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A Review on Soil Suction and its Determination Methods

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Abstract: Soil is in unsaturated state most of the time. For which suction is an important characteristic of. Also, it is the key and difficult point to study unsaturated soil. In this paper, soil suction and its classification are introduced through literature collation and analysis. At the same time, various methods of measuring suction and their advantages and disadvantages are summarized.

Keywords: Soil Suction; Determination Methods; Methods of Measuring Suction.

1. Introduction

In practical engineering, most of the soil is non-saturated. Unsaturated soil is a composite material composed of solid-liquid-gas three-phase. Its complex engineering properties are self-evident. It has always been one of the topics of academic concern. Suction is the water adsorption and retention capacity of soil matrix. It is the key and difficult point in the study of unsaturated soil [1].

The change of soil moisture content is an important factor in the change of suction, and the change of climate and groundwater level will cause the change of soil moisture content. The soil water characteristic curve shows the curve of soil suction changing with water content, indicating the strength of soil water holding capacity, which is closely related to soil permeability [2], strength [3] and deformation strength [4]. It is an important tool for studying unsaturated soil. Fully understanding the variation of suction is an important part of unsaturated soil. At present, although there has been great development in suction research, there are still many immature places. On the one hand, due to the three-phase complexity of unsaturated soil, it is difficult to accurately measure the relationship between suction and various influencing factors; on the other hand, the measurement of suction requires high precision and operation of the instrument, and the measurement time is long. Further understanding of the variation law of unsaturated soil suction has important practical significance for vegetation water use efficiency [5], support structure in geotechnical engineering, and parameter optimization of foundation design.

2. Classification of Soil Suction

Suction represents the work done to convert unit volume water from free water state to pore water state in soil. The total suction is the sum of matric suction and osmotic suction. The effect of each part depends on the mineral composition, water content and solute concentration of the soil.

2.1. Matric Suction

The matric suction is generated by the interaction between the surface of soil particles and pore water and pore gas. For sand, silt, silt and low plastic clay and other soils, which do not contain expansive clay minerals or less expansive clay minerals, the influence of pore salt solution concentration can be ignored, so the soil-water interaction is mainly reflected by matric suction.

In the 1950 s, scholars realized that the influence of suction should be considered to fully describe the basic behavior of unsaturated soil, and the difference between pore pressure and pore water pressure (ua-uw) was used to characterize the matric suction. This variable actually represents the capillary part of soil-water interaction, which is mainly affected by the water-air interface and is affected by the change of saturation. The capillary part of matric suction has two main effects on the basic behavior of unsaturated soil: (1) the change of matric suction will cause the change of average pressure of pore fluid, and then change the average contact stress of soil skeleton; (2) The gas-liquid interface has a tensile effect on the unsaturated soil particles, and the formation and disappearance of the bending surface will affect the structure of the unsaturated soil.

When the fine particle content in the soil is dominant, the matric suction is actually the approximate sum of the capillary part and the adsorption part. Which part is dominant depends on the mineral composition and water content of the soil. In fine-grained soil, the adsorption part is dominant. However, there is currently no effective test method to clearly distinguish the capillary and adsorption parts of matric suction.

2.2. Osmotic Suction

The presence of salt in the pore solution will also reduce the soil water potential energy and increase the measured suction value. The suction caused by the solute concentration in the pore solution is called osmotic suction. The osmotic suction is related to the type and concentration of solute and the semi-permeable membrane characteristics of soil. For soil with more expansive minerals, under the electric field generated by the negative charge on the surface of the particles, the clay will show a certain semi-permeable membrane characteristic, inhibiting the passage of some solutes in the pore solute.

3. Determination Method of Soil Suction

3.1. Determination Method of Total Suction

(1) Humidity meter

Thermocouple hygrometer can be used to measure the total suction of soil. In fact, it is to measure the relative humidity of gas in soil pores or air near soil. There are two basic types of thermocouple hygrometers, one is wet ring type and the other is Peltier type. The working principle of the two types of hygrometers is to measure the temperature difference between the non-evaporating surface (dry ball) and the evaporating surface (wet ball). The temperature difference between these two surfaces is directly related to relative humidity.

The difference between the wet ring type and the Peltier type hygrometer is that the way of humidifying the evaporation contact is different to increase the evaporation. In the wet ring hygrometer, the evaporation contact is humidified by injecting a drop of water into the small silver ring; in the Peltier hygrometer, evaporation is caused by the Peltier current through the evaporation contact. The Peltier current cools the contact below the dew point, so that a small amount of water vapor condenses on the contact. Peltier hygrometer is the most commonly used in geotechnical engineering. Its main working principle is Seeback effect and Peltier effect.

(2) Filter paper method

Filter paper method for measuring suction in soil has been developed in the field of soil science and has been widely used in agricultural soil science. The filter paper method has also been used in geotechnical engineering. However, at present, the filter paper method has not been widely accepted in geotechnical engineering, and further research on the application of this technology in engineering is needed.

In theory, the filter paper method can be used to determine the total suction or matric suction in soil. The filter paper is used as a sensor, and the filter paper method is an ' indirect method ' for measuring suction in soil. The filter paper method is based on the assumption that the filter paper can be balanced with the soil with a certain suction (in the sense of water flow). Water or water vapor exchange between soil and filter paper can reach equilibrium. When the dry filter paper is placed on the soil sample and in direct contact with the soil sample, water flows from the soil into the filter paper and reaches equilibrium. At this time, the matric suction of the soil is measured. When the dry filter paper is suspended above the soil sample (that is, not directly contacting the soil), the water vapor will enter the filter paper from the soil and reach equilibrium. The water content of the filter paper is measured when the equilibrium is reached, and the total suction of the soil is measured at this time.

The water content of filter paper has a certain relationship with the suction value. The same calibration curve of filter paper can be used to determine the matric suction and total suction. The filter paper method can be used to measure a wide range of suction values, usually in the laboratory, using undisturbed or disturbed soil samples taken from the field.

3.2. Determination Method of Soil Matric Suction

The matric suction can be measured directly or indirectly. Negative pore water pressure was measured by direct method. The pore water pressure is usually equal to the on-site atmospheric pressure, and the pore gas pressure minus the negative pore water pressure is the matric suction. The methods of testing matric suction mainly include tensiometer method, pressure plate method, Temple instrument (pressure film instrument), centrifuge method, filter paper method, thermoelectric sensor method, TDR probe, GDS four-dimensional stress path method and so on. Generally, high intake value ceramic plate is used to directly measure negative pore water pressure. In addition, there are several porous media sensors for indirect measurement of matric suction. The electrical and thermal properties of standard ceramics are functions of water content, which is also a function of matric suction. The matric suction in the sensor and its surrounding soil can be known by measuring the electrical or thermal characteristics of the sensor.

(1) Direct measurement

There are two types of devices commonly used for direct measurement of negative pore water pressure, namely tension meters and shaft translation devices (pressure plate apparatus and pressure membrane apparatus). The tension meter uses a high air entry value ceramic plate as the interface between the measurement system and the negative pore water pressure in the soil. Tension meters can be used indoors and outdoors. The shaft translation device can only be used for laboratory determination, but the measurement range of tension meters is generally small.

(2) Indirect measurement

The standard porous material can be used to make sensors to indirectly measure the matric suction of soil. The soil-water characteristic relationship of many porous materials has been determined to select the most suitable material to make the sensor. The porous material sensor is placed in the soil to balance the matric suction in the soil. At this time, the matric suction in the porous material is equal to the matric suction in the soil. The matric suction in porous materials can be inferred from the water content of porous materials. The water content of porous materials can be determined by measuring their conductivity or thermal conductivity. Conductivity and thermal conductivity are functions of water content and can be calibrated in advance. The conductivity and thermal conductivity of the porous material sensor under different matric suction conditions are measured at a fixed rate. In this way, according to the conductivity or thermal conductivity measured when the porous material sensor reaches equilibrium with the matric suction in the soil, the matric suction in the soil can be obtained from the calibration curve.

Among the methods mentioned above, tensiometer method, pressure plate method and filter paper method are most used in the measurement of matric suction. Tensiometer can be used in a relatively narrow area, high sensitivity, easy to operate, but the range is relatively small; the pressure plate method can measure the matric suction range slightly larger than the tensiometer, but the test period is long, and the reading of the volume change tube needs to be read many times. The filter paper method is an indirect method to test the matric suction. It can basically test the soil-water characteristic curve in the whole range (0-300000 kPa), and the operation is simple and is lower cost.

3.3. Measurement Method of Soil Osmotic Suction

(1) Saturated leaching method

Distilled water can be added to the soil to make the soil close to the fluid state, and then some water can be removed to measure the conductivity of the soil. According to the conductivity, the osmotic suction corresponding to the natural water content can be obtained by linear extrapolation. This method is simple, but the measured osmotic suction is not accurate.

(2) Squeezing method

The seepage suction in soil can be indirectly estimated by measuring the conductivity of pore water. Compared with pure water, the pore water with dissolved salt has higher conductivity. According to the conductivity of pore water, the total concentration of dissolved salt can be known, and the osmotic suction of soil is related to the total concentration of dissolved salt. The pore water in the soil can be taken out with a thick-walled cylinder piston extruder, and then the resistivity (or conductivity) of the pore water taken out is measured. Using the calibration curve, the seepage pressure of soil can be obtained according to the conductivity. The osmotic suction obtained by the squeezing method is close to the measured total suction minus the matric suction.

4. Conclusion and Prospects

(1) This paper introduces the common determination methods of soil suction. It can be seen that the determination of soil suction generally has high requirements for instruments and personnel, and the test methods applicable to various determination methods are limited. In order to obtain a relatively complete soil moisture characteristic curve, several test methods can be combined.

(2) The determination methods of soil suction are mostly time-consuming and laborious. Therefore, it is necessary to strengthen the research on the indirect determination methods of suction, such as using the basic physical properties of soil and pore distribution curve to predict the soil water characteristic curve, or based on big data combined with genetic algorithm and artificial neural network to establish empirical models.

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