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Discrete Element Analysis of Macroscopic Granular Behaviors Using Elastic Contact Models of Rough Surfaces

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Discrete element analysis based on the assumption of linear elastic contact stiffness has found widespread use for numerical modeling of kinematic behaviors of particulate assemblies. Use of linear elastic contact stiffness models for intergranular normal and tangential contacts may be computationally advantageous for investigating applications where local contact stiffnesses are rather inconsequential (e.g., industrial feeding). In contrast, the mechanical stability of granular assemblies can be influenced by load-dependent contact stiffnesses, which determines contact deformations during and after the formation of force chains. Further, in modeling mechanically stable states of granular assemblies, the intergranular forces at equilibrium may vary with respect to the kinematics of discrete elements in contact. Thus, for discrete element analyses aimed at characterizing observational behaviors of granular materials (e.g., simulations of tri-axial compression tests), considerations are warranted in accounting for the elastic contact of rough surfaces, wherein nonlinear normal contact stiffness depends as much on the characteristics of the surface topography as on the elastic properties of the granule itself. In the present study, an extended Hertzian theory of elastic normal contact between rough spheres (proposed by Greenwood and Tripp) is used to estimate effective pressure distributions by considering discrete microcontacts over nominal contact areas. In turn, the evolution of nominal contact areas derive from distributions constructed using power spectral density and scanning electron microscope images on ceramic spheres. Based on the assumption of no-slip conditions, tangential contact stiffness is subsequently evaluated, and the ratio of normal to tangential contact forces is derived in a functional form of normal contact displacement. Using the gravitational random-loose packing method, the effects of nonlinear contact force-deformation relationships are investigated for initial stress states of granular assemblies under hydrostatic conditions, which are subsequently subjected to standardized tri-axial compression test procedures. Results obtained from the separate contact modeling schemes are then compared. Further, physical test results are used as a benchmark in assessing volume-averaged stress versus strain for simulations of granular assemblies. By making use of various contact models, differences are highlighted between simulating granule-to-granule interactions using a linear secant stiffness approach (per Hertzian theory) versus nonlinear contact stiffness (per an extended Hertzian theory).

Keywords: Discrete element analysis, Granular assemblies, Nonlinear elastic contact stiffness, rough surfaces, Internal angle of friction