論 文 要 旨

Summary of Dissertation

専　　攻 Department	Graduate school of urban innovation
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論文題目 Title	Particle Shape and Deformation Characteristics of Granular Materials
和訳または英訳 Translation (J->E, or E->J)	粒状材料の粒子形状と変形特性

The significance of particle shape in dictating the spatial distribution and interlocking within granular materials is widely recognized for its influence on bulk behavior. Nevertheless, due to the complex and varied shapes found in natural granular materials, determining the isolated impact of particle shape on both macro and micro-mechanical responses poses a considerable challenge. Consequently, this doctoral study adopts a novel two-dimensional approach, both experimentally and numerically, to exercise control over particle shape and examine its effects on the macro and micro-mechanical behavior of granular materials.

Experimentally, an extensive examination is conducted to assess how the inclusion of angular particles into a round sample impacts both the macroscopic shear strength and microscopic particle motion within granular mixtures. The study involved two shapes of particles, namely circles and regular hexagons, with two distinct sizes for each shape. Initially, two samples are prepared: one with bidisperse circular particles and the other comprising bidisperse hexagonal particles. By gradually introducing hexagonal particles into circular samples, different proportions of angular content (0%, 25%, 50%, 75%, and 100%) are achieved. Biaxial shearing tests are then conducted on each sample under three different confining stresses. The macroscopic observations consistently demonstrate that increasing the angular content leads to a progressive enhancement in shear strength, indicating that the angularity of particles plays a vital role in determining the overall critical state strength of the granular mixtures. The presence of angular particles promotes interlocking configurations, resulting in improved shear strength. Additionally, with higher angular content, the mixtures exhibit greater dilation, indicating a greater tendency for particle rearrangement and expansion. At the microscopic level, it is observed that an increase in angular content generally leads to a decrease in overall particle rotations within the mixtures. Specifically, circular particles experience a significant reduction in rotations, whereas the rotations of hexagonal particles show a negligible effect. This finding suggests that round particles are more susceptible to the presence of angular particles, which restricts their rotational movement. In contrast, hexagonal particles are less influenced by the rotations of circular particles, indicating a unidirectional restriction. These findings contribute to a deeper understanding of the particle interactions and mechanical responses in granular mixtures, specifically regarding the influence of angular content.

A discrete element model (DEM) of the biaxial shearing test is then developed and validated by comparing it with the complete experimental data set. The model was calibrated and validated by comparing numerical results with corresponding biaxial shearing tests on circular (round) and hexagonal (angular) rods at microscopic and macroscopic scales. To systematically investigate the effect of roundness/angularity on granular behavior, the DEM model is used to simulate shearing response of bidisperse samples using eight (08) non-elongated convex polygonal-shaped particles. Macroscopically, it is observed that angular assemblies exhibit higher shear strengths and volumetric deformations, i.e., dilations. Moreover, a unique relationship is observed between the critical state stress ratio and particle roundness. Microscopically, the roundness shows a considerable effect on rotational behavior such that the absolute mean cumulative rotation at the same strain level increases with roundness. A decrease in roundness results in relatively stronger

interlocking, restricting an individual particle’s free rotation. Furthermore, the particles inside the shear band exhibit significantly higher rotations and are always associated with low coordination numbers. Generally, the geometrical shape of a particle is found to have a dominant effect on rotational behavior than coordination number.
Next, the systematic effect of particles aspect ratio (antonym: elongation) was investigated on shearing response of round and angular granular materials. Each of the eight polygonal shapes considered in roundness study were gradually stretched to generate five (05) cases of elongated particles, resulting in forty (40) different shape samples. Macroscopically, we observed a nonlinear tendency wherein as the aspect ratio decreased from 1, the critical state stress ratio initially increased, reaching a maximum, followed by a decreasing trend. This effect was more prominent in round samples. Microscopically, decreasing the aspect ratio from 1 reduced particle rotations and increased the mean coordination number. Elongated particles exhibited significant contact anisotropy, forming irregular force chains, facilitating interparticle sliding, and reducing overall strength. Additionally, we explored the impact of the interparticle friction coefficient. A high value of interparticle friction coefficient led to a monotonically increasing strength with elongation, underscoring the importance of accurately calibrating microscopic friction coefficients. Finally, the effect of particle shape is verified by changing boundary conditions. Interestingly, regardless of boundary conditions, the impact of particle shape on granular response remained consistent emphasizing the significance of particle shape in controlling the variation of granular response.