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Scaling behavior of drag forces in shallow granular media

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The drag forces on intruders slowly moving through shallow beds of granular media show different scaling behavior depending on the direction of motion. Plunging into the medium results in considerably more resistance than horizontal motion or withdrawing, and for beds of glass beads, the resistive force scales supralinearly with immersion depth. For sand, and unlike glass beads, significant shear-hardening is observed as the intruder moves through a freshly poured bed. The force on compact shapes, such as spheres and cubes scales with the intruder's volume. A simple model based upon the contact forces at the intruder's surface is used to estimate the enhancement of the local pressure ahead of the moving intruder.