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# The Development of comparison, evolution, and correlation between 2D and 3D studies of morphological parameters of sand particles through image-based analysis of X-Ray CT data of sand particles

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**Abstract**

In geotechnical engineering, it is critical to understand the engineering properties of granular soils. Predicting the engineering behavior of granular particles requires an understanding of their morphological characteristics. The analysis of morphological parameters of a granular particle e.g. sand particles must be carried out with the required degree of precision. As a result, image-based analysis is very effective in determining the intended outcome. This research is aimed at the image-based analysis of granular particles to develop an algorithm for the methodology and computation of morphological properties. The study was conducted on Red bluff sand particles that had been subjected to incremental one-dimensional compressive stresses. The sand particles were noticed to be compacted with the evolution of compressive stresses. The image has been segmented with the marker-based watershed approach. The morphological parameters selected for this study e.g., aspect Ratio, elongation, feret Shape, mean dimension, and shape factor have been analyzed both in two-dimensional and three-dimensional approaches. The comparison and evolution of both approaches for each parameter have been presented for the further prediction of the engineering property of the granular materials. The significant outcome is the development of the relationship between 2D and 3D studies of the morphological parameters.

***Keywords:*** *Granular soils; image-based analysis; morphological parameters; evolution; comparison.*

## 1 Introduction

### 1.1 Background and Motivation

The mechanical properties e.g. the stiffness, shear strength, and dilatancy of sands or granular materials are strongly reliant on the morphological parameters of the particles such as particle size and shape properties. (F. N. Altuhafi & Coop, 2011) (Cho et al., 2006)(Guo & Zhao, 2013) The sand response is determined by the morphology of the sand particle. Sphericity, roundness, and smoothness are all terms used to describe various scales relating to particle shape. For practical reasons, the morphological properties of 3D particles are often studied using projected 2D images. This emphasizes the need of establishing the correlations between the two-dimensional and three-dimensional particle descriptors. The quantitative study of sand particles can be conducted by image-based analysis of X-Ray CT data of those sand particles. (Su & Yan, 2020)(F. Altuhafi et al., 2013)(Yan & Su, 2018)

### 1.2 Research Objectives and Overviews

The objectives of this research project are to create a particle-level analysis using image processing algorithms (marker-controlled watershed algorithm), to compare 2D and 3D morphological parameter analyses of granular particles, and to comprehend how certain parameters, such as aspect ratio, elongation, feret shape, mean dimension, and shape factor, change in response to incremental stresses.

## 2 Materials and Methodology

### 2.1 Background Study

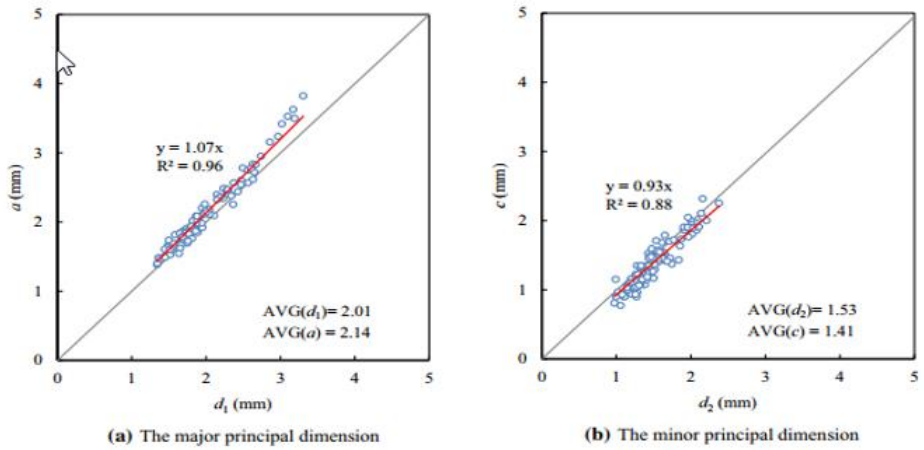



Figure 1. Background study and motivation for the development of correlation between 2D and 3D parameters (Su & Yan, 2020)

### 2.2 Methodology

The image processing of X-Ray CT data of sand particles was the focus of this study. In this study, the X-Ray CT data of RBS (Red Bluff Sand) particles subjected to increasing stresses of 0, 8, 16, 32, and 64 MPa were used [6]. In the beginning, the sand data were carefully cropped along several (XY, YZ, and ZX) planes to ensure that the cuboid region of interest (ROI) was chosen correctly. This was done to ensure that only the sand particle area enclosed by the CFRP cylinder was selected. Then, non-local means filtering was applied to the cropped image of the sand. The cropped and filtered image was then converted into a binary image to identify the sand particles from the voids among them. The binary image of the sand particles was next subjected to marker-controlled watershed segmentation, which was one of the most important steps in image processing. Proper segmentation of the sand particles ensured accurate measurement of morphological parameters. Afterward, the segmented sand particles were labeled to identify each particle. To enhance the accuracy of the analysis, the label image was resampled along the XY, YZ, and ZX planes. After the image processing was done, the morphological parameters were defined, and a largescale database of parameters e.g., aspect ratio, shape factor, and equivalent diameter was extracted from the image processing software to perform the intended analysis through computational software. (ThermoFisher Scientific, 2018)Some equations are as follows:

Equivalent Diameter 2D$= \sqrt{\frac{4 \text{ X Area}}{\pi}}$ Equivalent Diameter 3D$= \sqrt{\frac{6 \text{ X Volume}}{\pi}}$

Shape Factor 2D $= \frac{\text{Crofton Perimeter}^2}{4\pi \text{ X Area}}$ Shape Factor 3D $= \frac{\text{Area 3D}^3}{36 \text{ X } \pi \text{ X Volume 3D}^2}$

Aspect Ratio 2D $= \frac{\text{Minor principal dimension}}{\text{Major Principal Dimension}}$ Aspect Ratio 3D $= \frac{\text{Elongation index+Flatness index}}{2}$ (Su & Yan, 2020)

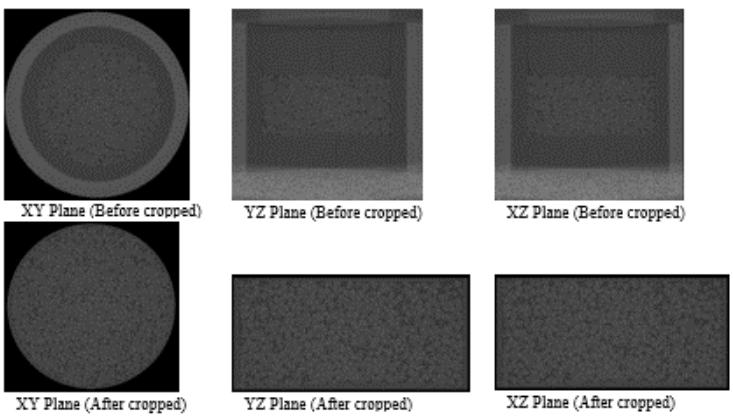



Figure 2. Cylindrical cropping of the greyscale image of RBS particles (all planes are included)

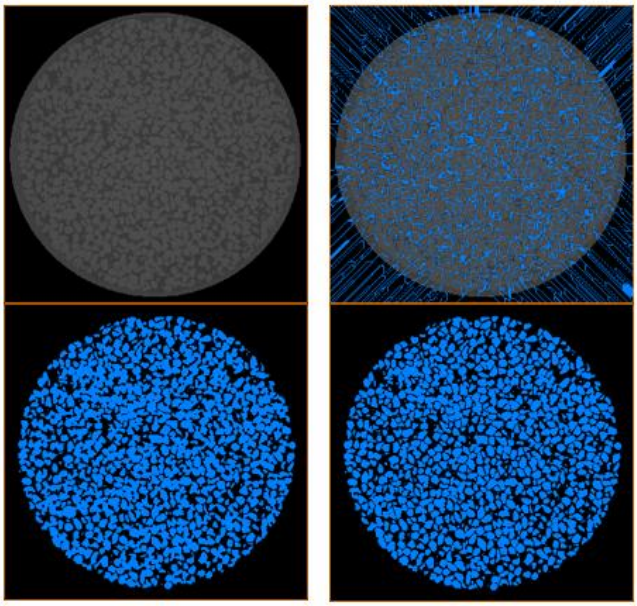


Figure 3. Marker-controlled watershed segmentation approach

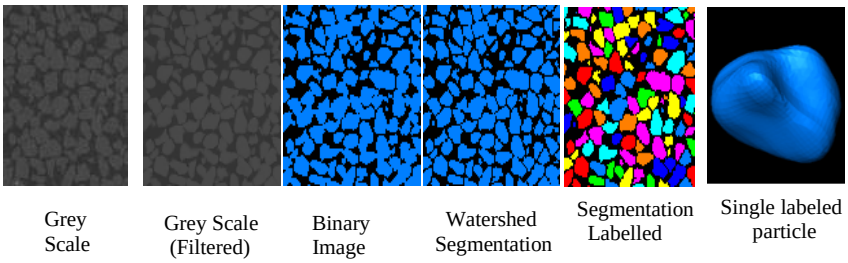



Figure 4. Overview of the image processing steps conducted

### 2.3 Algorithm of the image processing

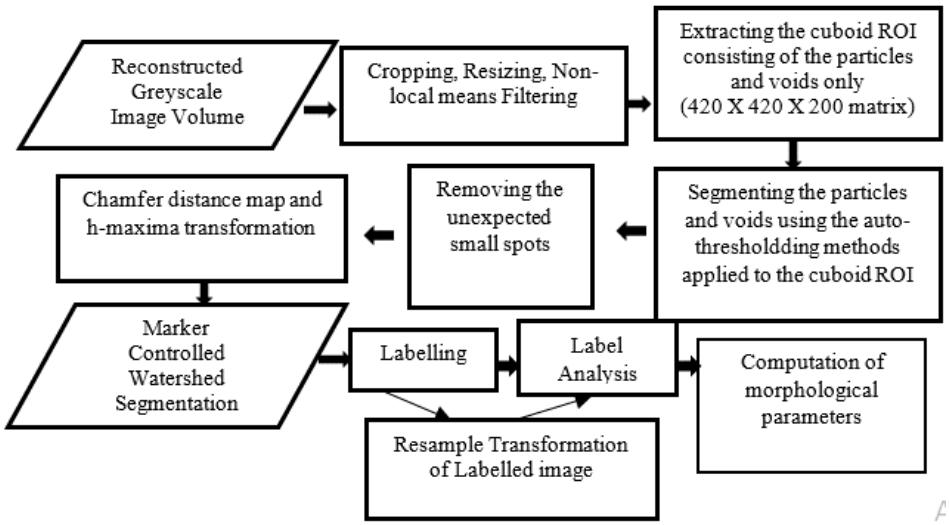
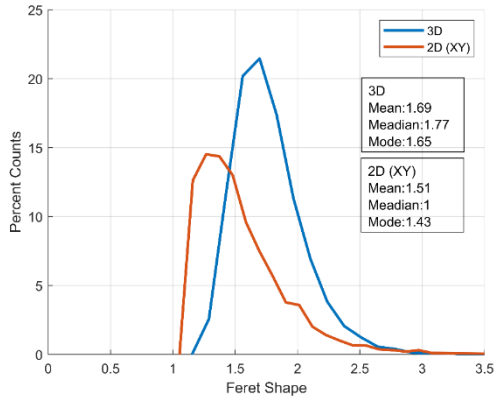



Figure 5. Marker Controlled Watershed Algorithm of Image Processing

## 3 Results and Discussion

### 3.1 Comparison of 2D and 3D parameters




An important morphological property of RBS particles is the Feret Shape 3D parameter, which results in a greater peak value than the Feret Shape 2D (XY) parameter because 3D produces a greater percent count than 2D. (XY). The 3D parameter returns a peak value that has been moved to the right. The 3D parameters' mean, median, and mode values are 1.69, 1.77, and 1.65 respectively. The mean, median and mode values of the three-dimensional Feret Shape are higher than those of two-dimensional (Along XY-Plane) values.

Figure 6. Comparison of 2D and 3D morphological parameters

### 3.2 Evolution of Morphological Parameters at incremental stresses

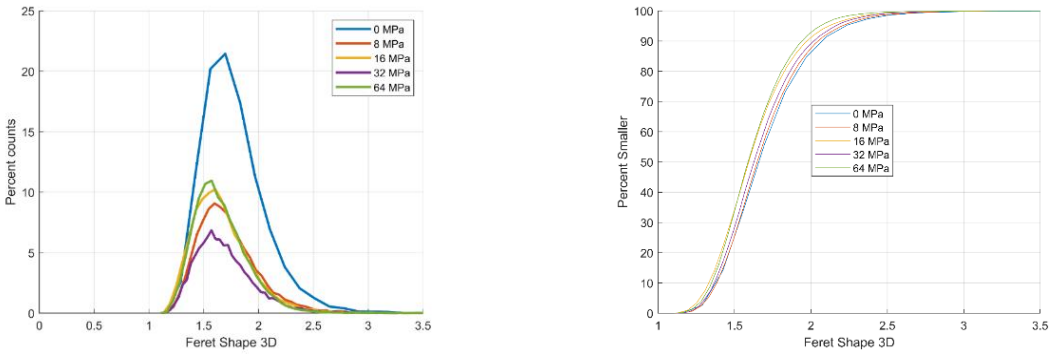



Figure 7. Evolution of 3D Morphological parameters (left) and cumulative percent curve (right)

For the case of the three-dimensional Feret Shape parameter, the evolution sequence is obtained for highly acceptable outcomes under progressive stresses. As the particle crushes at about 16 MPa compressive stress, the 32 MPa curve falls below the 8 MPa curve. The cumulative percent curves also support the proper sequence of evolution.

### 3.3 Regression curve of 2D and 3D Morphological Parameters at incremental stresses

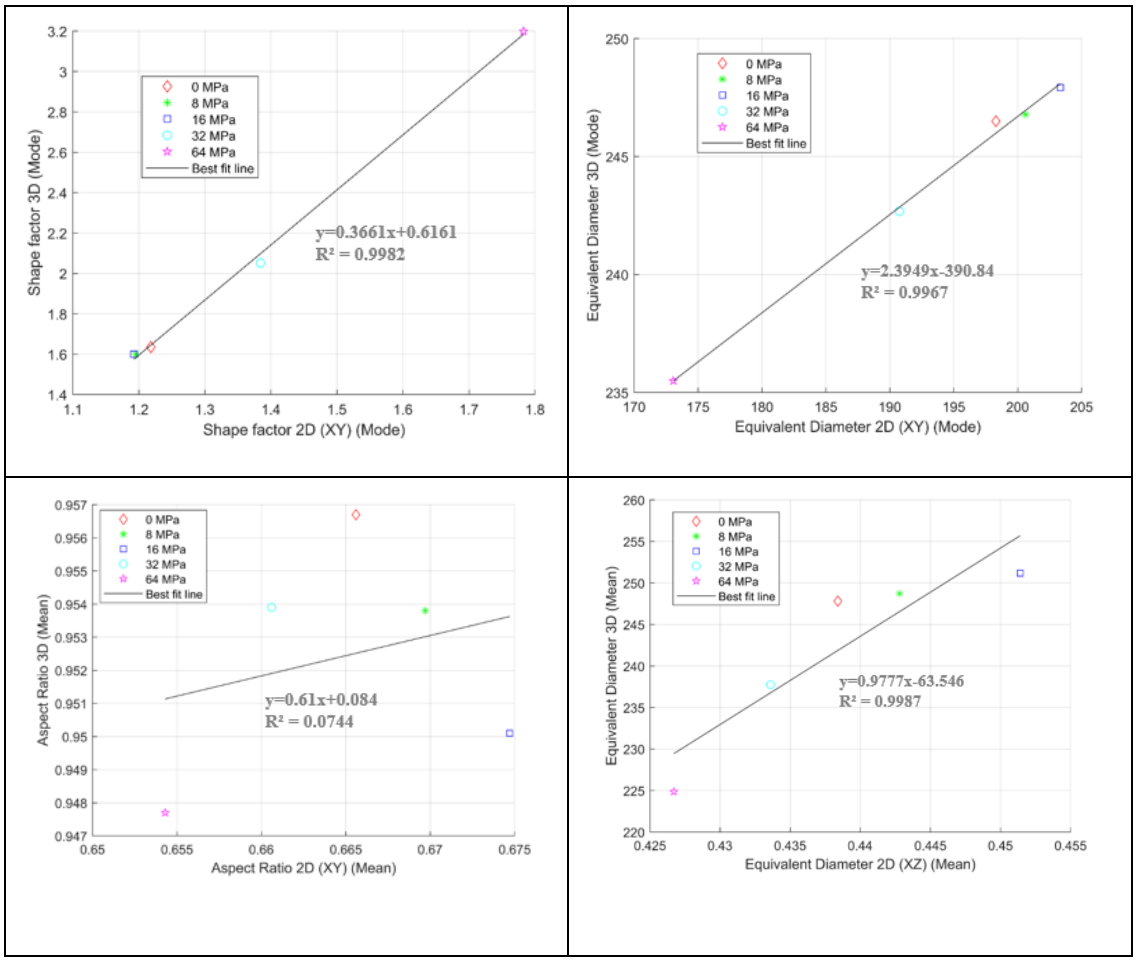



Figure 8. Regression curves of 2D and 3D studies of morphological parameters at incremental stresses

## 4 Conclusion

The outcome of this research is the correlation developed between the 2D and 3D morphological parameters of sand particles. Furthermore, the comparison between 2D and 3D parameters and the evolution of the morphological characteristics of sand particles under incremental stresses (0, 8,16,32,64 MPa) were also studied. To understand the evolution it should be kept in mind that the very first indication of yielding in sands is the beginning of particle breakage under compression. Although particle breakage is closely related to the tensile strength of a single soil grain, the initial density and grading of the initial sample have a significant effect on the likelihood of particle fracture. (F. N. Altuhafi & Coop, 2011) It is widely known that particle shape is a critical element affecting both the responsiveness and packing density of granular materials. Usually, evaluation of the shape of particles by analyzing two-dimensional images of the particles helps to study the desired behavior. (Cavarretta et al., 2009) As a result, the morphological parameters are selected in this research work for understanding the engineering property of the granular materials. The comparison will depict the deviation of morphological property and help to observe the desired accuracy of strength or other engineering properties of sands.(Budhu, 2010; Shen et al., 2019) (Li & Iskander, 2021)(Jiménez-Herrera et al., 2018).

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