Research Article

Experimental Study on Measurement of Drag Coefficient of Sandy Soil Nonlinear Vadose

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The seepage characteristics of sand affect its strength, mechanical deformation characteristics, and find safety and stability. The drag coefficient is a dimensionless physical quantity expressing the interaction between fluid and particles, it is also an important parameter that characterizes the permeability of granular soils. Through the seepage test of standard sand with single particle sizes and different grades, analyze the seepage laws of standard sand with different particle sizes in the Darcy and non-Darcy seepage. The relationship between parameters \( a \) and \( b \) in the seepage equation and porosity (\( n \)), average particle size (\( d_{50} \)), nonuniformity coefficient (\( C_U \)), and curvature coefficient (\( C_C \)), and their influence degree were studied. An empirical formula for determining the permeability coefficient of standard sand is established. By adding a correction factor and verifying its rationality, the empirical formula of standard sand permeability parameters is finally obtained.

1. Introduction

Sandy soil is the particles with a particle size greater than 0.075 mm accounting for more than 50% of the total mass. Coarse-grained soil refers to the soil with a particle size of 2 to 20 mm gravel content less than or equal to 50%. It is widely used in construction materials, dam filter material, foundation treatment, and other engineering materials. The seepage of water in the sand will exert seepage force on the soil particles, which will cause changes in the internal stress state, structure, and strength of the soil.

When the seepage force is too large, relative movement between soil particles and even overall movement of the soil body will occur, and seepage deformation or even destruction will occur [1, 2], causing damage to dams and foundation pits [3, 4], slope instability [5, 6], ground uplift, and other issues [7, 8]. Thaisiam et al. [9] believed that after seepage erosion, with the continuous movement of fine particles, some pores in the sand may be blocked or enlarged, which will result in the change of the soil permeability coefficient. Moffat and Fannin [10] proposed that seepage erosion causes the permeability coefficient of soil to increase from upstream to downstream. However, Benamar and Correia dos Santos [11] found that under the action of seepage erosion, the permeability coefficient of the downstream soil mass decreases, while the permeability coefficient of the upstream soil mass does not change much. In order to explore the factors affecting the permeability of sandy soil, Su et al. [12] carried out a single particle size and different gradation sand soil permeability tests and found that the factors affecting permeability are sand gradation, porosity, and particle size. Finally, the relationship between the permeability coefficient and various factors is fitted to provide guidance for the actual project. Liu et al. [13] concluded that the thin elastic layer assumption is significantly robust to the elastic layer assumption for simulating fracture opening and closing under coupled conditions. Due to the complex fracture geometry, the evolution of fracture permeability shows some heterogeneity. Qi et al. [14] collected a large number of seepage deformation test data of noncohesive soil (gravel soil and sand) and conducted comparative analysis and found that when the sample
unevenness coefficient is less than or equal to 5, there are two types of seepage deformation of noncohesive soil: Crushed gravel soil is piping and sandy soil is flowing soil. Ju et al. [15] used the head control tube to control the average hydraulic gradient of the entire soil column when the steady seepage flow was 0.8 and conducted permeability tests on medium sand, coarse sand, and gravel sand samples. In the experiment, it is concluded that the lower part of the coarse sand and gravel sand samples is easier to be carried away by seepage, and the increase in permeability coefficient is larger. The research results of scholars at home and abroad show that the seepage curve of low-permeability porous media (that is, the relationship between flow velocity and hydraulic gradient) is no longer a simple linear feature but presents a non-Darcy seepage feature. Researchers such as Liu [16], Zhu and Ling [17], Zhang [18], and Qian et al. [19] conducted a large number of indoor permeability experiments in terms of particle size, porosity, gradation, etc. Get the respective permeability coefficient formula. Each researcher has a different emphasis on sand selection and analysis factors, and the obtained formulas are also different in form, and none of them can be directly used for the determination of the permeability coefficient of standard sand and sand.

Through the single particle size and different grade standard sand particle seepage test, analyze the seepage law of different standard sand particles in the Darcy-non-Darcy flow zone. Study the relationship between the parameters in the seepage equation and the porosity, average particle size, nonuniformity coefficient and curvature coefficient, and the degree of influence, establish an empirical formula suitable for determining the permeability coefficient of standard sand, and verify its rationality by adding correction factors, and finally obtain the empirical formula of standard sand permeability parameters to guide the safety and stability analysis and evaluation of actual sand foundation engineering.

2. Materials and Methods

2.1. Physical Properties of Test Materials. The test material is Fujian standard sand. After the sand is fully dried, it is subjected to a screening test to obtain five particle size ranges of 0.1 to 0.25 mm, 0.25 to 0.5 mm, 0.5 to 1 mm, 1 to 2 mm, and 2 to 5 mm. The original grading curve is shown in Figure 1. The specific gravity of standard sand measured by the pycnometer method is about 2.65. Using PartAn 3D scanning equipment to measure the average particle size of standard sand, the results are shown in Table 1.

| Particle size (mm) | 0.1–0.25 | 0.25–0.5 | 0.5–1 | 1–2 | 2–5 |
|-------------------|-----------|----------|-------|-----|-----|
| The average grain diameter (mm) | 0.175 | 0.375 | 0.75 | 1.599 | 2.057 |

2.2. Experimental Scheme. First, the permeability tests of standard sand with different dry densities in a single particle size range were carried out. Dry density values of sand samples in the test are shown in Table 2. Second, the influence of different particle size ranges on the permeability of standard sand under the same dry density was studied. Finally, the data obtained from the test were processed, and the permeability results of different samples were compared.

2.3. Experimental Procedure. Standard sand is a noncohesive soil. In order to achieve a breakthrough in the seepage test under the state of Darcy flow to the turbulent zone, the
permeability test device adopts an improved device for measuring the permeability coefficient and drag force coefficient of sandy soil at a higher flow rate. The sample section is equally divided into five layers, each layer is 4.9 cm, and the sample is loaded by the subloading method. Five equal parts of the standard sand quality are loaded into each layer, and each layer is compacted with a compactor. Ensure that all samples just fill the sample section. The criterion for determining the saturation of the sample is that within 5 minutes, the data fluctuation of the flow meter and the differential pressure transmitter digital display instrument should not exceed 0.5 L/h and 10, respectively. During the test, all valves must be adjusted slowly to prevent excessively fast adjustment from causing greater disturbance to the sample.

3. Experimental Results and Analysis

3.1. Comparison of Seepage Experiments with Different Porosities in Different Particle Size Intervals. Conduct penetration tests on standard sands with different porosities in the five groups of single particle size intervals of 0.1 to 0.25 mm, 0.25 to 0.5 mm, 0.5 to 1 mm, 1 to 2 mm, and 2 to 5 mm. The relationship between the standard sand seepage velocity \( U \) and hydraulic gradient \( I \) in a single particle size range is shown in Figure 4.

It can be seen from Figure 4 that under the same hydraulic slope, as the porosity decreases, the seepage velocity in the sample gradually slows down. Analyzing the range of coefficients \( a \) and \( b \) in the simplified seepage formula, it can be seen that the value of \( b \) is one order of magnitude higher than the value of \( a \), and the values of \( a \) and \( b \) increase with the decrease of porosity.

3.1.1. Relationship between Drag Coefficient (a) and Porosity. In the permeability test, the control variables \( C_C, C_U, \) and \( d_{50} \) are fixed values, and the relationship between the drag coefficient and the porosity in each particle size range is explored. Refer to Ergun’s formula and initially draw up \( a \propto \lambda_1 (1 - n)^{1/3} \lambda_2^{1/3} \). As \( n \in (0, 10) \), according to the boundary
conditions: When \( n \to 0 \), \( a \to +\infty \), we have \( \lambda_2 < 0 \) and \( \lambda_1 > 0 \); when \( n \to 1 \), \( a \to 0 \), we have \( \lambda_2 > 0 \).

By determining the value ranges of the parameters \( \lambda_1, \lambda_2 \), and \( \lambda_3 \) and defining the type of the fitting function, the relationship between the drag force coefficient and the porosity in each particle size interval is shown in Figure 5.

It can be seen from Figure 5 that the drag coefficient \( a \) is positively correlated with \( (1 - n)^2n^{-3} \). The correlation between \( a \) and porosity \( n \) in each single particle size range is as follows: 0.84252, 0.80163, 0.95891, 0.85015, and 0.85994. The degree of correlation is above 0.8, with a good linear correlation. In the same particle size class, the increase of the dry density of the sample leads to the decrease of the internal porosity of the sample, which is manifested by the decrease of the seepage path or the weakening of the hydraulic path of the water cross section, resulting in the decrease of the overall permeability of the sample and the increase of the drag force coefficient.

3.1.2. The Relationship between Drag Coefficient \( (b) \) and Porosity. Compared with the aforementioned methods, the relationship between drag force coefficient and porosity was analyzed. Refer to Ergun’s formula and initially draw up \( a \propto \lambda_1 (1 - n)^2n^{-3} \). Since \( n \in (0, 1) \), according to the boundary conditions, when \( n \to 0 \) and \( b \to +\infty \), we have \( \lambda_1 < 0 \) and \( \lambda_1 > 0 \), and when \( n \to 1 \) and \( b \to 0 \), we have \( \lambda_2 > 0 \).

Define the type of fitting function by determining the value range of parameters \( \lambda_1, \lambda_2 \), and \( \lambda_3 \). The correlation between drag coefficient \( b \) and porosity \( n \) in different particle size ranges is shown in Figure 6.

From Figures 6(a) and 6(b), it can be seen that the drag coefficient \( b \) and \( (1 - n)^2n^{-3} \) are positively correlated, and the correlation is very high. In Figure 6(c), the relationship between \( b \) and \( n \) is completely inconsistent with \( (1 - n)^2n^{-3} \). Figures 6(d) and 6(e) show a positive correlation between fit \( b \) and \( (1 - n)^2n^{-3} \), but it is not very relevant. In the same particle size class, the decrease of the dry density of the sample leads to an increase in the internal porosity of the sample, which is manifested as an increase in the seepage path of the cross section of the water, which leads to an increase in the overall permeability of the sample and a decrease in the drag coefficient \( b \) value.

3.2. Comparison of Seepage Experiments in Different Particle Size Intervals under the Same Porosity. When the porosity is the same, the particle size of the sample accumulation is the only factor that affects its permeability. Multiple sets of samples are tested separately for seepage, and the test results are fitted and analyzed. The correlation between the drag coefficients \( a, b \) and the average particle size \( d_{50} \) is shown in Figure 7.

It can be seen from Figure 7 that the overall linear regression correlation between drag coefficient \( a \) and \( d_{50}^2 \) reaches 0.913, the overall linear regression correlation between drag coefficient \( b \) and \( d_{50}^2 \) reaches 0.861. Both have a good linear correlation. When the porosity is constant, as the average particle size \( d_{50} \) of the sample increases, the more pores formed between the particles, the larger the pore volume, and the large internal pores will not be filled by small particles. It shows that the water seepage channel is more open, the seepage resistance of the water flow is weakened, and it shows better permeability.

3.3. Seepage Experiment of Mixed Particle Size under Different Gradations. The particle size of the soil has a great influence on its permeability, the inhomogeneity coefficient \( C_U \) indicates the degree of unevenness of the particles, and the curvature coefficient \( C_C \) indicates the degree of continuity of the soil particles. In order to explore the influence of the inhomogeneity coefficient \( C_U \) and the curvature coefficient \( C_C \) on the permeability of the standard sand, seepage tests were carried out and the test results were compared and analyzed.

3.3.1. Effect of Uneven Coefficient on Drag Coefficient. In order to explore the influence of the \( C_U \) on the permeability of the standard sand, the value of the \( C_C \) of the sample is all 1. The \( C_U \) takes the values 5, 5.25, 5.5, 6, and 6.25 in sequence. The preloaded sample method is used to estimate the mass of the required standard sand samples of different grades to be about 3.5 kg. Control five groups of samples to have the same dry density (1.819 g/cm³). The relationship between the drag coefficient \( a \), \( b \) and the uneven coefficient in the five groups of different gradation tests is shown in Figure 8.

It can be seen from Figure 8 that the drag coefficients \( a, b \) and \( C_U^2 \) are all positively correlated. The correlation degree distribution is 0.98802 and 0.88682. When the curvature
Figure 5: Continued.
Figure 5: The relationship between the drag coefficient $a$ and the porosity $n$ of each particle size class: (a) single particle size 0.1–0.25 mm, (b) single particle size 0.25–0.5 mm, (c) single particle size 0.5–1 mm, (d) single particle size 1–2 mm, and (e) single particle size 2–5 mm.

Figure 6: Continued.
coefficient is a fixed value and the inhomogeneity coefficient increases, the permeability coefficient of the sample also increases. Control the average particle size to 1 mm and the effective particle size to 0.25 mm. From the calculation formula of the grading parameter, it can be known that when the $CU$ is 5.25, the corresponding value of $d_{60}$ is greater than the value of $d_{60}$ when the $CU$ is 5. This is, the proportion of coarse particles in the sample is greater than that of fine particles. And so on, when $CU$ is 6.25, the content of coarse particles is the largest. The arrangement and combination of coarse particles will form larger voids, while the content of fine particles is reduced, and these voids cannot be completely filled, resulting in a more developed internal hydraulic path, making it easier for water to pass through, that is, better permeability.

3.3.2. Effect of Curvature Coefficient on Drag Coefficient.

In order to study the influence of $CC$ on the permeability of standard sand, the value of $CU$ is all 6, and the value of $CC$ is 0.50, 0.75, 1.00, 1.25, and 1.50. Control five groups of samples to have the same dry density (1.819 g/cm$^3$). The relationship between the drag coefficient $a$, $b$ and the curvature coefficient in the five groups of different gradation tests is shown in Figure 9.

It can be seen from Figure 9 that the drag coefficients $a$, $b$ and $CC^{-0.5}$ are all positively correlated. The correlation degree distribution is 0.82742 and 0.80447. With the increase of $CC$, the content in the 0.5 to 1 mm particle size range increases, and the content in the 0.25 to 0.5 mm particle size range decreases accordingly. As a result, the pores formed by larger particles cannot be fully filled by fine particles, resulting in

Figure 6: The relationship between drag coefficient $b$ and porosity $n$ in each single particle size interval: (a) single particle size 0.1–0.25 mm, (b) single particle size 0.25–0.5 mm, (c) single particle size 0.5–1 mm, (d) single particle size 1–2 mm, and (e) single particle size 2–5 mm.
the easier flow of water inside the sample, better permeability, and the drag coefficient $a$ and $b$ values are getting smaller and smaller.

### 3.4. Empirical Formula Fitting

#### 3.4.1. Preliminary Empirical Formula Fitting of Drag Coefficient

According to the experimental data, the correlation between the average particle size, porosity, curvature coefficient and uneven coefficient, and the drag coefficient is studied by controlling a single variable and analyzing the boundary conditions. The values of drag force coefficients $a$ and $b$ were fitted by empirical formula with four parameters, $d_{50}$, $n$, $C_U$, and $C_{c_5}$, respectively, such as formulas (1) and (2).

The fitting results of the empirical formulas of the drag coefficients $a$ and $b$ are shown in Figure 10.

**Figure 7:** The relationship between drag coefficient $a$, $b$ and average particle size $d_{50}$: (a) the correlation between $a$ and $d_{50}$ and (b) the correlation between $b$ and $d_{50}$.

**Figure 8:** The relationship between drag coefficient $a$, $b$ and uneven coefficient: (a) the relationship between $a$ and $C_U$ and (b) the relationship between $b$ and $C_{c_5}$.
which leads to a large difference in the pore structure. Even if the same group of samples is affected by the preloading and postloading, the test results are also very different.

It can be seen from the aforementioned comparative analysis that the correlation between the $b$ value and the $d_{50}$, $n$, $C_U$, and $C_C$ parameters is weak. Therefore, you can choose to explore the correlation between the $b$ value and the $a$ value, and the fitting result is shown in Figure 11.

By comparing the drag coefficient $a$ value representing the coefficient of the $U - I$ linear segment and the drag force coefficient $b$ representing the coefficient of the $U - I$ non-linear segment, and the sample data $b_{Test}$ and $a_{Test}$, it is found that the drag force coefficient $b$ has a relatively stable magnitude and a higher drag coefficient $a$ is an order of magnitude. The correlation between the two is 0.85, so formula (2) can be used as a preliminary empirical formula for drag coefficient $b$.

### 3.4.2. Comparison of Empirical Formula Correlation

Use goodness of fit ($R^2$) to compare the fit of different empirical formulas to standard sand permeability data, the formula of $R^2$ is as follows:

$$ R^2 = 1 - \frac{\sum (I_{Test} - I_{Empirical-formula})^2}{\sum (I_{Test} - I_{Test})^2} $$

Among them, $I_{Test}$ is the $I$ value obtained from the test data, $I_{Test}$ is the average value of the test data, $I_{Empirical-formula}$ is the $I$ value calculated by the empirical formula. The preliminary empirical formula calculation value $I'$, the Ergun formula calculation value, the Van Gent formula calculation value, the Liu formula calculation value, and the correlation between the Jingsui Wu...
formula calculation value, and the experimental data $I_{\text{Test}}$ are listed in Table 5.

It can be seen from Table 5 that the preliminary fitting formula is only suitable for solving the permeability parameters of standard sand with a single particle size of 0.1 to 0.25 mm. The formula of Van Gent is suitable for the solution of standard sand permeability parameters in grading experiments. The formula of Liu is suitable for the solution of permeability parameters of standard sand in the interval of 0.5 and 1 mm. In general, the aforementioned five formulas are lacking in the process of solving the standard sand permeability parameters, and the correlation is low.

### 3.4.3. Improve Empirical Formula

There is a certain deviation between the empirical formula $I'$ and the standard sand drag coefficient in all particle sizes. However, the analysis of the empirical formula $I'$ and the experimental data show that there is a linear correlation between the two. The comparison is shown in Figure 12.

![Figure 11: The relationship between drag coefficient $a$ and $b$.](image)

![Figure 12: Comparison of fitting results between common seepage formulas and standard sand seepage experiment data.](image)

### Table 5: Comparison of fitting results between common seepage formulas and standard sand seepage experiment data.

| Particle size range (mm) | $N$ | $C_U$ | $C_C$ | The formula of this paper | Correlation comparison ($1 - (SSres/SStot)$) | Ergun | Van Gent | Liu | Jingsui Wu | $I''$ |
|-------------------------|-----|-------|-------|---------------------------|-----------------------------------------------|-------|----------|----|------------|------|
| 0.1–0.25                | 0.381 | 1     | 1     | 0.943 | –2.047 | –9.106 | 0.583 | –1.715 | 0.943 |
|                         | 0.455 | 1     | 1     | 0.982 | –3.361 | –7.231 | –0.056 | –2.544 | 0.982 |
|                         | 0.449 | 1     | 1     | 0.978 | –2.028 | –5.398 | 0.320 | –1.478 | 0.978 |
| 0.25–0.5                | 0.381 | 1     | 1     | 0.404 | –2.969 | 0.479  | –0.827 | –1.942 | 0.053 |
|                         | 0.381 | 1     | 1     | 0.219 | –2.570 | 0.799  | –0.724 | –1.905 | 0.005 |
|                         | 0.402 | 1     | 1     | 0.590 | –1.921 | 0.585  | –0.368 | –1.140 | 0.333 |
| 0.5–1                   | 0.381 | 1     | 1     | –4.672 | –1.380 | –30.410 | 0.694 | 0.090 | 0.189 |
|                         | 0.374 | 1     | 1     | –0.157 | –1.677 | –10.853 | 0.737 | 0.897 | 0.966 |
|                         | 0.381 | 1     | 1     | –2.131 | –2.126 | –18.772 | 0.825 | 0.783 | 0.629 |
| 1–2                     | 0.348 | 1     | 1     | 0.030 | –2.112 | –6.435 | 0.595 | –0.195 | 0.894 |
|                         | 0.361 | 1     | 1     | 0.154 | –1.824 | –3.976 | 0.529 | 0.063 | 0.902 |
|                         | 0.377 | 1     | 1     | 0.334 | –2.083 | –3.630 | 0.484 | 0.556 | 0.838 |
| 2–5                     | 0.344 | 1     | 1     | –0.213 | –2.158 | –5.067 | 0.551 | –2.059 | 0.853 |
|                         | 0.353 | 1     | 1     | –0.011 | –2.137 | –4.556 | 0.527 | –1.136 | 0.820 |
|                         | 0.381 | 1     | 1     | –0.134 | –2.335 | –5.394 | 0.509 | –0.140 | 0.819 |
| 0.1–5                   | 0.314 | 6     | 0.75  | –1.907 | –2.072 | 0.536  | –0.240 | 0.187 | 0.929 |
|                         | 0.314 | 5.5   | 1     | –2.093 | –2.281 | 0.490  | –0.321 | 0.181 | 0.963 |
|                         | 0.314 | 6     | 1     | –1.573 | –1.704 | 0.323  | –0.016 | 0.377 | 0.909 |
|                         | 0.314 | 6     | 1     | –2.169 | –2.303 | 0.838  | –0.530 | –0.066 | 0.952 |
|                         | 0.314 | 6.25  | 1     | –2.179 | –2.289 | 0.887  | –0.585 | –0.194 | 0.951 |
It can be seen from Figure 12(a) that there is a certain correlation between the data points obtained in the interval of 0.1 to 0.25 mm for a single particle size and the fitting formula $I'$. In order to make the empirical formula reflect the experimental data more accurately, a correction factor is introduced to improve the empirical formula. That is, add correction $C$. Assuming $I_{\text{test}}C \cdot I'$, exploring the correlation coefficient $C$ between the two is shown in Figure 12(b). The improved empirical formula is in good agreement with the experimental data points, and the correlation is high, which reflects that the improved empirical formula can be closer to the experimental results. The correlation coefficient between the single particle size interval and the gradation experimental data is not a fixed value, and the closer the coefficient is to 1, the better the empirical formula fits. The relationship between the coefficient $C$ and each parameter is shown in Figure 13.
The relationship between the parameters \( a \) and \( b \) in the seepage equation and the porosity, average particle size, inhomogeneity coefficient and curvature coefficient and their influence degree are studied, and the following research results have been obtained.

(1) Using electron microscope scanning and image processing technology, the data of the equal-area circle diameter of standard sand particles in the range of 1 to 2 mm and 2 to 5 mm in single particle size is measured, and the equal-area circle diameter is analyzed to show a right skewed distribution, and the equal-area circle is drawn. The diameter gradation curve to obtain the average particle size of standard sand is 1.599 mm and 2.057 mm, respectively.

The correlation between the modified empirical formula \( I'' \) and the empirical formula \( I' \) is shown in Table 6.

Comparative analysis shows that the calculation results of the revised empirical formula are more accurate. Finally, the empirical formula for the permeability parameters of the standard sand is obtained:

\[
I = C \left( a \cup b \cup r^2 \right),
\]

where

\[
C = 0.18 \cdot d_{50}^{0.3} \cdot (C_C \cdot C_U)^{0.8} \cdot (C_C + C_U)^{1.8} \quad \text{and} \quad a' = 40.95 \cdot d_{50}^{0.3} \cdot (1 - n)^2 \cdot n^{-3} \cdot C_C^{0.5} \cdot C_U^2.
\]

### Table 6: Comparison of the fitting accuracy between the modified empirical formula \( I'' \) and the empirical formula \( I' \)

| Particle size range (mm) | Dry density (g/cm³) | \( C_U \) | \( C_C \) | \( (1 - SS_{res}/SS_{tot}) \) |
|-------------------------|---------------------|-----------|-----------|-----------------------------|
| 0.1–0.25                |                     |           |           |                             |
| 0.1–0.25                | 1.446               | 1.00      | 1.00      | 0.9818                      |
| 0.25–0.5                | 1.640               | 1.00      | 1.00      | 0.9434                      |
| 0.5–1                   | 1.694               | 1.00      | 1.00      | -4.6715                     |
| 1–2                     | 1.693               | 1.00      | 1.00      | 0.1536                      |
| 2–5                     | 1.640               | 1.00      | 1.00      | -0.1111                     |
| 0.1–5                   | 1.8190              | 6.00      | 0.75      | -1.9065                     |
|                         | 1.8190              | 6.00      | 1.00      | -1.5727                     |
|                         | 1.8190              | 6.00      | 1.00      | -2.1685                     |
|                         | 1.8190              | 6.25      | 1.00      | -2.1786                     |
|                         | 1.8190              | 5.50      | 1.00      | -2.0925                     |

4. Conclusion

Through the single particle size and different grade standard sand particle seepage test, analyze the seepage law of different standard sand particles in the Darcy-non-Darcy flow zone. The relationship between the parameters \( a \) and \( b \) in the seepage equation and the porosity, average particle size, inhomogeneity coefficient and curvature coefficient and their influence degree are studied, and the following research results have been obtained.

(2) The results of the constant head seepage test show that porosity, average particle size, uneven coefficient, and curvature coefficient are the main factors affecting the drag coefficient \( a \) and \( b \) in the seepage equation. The drag coefficient \( a \) is related to the average particle size, porosity, and uneven coefficient. Both have a negative correlation with the curvature coefficient and have a high correlation. It is found that the permeability of standard sand increases with the increase of average particle size and porosity. When the uneven coefficient of the sample increases, the greater the curvature coefficient, the content of coarse particles increases while the content of fine particles decreases. The arrangement and combination of coarse particles will form larger voids and cannot be effectively filled. The hydraulic path inside the soil is wider, and the soil exhibits better permeability.

(3) The drag coefficient \( b \) has a negative correlation with the uneven coefficient and the curvature coefficient, and the correlation is high, but the correlation between the \( b \) value and the average particle size and porosity is relatively poor. By analyzing the relationship between the drag coefficient \( a \) and the drag coefficient \( b \) it is concluded that the two have a good functional relationship, and the correlation between
the two is very high. The empirical formula of standard sand is obtained by fitting, and the empirical formula is improved by adding correction items and its rationality is verified, and finally, the empirical formula for predicting the drag force coefficient of standard sand is determined. The empirical formula can be applied to different Darcy-non-Darcy flow zones. Prediction of the relationship between flow velocity and hydraulic gradient under the condition of particle size standard sand.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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