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Characterisation of the roughness of sand particles

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Abstract

The surface of soil grains is not smooth especially when examined at growing smaller scales. In geotechnical engineering there is increasing evidence of the significant role of surface roughness on the micro-mechanical behaviour of particulate samples. Characterizing the particles roughness is therefore an essential and pivotal step in the investigation on its role. Previous studies on the surface roughness generally used the optical interferometer and the roughness was calculated from the roughness profile which was separated from the measured surface profile so that the features at larger scale were not taken into account for the roughness. However, the approach used in this separation procedure is not clear, in particular that to what scale should features that contribute to the roughness be considered, and it may influence the roughness measured. Most research has been performed on engineered surfaces, but when applied to natural sand surfaces which are complex and mostly curved in nature, more uncertainties arise. In this paper, an alternative method is proposed which characterizes roughness with the aid of the power spectrum of the whole surface profile of sand particles. Results from natural quartzitic sand (Leighton Buzzard sand) tested using a high-resolution optical interferometer are presented. Fractal analysis was involved in the characterization. It was found that the sand roughness could be adequately characterized by the power spectrum and the fractal dimension calculated from a cut-off length scale that was inferred from surface area estimation

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Keywords: roughness; sand; power spectrum; fractal; interferometer

1. Introduction

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The physics behind contacts between objects are complex and depend on the surface conditions. Because of the practical implications such as wear, friction and heat transfer, a large body of research on surface characterisation and contact mechanics exists, but mostly based on engineered surfaces. The surface of soil grains often comprises small asperities across different scales so that we can consider most grains to be rough. In geotechnical engineering however, despite an increasing interest on the role of surface roughness on soil behaviour [1-3], characterising surface roughness is still empirical, with not-well-defined methodologies or using simplistic parameters that might not represent all the features of the roughness or lack objectivity. One of the main issues with characterising surface texture is determining the scale of the roughness so as to separate it from the overall form of the grain e.g. its shape. While there is a significant amount of research on the latter (e.g. [4,5]), studies on the roughness of real soil grains is rare. Here, we propose an alternative, objective method to analyse surface data.

2. Experiments

2.1. Material

Particles of Leighton Buzzard sand (LBS), a natural silica sand consisting of strong particles were tested. Grains of 1.18-2 mm diameter were selected, paying attention to select those of quarzitic mineralogy from visual inspection. A dynamic image analyser was used to determine their shape: the grains had an average sphericity (ratio of projected perimeter to that of the circle of similar area), of about 0.9 and convexity (ratio of projected area to that of the convex Hull area), of about 1.0.

2.2. Testing equipment and procedure

The roughness measurements were made with a Fogale Nanotech optical microscope equipped with white light interferometry. The surface topography is described by an interferogram that is a function of the sample height at discrete points. The interferometer has a lateral resolution of 0.184 μm (spacing of discrete points in the plane of x and y perpendicular to the plane of surface heights) and vertical resolution of around 3 nm for white light measurements.

All the surface measurements were made using a sub-section of the grain surface ("field of view") of dimensions 106.6 μm × 106.6 μm corresponding to 578 × 578 discrete points. This was larger than what has been used by previous researchers [6,7] but it was found that smaller sizes of the field of view lead to larger standard deviations [7]. The low reflectivity of the quartz meant that obtaining good measurements was laborious. A particular difficulty with soil grains is that many points of the irregular surfaces cannot be measured, which are then shown on the resulting graph as fail-to-detect points or invalid pixels. The areas measured were chosen so that invalid pixels in the observed areas were less than 1%, ensuring that removals of these points by interpolation of adjacent heights data had a negligible effect. Then the surface heights data for the 578×578 points were exported for analysis.

3. Results and discussions

3.1. Comparison of roughness determined using the motif method and by power spectral density

The measured surfaces are usually not flat and the curvature needs to be removed to examine how rough the surface is. Fig. 1 shows an example of the procedure frequently adopted with the aid of the software integrated within the optical microscope. The roughness morphology is separated from the whole measurements by assuming a motif, which describes the local curvature of the particle where the measurements are taken. A default value of the motif is generally used, which varies with the size of field view: for a small area of 20 μm x 20 μm it is 5.02 μm, and for 106.6 μm x 106.6 μm as used here it is 26.7 μm. There is no study available on the effect of the motif selection on soil grain roughness, but not knowing the scale of asperity at which roughness was separated may diminish further application of the data.