Water Retention Characteristics of Water Repellent Soils using Continuous Pressurization Method

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ABSTRACT: In this paper, the water retention test on water-repellent soils were performed investigating their water retention characteristics. For this, a newly established water retention testing system which uses a continuous pressurization method was utilized and the water repellent sand was prepared artificially. As a result, the testing time for the drying and wetting processes in the soil water characteristic curve using the method was remarkably shortened. The air entry value of the water-repellent soil is similar to that of the hydrophilic soil, while the water entry value and water infiltration value of the water repellent soil are smaller than the hydrophilic soil. Even with a limited data, this indicates that the effect of the repellent state on soil has a larger hysteretic behavior than the hydrophilic state on soil due to material characteristics.

1 INTRODUCTION

In general, a natural soil can be changed into a water repellent state as a secondary effect due to environmental pollution such as oil leaks and natural disasters like forest fires. Many studies have focused on water repellent soils under such a special environment (e.g., Derjaguin and Churaev, 1986; Rodriguez and Newaz, 1997; Nguyen et al., 1999; Frattolillo et al., 2005; Goebel et al., 2007; Kim et al., 2014 etc.). These results have led to a grasp of the physical, mechanical and hydraulic properties of water repellent soils. Creating the properties of the water repellent soil in the field of the geotechnical engineering has been applied in the field (e.g., Lourenço et al. 2015; Zheng et al. 2017).

On the other hand, unsaturated ground disasters, such as collapses of river levees and natural slopes caused by the infiltration and erosion of rainfall, are frequently occurring now. A better understanding of the infiltration phenomenon on unsaturated soils is an important issue for global environmental problems such as the safety evaluation and the contaminant transport of soils and groundwater. Therefore, to deal with these problems, the water retention characteristics of unsaturated soils must be obtained for engineering purposes.

Up until now, it has been much easier to get the drying curve of the water retention characteristic rather than wetting curve. To accelerate the testing procedure, the water retention test by the continuous pressurization method would be a new alternative against the pressure plate method by the conventional stepwise pressurization method for the testing efficiency and shortening of the test time (Kato et al. 2015).

In this paper, the water retention testing apparatus of the continuous pressurization method is used for evaluating water repellent soils which were artificially produced by silanization. From these results, the use of the continuous pressurization method and the water retention characteristics of the water repellent sands are discussed together.

2 TESTING PROGRAM

2.1 *Soil sample*

The soil sample used in this study is Toyoura sand which is a standard sand in Japan (specific gravity, G_s=2.64, maximum void ratio, e_{max}= 0.977, and minimum void ratio, e_{min}= 0.605). This material is relatively uniformized (coefficient of uniformity C_u=1.38) with the mean particle size D_{50}=0.161 mm. In this study, the Toyoura sand without any treatment are tested as hydrophilic soil whereas the Toyoura sand treated chemically by silanization using silane solution (Zycosoil manufactured by Zydex industries, dilluted ratio=1:100 with water) are tested as water-repellent soils. In the silanization, clean Toyoura sands were fully submerged into the silane solution and the chemical reaction then was allowed to occur for 72 hours under a constant temperature condition. The chemical reaction formula for the silanization is as follows.

Figure 1. A water droplet on water repellent Toyoura sand.

$$\equiv \text{Si-OH} + C_8H_{17}Si(OC_2H_5)_3 \Rightarrow \equiv \text{Si-O-Si}(OC_2H_5)_2C_8H_{17} + C_2H_5OH \quad (1)$$

Then, the mixture of sand and solution was oven-dried at 110°C for 24 hours. Figure 1 shows the water repellent Toyoura sand treated with the silanization.

2.2 *Testing apparatus used*

Figure 2 shows the schematic diagram of a testing apparatus improved and manufactured based on the continuous pressurization type. In the nonstationary type such as the pressure plate method increasing the supplying pressure, since the pore air and pore water pressures increases separately, it is impossible to measure the suction like the same testing apparatus using as the pressure plate method with the stepwise pressurization. Thus, a micro-tensiometer was adopted to measure the transient pore water pressure with the continuous change of the pore air pressure. The suction for the specimen is given as the pressure difference between the pore air and pore water pressures. The micro-tensiometer (25 mm in height and 3 mm in diameter, and the used ceramic porous cup has an air entry value, AEV of 100kPa) is placed vertically in the center of the pedestal as shown in Fig. 3, and measures the average pore water pressure of the specimen. In addition, a donut-shaped ceramic disk (AEV= 100kPa) in this device was installed in order to perform from water drainage to water absorption (drying and wetting processes) from the specimen (see Fig. 3).

After a specimen was placed in a pressure chamber, a specified air pressure equivalent to the pore air pressure, was applied to the saturated specimen. This pore air pressure was measured by a pore air pressure transducer connected to the chamber. Also, the pressurization and decompression speed of the air pressure were controlled by the electro-pneumatic controller through the D/A converter by the measuring program of the computer (see Fig. 2).

On the other hand, when the pore air pressure is applied to the specimen, the pore water pressure was measured by the pore water pressure transducer connected with the micro-tensionmeter. Measured data for the pore air pressure and the pore water pressure in the specimen were transferred to the computer by the data logger. Changes in the amount of water discharged from the specimen during the drainage and absorption processes were measured by an electronic scale and transferred to a data logger. Such measurements was automatically performed during the test.

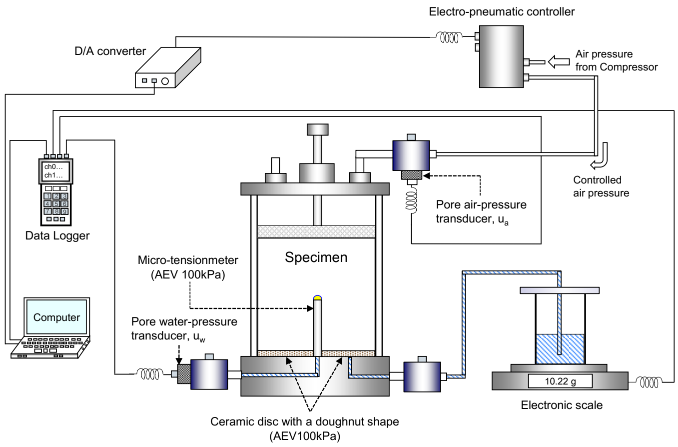


Figure 2. The schematic diagram of test apparatus.

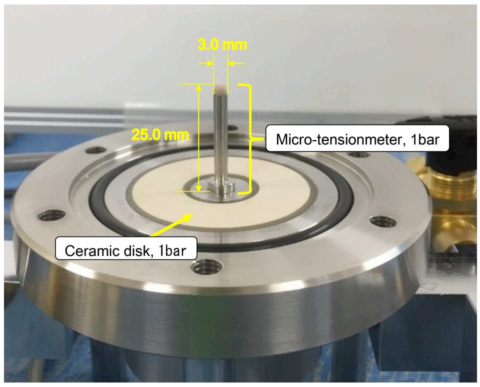


Figure 3. The micro-tensiometer installed in the center of the pedestal.

Table 1. Initial condition and AEV, WEV and WIV of hydrophilic and water repellent soils.

No.		γ_d (kN/m³)	S_{ri} (%)	AEV (kPa)	WEV (kPa)	WIV (kPa)
Hydrophilic Soil	1	14.4	48.2	2.7	1.1	8.0
	2	15.0	58.7	2.2	1.3	6.3
Water repellent Soil	1	15.1	51.4	3.0	0.7	1.9
	2	14.4	58.7	3.0	0.7	2.0

* Note: AEV: air entry value, WEV: water entry value, WIV: water infiltration value.

2.3 *Testing procedure*

The cylinder shape specimen of 50 mm in diameter and 50 mm in height was prepared using the static compaction method. The conditions of each specimen were summarized in Table. 1. Before setting the specimen, the ceramic disk and micro-tensionmeter are completely saturated with de-airing in water through vacuum, and the drainage lines connected to the weight-measuring device are also saturated with water. After the specimen is inserted into the test cell (acrylic mold), in order to secure the insertion space of the micro-tensionmeter, a hole of 25.0 mm in depth and 3.0 mm in diameter on the specimen is prepared using an electric drill on the specimen. The specimen is installed in the center of the pedestal in accordance with the drilled hole. At this time, it is careful that the micro-tensionmeter should be placed in the direction perpendicular to the specimen, because the inappropriate contact between the specimen and the micro-tensionmeter would affect the pore water pressure. After assembling the main body, the specimen is saturated by inundation. The pressurization and decompression processes are performed at a predetermined constant speed of pressure change for the chamber. For example, these processes in this study are performed under the pore air pressure conditions such as 0kPa → 80kPa→ 0kPa at 0.1 kPa/min. During the test, all data was recorded by the measuring system.

3 RESULTS AND DISCUSSION

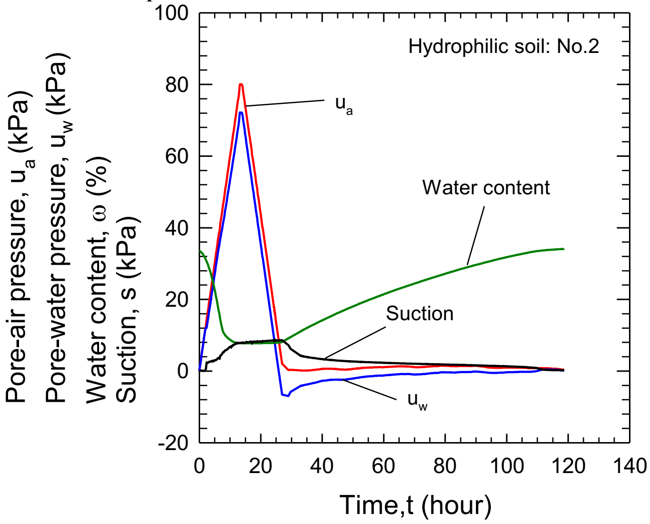
3.1 *Test results for hydrophilic soil*

The water retention test for each two cases using hydrophilic and water repellent soils (Toyoura sand) was carried out in this study. Figure 3(a) shows the relationship between elapsed time and the pore air pressure (u_a) supplied, the pore water pressure (u_w) measured and the water content of hydrophilic soil No.2. It is found that the drying and wetting processes of the soil water characteristic curve (SWCC) were finished at the testing time of 120 hours (5 days). It can be observed that the pore air pressure increased linearly to 80 kPa and then decreased to 0 kPa at 0.1 kPa/min. Because the water content through the drainage from specimen decreased, the measured pore water pressure is smaller than the pore air pressure. Thus, it should be noted that the difference of two pressures becomes the suction(s) value. The equation is as follows.

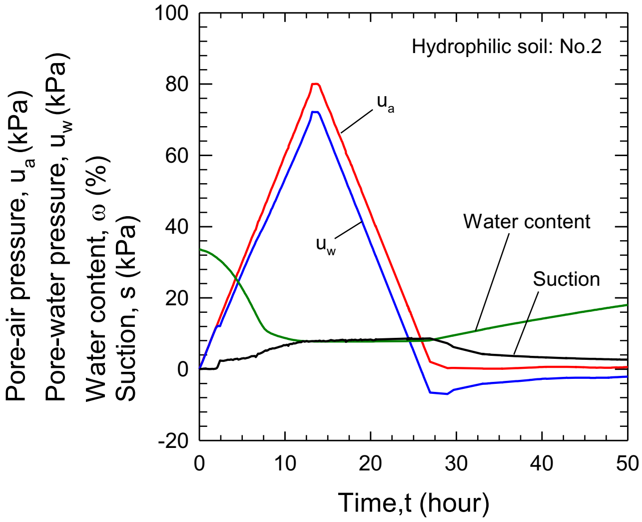
$$s = u_a - u_w \tag{2}$$

The most part of drying curve of the SWCC is obtained during these increasing and decreasing processes. These processes can be observed more specifically through the expanded relation within 50 minutes in the Fig. 3(b).

On the other hand, when the pore air pressure of 0 kPa was maintained after the testing time of about 30 hours, the negative pore water pressure was measured. During this process, the suction value decreased and the wetting curve of the SWCC was measured. It is found that the water content increases at this process. Figure 4 shows the SWCC of the hydrophilic soil No.2 obtained within the testing time of 50 hours through the water retention test by the continuous pressurization method. Thus, it was confirmed as a result that the testing time for the drying and wetting processes in the SWCC using the continuous pressurization method can be remarkably



(a) Full time.



(b) Expansion of time scale within 50 minutes

Figure 3. Measurement results of hydrophilic soil No. 2.

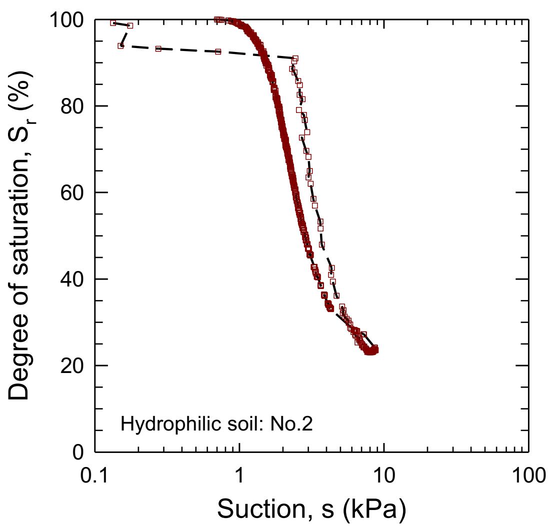
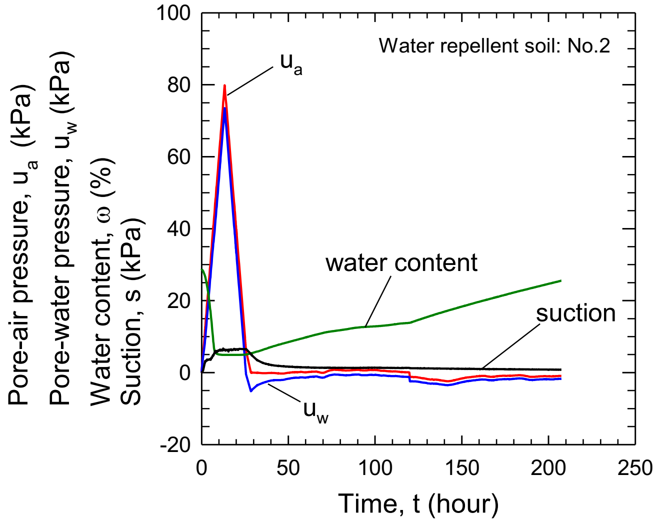
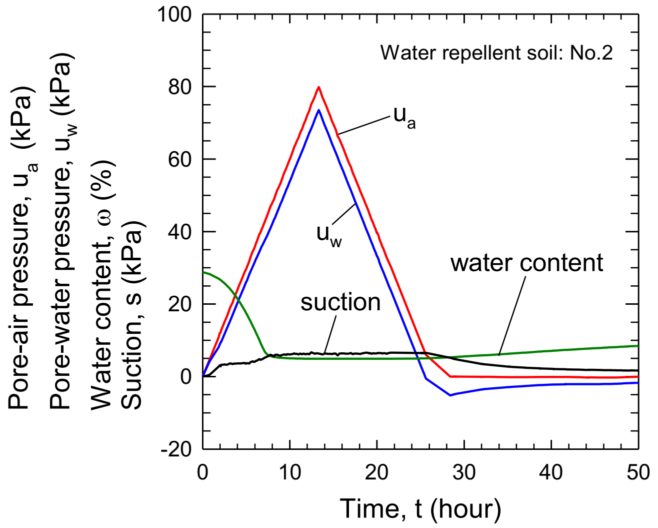


Figure 4. The SWCC of hydrophilic soil No. 2.

shortened. In addition, the results of the air entry value (AEV: 2.7kPa & 2.2kPa) and the water entry value (WEV: 1.1kPa & 1.3kPa) of the hydrophilic soil No.1 and No.2 in Table 1 are similar to those of Kato et al. (2014) using Toyoura sand.



(a) Full time



(b) Expansion of time scale within 50 minutes

Figure 5. Measurement results of water repellent soil No. 2.

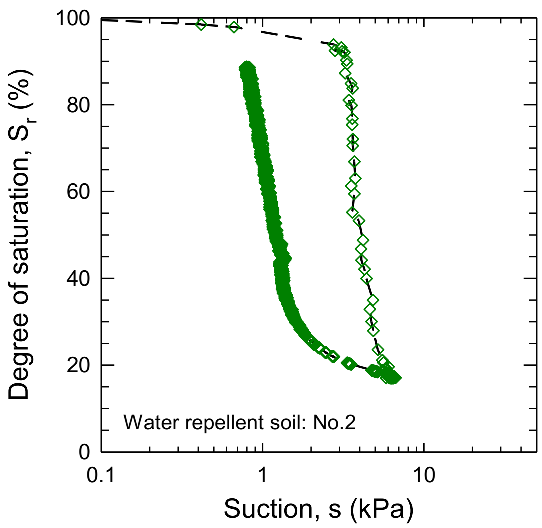


Figure 6. The SWCC of water repellent soil No. 2.

3.2 *Test results for water repellent soil*

Figure 5(a) shows the relationship between elapsed time and the pore air pressure supplied, the pore water pressure measured and the water content of water repellent soil No.2. The drying and wetting processes of the SWCC were finished at the testing time of 200 hours (8.3days). As shown in Fig. 5(a), unlike the water repellent soil, it is found that the elapsed time of the absorption process of the hydrophilic soil is longer than the water repellent soil. This process can be also observed more specifically through the expanded relation within 50 minutes in the Fig. 5(b). The SWCC of the water repellent soil could be also obtained through the water retention test by the continuous pressurization method as shown in Fig. 6. The results of the AEV: 3.0kPa & 3.0kPa) and the WEV: 0.7kPa & 0.7kPa) of the water repellent soil No.1 and No.2 were obtained.

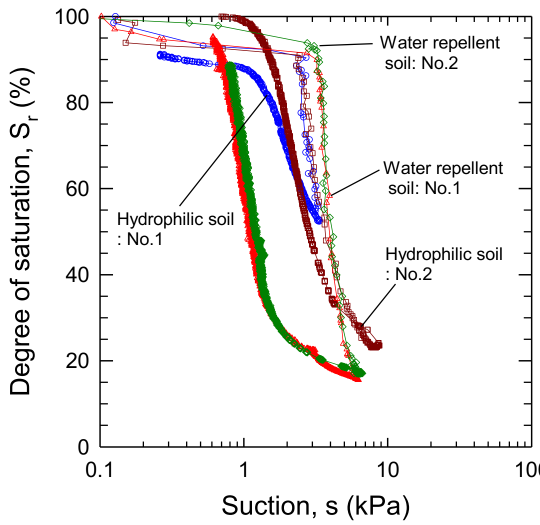


Figure 7. Comparison of the SWCCs of hydrophilic and water repellent soils.

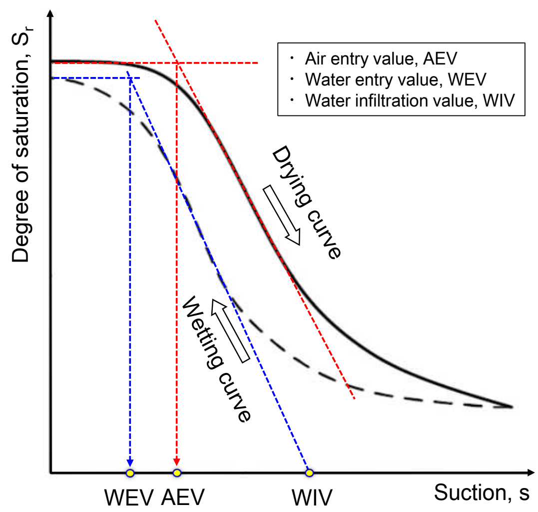


Figure 8. Definitions of AEV, WEV, and WIV in the SWCC.

3.3 *Comparison of test results of hydrophilic and water repellent soils*

Figure 7 shows the comparison of the SWCCs for 4 cases of hydrophilic and water repellent soils. The AEV, WEV, and WIV (water infiltration value) in this study are defined as shown in Fig. 8. In particular, the WIV represents an infiltration capacity that the water infiltrates into the specimen in the dry state. Based on this definition, the WIVs of the hydrophilic soil No.1 & 2 (8.0 kPa & 6.3 kPa) and water repellent soil No.1 & 2 (1.9kPa & 2.0kPa) were summarized in Table 1.

Although the AEVs of two soils are similar, the WEV and WIV of the water repellent soil are smaller than the hydrophilic soil. Thus, the water retention characteristic of two soils can be recognized from not only the difference of the WEV, but also the differences of the WIV more clearly. From these results, it can be said that the water can infiltrate into the hydrophilic soil more easily than the water repellent soil. In addition, it was found that the water-repellent soil has a larger hysteresis than the hydrophilic soil as a water retention characteristic.

4 CONCLUSIONS

The water retention test in this study was performed using hydrophilic and water-repellent soils of Toyoura sand to investigate its water retention characteristics. The modified water retention testing apparatus of the continuous pressurization method was used. The applicability of the test method and the water retention characteristics of the water repellent sand were examined. The following conclusions could be drawn:

(1) From the test results of the hydrophilic soil, it was confirmed that the testing time for the drying and wetting processes in the SWCC using the continuous pressurization method can be remarkably shortened. It was found that the continuous pressurization method could be also applicable for the water-repellent sand.

(2) The AEV of two soils are similar, whist the WEV and WIV of the water-repellent soil were smaller than the hydrophilic soil. Thus, the water retention characteristic of two soils could be recognized from not only the difference of the WEV, but also the difference of the WIV more clearly.

(3) Finally, it was found as a water retention characteristic that the water repellent soil has a larger hysteresis than the hydrophilic soil. It is expected that this characteristic of the water repellent soil could be applied as a ground material for prevention and mitigation of soil-structure (embankment, roadbed, etc.) disasters.

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