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Soil Water Characteristic Curve for Weathered Granite Soils - A Test Method

화강풍화토에 대한 함수특성곡선 - 실험방법에 대한 연구

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요 지

함수특성곡선은 불포화지반에서의 해석과 물성 추정 등에 반드시 고려해야 하는 지반의 고유 특성이다. 하지만 기존의 실험장비에 의한 실험 중에 발생되는 시료의 부피변화는 함수특성곡선 결과에 영향을 미치게 된다. 따라서 본 연구에서는 함수특성곡선 실험 중에 발생되는 부피변화를 측정하여 보다 정확한 함수특성곡선을 얻고자 하였다. 그리고 실험과정 중에 관측된 간극비의 변화를 통해 실험 초기의 포화과정이 시료의 구조를 변화시키고 있음을 알 수 있었다. 따라서 본 연구에서는 기존의 실험방법으로 실험을 수행한 시료에 대해 실험 초기의 포화과정을 생략한 실험을 수행하여 간극비의 변화가 상대적으로 크게 감소하는 것을 알 수 있었으며, 그 결과들을 비교, 분석하였다.

Abstract

Soil water characteristic curve (SWCC) is a unique characteristic that should be considered in the analysis of unsaturated soil and prediction of unsaturated properties. However, the volume change of soil specimens that happens in the existing apparatus affects the SWCC. Therefore, in this study, we intended to obtain more appropriate SWCC by measuring the change in the volume of the specimen in the SWCC tests. The measured change of void ratio indicates that the saturation step prior to the test changes the original structure of the soil specimen. Thus we carried out the test for the same specimen omitting the saturation step prior to the test. The change of void ratio by this test procedure is relatively small.

Keywords : Soil water characteristic curve, SWCC test procedure, Unsaturated soil, Volume change

1. Introduction

1.1 Overview of Soil Water Characteristic Curve

The soil water characteristic curve (SWCC) shows a relationship between the amount of water in a soil (i.e., gravimetric or volumetric water content) and soil suction (i.e., matric suction at low suctions and total suction at high suctions). The soil water characteristic curve represents fundamental information of unsaturated soil characteristics and hence it could be used for deducing property functions for the coefficient of permeability, shear strength and volume change (Sillers et al. 2001).

The soil water characteristic curve contains important

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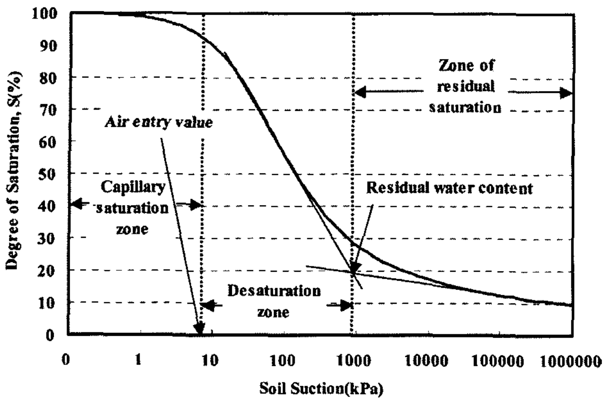


Fig. 1. Soil water characteristic curve illustrating the regions of desaturation

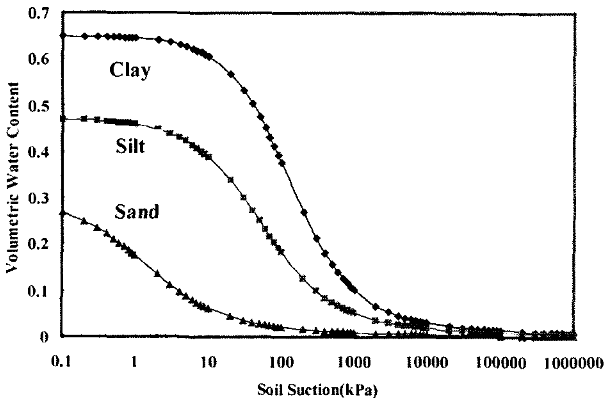


Fig. 2. Typical soil water characteristic curves for clay, silt and sand

information concerning the amount of water contained in the pores at any suction, the pore size distribution and the stress state in the soil water. Fig. 1 shows three stages related to the process of desaturation (i.e., increasing soil suction).

Experimental data for the soil water characteristic curve can be obtained from laboratory tests. A mathematical function can then be fitted to the soil water characteristic data. Many mathematical models have been proposed in the literature for representing the soil water characteristic curve. Fig. 2 shows three typical soil water characteristic curves for clay, silt and sand. The air entry value for the soils tends to increase as the soil particles become finer.

1.2 The Necessity for Studying Soil Water Characteristic Curve

The reliable coefficient of permeability function is required in order to perform seepage analysis for an unsaturated soils, including the seepage analysis for the slope stability analysis. However, there is no engineering soil property that can vary more widely than that of the coefficient of permeability. For saturated soils, the coefficient of permeability can vary more than 10 orders of magnitude when considering soils that range from gravel to clay. This wide range in coefficient of permeability has proven to be a major obstacle in analyzing seepage problems.

Then, numerous attempts have been made to predict empirically the permeability function for an unsaturated soil. These procedures make use of the saturated coefficient of permeability and the soil water characteristic curve for the soil. Therefore, the more precise equations have been developed for the soil water characteristic curve, the more reliable predictions have been made for the coefficient of permeability function. This becomes particularly valuable when one considers the difficulties of the work involved in measuring the coefficients of permeability for a unsaturated soil.

In this study, the test apparatus and procedure modified to obtain more reasonable soil water characteristic curve are presented and explained. The test results for weathered granite soils are also presented and discussed.

2. Tests for Soil Water Characteristics Curve

2.1 Test Equipment and Procedure

In general, the volumetric pressure plate extractor is widely used at low suction range (0~1500 kPa) and the osmotic desiccator is adopted at large suction range (beyond 1500 kPa), as equipments for obtaining soil water characteristic curves.

2.1.1 Existing Volumetric Pressure Plate Extractor (Fredlund & Rahardjo, 1995)

The maximum matric suction that can be attained with the volumetric pressure plate extractor is 200 kpa. This apparatus can also be used to study the hysteresis in the soil water characteristic curve associated with the drying and wetting process in the soil. For this purpose, some

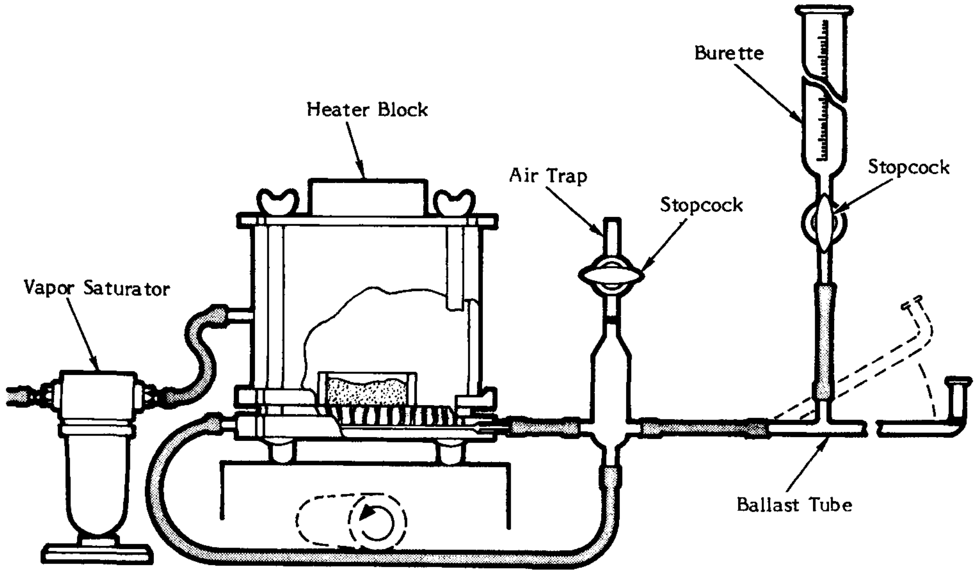


Fig. 3. Setup of the volumetric pressure plate extractor with its hysteresis attachments (Fredlund and Rahardjo)

hysteresis attachments are required, as outlined in Fig. 3.

The drying and wetting processes are performed on the same soil specimen when using the volumetric pressure plate extractor. During the drying process, tne matric suction increases, and pore-water drains from the specimen into the ballast tube. During the wetting process, the matric suction decreases, and water in the ballast tube is absorbed by the specimen. The drying branch of the soil water characteristic curve is first measured, followed by measurements for the wetting branch. Drying and wetting curves can be further repeated following the first cycle.

The test procedure commences with the insertion of the soil specimen into the retaining ring, which is then placed on top of the high air entry disk that has been saturated (This process is called the initial saturation process in the followings). The specimen is first saturated, and the hysteresis attachments are connected to the extractor. The hysteresis attachments are filled with water to the level marks. The air bubbles underneath the disk should be flushed prior to commencing the test by running the roller over the connection tube. This action will pump water from the air trap through the grooves beneath the disk to force air bubbles into the air trap. The trapped air bubbles are then released by adjusting the water level in the air trap to the level mark. This is accomplished by opening the stopcock at the top of the air trap and applying a small vacuum to the outlet stem of the air trap. The vertical position of the ballast tube is made level with the top surface of the disk or with the center of the specimen by placing the extractor on a support.

(1) Drying Portion of Soil Water Characteristic Curve

A starting point on the first drying curve should be established by applying a low matric suction to the soil specimen (i.e., raising the air pressure in the extractor to a low pressure). Water starts to drain from the specimen through the high air entry disk to the ballast tube. When the ballast tube is full of water, it should be drained to the burette. This is accomplished by applying a small vacuum to the top of the burette and opening the stopcock on the burette carefully. The outflow of water from the specimen stops when equilibrium is reached.

Diffused air is removed from the grooves underneath the disk using the pumping procedure. During the test, air diffuses through the pore water and the water in the high air entry disk, and comes out of the solution in the grooves beneath the disk. The removal of diffused air should be performed each time equilibrium is reached. This produces a more accurate measurement of water flow from the specimen. Also, the accumulation of diffused air below the high air entry disk will prevent the uptake of water by the soil during the wetting process.

The above described process is then repeated at increasing matric suctions (i.e., increasing air pressure in the extractor) until the drying curve is complete. Provision in the ballast tube should be made for the additional water outflow from the specimen at successively increasing matric suctions. The change in water volume reading in the burette for two successive equilibrium pressures provides the information necessary for the calculation of water contents of the soil.

(2) Wetting Portion of Soil Water Characteristic Curve

Upon completion of the drying process, the test can be continued with the wetting process. The soil matric suction is reduced by decreasing the air pressure in the extractor. A decrease in the air pressure causes water to flow from the ballast tube back into the soil specimen. The water volume required for the backflow may be in excess of the water volume in the ballast tube. In this case, water should be added to the ballast tube by opening the burette stopcock. Equilibrium is reached when the water flow from the ballast tube into the specimen has stopped. Following equilibrium, the water levels in the air trap and the ballast tube are again adjusted to their level marks, and the burette reading is taken for computing the water volume change. The procedure is repeated at decreasing matric suctions until the desired range of the wetting curve is obtained. Subsequent cycles of drying and wetting can also be performed if desired.

The final water content of the specimen corresponding to the last matric suction is measured at the end of the test. The final water content and the water volume changes between two successively applied pressures are used to calculate the water content corresponding to each matric suction.

2.1.2 Volumetric Pressure Plate Extractor Modified for the Measurement of Volume Change

During the wetting and drying process in the test for soil water characteristic curve, the volume change of the soil specimen occurs to some extent. The effect of volume change is different for each of the basic soil properties such as the void ratio, particle size distribution and compacted water content. Therefore, it is recognized to be necessary to correct the effect of the volume change for the soil specimen on the soil water characteristic curve, since the change of void ratio causes the volumetric water content of the specimen (Lee et al. 2000, Ng et al. 1998, 2000).

In this study, the volume change (i.e., the change of void ratio) could be measured by modifying the existing volumetric pressure plate extractor that can obtain the SWCC for both wetting and drying processes. The proximity transducer shown in Fig. 4 is the noncontacting transducers that operate on an eddy current loss principle. The device consists of a sensor and an aluminum target put on the top of the soil specimen. An eddy current is induced in aluminum target by a coil in the sensor. The magnitude of the induced eddy current is a function of the distance between the sensor and aluminum target. During the test, the distance between the proximity probe and the aluminum on the soil specimen changes, due to the volume change of the soil specimen caused by the wetting and drying process. Consequently, the magnitude of an eddy current caused changes and the change of the void ratio can be measured for the soil specimen. The difference of the modified volumetric pressure plate extractor from the existing apparatus is to measure a change of the void ratio at equilibrium state of each matric

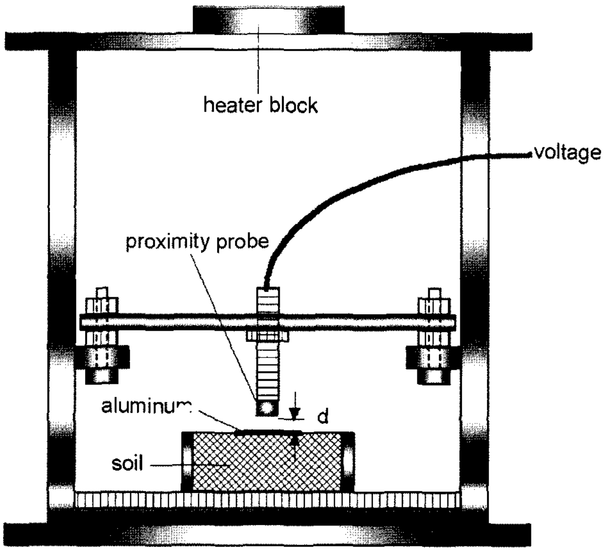


Fig. 4. Modified volumetric pressure plate extractor for the measurement of volume change

suction and to perform the tests without the initial saturation process. All the procedures of the modified apparatus are identical to those of the existing apparatus.

2.1.3 Osmotic Desiccator

To attain suction-water relationships in the higher suction range, osmotic desiccator testing was adopted. The specimen after completion of the volumetric pressure plate extractor tests was used to complete the soil water characteristic curves by placing it in glass desiccator with salt solutions. The salt solutions in the glass desiccators control the relative humidity and vapor pressure in the specimen. Four selected aqueous solutions such as Sodium Chloride, Magnesium Nitrate, Magnesium Chloride and Lithium Chloride which cover the range of higher suction were used. A summary of the selected salts and the associated humidities at a temperature of 23° centigrade are shown in Table 1 (Vanapalli, 1994).

2.2 Description of Soil Specimen

In this study, the soil water characteristic tests were carried out for undisturbed samples and compacted specimens of weathered granite soils, obtained from Okchun, Chochiwon, Yungi, and Seochang areas in Korea (Table 2, Table 3). These tests were here performed under

Table 1. Summary of saturated solutions humidities and equivalent total suctions used in osmotic desiccator tests

Salt	Temperature (℃)	Relative Humidities (%)	Equivalent Total Suctions (MPa)
Lithium Chloride	23	11.3	297.6
Magnesium Chloride	23	32.9	151.7
Magnesium Nitrate	23	53.4	85.6
Sodium Chloride	23	75.7	38

Lithium Chloride - $LiCl.H_2O+LiCl.2H_2O$
Magnesium Chloride - $MgCl_2.6H_2O$
Magnesium Nitrate - $Mg(NO_3)_2.\ 6H_2O$
Sodium Chloride - NaCl

Table 2. Conditions of specimen used in this study (I)

Area	Sample Code	Conditions	Void Ratio (e)	γ_d (g/cm^3)
Okchun (O)	O-N	Undisturbed Sample	0.73	1.53
	O-C1	Compacted at 0.95 $\gamma_{d,max}$ (wet side)	0.57	1.70
	O-C2	Compacted at 0.95 $\gamma_{d,max}$ (dry side)	0.57	1.70
	O-C2 (NS)	Same conditions as O-C2		
	O-C3	Void ratio of O-N, Compacted water content of O-C1	0.77	1.51
	O-C3 (NS)	Same conditions as O-C3		
Chochiwon (C)	C-N	Undisturbed Sample	1.02	1.33
	C-C1	Compacted at 0.95 $\gamma_{d,max}$ (wet side)	0.67	1.59
	C-C1 (NS)	Same conditions as C-C1		
	C-C2	Compacted at 0.95 $\gamma_{d,max}$ (dry side)	0.67	1.59
	C-C2 (NS)	Same conditions as C-C1		
	C-C3	Void ratio of C-N, Compacted water content of C-C1	1.00	1.34
	C-C4	Void ratio and Compacted water content of C-C2 with #40 sieve passing soils	0.67	1.59
Yungi (Y)	Y-C1 (NS)	Compacted at 0.95 $\gamma_{d,max}$ (wet side)	0.48	1.78
	Y-C2 (NS)	Compacted at 0.95 $\gamma_{d,max}$ (dry side)	0.48	1.78
	Y-C3 (NS)	Void ratio and Compacted water content of Y-C1 with #20 sieve passing soils	0.48	1.78
Seochang (S)	S-C1 (NS)	Compacted at 0.95 $\gamma_{d,max}$ (wet side)	0.61	1.64
	S-C2 (NS)	Compacted at 0.95 $\gamma_{d,max}$ (dry side)	0.61	1.64

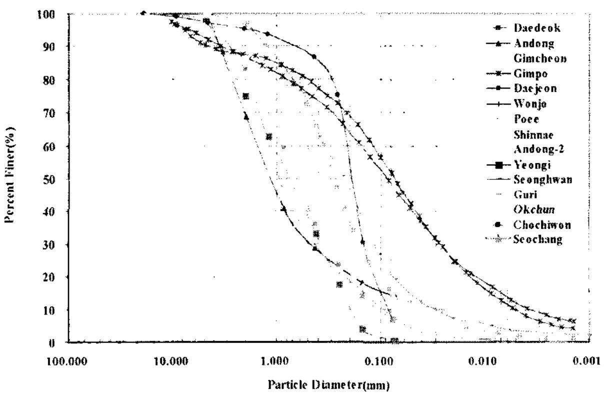
Note - 'NS' means that the process of saturation by submerging is omitted various conditions, that is, the conditions such as the compacted water content and void ratio are different, considering that the purpose of this study is to predict the soil water characteristic curve of weathered granite soils for the above conditions.

C-N, C-C1, C-C2, C-C3, O-N, O-C1, O-C2 and O-C3 specimens were tested following the procedure explained in the section about the existing volumetric pressure plated extractor. In other words, the test procedure commences with submerging and placing the specimen on top of the high air entry disk that has been saturated. Then the drying and wetting processes are performed on the same soil specimen.

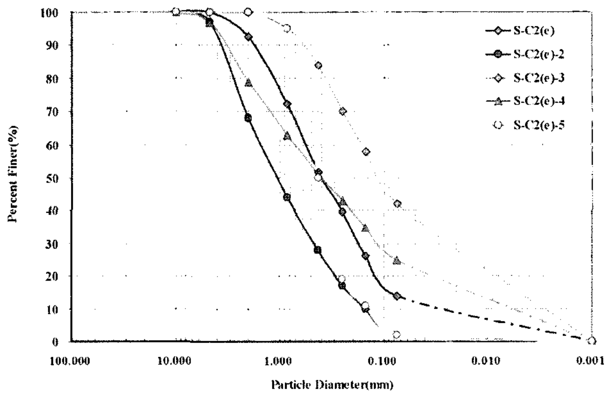
However, the tests for specimens such as C-C1 (NS), C-C2 (NS), O-C2 (NS), O-C3 (NS), Y-C1 (NS), Y-C2 (NS), Y-C3 (NS), S-C1 (NS) and S-C2 (NS) are performed without saturation process. To put it more concretely, the tests for theses specimens and the following 'NS' symbol-

Table 3. Conditions of specimen used in this study (II)

Sample Code	Conditions	Void Ratio (*e*)
S-C2(0.4)-2(NS)	Compacted water content of S-C2 Particle size distribution S-C2(e)-2 in Fig. 5 (b)	0.4
S-C2(0.4)-3(NS)	Compacted water content of S-C2 Particle size distribution S-C2(e)-3 in Fig. 5 (b)	
S-C2(0.4)-4(NS)	Compacted water content of S-C2 Particle size distribution S-C2(e)-4 in Fig. 5 (b)	
S-C2(0.4)-5(NS)	Compacted water content of S-C2 Particle size distribution S-C2(e)-5 in Fig. 5 (b)	
S-C2(0.6)-2(NS)	Compacted water content of S-C2 Particle size distribution S-C2(e)-2 in Fig. 5 (b)	0.6
S-C2(0.6)-3(NS)	Compacted water content of S-C2 Particle size distribution S-C2(e)-3 in Fig. 5 (b)	
S-C2(0.6)-4(NS)	Compacted water content of S-C2 Particle size distribution S-C2(e)-4 in Fig. 5 (b)	
S-C2(0.8)-2(NS)	Compacted water content of S-C2 Particle size distribution S-C2(e)-2 in Fig. 5 (b)	0.8
S-C2(0.8)-3(NS)	Compacted water content of S-C2 Particle size distribution S-C2(e)-3 in Fig. 5 (b)	
S-C2(0.8)-4(NS)	Compacted water content of S-C2 Particle size distribution S-C2(e)-4 in Fig. 5 (b)	
S-C2(0.8)-5(NS)	Compacted water content of S-C2 Particle size distribution S-C2(e)-5 in Fig. 5 (b)	



(a) Particle size distributions of weathered granite soils in Korea



(b) Particle size distributions of weathered granite soils used in this study

Fig. 5. Particle size distributions of weathered granite soils obtained in literatures and used in this study

specimens were carried out by repeating the drying process and wetting process at each initial condition.

Additionally, the more tests were carried out for some specimens (Fig. 5 and Table 3) artificially composed, in order to effectively use the test results to grasp the trends of the soil water characteristic curves for domestic weathered granite soils from the basic soil properties, including particle size distribution.

3. Discussion on the Test Results for SWCC

One of the features in the test process used in this study, is to measure the volume change of the specimen during the drying and wetting processes. The volume changes measured were used in the computations of volumetric water content in SWCC. In other words, the volumetric water content was computed as the ratio of water content to the total specimen volume that was corrected by measuring the volume change. Thus examples of the comparison between soil water characteristic curves obtained in the cases that were corrected for the volume change of the specimen and those for the cases that were not corrected for the volume change are shown in Fig. 7 and Fig. 8.

As the figures indicate, the soil water characteristic curves that do not correct the volume change developed during the test, show bigger water contents for corresponding suction values, in comparison with the results that were corrected for the volume change. This phenomenon is also observed in the test results for other specimens.

Fig. 9～Fig. 10 represent the change of void ratio and the soil water characteristic curves obtained by correcting the volume change. The trends of other test results are similar to these examples represented here.

The other feature of the test process used in this study, is to start the test without the saturation process by submerging (Fig. 11～Fig. 12). As shown in the test results (Fig. 9～Fig. 10), by adopting the saturation process as in the existing test procedure, the pore increased during the saturation process. This may largely change the original structure of the specimen, since the size and distribution of void undergoes a change. These changes of the void extremely affect the SWCC. Furthermore, these swelling phenomena were measured much more in the samples compacted in the dry side of OMC. Additionally, the hysteresis in the soil water characteristic curves obtained under this test procedure becomes bigger. This phenomenon was conjectured to happen, because the pores became bigger due to saturation and accordingly, the ink bottle effect, which is recognized as cause of hysteresis, could be larger. However, the changes in the

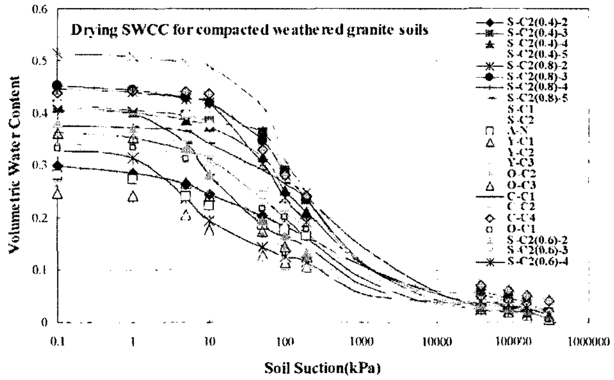


Fig. 6. The Last Drying SWCC tested in this study

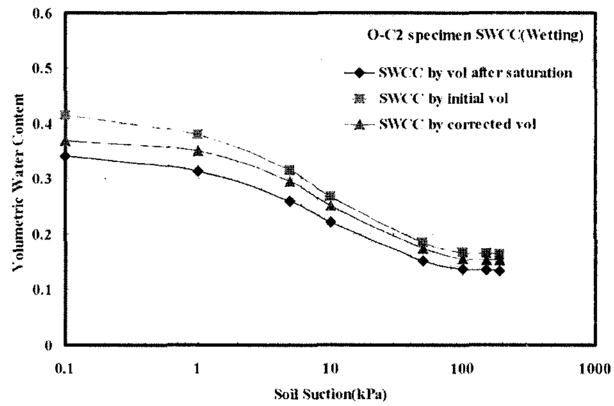


Fig. 7. Wetting soil water characteristic curves (O-C2)

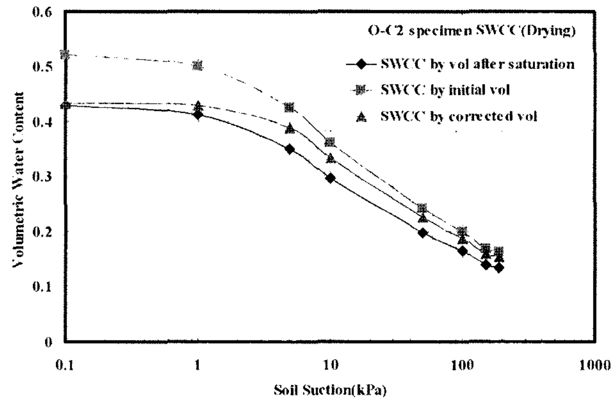


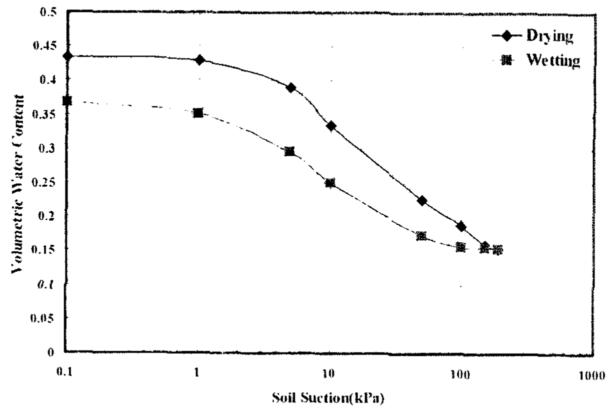
Fig. 8. Drying soil water characteristic curves (O-C2)

void ratio were relatively small in the test results conducted without the saturation process by submerging. And it was found from the test results that the swelling in saturation process becomes larger as the specimen is denser, finer, or compacted at dry side, and the air entry value is generally larger as the specimen is finer (Lee, 2004).

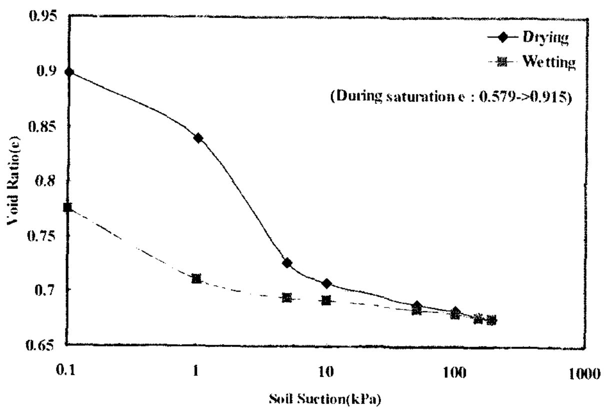
Actually, it will be most pertinent to take any test procedure that is suitable to the soil considered, in order to simulate the soil behavior, since the SWCC is used as a property. For example, in the case of the surface of slope exposed to the atmosphere, it will be proper to carry out the test repeating the drying/wetting procedures under the condition that normal stress is small or zero, because overburden load is small and drying/wetting procedures are repeated, in that case. Incidentally, the specimens compacted at dry side of OMC, such as O-C2 (NS) showed that the first wetting SWCCs have the steeper slope, comparing with those of the specimens compacted at wet side of OMC, such as O-C3 (NS). It is conjectured that these results are worth to be considered in the analysis of any manmade soil structures. In fact, most soils are not compacted at the recommended wet side in the field. Therefore, it is inferred that these soil water characteristic curves are particularly useful in the seepage analysis for the first saturation of these soils compacted at dry side, since the slope of SWCC has an effect on the unsaturated permeability.

We think that it is reasonable to adopt the test method and procedure, considering the stress condition, the change procedure of water content, and the volume change of the specimen according to change of the water content, in order to obtain the suitable SWCC, in other conditions including the above examples.

All the drying soil water characteristic curves of weathered granite soils tested in this study, are presented in Fig. 6.

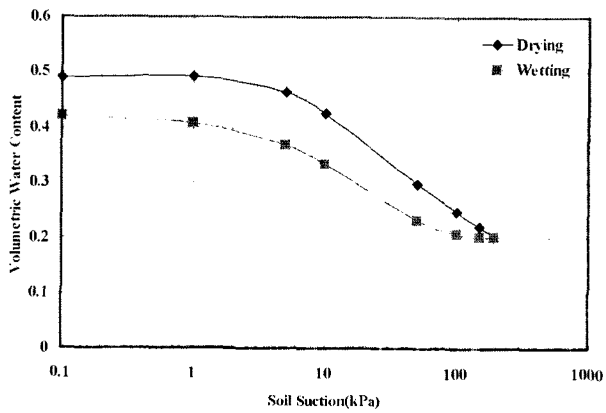


(a) Soil water characteristic curves for each process

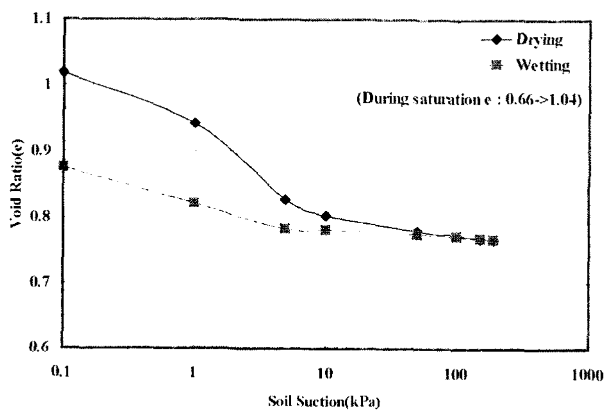


(b) Change of the void ratio during the test

Fig. 9. SWCC and change of the void ratio for O-C2

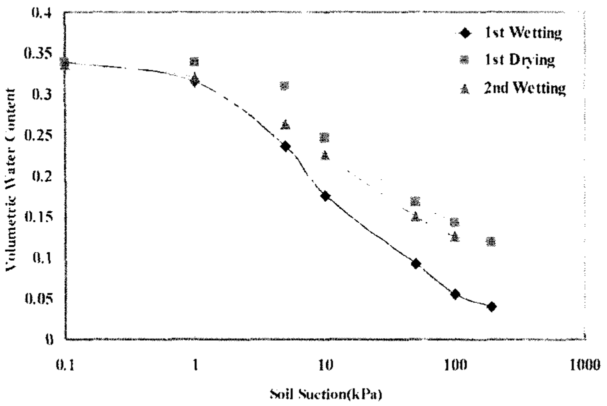


(a) Soil water characteristic curves for each process

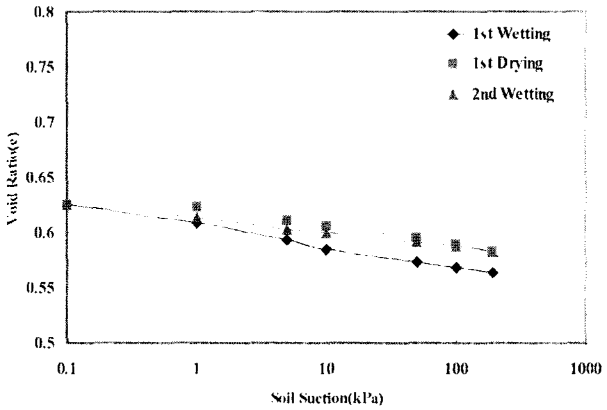


(b) Change of the void ratio during the test

Fig. 10. SWCC and change of the void ratio for C-C2

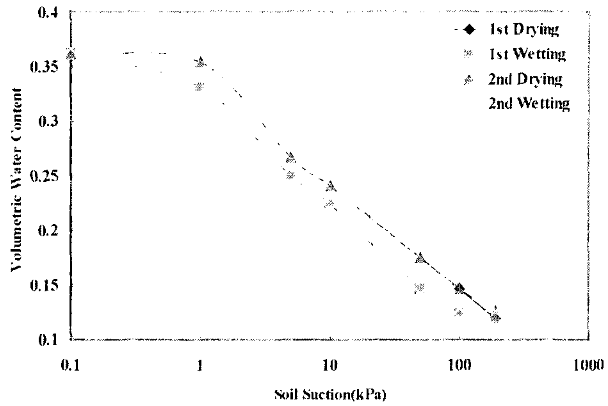


(a) Soil water characteristic curves for each process

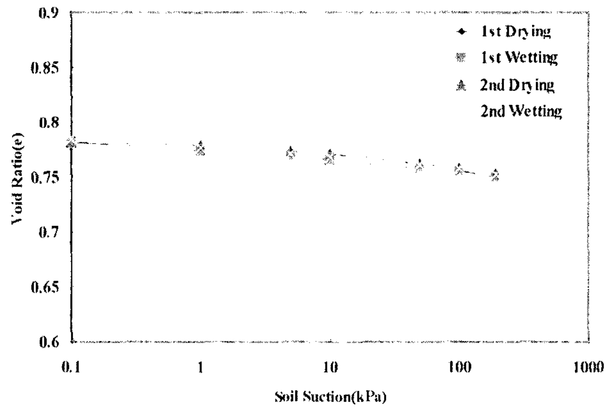


(b) Change of the void ratio during the test

Fig. 11. SWCC and change of the void ratio for O-C2 (NS)



(a) Soil water characteristic curves for each process



(b) Change of the void ratio during the test

Fig. 12. SWCC and change of the void ratio for O-C3 (NS)

4. Conclusions

We modified the apparatus and the test procedure in order to reasonably obtain soil water characteristic curve and carried out the tests for weathered granite soil. The following results were obtained:

(1) The volume of specimen varies in the drying and wetting process of SWCC tests. The magnitude of the volume change was especially large during the initial saturation stage. Therefore, we modified the existing VPPE (volumetric pressure plate extractor) to measure the volume change.

(2) The SWCC which did not correct the volume change overestimated the water content at any suction value compared with the results of the SWCC correcting the volume change.

(3) It is conjectured that the hysteresis was largely generated and the original structure of the specimen was changed, since the excessive volume change happened during the initial saturation stage in the test procedure including the initial saturation stage.

(4) The hysteresis of SWCC showed the decreasing trend from the tests that eliminate the initial saturation stage and repeat the drying and wetting processes.

(5) The specimens compacted at dry side of OMC showed that the first wetting SWCCs were different from those of the specimens compacted at wet side of OMC. These results are worth to be considered in the analysis of most soil structures compacted at the dry side in the field. In particular, it is inferred that these soil water characteristic curves are useful in the seepage behavior analysis for the first saturation of these soil structures compacted at dry side.

(6) It was found from the test results that the swelling in saturation process becomes larger as the specimen

is denser, finer, or compacted at dry side, and the air entry value is generally larger as the specimen is finer.

(7) It seems reasonable to conclude that it is a rational method to directly start the test in the initial state of the specimen without conducting the saturation process and to correct the effect of the volume change, in order to reasonably obtain the soil water characteristic curve by experiments.

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