Evaluation of Clogging through Scanning of Field Samples

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The aim of this study was to investigate and quantify clogging of porous concrete. Determination of porosity from observation, analysis and processing of images obtained from computed tomography enabled to qualitatively relate porosity characteristics with clogging. Porosity computations, of image slices added up to build the whole volume, of older samples are found to be of less magnitude than that of the new ones. Also observed was samples with high cement paste (mortar) content have reduced porosity i.e. clogged.

Key Words: X-Ray Computed tomography, Porosity, Clogging, Porous Concrete, Segmentation, Image Filtering, Image centering.
1. **Introduction**

Pervious concrete, historically known to start being used in 1852, is gaining increased demands because of its physical ability to drain water fast from roads, parking lots and partly because of governmental legislations for clean water. The engineering properties of pervious concrete could generally be studied in its two phases, fresh and hardened. Fresh pervious concrete is plastic and relatively stiffer than structural concrete and exhibits a slump of around 20 - 50mm. In the hardened phase, density of 1600 - 2000 kg/m³, porosity of about 20%, permeability of 0.2 - 1.2cm/s, compressive strength of 3.5 – 28MPa are the most common engineering properties. In addition, pervious concrete is known for its good resistance against abrasion, sulfate, freezing and thawing. Pervious concrete has wide ranges of applications, parking areas being the main focus of this paper; it can be used in residential roads, alleys, and driveways, sidewalks and pathways, slope stabilization, well linings [6].

The objective of this study is to use a non-destructive computed tomography (CT) scanning and image processing to quantify porosity, compare results for a number of samples from different parking lots and evaluate any possible clogging.

**Materials and Methods**

Prior selecting parking lots for coring, the permeability of 17 pervious parking lots was measured throughout California. Four parking lots were selected with their relative permeability ranging from low to high. Two representative core samples (except parking lot 4) were obtained from each of the four selected parking lots. Sample cores were obtained using a portable coring machine, which drilled 4 inch inner-diameter cores. Because these cores are from parking lots, the typical core depth was between 4 to 6 inches. The method for coring these samples was modified in the following ways to preserve the void pathways while minimizing the removal and introduction of clogging materials. The standard coring method uses water to cool the drill bit in order to keep the drill bit from wearing out quickly. However, using water as cooling method will create slurry that may interfere with the clogging investigation. To prevent this problem, we used
air instead of water to avoid the obvious effects on the void pathways. A photo view of a typical pavement coring within a parking lot is shown in Figure 1. As shown, to reduce the effects on the void pathways, a non permeable paper patch was glued to the pavement surface over the cored area so that the air used to cool the drill bit could not pass through the cored sample, and would pass around the core instead.

![Figure 1. Photo view of a typical parking lot coring operation](image)

These core samples were shipped to the Washington State High-Resolution X-Ray Computed Tomography (WAX-CT) Laboratory for scanning to determine the porosity distribution with depth. The relevant information of core samples is presented in Table 1. As shown, nine core samples were scanned. The first two core samples (QP45-3 and RW 475-3) were obtained from UCPRC Richmond field station laboratory. QP45-3 is a 24mm overlay open graded asphalt concrete on top of 96 mm conventional asphalt concrete pavement. This core was obtained as part of the noise study site located on west bound of highway 80 near Davis. The open graded overlay pavement was built in November 2005 and the core was taken in August, 2006. Therefore, the age of this core sample was 10 months. The second core sample (RW 475-3) is a 60 mm core taken from a big slab compacted by the rolling wheel compactor that was produced in the lab. The aggregate used in slab was Syar Rock (basalt) and the binder was PG64-16. This core sample was not used in the field and therefore it is considered as new. The remaining seven core samples were obtained from four different parking lots in which their age and permeability are also reported in Table 1.
<table>
<thead>
<tr>
<th>Core sample No.</th>
<th>Diameter (mm)</th>
<th>Height (mm)</th>
<th>Sample type</th>
<th>Sample ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>120</td>
<td>Open graded AC overlay on top of conventional AC pavement</td>
<td>QP45-3</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>60</td>
<td>Laboratory produced open graded pavement with modified binder</td>
<td>RW 475-3</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>163</td>
<td>First field core sample from parking Lot 2</td>
<td>PL 2-1</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>151</td>
<td>Second field core sample from parking Lot 2</td>
<td>PL 2-2</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>147</td>
<td>First field core sample from parking Lot 4</td>
<td>PL 4-1</td>
</tr>
<tr>
<td>6</td>
<td>100</td>
<td>100</td>
<td>First field core sample from parking Lot 6</td>
<td>PL 6-2</td>
</tr>
<tr>
<td>7</td>
<td>100</td>
<td>105</td>
<td>Second field core sample from parking Lot 6</td>
<td>PL 6-3</td>
</tr>
<tr>
<td>8</td>
<td>100</td>
<td>189</td>
<td>First field core sample from parking Lot 12</td>
<td>PL 12-1</td>
</tr>
<tr>
<td>9</td>
<td>100</td>
<td>126</td>
<td>Second field core sample from parking Lot 12</td>
<td>PL 12-3</td>
</tr>
</tbody>
</table>

Tomographic techniques combine information from radiographic projections taken at different angles to produce a detailed map of internal properties of the object. In recent years, systems for acquiring and processing this data have been developed and are in regular use in medical and industrial applications. The term "computed tomography," or CT, refers to the use of a computer to combine the projection data into a complete map.

Images obtained from scanning are processed before enabling determination of required physical properties. In doing so a very important step is Image-segmentation. Of the many available segmentation methods, adapted here is Otsu’s method of image segmentation [4] which has been proved, by many researchers, to give a robust thresholding technique. In this method, image histogram is normalized for brightness and is divided into two regions; one with the pixel values less than the threshold, called the background and the one with values greater than the threshold is termed foreground. The concept behind this method is to find a threshold value which minimizes the within-class variances of background and foreground voxel classes, which is equivalent to maximizing the variance between the means of the two clustered classes [3, 4]. In Otsu’s thresholding technique, for an image taking on discrete voxel values k, the optimal threshold is given by equation 1[3, 4, and 7]:
\[
\theta_{\text{Otsu}} = \arg\max_{\theta} \left\{ \sum_{k < \theta} p(k) (\mu_0 - \mu)^2 + \sum_{k \geq \theta} p(k) (\mu_1 - \mu)^2 \right\}
\]

(1)

where

\[ p \] is the normalized histogram
\[
\mu := \text{Mean}\{f(x)\}
\]
\[
\mu_1 := \text{Mean}\{f(x) \mid f(x) \geq \theta\}
\]
\[
\mu_0 := \text{Mean}\{f(x) \mid f(x) < \theta\}.
\]

2. X-Ray CT Scan and Image Processing

Nondestructive FlashCT (Flat panel Amorphous Silicon High-resolution Computed Tomography) x-ray test set up process is shown in Figure 2. The X-ray CT scan set up at Washington State University involves two X-ray sources that are capable of generating a 420 keV and 225 keV voltages [5, 7]. The 420 keV source is preferably used for relatively bigger samples where sufficient detail of sample constituent structures can be visualized with a relatively lower resolution. The 225 keV source is employed to attain micro focused enhanced resolution and suits best to for smaller samples and samples consisting of very fine details like hair size cracks. These X-ray sources are networked to a central workstation, a processing platform that consists of four parallel computing processors each consisting of a double core CPUs and set of softwares that control the scanning process and subsequent image analyses.
Scanning of the samples is initiated with the specifically devised acquisition software called FlashCT DAQ a program that controls hardware operation, calibration and scanning [1]. Once the scan parameters have been entered, it will rotate the object and collect radiographic images at the desired angles. It saves these datasets as unified directory structure file (UDS) for later processing and reconstruction by the Data Processing System software. The UDS header files (Text file containing data fields separated by linefeeds) are processed with a program called FlashCT DPS which gives a reconstructed image of the scanned slices. Calibration files are used to correct for pixel to pixel differences in the detector i.e. bad pixel correction. They are radiographs taken with the object removed from the field of view, and they range from completely dark images where an image is taken with no exposing radiation, to light fields where an image is taken with fill exposure [1].

Centering the axis of rotation in the middle of the cropped region of the detector, while aligning the system, is one challenging part of the scanning procedure. A one pixel offset of an image may result in reduction of resolution of about 50% [1].

Figure 2. X-Ray FlashCT setup and associated processes
An algorithm that analyzes the sinogram and determines the center of rotation from the given data is employed to solve the centering problem. Once the center of rotation is determined, the sinogram can be shifted to place the center of rotation in the middle of the sinogram. Figure 3 shows slice images of a slice before and after correction is done for centering.

![Before Centering Correction](image1)
![After Centering Correction](image2)

**Figure 3.** Images of a slice from Sample RW475-3

The reconstructed images of the slices are converted into a 3-Dimensional image with third type software FlashCT VIZ. Finally, the processed image is analyzed with MFC software to get the XY, XZ and YZ-sliced image formats that any other image processing software could handle. In this specific case, the image processing softwares used are MATLAB [2] and Image-Pro-Plus. The overall processes involved with X-Ray CT scanning are shown, diagrammatically in Figure 2 and as flow chart in Figure 4.
Figure 4. Flowchart for the Porosity Determination Process using X-Ray CT

In image processing, the slices undergo an important process called segmentation, which involves the identification of solid and voids in the slices under analysis. Figures 5 show original scanned (gray colored) and segmented (black and white) images. The distribution of pores as obtained using this technique for the typical old and new specimen slices is as shown in Figure 7.
3. Results and Discussion

Figures 6(a) and (b) show 3D images of samples RW475-3 and QP45-3 respectively as reconstructed with Image Pro plus. Images such as these can be evaluated quantitatively. For example, one can notice that there is no indication of clogging in sample RW475-3 and
the top 24mm of sample QP45-3. Clogging can be observed in the bottom 96mm of QP45-3.

(a) Sample RW475-3, No Clogging

(b) QP45-3: Top 24mm, No Clogging  (c) QP45-3: Bottom 96mm, clogging observed

**Figure 6.** 3D-Images Reconstructed by Image Pro Plus from 2D-slices

As shown in figure 7 (a) the bottom impermeable core sample exhibit low porosity which is asserted as indication of clogging. This can be noted in the segmented image which shows near white; white color representing solids and black the air voids.
(a) Slices from bottom impermeable fraction of core QP45-3: Clogging observed

(b) Slices from top permeable fraction of core QP45-3: porous (No Clogging)
The plot of porosity versus specimen depth for open graded overlay samples obtained from the field and made in the lab is shown in Figure 8. As shown, for sample QP45-3 it appears that there is some evidence of clogging at about 7 mm below the surface. However, the porosity remained at 20% and higher and hence the effect of this slight reduction in porosity will not interfere with water flow. This top surface clogging is good news for two reasons: (1) there is a possibility of self cleaning by tire pressure during rain event, and (2) it is easier to remove these particles by vacuum or other cleaning mechanisms. The porosity of new open graded polymer modified pavement core sample (RW475-3) appears to remain at 20% and higher throughout its depth. Figure 8 shows the porosity distribution with depth for core samples obtained from parking lots. It can be seen that porosity for PL 6_2 and PL 6_3 are lower compared to porosity of samples from parking lots PL2 and PL4. These results can be confirmed with porosity results shown in Table 2. The plots of the porosity versus depth and average porosity of individual samples are also presented by Figures 9 through Figure 14. The average porosity is computed by normalizing the porosity distribution over the total depth of samples. In each plot, the red bold line indicates the average porosity of the sample.
The average porosity obtained by scanning was verified by measuring the overall porosity of the samples in the laboratory using a Gravimetric method where the samples are immersed into water for complete saturation and soil mechanics correlations are used to compute porosity.

The results obtained from both methods are shown in Table 2. Generally, comparable results are obtained by both methods. In a few samples, the porosity obtained by the gravimetric method is less than the average value computed over the depth from X-Ray CT scanning. This may be attributed to the inability of voids, due to clogging in the samples and isolated voids, to take in water in gravimetric test procedure.

Table 2. Average porosity of core samples based on scanning and gravimetric methods

<table>
<thead>
<tr>
<th>Sample</th>
<th>Average porosity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Scanning method</td>
</tr>
<tr>
<td>QP45-3</td>
<td>26.5</td>
</tr>
<tr>
<td>Open graded section</td>
<td>7.9</td>
</tr>
<tr>
<td>QP45-3 entire section</td>
<td></td>
</tr>
<tr>
<td>RW 475-3</td>
<td>22.96</td>
</tr>
<tr>
<td>PL 2_1</td>
<td>34.51</td>
</tr>
<tr>
<td>PL 2_2</td>
<td>17.39</td>
</tr>
<tr>
<td>PL 4_1</td>
<td>25.87</td>
</tr>
<tr>
<td>PL 6_2</td>
<td>9.60</td>
</tr>
<tr>
<td>PL 6_3</td>
<td>8.26</td>
</tr>
<tr>
<td>PL 12_1</td>
<td>14.1</td>
</tr>
<tr>
<td>PL 12_3</td>
<td>22.03</td>
</tr>
</tbody>
</table>

Therefore, the porosity obtained in the gravimetric testing procedure can be referred to as “effective porosity” of the samples. The gravimetric method is useful for ensuring the X-ray CT values are within the reasonable range. However, the X-ray CT results are accurate enough to detect the clogs, which have significantly lower density than the real constituent of the samples, and include the volume occupied by that specific material as a void space and hence considered as a superior method.

One general comment about the samples is that they all have a rough bottom face due to sample coring. This causes loss of accuracy in determining the average height and hence total volume of samples both in the gravimetric and x-ray CT techniques of porosity determination. Because of this, one has to disregard X-ray slices taken near rough surfaces.
Figure 8. Porosity distribution for old and new porous friction course samples
Figure 9. Porosity distribution for parking lot samples
Figure 10. Porosity vs. depth and average porosity for QP45-3, RW 475-3 (old and new)
Figure 11. Porosity vs. depth and average porosity for parking lot 2 samples
Figure 12. Porosity vs. depth and average porosity for parking lot 4 sample
Figure 13. Porosity vs. depth and average porosity for parking lot 6 samples
Figure 14. Porosity vs. depth and average porosity for parking lot 12 samples
REFERENCES


Appendix A: Reconstructed 3D-Images

PL2_1

PL2_2