How smooth do we need it?

Understanding lunar surface preparation requirements

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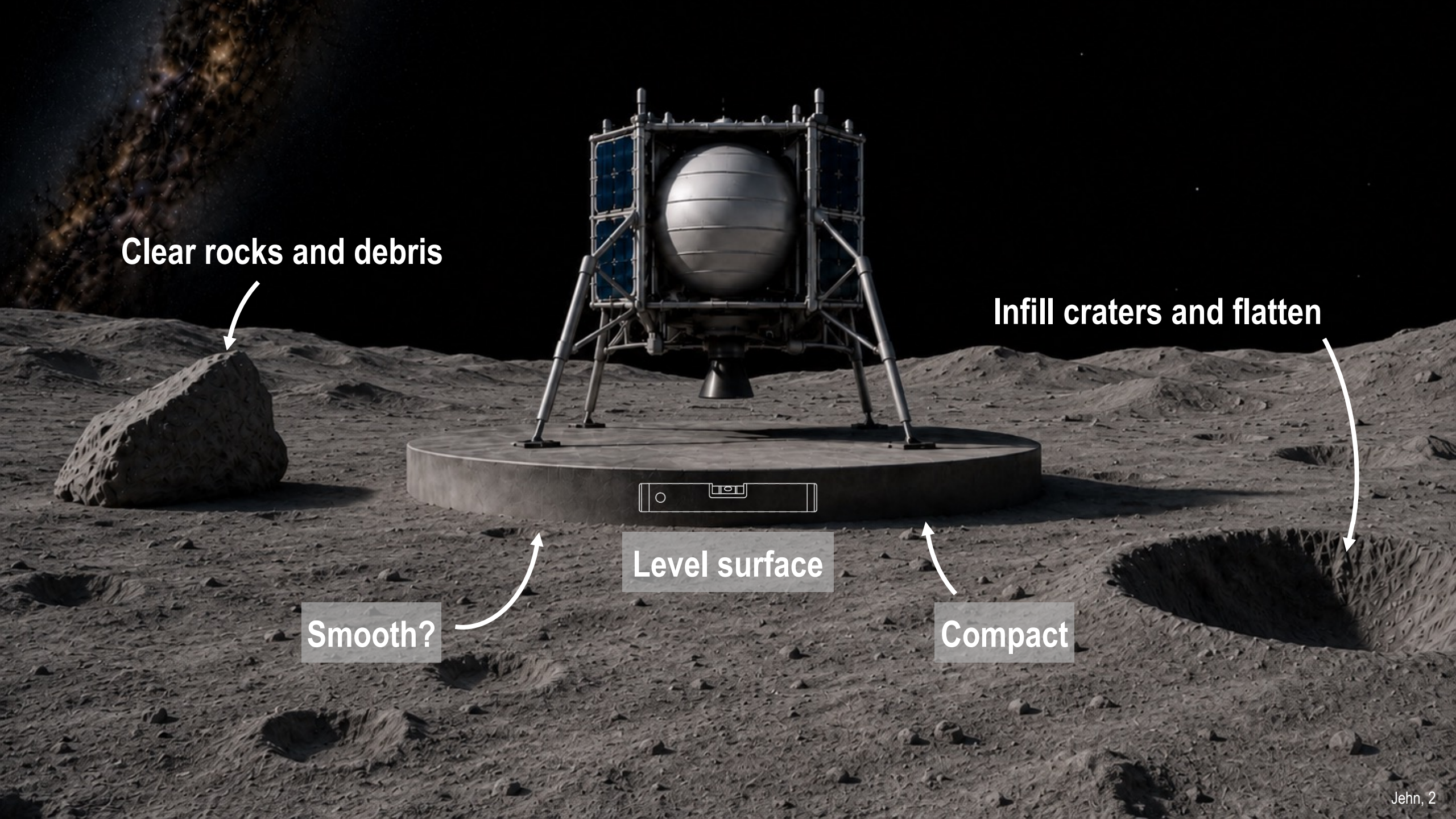
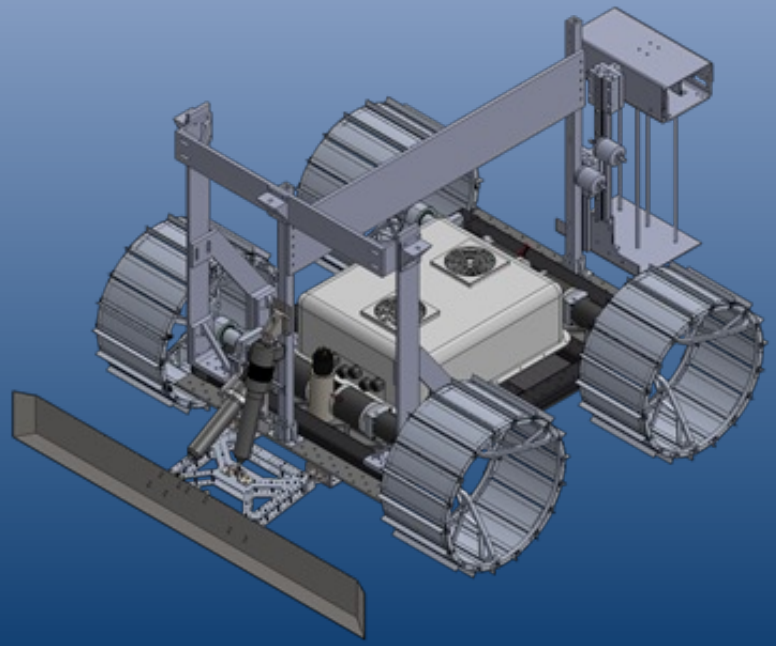

Clear rocks and debris
Infill craters and flatten
Level surface
Smooth?
Compact

NASA LuSTR 2021 end state requirements:

- 10 m diameter graded area
- level to <1°
- **<1 cm Root Mean Square (RMS)**
- Compact to 90% relative density



For a continuous surface profile along a length, the RMS smoothness is calculated using the integral:

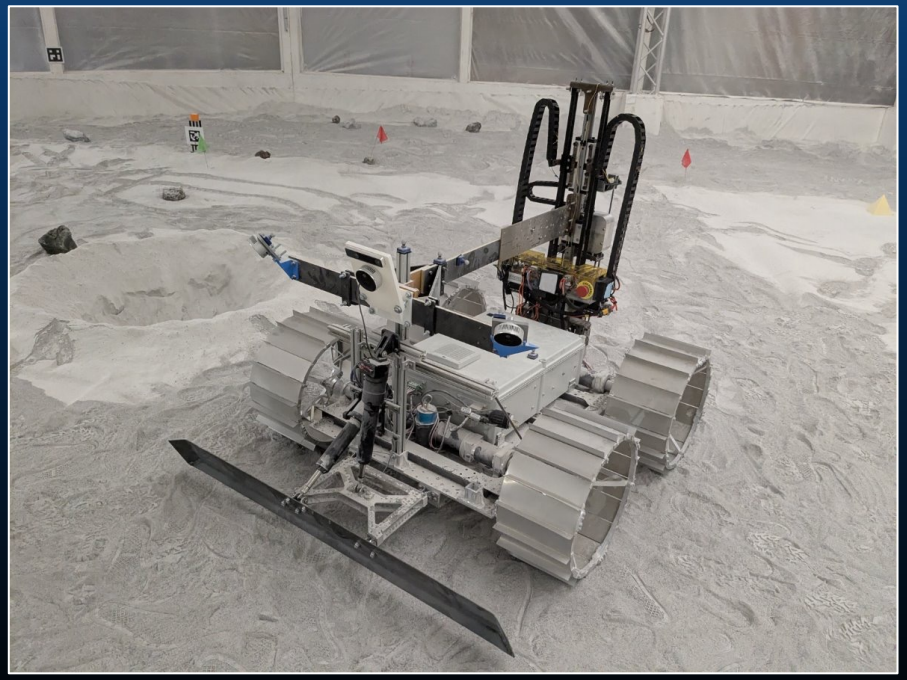
$$R_q = \sqrt{\frac{1}{L}\int_0^L Z(x)^2 dx}$$

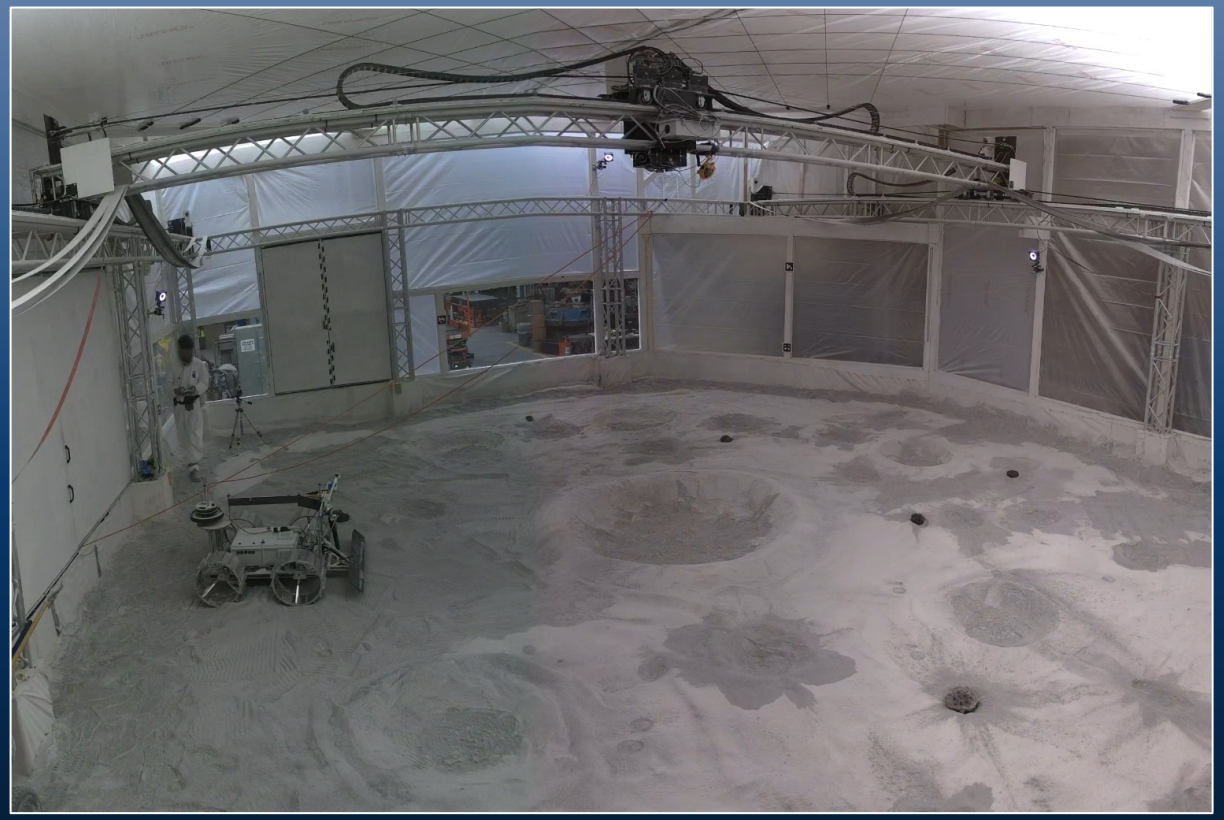
Where:

R_q = RMS surface roughness

L = Sampling length

$Z(x)$ = The height of the surface profile at position x relative to the mean line





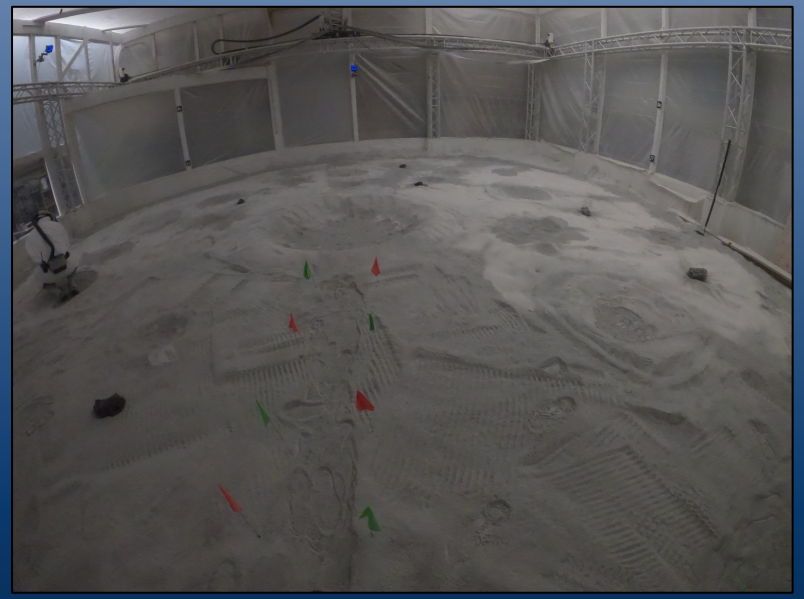
Clearing, flattening, and infilling craters (grading)

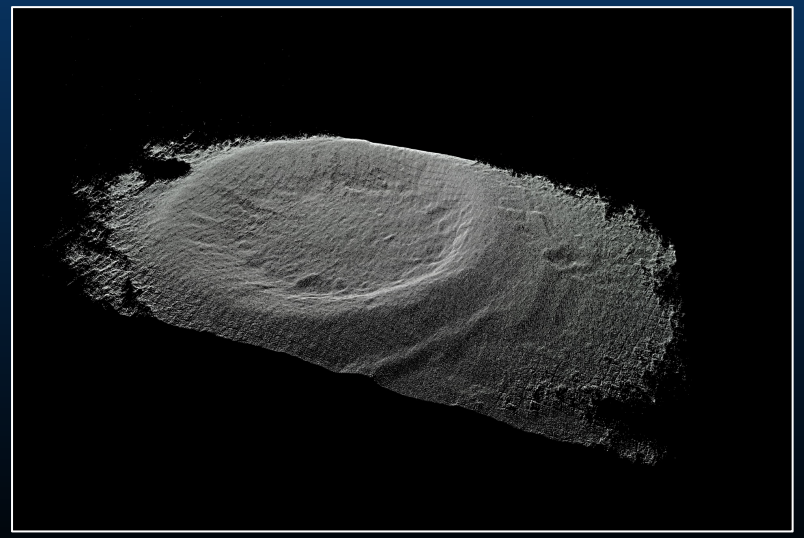
Flattening surface via back-blading (smoothing)

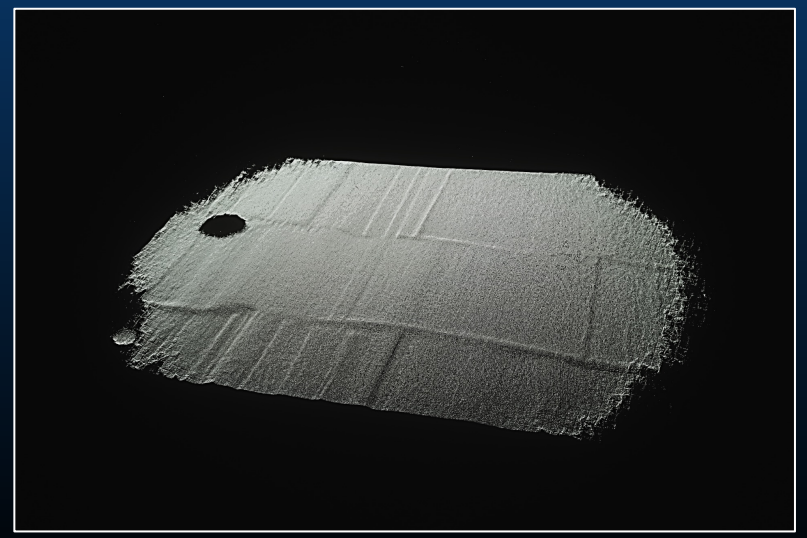
Pre-grading

Post-grading

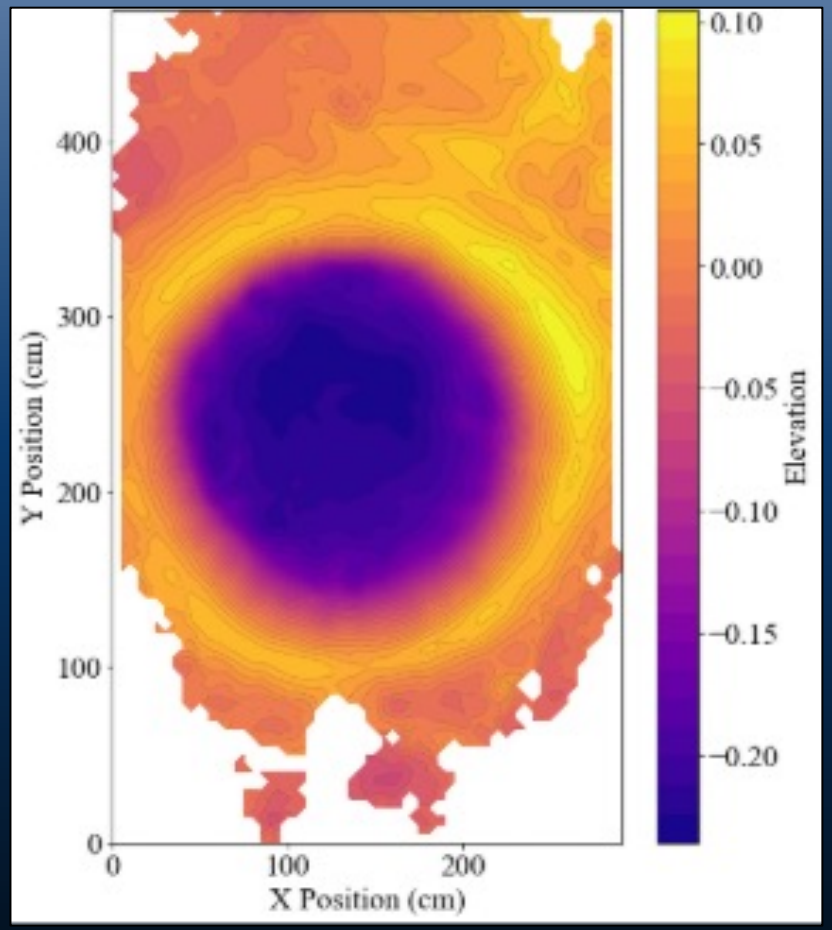
Post-smoothing



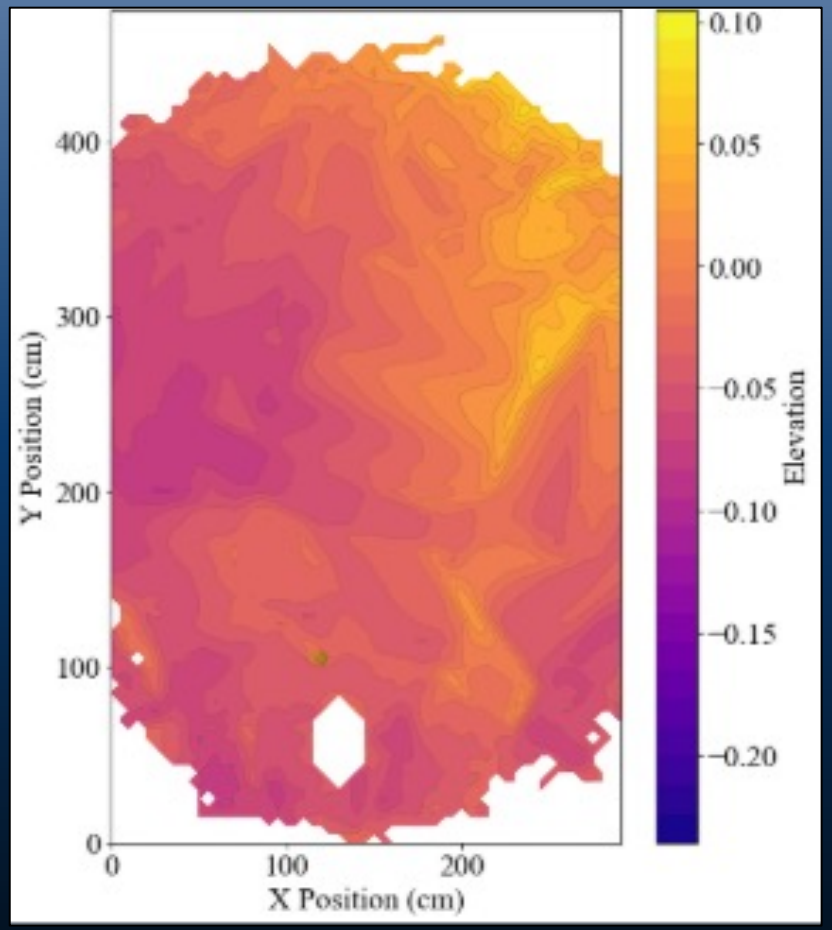




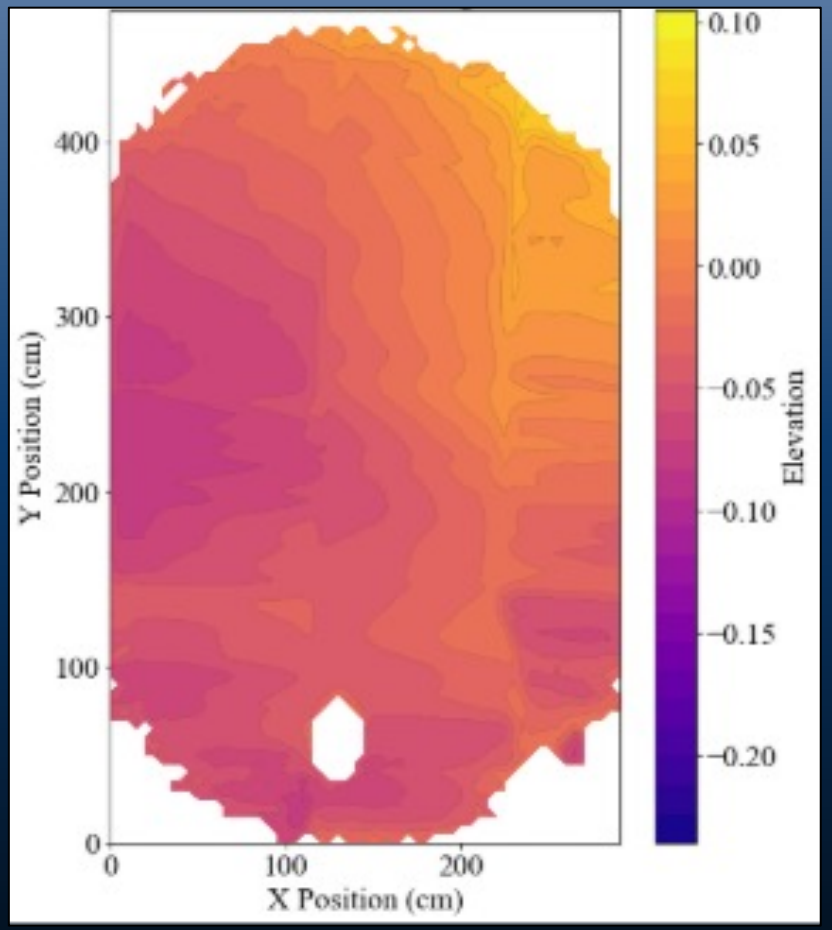
Pre-grading

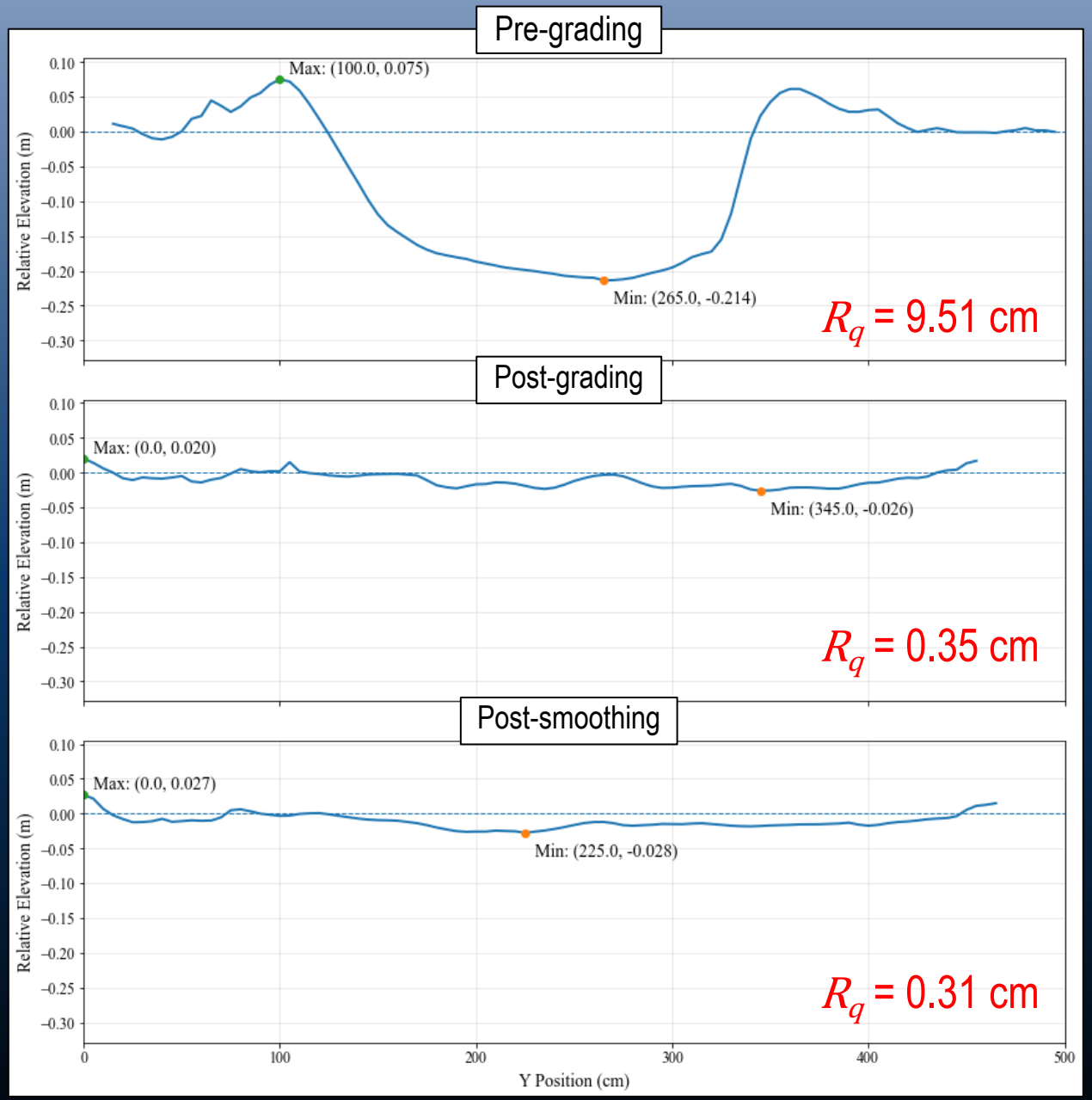


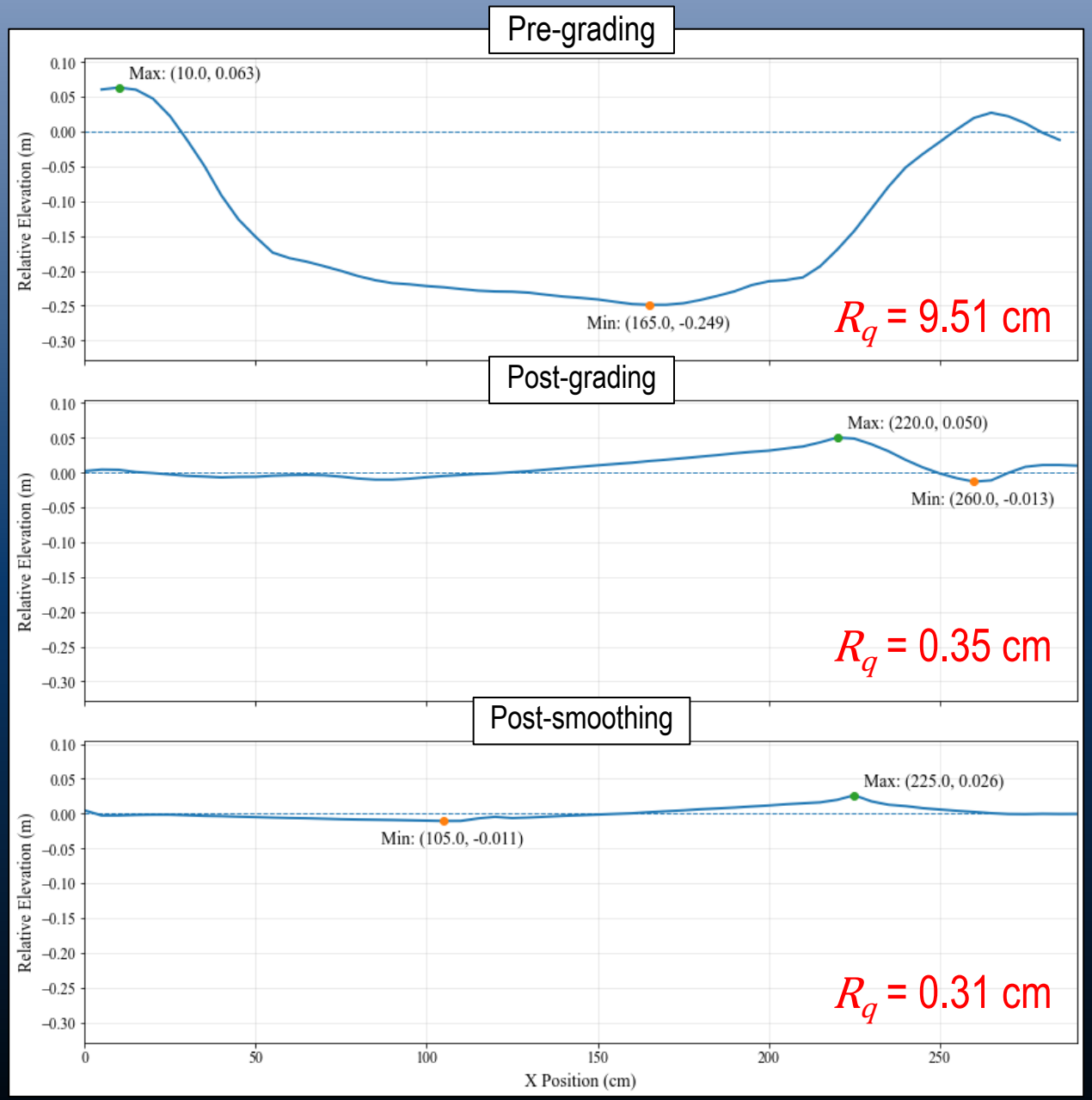
Post-grading



Post-smoothing




Pre-grading
Max: (100.0, 0.075)
Min: (265.0, -0.214)
R_q = 9.51 cm
Post-grading
Max: (0.0, 0.020)
Min: (345.0, -0.026)
R_q = 0.35 cm
Post-smoothing
Max: (0.0, 0.027)
Min: (225.0, -0.028)
R_q = 0.31 cm
Relative Elevation (m)
Y Position (cm)


Pre-grading
Max: (10.0, 0.063)
Min: (165.0, -0.249)
R_q = 9.51 cm
Post-grading
Max: (220.0, 0.050)
Min: (260.0, -0.013)
R_q = 0.35 cm
Post-smoothing
Max: (225.0, 0.026)
Min: (105.0, -0.011)
R_q = 0.31 cm
Relative Elevation (m)
X Position (cm)

How does the terrestrial construction industry handle smoothness requirements?

International Building Code (IBC)

Section 1809: Shallow Foundations (1809.2: Supporting Soils)

Shallow foundations shall be built on undisturbed soil, compacted fill material or controlled low-strength material (CLSM).

American Association of State Highway and Transportation Officials (AASHTO)

Guide Specification for Highway Construction

Section 200: Earthwork (204.3: Construction)

Ensure the finished subgrade surface is smooth and conforms to prescribed elevations before constructing the base or surface course. Limit the maximum variation from the subgrade to the prescribed elevation to 12 mm (0.47 in).

Section 300 Base Courses (304.3: Construction)

Finish the surface so that deviations do not exceed 15 mm (0.59 in), longitudinal or transverse.

How does the terrestrial construction industry handle smoothness requirements?

Unified Facilities Guide Specifications (UFGS)

Division 31: Earthwork

Section 31 00 00

3.5: Subgrade Preparation

(3.5.2: Subgrade for Structures, Spread Footings, and Concrete Slabs)

After final rolling, the surface of the subgrade for buildings and pavements must not show deviations greater than 15 mm (0.59 in) when tested with a 4 m (13.12 ft) straightedge applied both parallel and at right angles to the centerline of the area.

Federal Aviation Administration's (FAA)

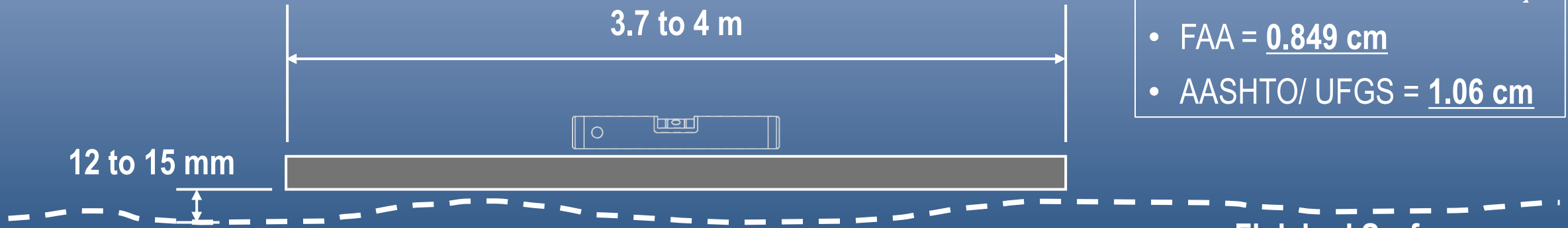
Standard Specifications for Construction of Airports

Part 3: Sitework

Section P-152: Excavation, Subgrade, and Embankment

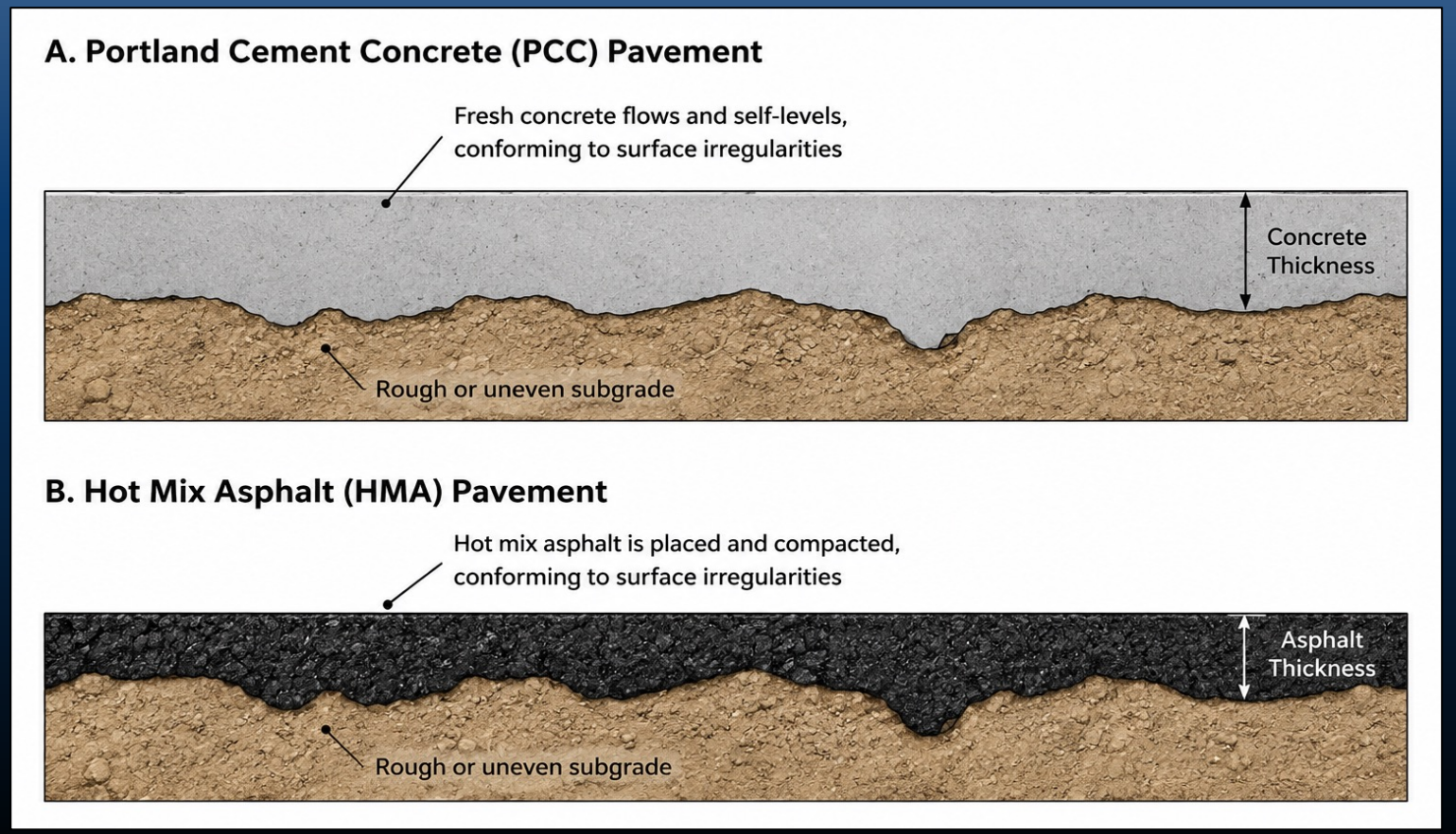
(152-2.13: Surface Tolerances)

The finished surface shall not vary more than 12 mm (0.47 in) when tested with a 3.7 m (12 ft) straightedge applied parallel with and at right angles to the centerline.



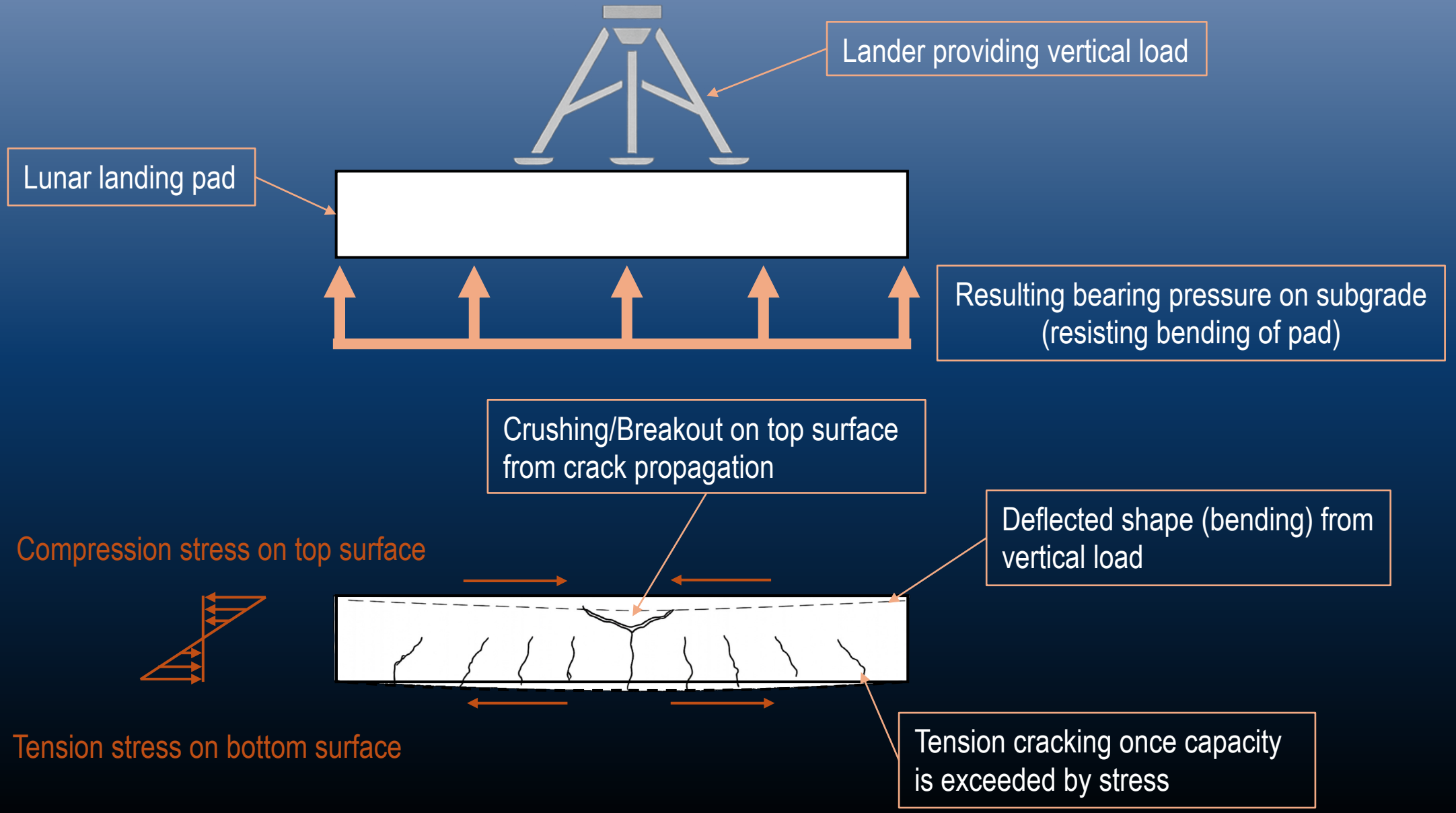
RMS surface roughness (R_q)

- FAA = **0.849 cm**
- AASHTO/ UFGS = **1.06 cm**



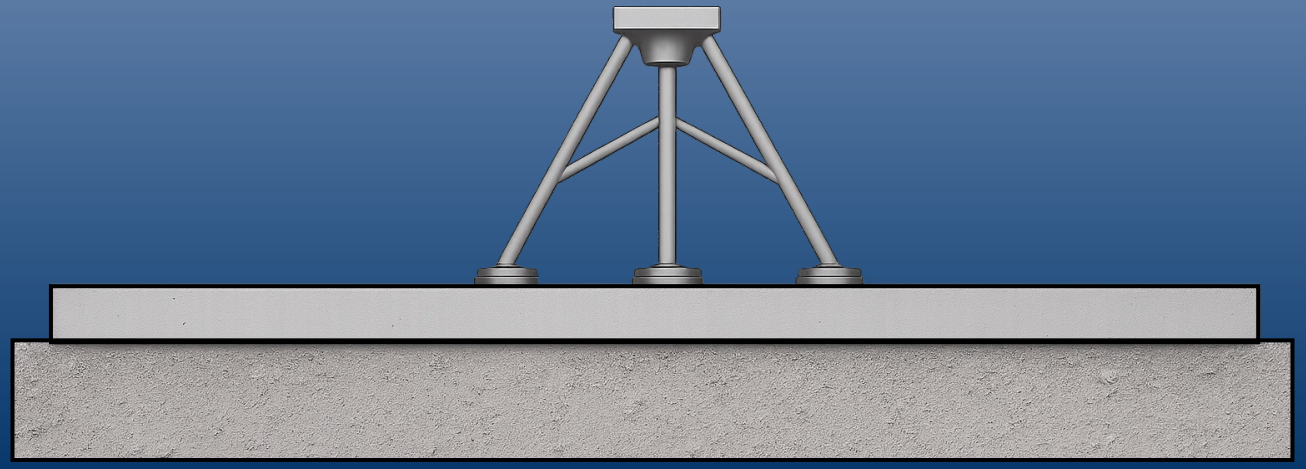
- Both concrete and asphalt pavements conform to the underlying surface profile.
- Surface smoothness requirements help ensure the finished pavement is within tolerance.

Do smooth surfaces guarantee good performance?

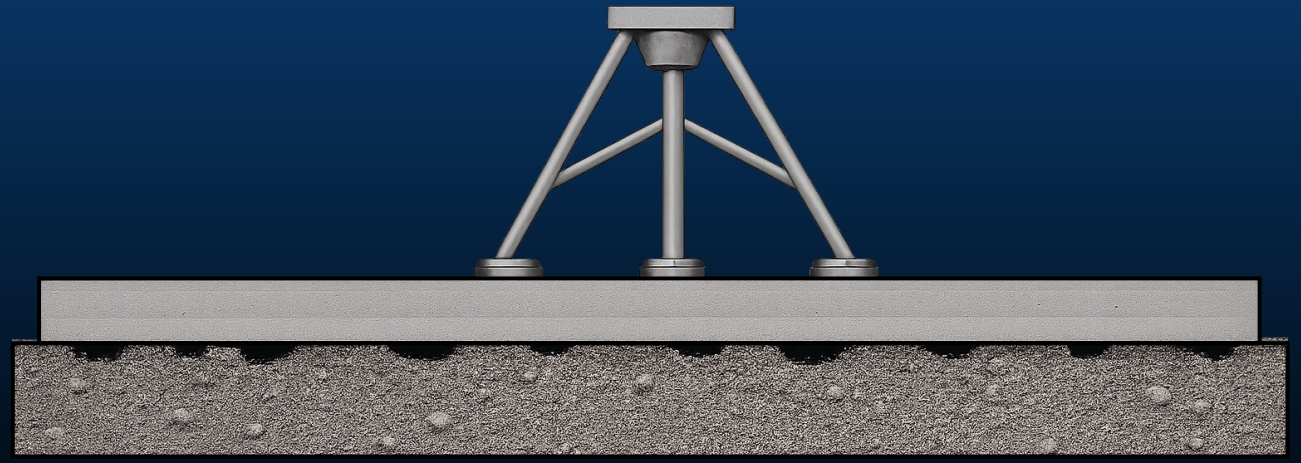


Do smooth surfaces guarantee good performance?

Smooth low-density surface



Rough high-density surface



Do smooth surfaces guarantee good performance?

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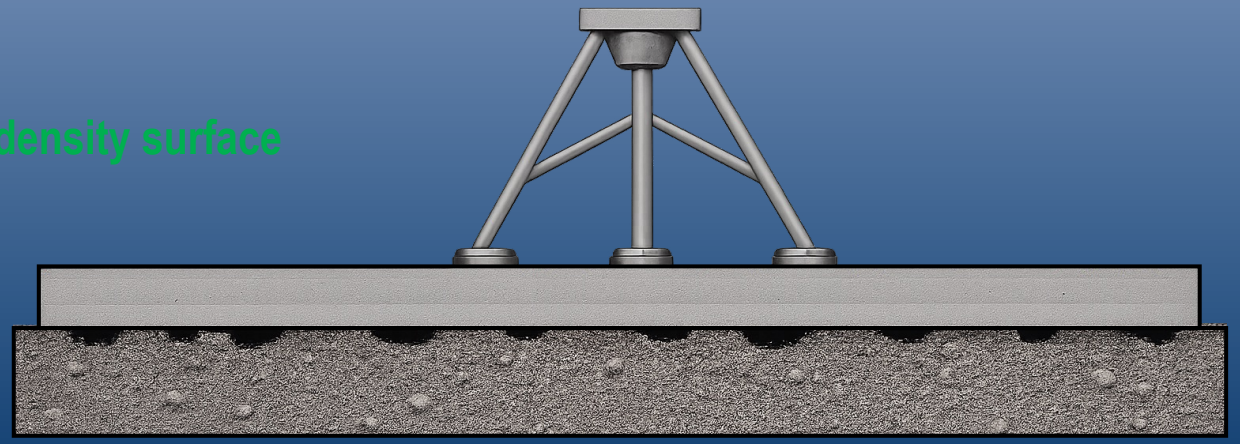
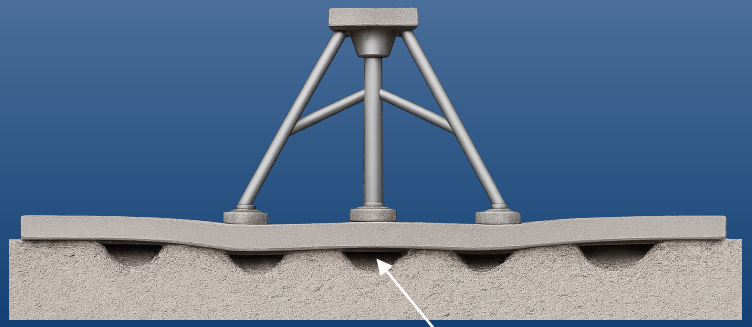
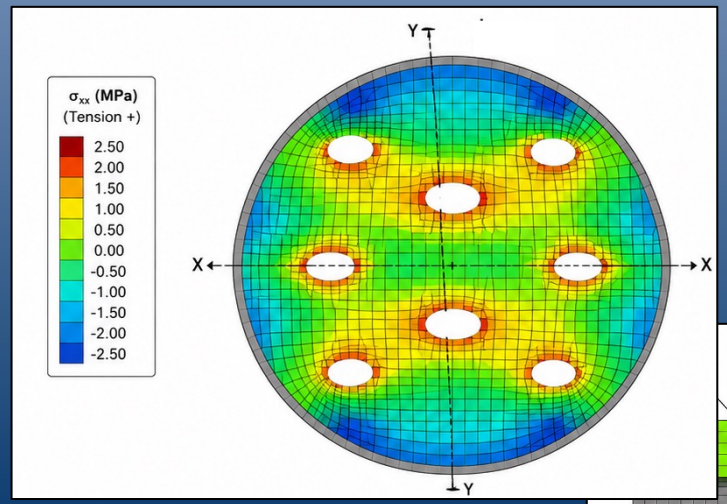


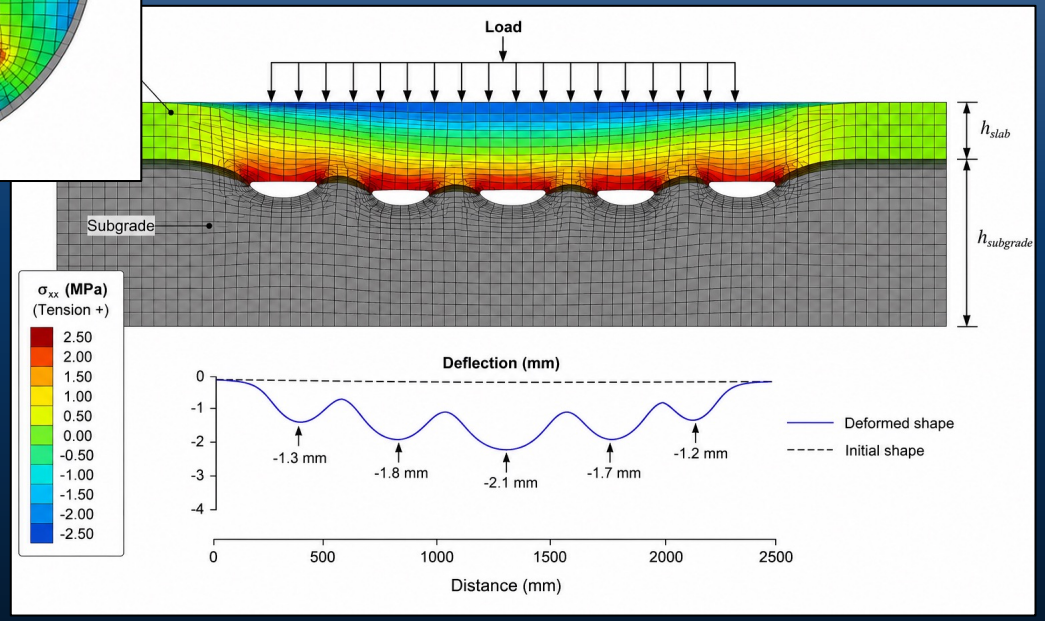
- Smoothness should not be the primary metric for verifying that all surfaces are adequate to receive and support infrastructure.
- We should be worrying about **foundation conformability**, **regolith deformation**, and **bearing capacity.**
  - These are related to the **density state and profile** of the subgrade.
- The solution is system-dependent. Understanding the mechanics of foundation-regolith interaction is the key.

Surface preparation is a soil-structure interaction problem



Voids will create additional bending stresses, **BUT** not nearly as much as soft subgrades would.





The required level of preparation depends on the ability of the foundation system to bridge imperfections in the subgrade

Required smoothness is system-dependent

Each has a different tolerance to:

- Bearing stress
- Settlement (subgrade deformation)
- Slope and levelness
- Density variations
- Local roughness

There is no single lunar smoothness requirement

Measure performance, not just geometry

Step 1	***Step 2***	***Step 3***
Laboratory Measurements	Determine Engineering Requirements	Field Preparation and Verification
<u>Density-Deformation Relationship</u> • Standard and modified Proctor • Consolidation testing	<u>Foundation Design</u> • Regolith displacement • Regolith bearing capacity • Foundation conformability • Required regolith relative compaction	<u>Field Testing</u> • Cone Penetrometer (CPT) • Plate Load Testing (PLT) • Electrical Density Gauge (EDG) • Nuclear Density Gauge (NDG)

CPT: ASTM D5778

PLT: ASTM D1194

EDG: ASTM D7830

NDG: ASTM D6938

Relative Compaction

$$\frac{Feild\ Density}{Maximum\ Lab\ Density}$$

What do you think?

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