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Research Paper

Generation of realistic sand particles with fractal nature using an improved spherical harmonic analysis

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ABSTRACT

Based on X-ray micro-computed tomography images of natural sand particles, a set of spherical harmonic descriptors and an associated fractal dimension were introduced to characterise the multi-scale particle morphology. Based on the statistics of the fractal dimensions for different types of sands, this study proposed a practical method to generate realistic sand particles with the major morphological features of their mother sands. To validate this method, two virtual sand assemblies were generated, whose 3D printing and shape parameters were compared with those of real sand particles. Furthermore, these generated particle morphologies were incorporated into DEM simulations of granular column collapse.

1. Introduction

The science behind the particle morphology of natural sands has interested geotechnical and geological researchers for many decades. Many experimental studies proved that the mechanical properties of sands, such as compressibility, shear strength, dilation and crushability, are highly influenced by the morphological features of the constitutive particles [1–4]. As an alternative to investigating fundamental soil behaviours, the discrete element method (DEM) [5] has made substantial contributions towards elucidating the micromechanics of the particle morphology affecting the mechanical properties of granular soils [6–9]. In this context, a key issue is how to best reflect the particle morphological effect in DEM simulations of sands.

Generally, two common methods have been utilised by researchers to reflect the particle shape effect in DEM simulations of granular soils. The first method is to implement a rheology-type rolling resistance model [10,11] between the interparticle contacts that is capable of reflecting the anti-rotation effect induced by the surface texture and roughness of the sand particles. Compared to the rolling resistance model, a more direct method to reflect the particle shape effect is to incorporate irregular particle shapes into the DEM simulations. For example, clump logic is a common method used to rebuild ideally shaped particles (e.g., ellipsoids and polyhedrons) by bonding a group of elementary spheres together as a rigid body [8]. However, the generated particle shapes are always artificial and simplified. It is still difficult to generate realistic particle morphology in a DEM framework.

Within the last 20 years, the development of X-ray micro-computed tomography (μCT) technology has provided a powerful tool for the three-dimensional (3D) visualisation and characterisation of the micromechanical behaviours of sand particles, such as particle kinematics [12,13] and local shear band formation [14–16]. More recently, the use of high-resolution X-ray CT technology has allowed the identification of the microstructure and micromorphology of natural sand particles [17,18]. To implement the particle morphology into DEM studies, a prior issue is to reconstruct the 3D particle surface based on the CT information. A simple method for the said reconstruction is to use an image processing technique called the marching cubes algorithm, which can extract a polygonal mesh of an isosurface from 3D scalar voxels [19,20]. However, the particle surface generated from the marching cubes method has artificial stair-steps, which always results in inaccurate measurement of the shape parameters, e.g., surface area and local roundness, and may bring difficulty in generating clumps in the DEM framework. To overcome this problem, the authors introduced a more sophisticated method using spherical harmonics to represent and reconstruct the 3D particle surface of granular soils [21–23].

Based on the reconstructed particle surface, realistically shaped particles can be generated in the DEM framework by using advanced clump template logics [24,25]. However, due to the cost and resolution

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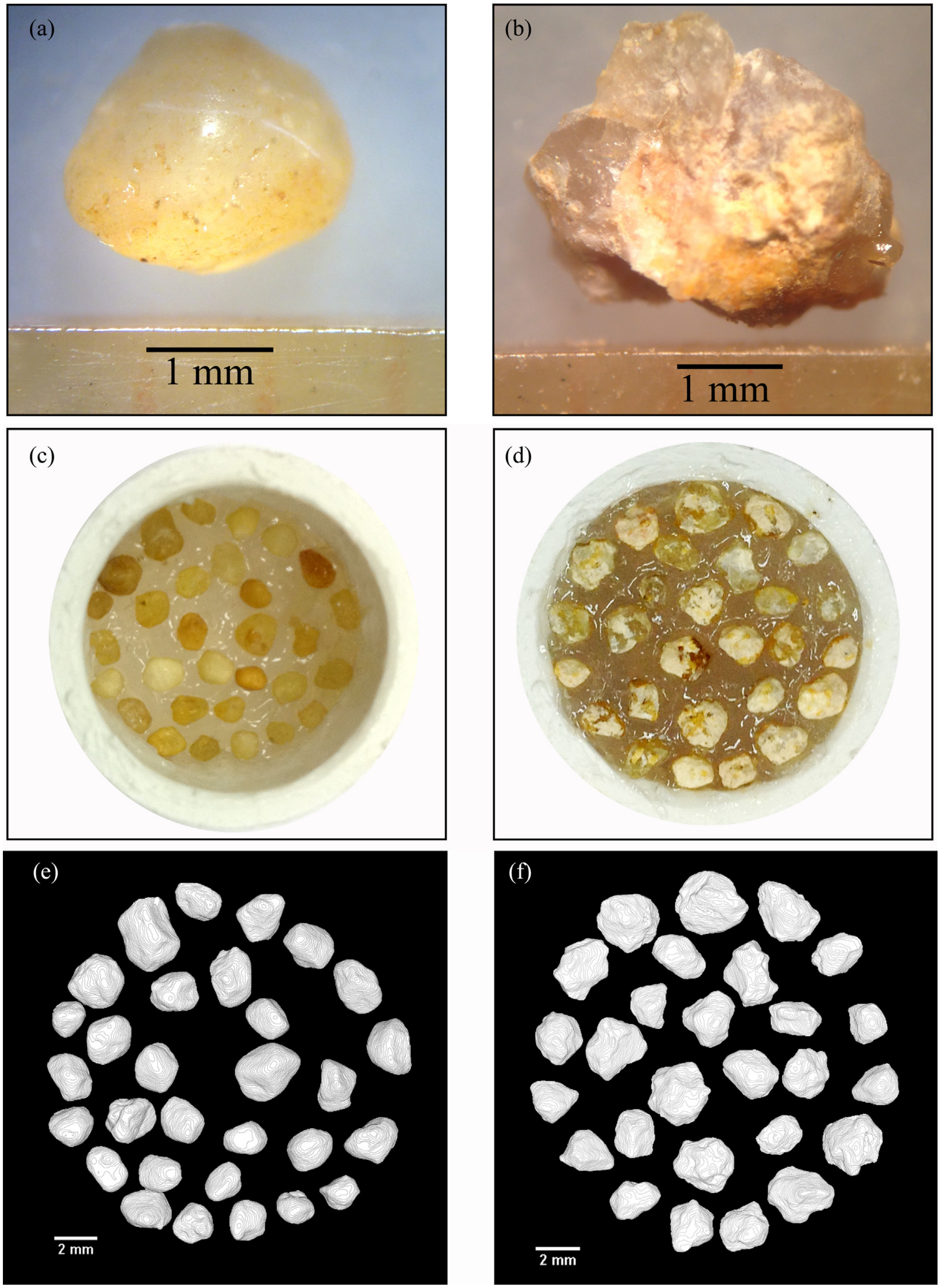

Fig. 1. (a) Microscopic view of a Leighton Buzzard sand (LBS) particle; (b) microscopic view of a highly decomposed granite (HDG) particle; (c) Leighton Buzzard sand specimen, (d) highly decomposed granite specimen; (e) μCT images of Leighton Buzzard sand particles; and (f) μCT images of highly decomposed granite particles.

requested of μCT scanning, the number of scanned sand particles was always limited, which in turn limited the number of obtained clump templates. Thus, the particle morphologies within the DEM sample were always monotonic and repetitive and not capable of reflecting the effect of the real particle morphology of natural sands. For certain types of natural sand, the morphological features of its component particles are totally random and distinct from each other but hold certain statistical similarity.

To consider the effect of realistic particle morphology within the DEM framework, a large number of randomly shaped particles need to