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# *INTERPRETATION OF GEOPHYSICAL MEASUREMENTS USING X-RAY TOMOGRAPHY OF SAND SAMPLES*

Sara Johansson*[1], Erika Tudisco[2], Matteo Rossi[1] & Stephen Hall[3]

[1]Engineering Geology, Lund University, Sweden
[2]Geotechnical Engineering, Lund University, Sweden
[3]Solid Mechanics, Lund University, Sweden

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**Summary:** Geophysical measurements on sand samples were combined with X-ray tomography. The reconstructed images were segmented and image analysis were used to calculate different properties of the grains as well bulk properties relevant to interpret the geophysical data.

## 1. INTRODUCTION

The geophysical method spectral induced polarization (SIP) is based on the principle of injecting alternating currents through electrodes installed in the ground while measuring the amplitude- and phase shifts in different potential electrode pairs along the ground surface. The induced polarization effect can be described as a charge-up effect that varies with different micro geometrical characteristics of subsurface materials. To understand the SIP mechanisms of geological materials, a lot of research has focused on laboratory SIP measurements on homogeneous sand samples [1]–[3]. In this study, SIP measurements on two different sand samples were combined with X-ray tomography. The reconstructed images were segmented and image analysis were used to calculate different properties of the grains as well bulk properties relevant to interpret the SIP spectra. This is the first known combination of the two methods. One main advantage with the use of X-ray tomography is that the conditions of the present sample can be studied in detail. With this approach, relevant material properties can be calculated from the same sample as the SIP spectra is measured on and sampling uncertainties can therefore be avoided.

## 2. EXPERIMENTAL METHOD

The sample holder geometry follows the general recommendations for SIP measurements, consisting of a glass cylinder with four electrodes. The sample holders were packed with two types of water saturated sand samples; a clean silica standard sand with a main grain size of 210µm as well as a 250-355µm sand fraction that was sieved from a medium sand with a broader grain size distribution.

The SIP measurements were performed with a ZWL-SIP04 impedance meter in the frequency range 0.01-1000Hz. After the SIP measurements, the samples were scanned with X-ray transmission tomography at the X-ray tomograph (Zeiss Xradia XRM520) laboratory at Lund University. The tube potential 100kV, power 9W and exposure time 6s was used for the imaging. The entire cross section of the sample holder (diameter 2.4cm) was imaged over a height of 4cm with a pixel size of 13um and 1601 projections. A LES filter was used and the data was reconstructed with the Zeiss Scout- and scan Control system reconstructor. The reconstructed images were filtered in Matlab with a Wiener filter which removed some noise. After the filtering, each image was transformed to binary images with the histogram based threshold method. 3D segmentations of individual objects in the images were then performed (Matlab function watershed). Figure 1a-c illustrate the segmentation process. Calculation of various grain properties were performed with the Matlab function regionprops. The sample porosity was calculated from difference between the summarized volumes of all grains normalized by the total imaged volume.

One of the material properties that is considered to be most important for SIP spectra is the specific surface area in relation to pore volume ($S_{por}$). The specific surface area in relation to pore volume is usually calculated as $S_{por} = S_m \cdot \rho_d \cdot (1-\phi)/\phi$ where $S_m$ is the specific surface area ($m^2/g$) of sample (usually measured with the

* e-mail: sara.johansson@tg.lth.se

nitrogen BET method) and $\rho_d$ is the particle density (kg/m$^3$) and $\phi$ is the porosity [2]. Here, the surface area was calculated per unit volume instead of per unit mass. There was therefore no need to know the particle density of our samples (kg/m3) in our calculations of $S_{por}$.

## 3. RESULTS

Figure 1d shows the SIP spectra of the two different sands, while figure 1e-f shows the calculated grain size and grain volume distributions. The calculated porosity, $S_{por}$ and proportions of high density grains were 37%, 9.5 µm$^{-1}$ and 1.1% for the coarser sand fraction. For the finer sand fraction, the corresponding values were 36%, 13.7 µm$^{-1}$ and 0.07%. The porosity values calculated from the images are close to the values calculated from the measurements with a lab scale during the preparation of the samples (34-35%). The calculated $S_{por}$ values are in the same order of magnitude as values obtained for sands with the nitrogen BET method in previous research (e.g. values of 2-9 µm$^{-1}$, see [1], [3]). Our calculated $S_{por}$ values can however also be slightly overestimated due to a slight overestimation of the sample porosity and oversegmentation of some grains leading to an overestimation of the surface areas. One advantage of using X-ray tomography to calculate $S_{por}$ is that knowledge/approximation of the particle density of the sand grains is not needed. In many sands, the mineral composition and mineral densities of grains can vary. There are therefore uncertainties also in the traditional way of calculating $S_{por}$.

It can be seen in figure 1d that the coarser sand gives a higher SIP response compared to the finer sand. This is an unexpected result since finer grain sizes generally are expected to give higher SIP responses due to higher $S_{por}$ values [1]. We therefore draw the conclusion that the higher SIP values probably can be related to the differing mineralogy of both sands.

To conclude, there is a great potential of using X-ray tomography to investigate the SIP spectra of geological materials. Besides calculating micro geometrical properties, the data can be for example be used to create a mesh of the pore space. This mesh could be used to increase the understanding of the SIP mechanisms though modelling, and the use of X-ray tomography can therefore potentially also be used to extend the understanding of SIP spectra to inhomogeneous and anisotropic samples and materials.

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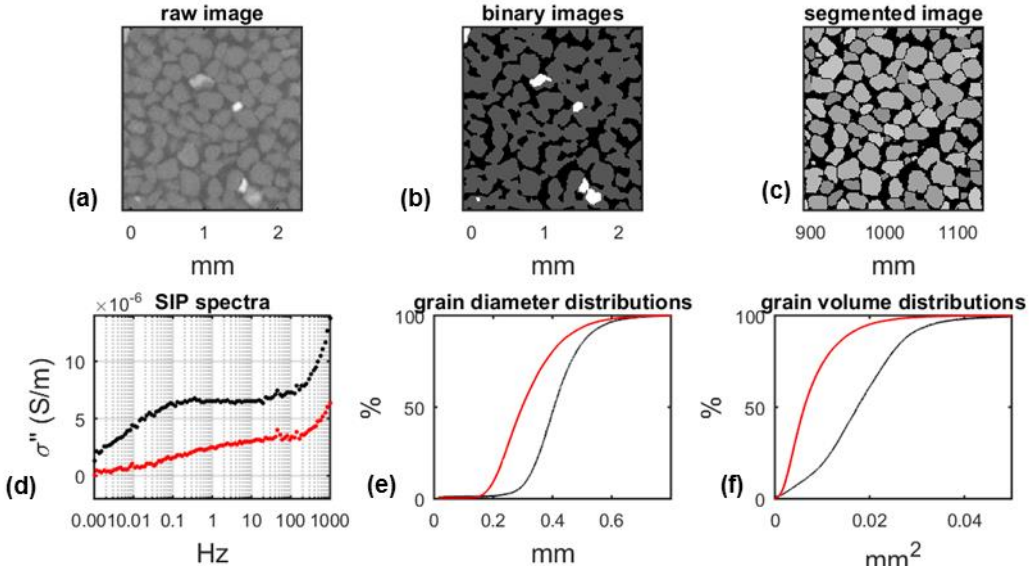


**Figure 1:** (a-c) Segmentation process. (d) SIP data, black: 250-355µm sand, red: 210µm sand. (e-f) Calculated sample properties.