Discussion on the Determination Method of Permeability Coefficient in Construction

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Abstract: The permeability coefficient K of groundwater in geotechnical engineering is an important parameter in construction calculation. In this paper, various mathematical expressions of geotechnical permeability coefficient are briefly described, and the method of determining K value through various permeability tests in the laboratory and in the field. Taking the building foundation engineering as an example, this paper focuses on the determination ways and methods in practical engineering. According to the theory of probability and statistics, combined with the actual situation of engineering investigation, the value method of K under the condition of small sample size are analyzed and some suggestions are put forward.

1. Introduction

The construction of foundation engineering is closely related to groundwater. Correctly determining the permeability coefficient of groundwater plays an important role in formulating a scientific, feasible, economical and reasonable foundation engineering construction scheme, adopting appropriate construction technology and drainage measures, improving the construction environment conditions and reducing the project cost. In practice, how to reasonably select the permeability coefficient of each rock and soil layer in the engineering site and provide reliable characteristic indexes for design and calculation is the primary work content of geotechnical engineering investigation, and it is also an important theoretical issue worthy of further discussion.

2. Darcy Law and Permeability Coefficient

2.1 Darcy's Law and Its Mathematical Description

Darcy's law is a basic law in soil mechanics that expresses the physical relationship between groundwater seepage velocity v(x, y, z) and water potential gradient j(x, y, z) in soil pores under laminar flow, and it is a simplified test law. Its significance lies in that the linear relationship between V and J is given from the macroscopic point of view, without paying attention to the interaction between soil and water from the microscopic point of view. In the actual groundwater flow, both K and J values are variables. Because of different angles of argument, Darcy's law can be described by different mathematical models.

The mathematical model of Darcy's experiment is:

$$v = \theta / A = K \cdot j \text{ 或 } v = -K \frac{\partial H}{\partial S}$$

Darcy's law can also be directly derived from the momentum balance differential equation of pore water seepage. Three-dimensional seepage of homogeneous isotropic porous media can be extended to:

$$v = -K(v_x, v_y, v_z)^T = -K\left(\frac{\partial H}{\partial x}, \frac{\partial H}{\partial y}, \frac{\partial H}{\partial z}\right)^T$$

Three-dimensional seepage in heterogeneous isotropic porous media;

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$$v = -K(x,y,z)\left(\frac{\partial H}{\partial x},\frac{\partial H}{\partial y},\frac{\partial H}{\partial z}\right)^T$$

Darcy's law can be simplified to the same expression mentioned above, but the meaning of K is different, when groundwater flows in anisotropic porous media or unsaturated porous media.

2.2 Permeability Coefficient

The proportional coefficient K=K(x, y, z) in the above formula is called the permeability coefficient, which can be expressed as K=v/j or $Ki=n_{rw}/a_i$, and its value is related to the porosity n, the laminar flow resistance coefficient ai(i=x, y, z) of the unit pore fluid, the seepage water potential, the properties of the fluid, etc. It is an important quantitative index to reflect the permeability of rock and soil, which is equivalent to the seepage velocity v when the hydraulic gradient j=1. The engineering investigation revealed that the groundwater in shallow saturated soil layer about 30m deep on both sides of Qiantang River is mainly pore phreatic water and local upper stagnant water. At present, the basement in this area has a maximum of 3 floors, and the depth of building foundation pit is generally less than 15m. Therefore, this paper mainly discusses the permeability coefficient of pore phreatic water in loose sediments of Qiantang River alluvial plain.

3. Determination Method of Permeability Coefficient and Its Applicability

3.1 Determination Method of Permeability Coefficient

Permeability coefficient can be directly measured by experiment. There are two kinds of determination methods: indoor penetration test and field test.

3.1.1 Indoor Penetration Test

The test can be divided into constant water head method and variable water head method. The constant head method is suitable for sandy soil, gravel soil, etc. The Darcy penetration test mentioned above also belongs to this category. Variable head method is suitable for silt, cohesive soil, etc. Because the permeability coefficient of cohesive soil is small and the amount of water flowing through the sample is also small, it is difficult to measure accurately, so the variable head method is adopted.

3.1.2 Field Test Method

Field test and determination methods commonly use borehole pumping test or borehole water injection test. The whole or incomplete submersible pumping well test should be adopted in the construction project.

3.1.3 Empirical Method

It is determined that K generally adopts B. Hansen's Ultimate Bearing Capacity Formula for loose sand; Sainarasinghe and other formulas are used for cohesive soil. Most natural sedimentary soil layers encountered in civil engineering are composed of several layers of soils with different permeability coefficients, which are macroscopically heterogeneous. The commonly used research method is to treat the movement of groundwater in heterogeneous soil layer (equivalently) as that in homogeneous soil layer. The equivalent permeability coefficient is related to the direction of water flow. Due to the different seepage directions, it can be divided into three situations: parallel plane, vertical plane and oblique plane. In geotechnical engineering investigation, only two permeability coefficient values of horizontal and vertical layers are generally provided. It is more common in engineering that the elevation of the same water-bearing layer revealed by different boreholes is inconsistent, that is, the direction of seepage flow is neither horizontal nor vertical along the layer, but arbitrarily oblique. At this time, K'_V and K'_H obtained by the above method are only an approximate value (special case). A more accurate method is to calculate its equivalent (average) permeability coefficient K “m first, and then calculate the K_V and K_H values concretely.

3.2 Applicability

(1) The equipment for measuring K value in the laboratory is simple and the cost is low. However, because the permeability of soil is related to the structure of soil, coupled with the disturbance during sampling, it is difficult to obtain representative undisturbed soil samples, especially sand. Therefore, the obtained K value can hardly reflect the actual permeability of soil. Field measurement of permeability coefficient can obtain a more reliable K value, especially for homogeneous coarse-grained soil layer. At present, there is no more superior method to replace it. However, the field test takes a long time and costs a lot, which is beyond the affordability of ordinary engineering projects. According to the author's understanding, the large-scale on-site water pumping (injection) test of different rock and soil layers in this area was only tested in 1960s and 1970s by the Hydrogeology Engineering Geology Brigade of the former Provincial Bureau of Geology and Mineral Resources. The obtained data has high reliability and great utilization value, and the depth involves the whole Quaternary loose sedimentary layer, including aquifers of various types of groundwater, and the test range is wide and systematic. However, after decades of large-scale civil engineering activities and extensive exploitation and utilization of groundwater, the test data of that year is far from the actual situation today. On the contrary, real-time valuable empirical data that can be used for design and calculation are sparse.

(2) The equivalent permeability coefficient of layered soil layer is obtained by laboratory test. K_H value is the average value of the permeability coefficient of each soil layer weighted according to the corresponding soil layer thickness, which depends on the thickness H' and permeability K' of the most permeable soil layer, and can be approximately expressed as KH = K' H'/H. While the K_V perpendicular to the layer depends on the thickness H “and water permeability K” of the least permeable layer, and can be approximately expressed as kv = K' H'/H.

(3) In the national standard *Code for Investigation of Geotechnical Engineering (GB50021-2001)*. According to the relationship between soil permeability and consolidation process, it is pointed out that consolidation coefficient, volume compression coefficient and permeability coefficient KV and KH [2] can be measured by consolidation test for soft soil with low permeability. However, this method, like other indoor test methods, has many errors caused by human factors, and sometimes the calculated results are several orders of magnitude different from the measured values tested by other methods.

4. Several Application Problems of Permeability Coefficient

Permeability coefficient, with its irreplaceable position, or independently or in the form of Darcy's law, has always run through many disciplines closely related to construction engineering, such as groundwater dynamics, soil mechanics and foundation engineering, soil elasto-plastic mechanics, engineering geotechnical hydraulics, fluid mechanics, etc.

(1) From the vertical (KV) and horizontal (KH) permeability coefficients and Darcy's law, the basic equation of plane steady flow can be deduced [3]. When groundwater permeates in isotropic homogeneous soil, $K_x=K_y=K_z=K,\Delta^2V=0$, where $V=V(x, y, z) =-K_H$ is the velocity potential function and Δ^2 is Laplace operator.

(2) When designing various building foundations, calculate and determine the anti-floating fortification water level of basement and the uplift force of groundwater on structures; The calculation of consolidation settlement compression deformation (consolidation degree of foundation, final settlement, time factor, etc.) of the stressed layer of foundation is related to the permeability coefficient of the corresponding soil layer.

(3) In the calculation of seepage force (hydrodynamic force) J, and in the study of seepage failure phenomena such as quicksand (soil) and piping caused by J, it is found that the failure of seepage force is closely related to the particle size distribution, density and water permeability of soil, that is, it is related to the permeability coefficient K of soil. The larger the permeability coefficient of soil, the lower the critical hydraulic gradient when quicksand (soil) occurs. In recent years, the research on the retaining structure of wrecked foundation pit also found that all of them are related to the seepage failure of groundwater. As we all know, the water inflow of foundation pit is directly related to k value.

5. Discussion on the Determination Method of K Value in Engineering

5.1 Engineering Examples

The test data and statistical results of permeability coefficient of foundation soil layer of Agricultural Development Building are listed below. The project site consists of three 28-story tall buildings with two basements. The perimeter of the foundation pit is about 455m, and the excavation depth is 9.8~11.4m. The east side is the established farm house; The south side is next to Star Plaza (18th floor, frame, prestressed pipe pile foundation); The west side is close to the sidewalk and subway stop (under construction) of Shixin North Road, with dense pipelines under the sidewalk, and the current situation around the foundation pit is very complicated.

The equivalent permeability coefficient of layered soil is calculated by the following formula:

$$\bar{K}_{Vm} = \frac{\sum_{i=1}^{4} M_i}{\sum_{i=1}^{4} \frac{M_i}{K_i}} = 7.83, \quad \bar{K}_{Hm} = \frac{\sum_{i=1}^{4} K_i M_i}{\sum_{i=1}^{4} M_i} = 12.74$$

According to the statistics, $K_V max=22.0$, $K_V min=3.1$ and $R_V=18.9$.

Standard deviation $S_V=5.56$, coefficient of variation $C_V=0.7024$, $K_H max=27.0$, $K_H min=2.8$, range $R_H=24.2$, standard deviation $S_H=8.6$, coefficient of variation $C_H=0.6771$. It can be seen that:

(1) Compared with hierarchical calculation, the weighted average calculated by formula is simpler, and the kurtosis and skewness of the mean value of arithmetic average method are reduced.

(2) Compared with the silty clay of layers ② and ③, the K value of layer soil becomes larger and gradually tends to the side of permeable soil layer.

(3) R, S and C, which represent the degree of data dispersion, are all large, indicating that the data size is wide and scattered. No matter horizontal or vertical, the soil layer④is generally an interbedded layer composed of soils with different water permeability.

5.2 Analysis and Discussion

The author comprehensively analyzes and compares the experimental studies of permeability coefficient given by several geotechnical engineering investigation reports, and holds that the following problems generally exist: First, the number of samples is too small, the longitudinal sampling depth is even less than the excavation depth of foundation pit, and the measured data is not representative and does not meet the statistical requirements; Second, the test data of different laboratories are very different, and some similar soils in the same site are 10 ~ 20 times different; Third, the determination of K value is not divided into K_V and K_H, so a general K value is proposed, or $K_V > K_H$, which is inconsistent with the conclusion that K_H is always greater than K_V. Therefore, the survey unit should strictly follow the requirements of geotechnical engineering survey specifications [2, 5], consider the sampling spacing in the vertical and horizontal directions, collect enough representative geotechnical samples, and send them to a qualified laboratory for testing to determine the K value. The size of sample capacity reflects people's generalization and understanding of sampling population, and reflects the quality level of geotechnical engineering investigation. The position of the sample of high-rise building with basement should at least exceed a certain depth of the foundation pit, which provides reliable design parameters for the construction scheme of foundation pit engineering.

6. Conclusion

To sum up, the permeability of soil is one of the key problems in soil mechanics, and K is the main index to characterize the permeability of soil. In building engineering, the permeability of soil mainly involves three basic problems: seepage calculation, seepage failure and seepage control. No matter which problem, K value plays an important role. However, people's understanding of its importance is still different in different degrees.

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