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# Use of digital image analysis combined with fractal theory to determine particle morphology and surface texture of quartz sands

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ABSTRACT

The particle morphology and surface texture play a major role in influencing mechanical and hydraulic behaviors of sandy soils. This paper presents the use of digital image analysis combined with fractal theory as a tool to quantify the particle morphology and surface texture of two types of quartz sands widely used in the region of Vitória, Espírito Santo, southeast of Brazil. The two investigated sands are sampled from different locations. The purpose of this paper is to present a simple, straightforward, reliable and reproducible methodology that can identify representative sandy soil texture parameters. The test results of the soil samples of the two sands separated by sieving into six size fractions are presented and discussed. The main advantages of the adopted methodology are its simplicity, reliability of the results, and relatively low cost. The results show that sands from the coastal spit (BS) have a greater degree of roundness and a smoother surface texture than river sands (RS). The values obtained in the test are statistically analyzed, and again it is confirmed that the BS sand has a slightly greater degree of sphericity than that of the RS sand. Moreover, the RS sand with rough surface texture has larger specific surface area values than the similar BS sand, which agree with the obtained roughness fractal dimensions. The consistent experimental results demonstrate that image analysis combined with fractal theory is an accurate and efficient method to quantify the differences in particle morphology and surface texture of quartz sands.



## 1. Introduction

Particle size and grain shape reflect soil composition, grain formation and release from the mineral matrix, transportation, and depositional environments (Santamarina and Cho, 2004). Quantification of the distribution of particle sizes and the particle shape parameters is important in the characterization of granular soil and it is often used in estimating mechanical and hydraulic properties of sandy soils. Particle shape characterization is scale-dependent: morphology represents large scale and surface texture represents small scale.

The most widely used procedure to determine particle size distribution is by conventional sieve analysis. The accuracy of sieving will be better for spherically shaped grains. Flaky particles tend to pass diagonally through the sieves with square holes, and the rod-shaped particles are about 2.5 times the volume of the spherically shaped particles (Lees, 1964). Conventionally, the particle morphology (i.e. sphericity and roundness) is described by visual comparison using standard charts (Krumbein, 1941; Krumbein and Sloss, 1963) and only a qualitative description of the grain shapes is obtained. The comparison of individual grain using standard charts is time-consuming, subjective and difficult to automate.

Digital image analysis is a measurement technique that can reduce execution time and permit more accurate measures of interest (Brzezicki and Kasperkiewicz, 1999; Werner and Lange, 1999; Lundqvist and Akersson, 2001). The steps of this technique, which include capture, handling and storage of images, are being increasingly facilitated by the increasing technological advancement of computers and electronics. Several publications used both two-dimensional (2D) and three-dimensional (3D) digital image analysis methods to quantify the particle texture parameters. The 3D image analysis may be computationally expensive. Furthermore, the scanning electron microscopy used to capture 3D digital images

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of grains is a relatively expensive and complex device (Cox and Budhu, 2008). The parameters required to define grain shape (i.e. sphericity) can be obtained directly from a 2D digital image analysis method. For practical purpose, a simple approach is preferable.

The primary purpose of this paper is to present a simple, reliable, relatively low-cost and reproducible methodology that can identify representative sandy soil texture parameters. The paper presents and discusses the use of 2D image analysis combined with fractal theory as a measurement tool to evaluate the texture parameters of two sandy soils sampled from the state of Espírito Santo, Brazil: a river sand (RS) and the other whose source is located at a sand deposit near the beach (BS). The two quartz sands were selected, because they are the most commercially used sands in that region.

## 2. Previous published studies

The morphological characteristics of sandy soils directly affect the behavior of earth structures and are relevant topics in the fields of geology and geotechnical engineering. Along this line, analysis of the influence of geometrical aspects of soil grains is usually restricted to the particle size distribution measured by sieve tests. However, the accuracy of sieving will be better for spherically shaped grains and the test cannot determine the textural parameters, such as shape and roughness.

In geotechnical engineering, the procedure for evaluating the morphology of grains is often performed by visual comparison with standard images (Fig. 1), in which the degrees of sphericity and roundness are verified grain by grain (Krumbeim and Sloss, 1963; McLane, 1995). However, in addition to being time-consuming, this test technique is extremely subjective and dependent on operator's experience.

The demands of tight deadlines and greater measurement accuracies have stimulated the use of alternative measurement techniques, such as image analysis (Brzezicki and Kasperkiewicz, 1999; Werner and Lange, 1999; Lundqvist and Akersson, 2001). This technique has been particularly driven by technological advances in the fields of computing and electronics and the development of increasingly more powerful and accessible personal computers. The combination of these factors allows for capturing, manipulating and storing images at higher resolutions and even 3D analysis (Wang et al., 2004; Fernlund, 2005).

Some main properties of granular soils considered in geotechnical engineering are particle size and distribution, morphology (roundness and sphericity), surface texture (local roughness features) and mineralogical composition. The primary factor that influences the physical characteristics of the grains is their transport agent, because size depends on velocity and transport means. Both the morphology and surface texture are influenced largely by the transport medium, where the grain shape also depends on the traveled distance (Patro and Sahu, 1977).

Due to the ease of implementation and the fact that no sophisticated equipment is required for implementation, determining the particle size distribution by sieving tests has been the physical characterization technique most commonly used for sands. If all grains were composed of particles whose shapes were perfect spheres with smooth surfaces, the sieving classification would be simple, because the mesh openings of the sieves correspond to the minimum diameter of the grain retained and the maximum diameters of the grains that can pass through it. However, particles have irregular shapes and their surfaces are rarely smooth. Therefore, the information obtained by this test is not sufficient to evaluate the textural aspects, such as shape and texture.

Furthermore, Kwan et al. (1999) warned that when interpreting the results of particle size determined by sieving, one must consider that particles passing through a square mesh sieve can have larger dimensions than the mesh size. An elongated particle with a length greater than the screen opening can pass without difficulty. In this case, the sieve opening is a measure of the lateral dimension of the particle. Moreover, lamellar particles can pass laterally through the square mesh sieve. In this case, the width of the particle can be larger than the aperture, though it must be smaller than the diagonal length of the mesh opening (see Fig. 2) (Maerz, 2004).

### 2.1. Degree of sphericity

As an alternative to minimize the deficiencies observed in the sieving test, regarding the shape of the grains (morphology), the degree of sphericity is used, which is an index of the most commonly found shape and provides an indication of how close the grain is to a sphere.

There are numerous variations in the sphericity definitions, and the quantification of grain shape requires specification of the used definition. According to McLane (1995), sphericity was originally defined by Wadell (1932) as the ratio between the diameter of a sphere of the same volume as the particle and the diameter of the smallest circumscribed sphere, but this definition is not widely used. Furthermore, Scarlett (1996) stated that two particles with similar shape but different sizes may have the same sphericity as described by Wadell (1932), and thus this parameter alone is not a good factor to represent particle shape. Sphericity is also expressed

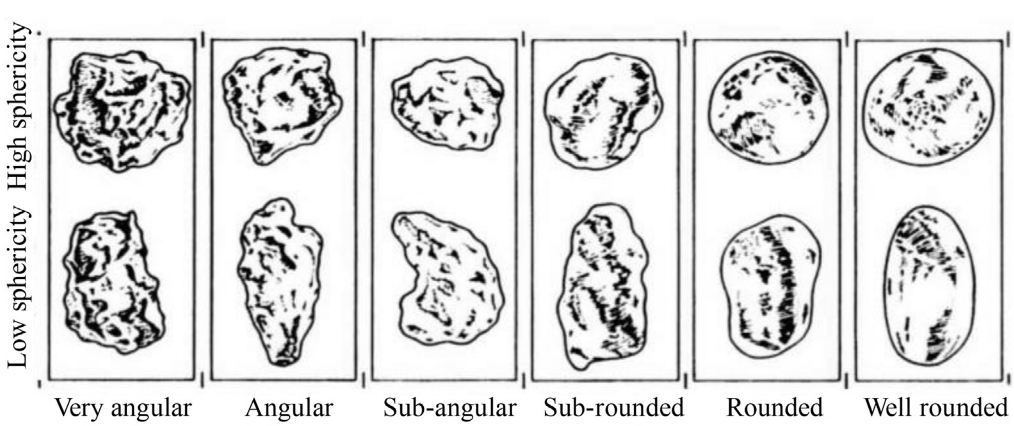


**Fig. 1.** Examples of particle shape characterization (Powers, 1953; McLane, 1995).