X-RAY MICROCOMPUTED TOMOGRAPHY (μCT) BASED METHODOLOGY TO INVESTIGATE THE EFFECTS OF FLOW IN GRANULAR MEDIA

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Summary: Winter stormwater in cold regions has a high concentration of sodium chloride, a typical deicing salt. Its flow through filter media results in faster reduction of infiltration rate and more pollution of water bodies. This topic is being studied using x-ray microcomputed tomography (μCT), by scanning the samples before and after flow. The effects of flow are investigated using μCT data, image processing, and computer simulations using coupled DEM-CFD.

1. INTRODUCTION

Understanding the effects of flow in granular media is important to improve the performance of such materials used in several fields. The effects include change in hydraulic conductivity and pore water pressure, internal migration and/or washout of particles, clogging or enlargement of pore structures, and ion-exchange causing pollutant release and/or entrapment. Due to the extremely complex physical features of granular media (particle shape, size distribution, etc.) and even more complex pore structure, traditional research of these topics was limited to external observations of the samples in flow tests (flow rate, turbidity, ionic concentration, etc.).

Application of deicing salt is necessary to prevent skidding on highways and even driveways. As sodium chloride (NaCl) is the most economical and easily available deicing salt, winter stormwater contains a high concentration of NaCl. In the United States, the stormwater is treated on site in the detention ponds where stormwater filter media (SFM) shall entrap pollutants, so that statutory requirements of the USEPA Clean Water Act can be met with by the city governments. Research indicates that NaCl concentration in stormwater results in faster clogging of SFM, in addition to adverse release of pollutants to downstream [1], [2], [3], [4]. This abstract describes our x-ray μCT based research on the effects of "NaCl-laden stormwater flow" in SFM. As external observations in flow tests were not sufficient to understand the clogging of and pollutant-release from SFM, a prior study by this author used the mercury intrusion porosimetry (MIP) to estimate the pore size distribution of SFM, before and after conducting flow tests [5]. Considering the several advantages of x-ray μCT over MIP, the current research by this author utilizes x-ray μCT to estimate the internal structure of SFM, pre- and post-flow, to make the internal structure thus obtained to understand the clogging of and pollutant-release from SFM.

2. RESEARCH METHODOLOGY

The experiments are being conducted with soils and soil-compost mixtures. The particle size distribution (PSD) is controlled by sieving a large batch of materials into small ranges of different sizes, and mixing them in fixed proportions to make up each sample, so that PSD is consistent between the samples. All samples are compacted into polycarbonate tubes measuring 20 mm internal diameter and 20 mm high. They are compacted at a water content of 10% to achieve a dry mass density of 1.5 g/cm^3 (+/- 3% variation) by following a consistent compaction method. The samples are dried and scanned (before the flow tests) to a resolution of 15 μm using a SkyScan 1173 μCT system. Flow tests are conducted on the scanned samples using a flow cell that accommodates a sample, and a tank that maintains water supply at a constant-head difference. The flow tests are conducted, measuring the flow rate at regular intervals and testing the effluent for water-quality parameters, until the flow rate reduces to an asymptotic minimum or about 5000 pore volumes. The flow tests are conducted at two different hydraulic gradients (constant-head difference per unit sample length), NaCl concentrations of 0 mg/l, 150 mg/l, and 600 mg/l), on triplicates of samples. After the flow tests, the samples are dried and scanned to the same resolution of 15 μm using the same SkyScan 1173 μCT system.

Proper understanding of the SFM deterioration mechanism can only be developed by treating the SFM as a collection of discrete particles and quantifying the hydrodynamic conditions. Discrete element method (DEM) and the computational fluid dynamics (CFD) have developed in the last few decades owing to rapid growth in the parallel computing power and algorithms. A few recent studies have outlined the methods to couple the DEM and CFD to understand the effects of flow in granular media [6], [7], [8]. In this study, we are using the set of images obtained from the analysis by µCT system to reanalyze by Avizo Fire and to construct the internal structure of the samples, pre- and post-flow. This is being done to conduct two-way coupled DEM-CFD simulations using the Particle Flow Code (PFC) as DEM and Ansys Fluent as CFD. The two-way coupling enables mutual sharing of the results between these two software programs, for each small time step, paving the way to better understand the mechanisms that cause clogging of and pollutant-release from SFM.

3. RESULTS

The flow test results include the change of flow rate and water-quality with time. The µCT and Avizo Fire results include the pre- and post-flow (1) porosity distribution in the vertical (flow) direction, (2) pore size distribution in the whole sample, and (3) sizes and 3D positions of analyzed individual objects. The last one is being used to construct the internal structure of the samples, pre- and post-flow, for conducting the two-way coupled DEM-CFD simulations. The results of these simulations are currently being analyzed to draw conclusions.

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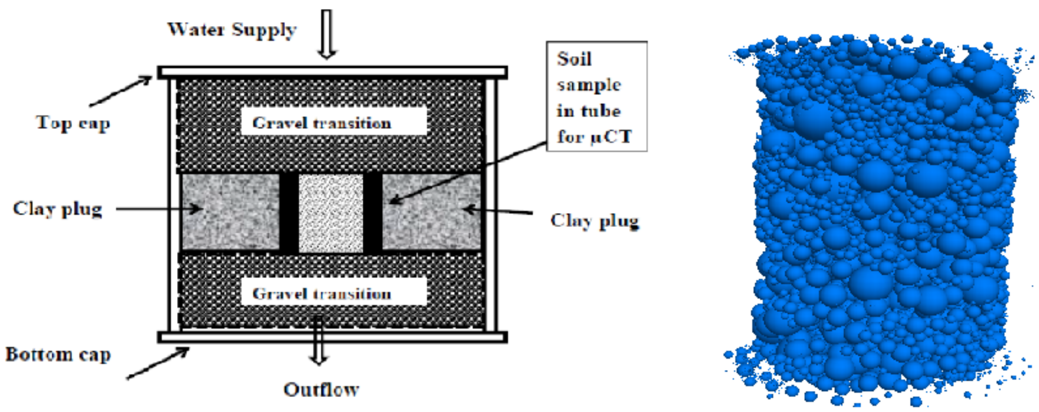

(a) (b)

Figure 1: (a) Schematic of the flow cell accommodating sample in a polycarbonate tube
(b) Reconstruction of a sample using µCT images and Avizo Fire.