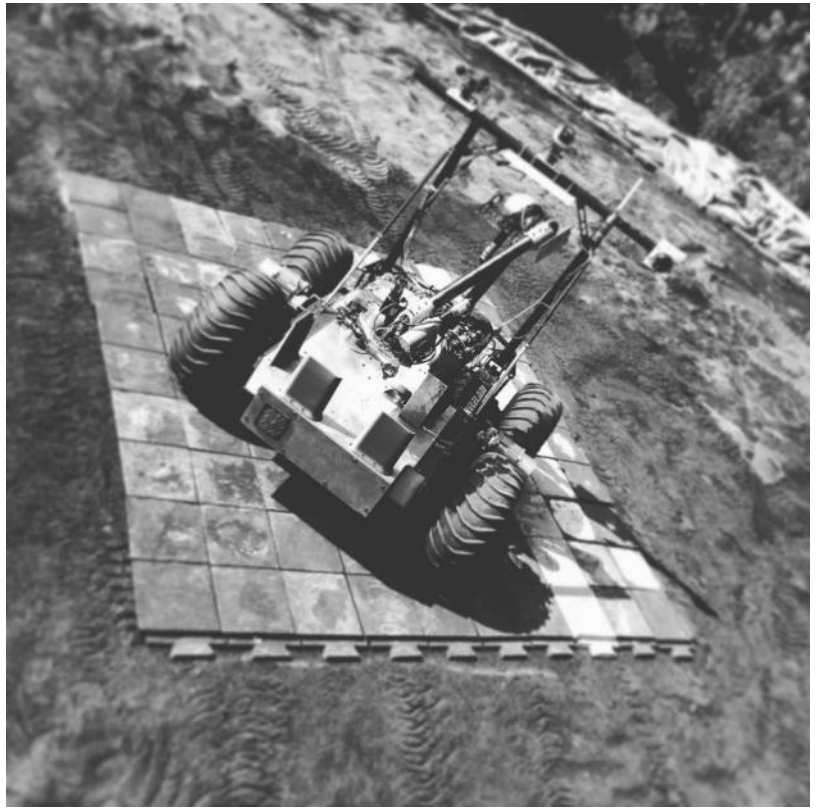


Initial Observations from Test Results

- Successfully constructed robotically through teleoperations from start to finish a full scale VTVL Pad.
- Successfully designed and constructed thermally and chemically stable pavers using only basalt without additives
- Breakage appears to have occurred and/or originated at boundaries where paver thickness changed
- Apron retained integrity with almost no disturbance of surface gravel
- Paver gaps appear to play large role in paver displacement, but little role in gas intrusion to substrate
- 1,926°C plume only glassified top layer to 0.4 to 1.6 mm, beneath looked as if untouched

A Landing Pad does make a difference – Morpheus Project

Questions?



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