NON-DESTRUCTIVE SOIL TESTING USING X-RAY COMPUTED TOMOGRAPHY

A report to the
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by

Brent Daniel Nielsen
Master in Science in Civil Engineering

and

Dr. Robert L. Mokwa
Assistant Professor
Department of Civil Engineering

Montana State University
Bozeman, Montana

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Chapter 1

Introduction

The research described in this thesis is part of a larger project funded by the Western Transportation Institute to investigate the frost heave phenomenon in soils. This study involved the use of x-ray computed tomography (CT) scanning techniques to measure the microstructure of soil, including porosity, particle properties, and void space properties.

This research had two main objectives. The first was to configure the Montana State University Civil Engineering Department's computer-aided tomography scanner to perform CT scans on soil samples. The second objective was to use the CT scanner to develop non-destructive test procedures to determine geotechnical index properties of soils. Test methods were developed in this study to determine porosity, grain size distribution, and pore size distribution.

The mechanical behavior of granular soils is highly dependent upon the soil microstructure. Soil microstructure includes the shape, distribution, and arrangement of particles and void space within a soil. Historically, micro properties of soil have been difficult to measure, so geotechnical engineers commonly use soil macroscopic properties to estimate soil behavior. In the past, the observation and measurement of soil microstructure has been a time consuming and destructive process. Traditional methods to measure soil microstructure involve impregnating soil specimens with a hardening agent such as resin or Wood's metal that replaces air and water in the soil's void space. Once the specimen is cooled and hardened, it is cut into thin coupons and polished. These thin slices are then measured with image analysis techniques (Jang 1999). This procedure is extremely time consuming and may alter the microstructure of the soil – the actual properties being measured.

X-Ray CT scanning has been shown to be useful for measuring soil microstructure (Phillips 1997, Alshibli 2000). An x-ray image is a picture of the x-ray linear attenuation coefficient of an object, which is related to the density of an object (Phillips 1997). A material with high density will attenuate more x-rays than will a low-density material; therefore, two materials of different densities will appear differently in an x-ray image. The digital image created during the x-ray CT process provides an internal cross-section, in which different materials can be distinguished. The field of CT scanning in geotechnical engineering is in its infancy, but it is showing growth as the technology continues to develop and its use is encouraged. Over the last decade, researchers have experimented with the use of x-ray CT scanning technologies to measure physical density, void ratio, and soil aggregate size distribution (Phillips 1997, Alshibli 2000, Tollner 1998).

The advantages of x-ray CT scanning include time savings and minimal sample disturbance. Tollner (1998) noted that x-ray CT scanning can provide aggregate size data consistent with traditional testing methods but without the time-consuming sample preparations involved with traditional tests. In particular, CT scan testing provides significant savings in time and effort when compared to sample coupon preparation techniques. The non-destructive nature of CT scanning allows the same soil sample to be scanned many different times. Since the sample is not affected by the testing, CT scanning provides an opportunity to investigate particle and pore interactions at any time and location within the sample. With the proper test equipment, CT scans could even be taken as a sample is loaded or experiencing changes in stress state or environment.

The research described in this thesis was designed to develop non-destructive soil testing methods using x-ray CT scan techniques. The first objective of the research was to perform high quality CT scans on soil samples using the Montana State University Civil Engineering Department’s custom-built CT scanner. The scanner was originally purchased to study snow and ice formations, and experiments indicated that the scanner had the capability to produce high quality CT scans of granular soil samples. The second objective of this research was to develop testing methods to determine geotechnical index properties from the CT scan images of the soil materials. The methods developed in this research would draw from established image processing techniques and mathematical morphology topics.

The soil index properties determined from CT scans in this research include porosity, grain size distribution, and pore size distribution. The results from the CT testing techniques were compared with results from traditional geotechnical laboratory tests. Results from the porosity and grain size distribution tests were used to validate the CT scan testing methods, since the mechanical laboratory tests to determine these index properties are simple and straightforward. Traditional geotechnical test methods for determining pore size distribution in soils are typically difficult to perform and require significant time and effort. However, it is recognized that pore size and pore size distribution are directly and fundamentally related to the three most important engineering characteristics of soils: permeability, compressibility, and strength. Therefore, the pore size distribution CT testing methods developed in this study are of particular interest to researchers and practitioners.

The CT testing techniques developed in this research may be used in future studies to measure the effects of microstructure properties on freezing behavior of soils. In particular, CT testing may be utilized to easily and non-destructively measure pore structure parameters such as porosity and pore size distribution and how those structures behave under freezing conditions. Frost heave behavior in soils has been shown to be related to pore size distribution; however, pore size distribution has historically been difficult to measure experimentally (Gaskin 1973). The CT testing methods developed in this research may provide simpler and more non-destructive means to measuring pore size distributions than current experimental techniques.