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CT Tomography of Wide Gradation Gravel Soil and Its Permeability Determination

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Abstract: Through CT scanning of three gravel soil samples, Avizo software was used to carry out three-dimensional reconstruction, and the porosity, specific surface area and tortuosity of gravel soil samples were obtained with the help of the internal algorithm of the software. The experimental data and the data obtained after software processing were respectively substituted into the Kozeny-Caman equation to calculate the permeability of gravel soil samples. Using overlapping sphere theory combined with linear path function and gravel soil itself linear path function for comparative analysis.
Keywords: Gravel; CT scan; 3D model; Linear path function

1. Introduction

In geotechnical engineering, the soil is an effective porous medium, and the fluid movement in soil is known as seepage. Geotechnical engineering faces the critical problem of seepage. The pore structure of the soil impacts the permeability of soil samples. As a result, the study of the internal microstructure of the soil is related to porosity.

Using high-resolution 3D X-ray microscopic imaging equipment, scan the 2D grayscale images of gravel rock samples to create a 3D model of the soil mass. The finished 3D model, which is essentially the same size and shape as the study object, can accurately depict the internal pores and cracks of the rock sample.

G. S. Warner et al.[1] using x-ray scanned a soil core to determine if macropores could be distinguished and characterized. JU Yang et al.[2] were investigated the geometric features and the distribution properties of pores in rocks by means of CT scanning tests of sandstones. Garboczi, E. J.[3]said that the overlapping sphere (OS) percolation model is useful for testing composite material ideas and other applications.

2. Experimental parameters of gravel soil samples and software scanning analysis results

2.1 Laboratory test data of gravel soil samples

The three samples of gravel soil utilized in this article were each artificially sieved in the lab before being combined and molded. The particle size distribution range is 0.075–10mm, and the middle 0.5–1mm is missing. Among them, coarse particles with a size of 2–10mm are employed as the skeleton, and tiny particles with a particle size of 0.075–2mm are used as filler particles. The three soil samples differed by 3% between fine particle content less than 0.5 mm and coarse particle content greater than 2 mm. The goal of setting up soil samples with various particle size gradations is to alter particle size distribution, internal structure, and the porosity of each gravel sample.

2.2 Structural scanning results of gravel soil samples

The CT scan findings of soil samples were loaded into the software for 3D reconstruction, and a 600×600×600 pixel cube 3D model was generated from the reconstructed 3D cylindrical gravel model, which is more practical for computer computation and more representative of the description of gravel soil samples.

Combining the three sets of data measured in the laboratory, it can be seen that the data measured by the 3D model are slightly different from the experimental data. This difference is because the manually determined intensity range is larger during image segmentation, some non-porous soil particles are defined as pores.

2.3 Sample pore structure characteristics

We think of a pore network as a complex comprising pores and channels. The pore segmentation method divides an entire connected pore into numerous pores. The computer software can calibrate each pore and create statistics after dividing an entire connected volume, and then scan the pores one at a time to determine the diameter, volume, and surface area of each pore and determine the maximum pore diameter 0.468 cm, 0.389 cm, and 0.422 cm, and the average pore volumes are 3.15×10^{-3} cm^3, 2.52×10^{-3} cm^3, and 2.96×10^{-3} cm^3, respectively.

3. The theory of the overlapping sphere model

The overlapping sphere model, which randomly adds spheres with radius R as pores in the obtained porous material model, is one of the most important theoretical models for heterogeneous media. This model is deemed appropriate for analyzing the microstructure of rock and soil during seepage, because during the seepage process, fluid may remove certain tiny particles and increase the pore volume of rock and soil. The porosity φ_1 is , where η is the reduced density, η=ρV, V and ρ are the total density (number of balls per unit volume) and ball volume, respectively. The linear path function is given by Lu and Torquato[4]:

$$L(\mathrm{x}) = \varphi_1^{1+\frac{3x}{4R}}$$

4. Analysis results

4.1 Permeability analysis

The internal structural parameters measured in the laboratory and measured in the 3D model were substituted into the Kozeny-Carman equation, respectively. The obtained permeability is displayed in the table below:

Table 1 Permeability calculated from laboratory and software data

k（cm^2）	soil sample1	soil sample 2	soil sample 3
Measured	2.940×10^{-4}	3.708×10^{-4}	3.216×10^{-4}
Software data	6.212×10^{-5}	7.373×10^{-5}	6.553×10^{-5}

It can be seen from Table 1 that the permeability value calculated by the software data is lower than that calculated by the experimental data. The main reason is that the porosity obtained by the software is relatively high and the specific surface area is relatively low.

The permeability obtained by the two groups is treated as the mean value as their final permeability, which were: 1.78×10^{-4} cm^2, 5.54×10^{-4} cm^2, and 1.94×10^{-4} cm^2.

4.2 Discussion on characteristics of gravel soil

Combining linear path function and overlapping sphere model, based on the data of porosity and specific surface area measured in the laboratory. We can get the overlapping sphere system parameters of soil sample 1 to soil sample 3:

Table 2 Overlap ball system parameter table

	Reduced density η	Overlapping System Radius R（cm）	Sphere number density ρ（cm^{-3}）
soil sample 1	1.496	0.282	15.877
soil sample 2	1.465	0.303	12.579
soil sample 3	1.444	0.328	9.774

The table shows the general parameters of the overlapping sphere system of the same gravel soil sample with constant porosity and specific surface area. Then compare it to the linear path function of the gravel soil sample itself.

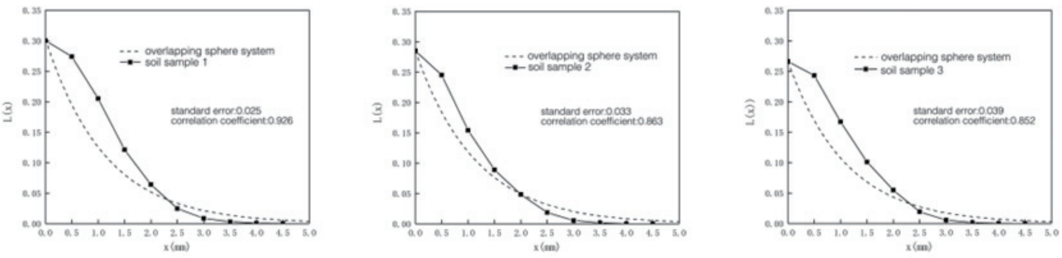

Fig. 1 Comparison of pore linear path function of gravel soil sample and pore linear path function of overlapping sphere system

The curves in the figure show that the trends for the three soil samples are roughly the same. Fig.1 displays the overlapping sphere system's standard errors and correlation coefficients. The standard errors of soil samples 1 through 3 are 0.025, 0.033, and 0.039, suggesting a small difference between those two systems. The correlation coefficients are 0.926, 0.863, and 0.852, the values are all greater than 0.85, indicating that the fitting effect is good. Ultimately, it can be said that the overlapping sphere system can more accurately represent the real gravel soil sample.

5. Conclusion

In this paper, based on CT scanning technology combined with Avizo software, three-dimensional reconstruction of gravel soil was carried out, and the basic structural parameters of gravel soil samples were successfully obtained, the method is reliable.

Comparative analysis of gravel soil samples using linear path function and overlapping sphere theory, the correlation coefficients are all above 85%, and the standard errors are all less than 0.04, showing good results.

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