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X-RAY IMAGE ANALYSIS OF POROSITY OF PERVIOUS CONCRETES

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ABSTRACT: The use of permeable pavement is one of the most promising tools to control runoff and water quality, therefore enabling low impact development (LID), along with several other benefits. The porosity of the permeable pavement is the most important property of the pavement in current state of the practice. In this article, the porosity of a pervious concrete sample made in laboratory was evaluated by two approaches: measuring weights and X-ray image analysis. Two different X-ray imaging apparatus, 2D and 3D, were used to construct cross-sectional planar images of a cylindrical pervious concrete sample. It was found that the porosity estimate from 2D X-ray was close to the results with measuring weights, but that of 3D X-ray was rather larger under X-ray imaging configuration and image analysis technique used. The viability of using X-ray images to evaluate the pore characteristics of permeable pavement, and future applications are discussed.

Keywords: Porosity, Pervious Concrete, Permeable Pavement, Green Infrastructure, Low Impact Development

1. INTRODUCTION

In urban area, many traffic infrastructures such as highways, parking lots, sidewalks, and small roads (say, for bike) are paved. During urbanization, therefore, natural permeable green and soil surfaces are replaced by pavements, which traditionally designed to be impermeable. Development with impermeable surfaces adversely affects the stormwater management and increases the runoff in urban area. Permeable pavement systems are one of the most promising techniques to control runoff and water quality. In addition, permeable pavements have other benefits such as skid resistance, water quality control, noise control, and surface temperature reduction.

The concept of pervious pavement is, though, not very new but some of early pervious pavements have been a couple of decades. There are some but no unified design guides available (NRMCA, 2004; Paul et al., 2004; John et al., 2009; ACI, 2008; ACI, 2010). In current state of the practice, the most important property of pavement material is the porosity, the ratio of the volume of internal pore to the gross (total) volume of pavement.

Montes et al. (2005) used the submerged weight of the pervious concrete for porosity estimation, and Neithalath et al. (2006) the difference of saturated and drained weights of the concrete. There are also studies that utilize the X-ray image to identify the pore in pervious materials such as concrete, asphalt, and geotechnical materials (Jung et al., 2011; Kim et al., 2012; Kang et al., 2012).

This paper presents the procedure and results on the estimation of the porosity of a laboratory pervious concrete sample using X-ray images.

2. PERVIOUS CONCRETE

A pervious concrete sample was made, in laboratory, to be 4.8-cm wide and 8.5-cm deep as shown in Fig. 1. The crushed stone was used for aggregates of the concrete sample. The crashed stone was screened and only the particles in 1.18 ~ 2 mm range has been selected. Aggregates were washed 3 times with water before mixing. Portaland cement was used as a binding material, and the mixture proportion is shown in Table 1.

Fig. 1 Laboratory pervious concrete sample

Montes et al. (2005) used the submerged weight of the pervious concrete for the porosity estimation. In this paper, the porosity estimation was made following the work of Montes et al. (2005) and Ahn et al. (2013). The porosity P of pervious concrete can be estimated based on the following equation:

$$P = 1 - \frac{\frac{(W_D - W_S)}{\gamma_w}}{V_T} \quad (1)$$

where W_D and W_S are the dry and submerged weights of the sample, V_T is the total volume of the sample and γ_w is the unit weight of water.

Table 1 Mixture proportion

Material	Weight per volume (kg/m^3)	Content (%)
Aggregate	1,590	70.7
Cement	477	21.2
Water	183	8.13
Total	2,250	100.0

The submerged weight of the pervious concrete sample was measured by using the electronic scale with a wired mesh basket attached, shown in Fig. 2. The sample was saturated more than 3 hours submerged under water to measure W_S with slight impacts applied to the sample for every 30 minutes to accelerated saturation (Ahn et al., 2013). For the measurement of W_D , the saturated sample was drained in the air for 24 hours and assumed that the sample is in saturated-surface-dry condition. The 3-hr saturated and 24-hr air-drained weights were 147.47g and 247.69g, respectively. Given the volume of the sample 153.81 cm^3, the porosity was calculated to be 34.8% based on Eq. (1). Details and validations of this procedure can be found in Ahn et al. (2013).

Fig. 2 Measurement of submerged weights

3. X-RAY IMAGE ANALYSIS

X-ray CT is a powerful tool to investigate inside the sample of a porous material and analyze the pore characteristics. Pusan National University has three X-ray machines with different specifications. In this study, two X-ray apparatus (one 2D and one 3D) with the specifications in Tables 2 and 3 were used to get the images of the pervious concrete sample. Using the 2D X-ray, 30-mm length along the longitudinal direction of the concrete sample was selected around the mid-point of the cylinder, and X-rayed with 0.5-mm increments, therefore resulting in total 61 circular cross-sectional images. With the 3D X-ray, the projection of whole sample was taken with 2° increments in tangential (circular) direction of the cylinder, therefore making 180 projections when fully rotated.

Table 2 Specifications of 2D X-ray equipment

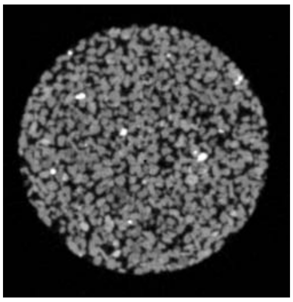
Item	Description
Manufacturer	X-Tek
Model number	VENLO450-ACTIS
X-ray tube voltage	450 kV
X-ray tube current	4.8mA

Table 3 Specifications of 3D X-ray equipment

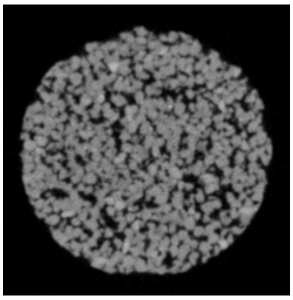
Item	Description
Manufacturer	X-Tek
Model number	HMK CT – 225
X-ray tube voltage	225Kv
X-ray tube current	1.0mA

Based on the results of X-rays, planar images were constituted using a software VGStudio MAX (VGStudio MAX, 2004). Fig. 3 presents the planar images from 2D and 3D X-rays. It was found that the image from 3D X-ray was not clear but burred with more noise than that of 2D X-ray.

For image processing and estimation of the porosity, the image inside the sample was first cropped. Given cross-sectional images from X-rays were 16-bit grayscale, which means that 2^{16} = 65536 gray levels can be used to represent different shades of gray from black (gray level = 0) to white (gray level = 65535). To distinguish the pore (dark) from the solid (bright), the cropped images were converted to purely black and white images by determining the limit of black and white based on the Otsu's method (Otsu, 1979) implemented in MATLAB Image Processing Toolbox (MathWorks, 2011). Based on black and white images exampled in Fig. 4, the numbers of black and white pixels were counted; the number of black pixels over the total pixels makes the porosity.

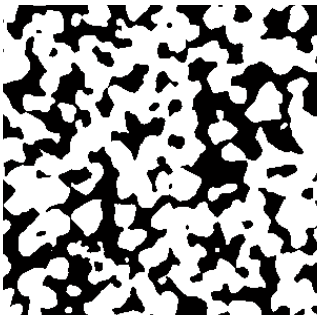


(a) 2D X-ray

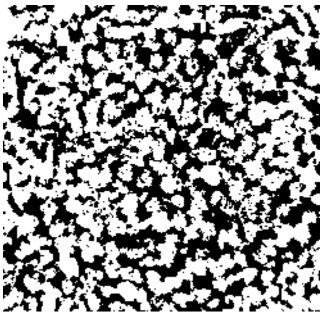


(b) 3D X-ray

Fig. 3 Planar images from 2D and 3D X-rays



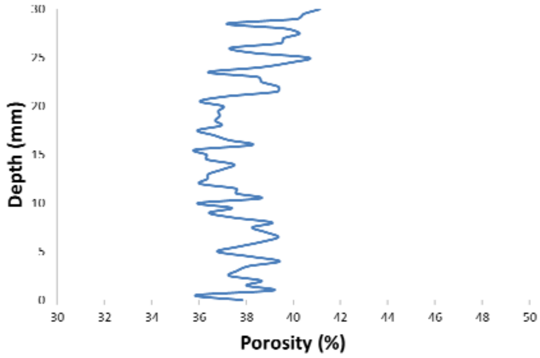
(a) 2D X-ray



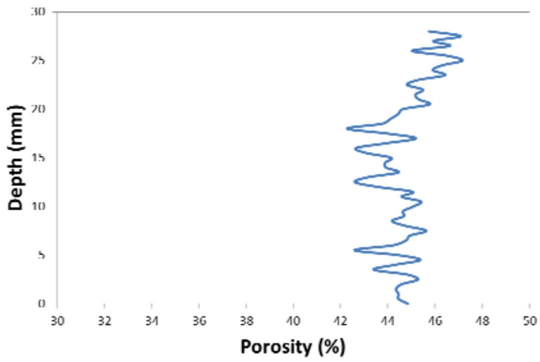
(b) 3D X-ray

Fig. 4 Black and white images from 2D and 3D X-rays

The results of porosity estimates are presented in Fig. 5 with respect to the depth of the sample. The results of 2D X-ray in Fig. 5(a) is from 61 planar images taken over 30-mm length with 0.5-mm increments. The results of 3D X-ray in Fig. 5(b) were reconstitute images at the same heights where the images of 2D X-ray were taken for comparison purpose. The averages of the porosities from 2D and 3D X-ray equipment were 37.9% and 44.2%, respectively. It is noted that the porosity measured using submerged weight was 34.8%. The results of 2D X-ray is close to the value from weight measurements, but not 3D X-ray, under given X-ray imaging configuration and image analysis (Otsu, 1979) described.



(a) 2D X-ray



(b) 3D X-ray

Fig. 5 Porosities with depth from 2D and 3D X-rays

4. DISCUSSION

There are several sources to make scatters in the porosity values based on both weight measurement and X-ray image analysis. In evaluating the porosity from Eq. (1), the sample should be completely saturated when the submerged weight is measured. The weight of drained or dried solid sample can also differ corresponding to how it was drained or dried. As of X-ray image analysis, first concern is to take X-ray image of the sample under proper setup, such as adjusting tube voltage and current and use of physical filter, which may determine the quality of the image. Then, proper image processing should be done to filter out noise and scatters, which was conducted by commercial software VGStudio MAX (2004) in this paper. The threshold of black and white, which are void and solid respectively, should be properly made, and Ostu's method (Otsu, 1979) was applied in this study. The fact that the results of Eq. (1) and 2D X-ray image are close may sooth these arguments, but more investigation should be invested to clear out the issues addressed here.

X-ray image analysis will make a useful tool inspecting pore spaces of the pervious pavement; for example, Kayhanian et al. (2012) was able to successfully inspect the degradation of the porosity of the permeable concrete pavement due to clogging.

5. CONCLUSION

The porosity of the pervious concrete material was evaluated by measuring weights and analyzing images from two different X-ray equipment. The results from 2D X-ray was close to that from weight measurements; not the case for 3D X-ray, under given X-ray and analysis conditions.

As sequential study, authors plan to investigate the effect of gradation of aggregate in pervious concrete on the pore shape and hydrologic performance of pervious concrete.

6. ACKNOWLEDGEMENTS

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