Landing on an asteroid: Simulations and image analysis of the OSIRIS-REx spacecraft touch-down on (101955) Bennu

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Spacecraft exploration of near-Earth asteroids (NEAs) has shown that their surfaces are composed of both fine regolith and larger meter-scale boulders. For asteroid sample-return missions, characterizing the geotechnical properties of the surface is critical for ensuring spacecraft safety and sampling success. Constraints on these geotechnical properties from remote observations can provide insight into their expected response from an interaction with a spacecraft; however, there is still a poor understanding of the behavior of granular materials in the low-gravity environment of NEAs. Here, we show direct simulations of the OSIRIS-REx spacecraft touching down on the NEA (101955) Bennu and compare them to images taken during the OSIRIS-REx sampling attempt on October 20, 2020. We discuss how these simulations, combined with observations of the surface and telemetry from spacecraft proximity operations, may provide insight into the behavior of granular materials in low gravity.

We discuss the results of varying the angle of friction, ϕ, and subsurface porosity as it is most pertinent for interpreting the data returned by OSIRIS-REx during the sampling maneuver. In our simulations, we found that the angle of friction of the material can strongly influence its response to an impact by a relatively massive spacecraft. We found that for low angles of friction, the OSIRIS-REx Touch and Go Sample Acquisition Mechanism (TAGSAM) is essentially unperturbed by the spacecraft. Past a friction angle of approximately 30 deg, the constant-force spring of TAGSAM engages. The porosity of the sub-surface can influence the manner in which the regolith resist the load of a spacecraft by changing the number of grain-to-grain contacts in the medium. These grain-to-grain contacts build a network of contacting particles known as a force chain, which we visualize in Fig. 1 for two different cases of regolith friction angle.

The value of ϕ for terrestrial granular materials typically ranges between approximately 20 and 40 deg and is controlled by the physical properties of individual grains such as size, shape, and roughness. We find that, for cases with high ϕ, the grains more strongly interlock in response to motion-loading from the spacecraft’s intrusion. This allows the regolith to more readily resist penetration, leading to the spacecraft resting at shallower depths. For these same values of ϕ, a more porous bed may have a different response, as there would be fewer surfaces for particles to develop frictional contacts, allowing TAGSAM to penetrate deeper in to the bed.

Keywords: Asteroid, OSIRIS-REx, Regolith

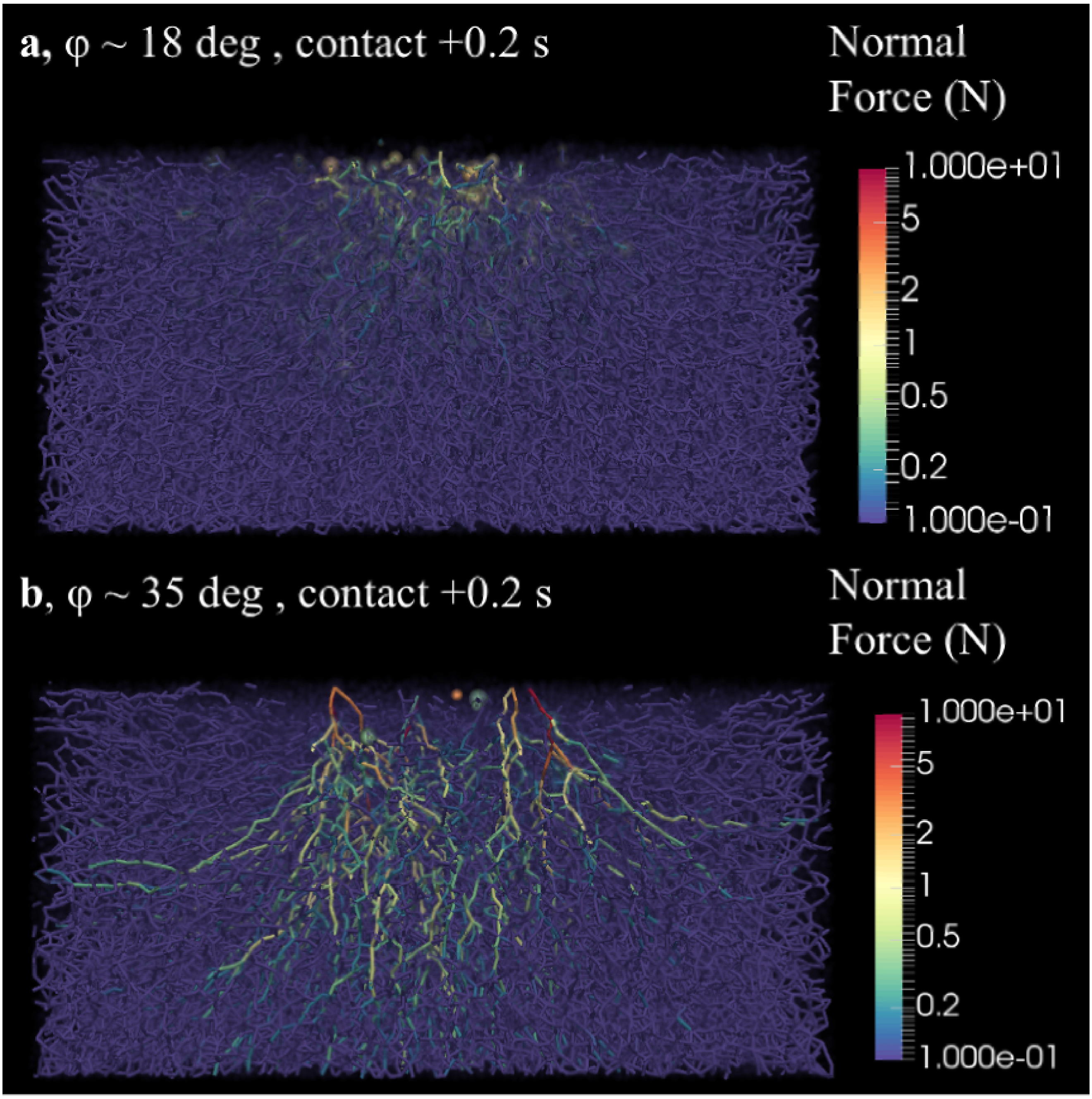

Figure 1. Snapshot of simulations showing the force-chain network for two simulation cases where the horizontal dimension is 120 cm, and the vertical dimension is 60 cm. The color represents the normal force (N) that each particle experiences 0.2 s after contact. **a)** For regolith with low φ, the force chains are relatively shallow and weak. **b)** For regolith with high φ, the force chains are relatively deep and strong.

