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A resistive force model for complex intrusion in granular media

TINGNAN ZHANG, School of Physics, Georgia Institute of Technology, CHEN LI[1], Department of Integrative Biology, University of California, Berkeley, DANIEL GOLDMAN, School of Physics, Georgia Institute of Technology — Intrusion forces in granular media (GM) are best understood for simple shapes (like disks and rods) undergoing vertical penetration and horizontal drag. Inspired by a resistive force theory for sand-swimming [1], we develop a new two-dimensional resistive force model for intruders of arbitrary shape and intrusion path into GM in the vertical plane. We divide an intruder of complex geometry into small segments and approximate segmental forces by measuring forces on small flat plates in experiments. Both lift and drag forces on the plates are proportional to penetration depth, and depend sensitively on the angle of attack and the direction of motion. Summation of segmental forces over the intruder predicts the net forces on a c-leg, a flat leg, and a reversed c-leg rotated into GM about a fixed axle. The stress profiles are similar for GM of different particle sizes, densities, coefficients of friction, and volume fractions. We propose a universal scaling law applicable to all tested GM. By combining the new force model with a multi-body simulator, we can also predict the locomotion dynamics of a small legged robot on GM. Our force laws can provide a strict test of hydrodynamic-like approaches to model dense granular flows.

[1] Maladen et al, J. R. Soc. Interface, 8, 1332, (2011)

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