Recent Techniques for Measuring the SWRC of Unsaturated Compacted Bentonite Buffer

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1. Introduction

This paper introduces the principal concept of soil-water retention curve (SWRC) and reviews the SWRC measurement technique reported in the literature. In addition, a measurement technique suitable for the SWRC measurement of unsaturated compacted bentonite buffer is suggested.

2. Soil-Water Retention Curve

The soil-water retention curve represents the relationship between suction versus volumetric water content in unsaturated media. This is an important input data for analyzing the water movement and mechanical behaviour of unsaturated media. The suction (S) is determined by measuring the water potential (ψ), and it is the negative value of water potential. That is, $S = -\psi$.

The water potential is conceptually the water movement capacity in the unsaturated medium. The total water potential (ψ_t) is expressed as the sum of the matric potential (ψ_m), osmatic potential (ψ_o), gravitational potential (ψ_g), and mechanical pressure potential (ψ_p) as follows:

$$\psi_t = \psi_g + \psi_m + \psi_o + \psi_p \qquad (1)$$

Once the SWRC is determined by measuring the water potential, the next step is to determine the retention model that best fits the experimentally obtained SWRC. Many retention models are presented in literature. Of these models, van Genuchten equation has been widely used for analyzing the hydro-mechanical behaviour of the unsaturated bentonite buffer.

3. Axis translation technique(ATT)

The ATT was first proposed by Hilf (1956). This technique, which has been widely used in the field of civil engineering, assumes liquid transfer (i.e., the liquid phase in a porous medium undergoes an increase in pressure equal to that of the gaseous phase) and does direct measurement of matric water potential. The main reason for the use of this technique is to avoid cavitation when measuring matric water potential greater than 10 kPa. In the ATT, the pore water pressure in the porous medium is increased to a positive reference pressure (u_w). Matric water potential in the medium is applied by increasing the pore air pressure (u_a). A high-air entry ceramic disk is normally used to provide separation between water and air pressure. The ceramic disk is not an impermeable membrane to dissolve salts in the medium. Therefore, water flow due to osmatic effects is bypassed since the water flow is an advective process in this case. The matric water potential (ψ_m) is determined by the following equation: $\psi_m = u_a - u_w$

4. Vapor equilibrium technique(VET)

This technique overcomes the limitation of the ATT for applying high suction. The VET, which indirectly determined the total water potential from the measured relative humidity (RH), assumes vapor transfer and equilibrium with pore water in the porous medium. The thermodynamic relationship between total water potential and relative humidity is based on Kelvin's law:

$$\psi_t = 10^{-6}\,(RT/V_w)\ln(RH/100) \qquad (2)$$

where ψ_t is total water potential[MPa], R is universal gas constant[8.3143 J/K mol], T is absolute temperature, V_w is molar volume of water[1.8×10^{-5} m^3/mol]. The equilibrium requirement is that the potential of water in its liquid and vapor phases must be the same. Therefore, the water exchange between the pore water and the vapor includes the effect of capillary action, osmatic force, and sorptive forces. This technique is applied especially in the case of high water potential values. Two types of tests are mainly used in this VET technique: cell method and block-sensor method.

Cell method The water potential has been determined in cells kept inside desiccators in which the water potential can be controlled. Imposing a relative humidity is based on the fact that this conditions the pressure of the water and gas in the pores. This humidity may be imposed by means of any salt solutions that know its water activity. The measurement sample exchanges water with the atmosphere until thermodynamic equilibrium is reached with vapor pressure of the solution, as a result of which total water potential is changed. The water potential in the pores of the sample is determined by means of the Kelvin's law of eqn. (2). However, this technique has a limitation to take a long time to reach the thermodynamic equilibrium when applying it to highly compacted bentonite buffer.

Block-sensor method The water potential can be determined at constant volume and as a function of the salinity of the interstitial water as well as temperature. The most important feature of this method is that the time required for measurement can be greatly shortened comparing with that of the cell method. This method consists of the measurement, through a capacitive sensor, of the relative humidity of blocks of bentonite highly compacted to different dry densities and water contents. Fig. 1 shows an experimental apparatus for measuring the total suction of compacted bentonite with hygroscopic water content [1]. The compacted bentonite is prepared by adjusting the water content of the powdered bentonite and then compacting it to a desired dry density. The adjustment of the water content is done by adding de-mineralized water to the dried bentonite by pre-weighed amounts using an ultrasonic humidifier. After the water content adjustment, the bentonite is compacted in a cylindrical cell (0.05 m in inner diameter and 0.05 m in length) to a desired dry density using a hydraulic press; a hole is drilled in it to allow a capacitive hygrometer sensor to be installed inside; then it is left in a desiccator for more than 3 days for its water content equilibrium. The compacted bentonite and connecting devices are assembled, which is followed by measuring the relative humidity of the compacted bentonite. The total suction of the unsaturated compacted bentonite is determined from the measured relative humidity using Kelvin's law of eqn. (2).

5. Summary and Conclusions

The SWRC represents the relationship between suction and volumetric water content. The suction can be determined by measuring the water potential. The total water potential of the unsaturated media includes matric potential, osmatic potential, gravitational potential and mechanical pressure potential. The soils of the civil engineering field usually determine the suction by measuring the matric potential, while the suction of the bentonite buffer should be determined by measuring the total water potential because the contribution of the osmatic potential to it is also important. To determine the suction of the unsaturated compacted bentonite buffer, a block-sensor method based on VET was appropriate and effective.

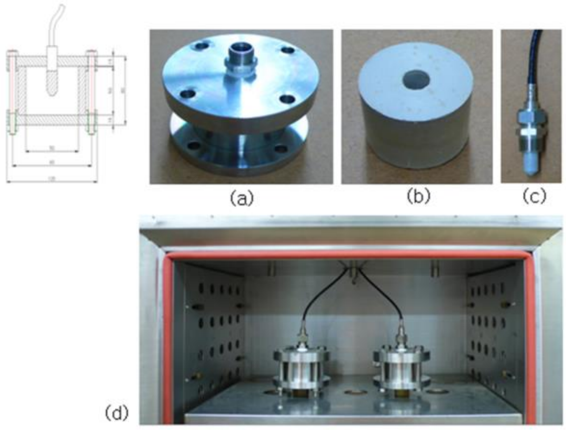

Fig. 1. Experimental apparatus for the suction measurement: (a) cylindrical cell and its housing (b) compacted bentonite (c) relative humidity sensor (d) dry oven with installed cylindrical cells [1].

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REFERENCES

[1] Jae Owan Lee, Won Jin Cho, Sangki Kwon, "Suction and water uptake in unsaturated compacted bentonite", Annals of Nuclear Energy 38, 520-526 (2011).