Excavation Force Models and Tool–Soil Interaction

Preliminary Estimates of Excavation Forces Required Across Lunar Regolith Zones (L1–L5)

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Overview

This technical note presents preliminary estimates for the excavation forces required across defined lunar regolith zones L1 through L5. These estimates are grounded in established terrestrial excavation principles, including tool-soil interaction mechanics, cutting resistance behavior, and empirical force ranges observed in granular and fractured geomaterials. However, these terrestrial models have been carefully adapted to account for the unique environmental constraints of the lunar surface, namely: vacuum conditions, reduced gravitational acceleration (~1/6g), and the well-documented electrostatic properties of fine regulates.

The force ranges provided reflect the anticipated mechanical response of lunar regolith under excavation, with consideration given to depth, density gradients, block content, and transition into fractured megaregolith. This classification aligns with excavation zoning frameworks (L1–L5) based on regolith depth and mechanical behavior.

It is important to emphasize that all figures presented are **provisional**. They serve as initial guidance for mission planners, tool designers, and contractors preparing excavation systems for lunar deployment. The absence of comprehensive in-situ data from depths beyond the Apollo and Chang'e mission profiles necessitates a conservative engineering approach. These values should be continually refined as additional lunar regolith mechanics data becomes available through future surface missions, subsurface investigations, and laboratory simulation programs.

Ultimately, these force estimates are intended to inform equipment sizing, energy budget planning, and operational risk assessments during the conceptual and preliminary design phases of lunar infrastructure projects.