

Discrete Element Modeling and Shape Characterization of Realistic Granular Shapes

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ABSTRACT

This paper documents a methodology for characterizing granular materials in three dimensions using two-dimensional shape descriptors. This paper demonstrates that Fourier-based three-dimensional shape descriptors can be constructed for sands having a common geologic origin, using a statistical combination of two-dimensional projections. A skeletonization algorithm is developed in this study to model irregular particle shape for discrete element simulation. The two-dimensional and three-dimensional particle shapes are then implemented within discrete element modeling software to evaluate the influence of grain morphology on shear strength response of granular soil by using discrete simulation of direct shear test.

KEY WORDS: Shape characterization; skeletonization; discrete element modeling; overlapping discrete element cluster; granular media.

INTRODUCTION

The behavior of cohesionless soils is strongly influenced by inherent particle characteristics including particle morphology (Sukumaran, 1996). Characterization of particle morphology becomes especially difficult for granular materials (Sukumaran & Ashmawy, 2001), but it is necessary if discrete element modeling of realistic shapes have to be done. Discrete element simulations help to visualize the micro-fabric and contact forces between particles and help to better understand the micro-mechanics of granular media.

Substantial research on particle morphology has been conducted to evaluate the effect of grain shape on the mechanical response of granular soil. However, in spite of significant progress in particle shape characterization and reconstruction through digital imaging, majority of the available resources describing the particle shape modeling technique remains limited to two-dimensional modeling and characterization, with minimal progress in three-dimensional domain due to lack of quantitative information about particle geometries, and experimental and numerical difficulties associated with characterizing

and modeling irregular particle shape. These limitations warrant accurate modeling and quantitative characterization of three-dimensional particle shape to understand the micromechanics of granular soil in its entirety.

The overall objectives of the paper can be broken down into three major aspects. The first aspect is the determination of statistical 3-D descriptors that can be used to characterize sand particles from a particular geologic origin. The sand samples that will be discussed in the paper include Michigan Dune sand and Daytona Beach sand. The second aspect is to synthesize three-dimensional images of sand particles from the two-dimensional images and to validate their geometry. The final phase of the project is to use the synthesized particles in a Discrete Element Model for obtaining a better understanding of micro-mechanics of granular media when sheared in a direct shear box.

THREE-DIMENSIONAL SHAPE CHARACTERIZATION

The method utilized for three dimensional shape description combines the techniques of boundary unrolling, complex Fourier analysis and Principal Component Analysis (PCA) to yield a method possessing the four most desired attributes of a shape characterization algorithm: uniqueness, parsimony, independence, and invariance. It also possesses the following secondary attributes: reconstruction and automatic collection.

The overall premise for the study is shown in Fig. 1 (Corriveau, 2004; Barrot, 2005; Giordano, 2007). In the statistical mix characterization step, single projections of multiple particles are captured using a standard digital camera and microscope. Next, each image is processed so that only the boundary of each particle remains. The boundary for each particle is “unrolled” and converted into a complex periodic function. The one dimensional function for each particle is resampled and normalized to ensure that the same number of points (and corresponding frequencies) exist between all particles and that the magnitudes of the FFT’s lie within the same range. Fig. 2 depicts the process of converting a two-dimensional projection into a one-