Creep and Long-Term Deformation of Compacted Regolith

Surface Operations Breakdown Into Subtasks With Time Estimates

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Disclaimer

This brief tech addresses lunar geotechnical conditions and provides provisional engineering perspectives based on terrestrial soil mechanics adapted for low-gravity environments. The recommendations presented here require validation through in-situ testing and mission-specific reconnaissance before implementation. All Brief Techs represent the views of the author and are provided strictly for educational and professional development purposes. They are not endorsed by any employer, agency, or standards body, and must not be used as formal design guidelines or a substitute for in-situ investigation and testing.

Scope and Intent

This brief tech addresses the long-term deformation (creep and settlement) of compacted lunar regolith pads subjected to operational loading and repeated environmental cycling over months and years.

It is written for mission planners, surface infrastructure engineers, equipment manufacturers, and contractors responsible for delivering and maintaining surface platforms that remain within strict performance tolerances.

The intent is not to model creep in theoretical terms, but to define the operational envelope and provide construction and maintenance strategies that are both feasible and aligned with lunar field conditions. This includes the mechanical and thermal behavior of compacted regolith under:

- Repeated *lunar day-night thermal cycling* (≈ +120 °C to – 170 °C at the surface) and the associated volume changes at depth.
- *Low-gravity creep effects* that differ from terrestrial analogues, with lower confining stresses leading to slower but persistent particle rearrangement.
- Static and dynamic operational loads, from fixed structures (reactors, telescopes, ISRU modules) to moving equipment.

The scope covers:

- Identification of realistic settlement magnitudes over a 5–10-year period.
- In-situ monitoring approaches for deformation tracking.
- Maintenance and recompaction intervals are tied to mission operations.
- Recommendations for designing pad thickness and compaction levels to reduce operational risk.

Operational Relevance and Performance Risk to Precision Installation

The industry's current approach to lunar surface preparation remains short-sighted when it comes to the long-term stability of compacted regolith platforms. While compaction is routinely discussed as a "construction step," its performance over the years under lunar environmental and operational conditions has not been addressed with the same rigor applied to initial build-out. This oversight carries direct operational, financial, and safety implications for high-precision or high-risk facilities.

On the Moon, certain infrastructure types are intolerant to even minor foundation deviations. Radio telescopes, optical observatories, in-situ resource utilization (ISRU) modules, and compact fission reactors all require sub-centimeter alignment stability to function as intended. This is not a design preference; it is a performance threshold dictated by the physics of their operation.

In radio astronomy, for example, the beam shape and pointing accuracy of a large-dish antenna depend on maintaining its reflector geometry to within a fraction of the wavelength being observed. A vertical displacement of just a few millimeters across the support ring can produce measurable phase errors, degrading sensitivity and introducing pointing offsets that compromise long-duration interferometric baselines.

For optical observatories, mirror alignment tolerances are even tighter. A slow tilt caused by settlement-induced rotation of the base plate can lead to persistent image distortion, misalignment of adaptive optics systems, and loss of calibration integrity. Unlike terrestrial systems, such misalignments cannot be corrected through easy re-leveling; any adjustment requires EVA operations, downtime, and risk to both crew and hardware.

ISRU modules and reactors introduce a different set of risks. Here, mechanical efficiency and structural integrity are the drivers. For reactors, displacement of a few millimeters in the supporting slab can alter load distribution, introducing eccentric stresses into containment and support frames. This, over time, can produce structural fatigue, unexpected thermal bridging, or even micro-cracking in shielding elements. For ISRU plants, settlement beneath rotating or reciprocating machinery can induce shaft misalignment, increase wear on bearings, and reduce the efficiency of power transmission systems.