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A method to estimate Soil-Water Characteristic Curve for weathered granite soil

Une méthode pour estimer la courbe caractéristique sol-eau (SWCC) de sol de granit érodé

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ABSTRACT
Soil water characteristic curve (SWCC) is an important property that should be considered in the analysis of flow in unsaturated soils, the stability analysis due to infiltration of rainfall into slopes, the prediction of other unsaturated properties, etc. Therefore, in this study, we intended to obtain more accurate SWCC by measuring the volume change of the specimen in the SWCC tests. Thus we were able to grasp the change of void ratio during the SWCC tests. Additionally, a method reasonably predicting the SWCC for Korean weathered granite soils was suggested, based on the test results obtained from the experiments conducted in this study. In other words, a method to estimate the parameters used in Fredlund and Xing's equation was proposed using an ANN (artificial neural network). The particle size distribution, compacted water content and void ratio were used as input data in the ANN model for predicting the parameters, since it was confirmed that these basic soil properties have a relationship with the parameters obtained from the test results and the fitting results. The network model connection weights and biases presented in this study produced reliable predictions, and the precision of the prediction results from the proposed method was high, in comparison with the prediction results of other prediction methods.

RESUMÉ
La courbe caractéristique sol-eau (SWCC) est un élément important, qui doit être pris en compte dans l'analyse de l'écoulement de l'eau dans les sols non saturés, l'analyse de stabilité par suite de l'infiltration des précipitations dans les pentes, la prédiction d'autres éléments non saturés, etc. De ce fait, nous avions l'intention dans cette étude d'obtenir une courbe SWCC plus précise en mesurant le changement de volume des échantillons durant les essais de courbe SWCC. Ainsi nous avons pu saisir le changement de l'indice de vide durant les essais. De plus, une méthode raisonnablement prévisible de la courbe SWCC pour les sols de granit érodé de Corée a été suggérée, basée sur les résultats d'essais obtenus lors d'expérimentations conduites dans cette étude. Autrement dit, une méthode pour estimer les paramètres utilisés dans l'équation Fredlund & Xing a été proposée en utilisant un réseau de neurones artificiels (RNA). La distribution de la taille des particules, la teneur en eau comprimée et l'indice de vide ont été utilisés comme données d'entrée dans le modèle RNA en vue de la prédiction des paramètres, car il a été confirmé que ces éléments de base du sol affectent les paramètres obtenus avec les résultats d'essais et les résultats d'ajustements. Les poids et préjugés de la connexion du modèle réseau présentés dans cette étude ont fourni des prédictions fiables et la précision des résultats de prédiction issus de la méthode proposée a été plus élevée comparé aux résultats de prédiction d'autres méthodes.

1 INTRODUCTION

The unsaturated soil condition exists above the ground water table. The unsaturated soils exhibit different behavior from the fully saturated soils because of the matric suction. The matric suction varies according to the water content. The lower the water content is, the higher the matric suction. The relationship between the matric suction and the water content (degree of saturation) is represented by the SWCC. The SWCC is the most fundamental and important soil property in the unsaturated soil engineering. The SWCC has been used for analyzing the flow of water in unsaturated embankments and the stability due to the infiltration of rainfall into slopes.

Generally the SWCC has been obtained by laboratory tests using one of the common test equipments such as Tempe cell, volumetric pressure plate extractor, desiccator, etc. However the high cost and time-consumption of the testing prevent the unsaturated soil engineering from being applied for the practical design or analysis. To overcome this difficulty, indirect estimation techniques for unsaturated properties such as unsaturated shear strength and permeability have been studied by many researchers. The SWCC is closely interconnected with the basic soil properties such as the particle size distribution (PSD) and void ratio. Thus, the most common method is to predict the SWCCs from PSD using Pedo-Transfer Function (PTF) which was suggested by Fredlund et al. (1997) and others. Besides, Arya & Paris (1981) proposed the physico-empirical model to estimate the SWCC. However, unfortunately the established techniques seem to be inappropriate for the weathered granite soils widely located in South Korea.

In this paper, an estimation method using Artificial Neural Network (ANN) technique is suggested. The estimated results are compared with those obtained from other estimation techniques. The ANN technique gives better results for the Korean weathered granite soils.

2 MATHEMATICAL MODEL FOR SWCC

Many mathematical models have been proposed for representing the SWCC. Brooks & Corey's model (1964) is a representative two-parameter model. Fredlund & Xing (1994) proposed a three-parameters model which shows a continuous SWCC over the entire range of soil suction up to 1,000,000 kPa. The three-parameter models allow more flexible shape than the two-parameter models. Fredlund & Xing's SWCC equation is selected in this study since the fitting parameters are meaningful values related to the soil science.

The Fredlund & Xing's model is written as follows:

$$S = \frac{1}{\left[\ln\left\{ e + \left(\frac{\psi}{a} \right)^n \right\} \right]^m} \tag{1}$$

$$\theta = \frac{s}{\left[\ln\left\{e + \left(\frac{\psi}{a}\right)^n\right\}\right]^m} \qquad (2)$$

where S is the degree of saturation, θ is the volumetric water content, s is the volumetric water content at saturation, ψ is the matric suction and a, n, m are the curve-fitting parameters. The parameter a is related to the air-entry value; the parameter n is related to the pore-size distribution of the soil and the parameter m is related to the residual value of the model.

3 LABORATORY TESTING RESULTS

The volumetric pressure plate extractor and desiccator equipments were used to measure the SWCCs of the weathered granite soil located in several Korean areas. The volumetric pressure plate extractor is used for measuring the range of matric suction from 0.1 kPa to 200 kPa; the desiccator for higher matric suction range. The volumetric pressure plate extractor was modified to measure the volume change of the specimen during the wetting and drying process. This consideration is necessary since the volume change of the specimen induces the changes in the void ratio and the volumetric water content.

The final drying stage of SWCCs was selected as the testing result for fitting the data to the Fredlund & Xing's model because the difference between the drying and wetting process becomes small when they are repeated. All the tested SWCCs of the Korean weathered granite soils are presented in Fig. 1.

The SWCC data points were fitted to the Fredlund & Xing's model, and s, a, n and m values were obtained. From the results, the m parameter was not sensitive to the basic soil properties, and the range of the m value was narrow. Thus, the m value was fixed to 1.7, which is an average value of m values obtained from the fitting results.

4 ARTIFICIAL NEURAL NETWORK TECHNIQUES

The indirect estimation methods of SWCCs have been studied by several researchers. Most methods are based on the Pedo-Transfer Function. However, the methods are not appropriate for Korean soils in spite of their reasonable logic, because the weathered granite soil has its own characteristics. Therefore we proposed a new estimation method to properly predict the SWCCs from the basic soil properties. From Fig. 1, we could find the Fredlund & Xing's SWCC model properly represented agreeable data fitting results. Hence a method to estimate these fitting parameters (s, a, n) was proposed using an Artificial Neural Network (ANN).

The PSD, compacted water content and void ratio were chosen as input data in the ANN model for predicting the parameters since it was confirmed that the basic soil properties mentioned were affecting parameters on the SWCCs in view of the test results and the fitting results.

4.1 *Data base and ANN model structure*

The basic properties such as sand, silt and clay percent by AASHTO classification system, void ratio and compacted water content were considered as input parameters in the neural network model, and the parameters (Δs, a, n) as target. The variation of volumetric water content during saturation process (Δs) was used instead of s in order to effectively predict the s parameter. The s and n parameters were the values used in the original Fredlund & Xing equation.

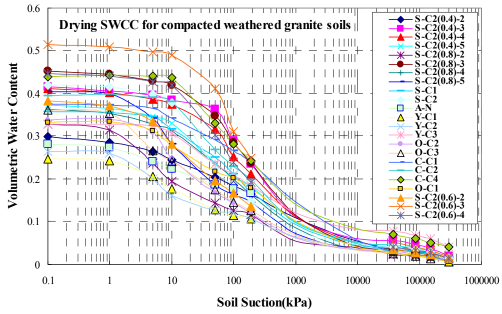


Figure 1. SWCCs obtained in this study during drying process

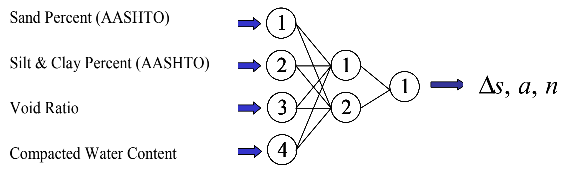
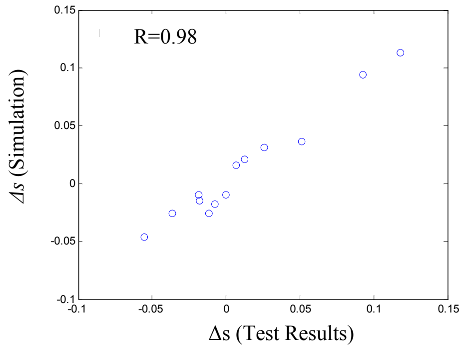
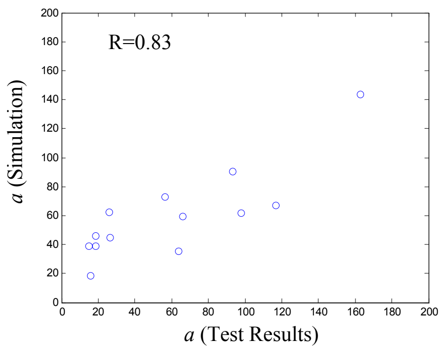


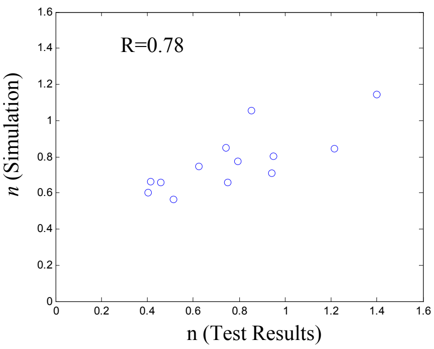
Figure 2. Network structure(4-2-1) used in this study



(a) Δs parameter values

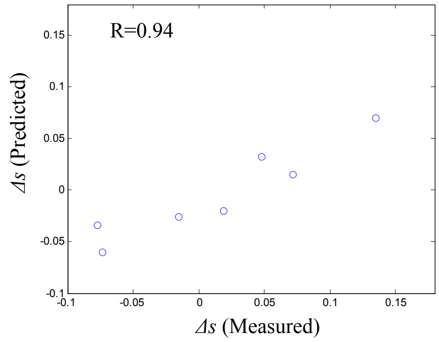


(b) a parameter values

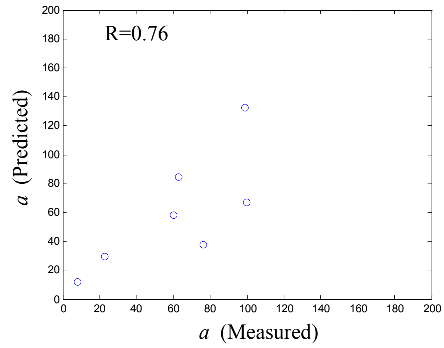


(c) n parameter values

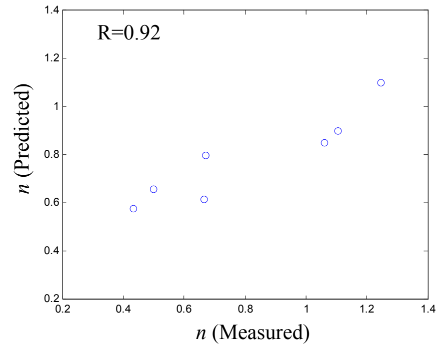
Figure 3. Simulation results of ANN



(a) Δs parameter values



(b) a parameter values



(c) n parameter values

Figure 4. Comparison of predicted and measured parameters

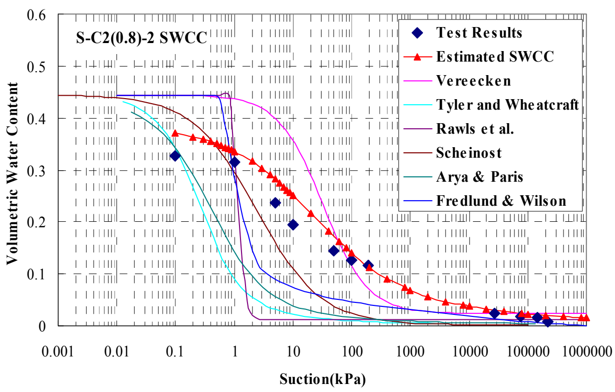


Figure 5. Comparison of SWCC obtained by test and other prediction methods

However, a parameter value was the value used in the Fredlund & Xing equation with which m parameter value was fixed to 1.7. This is expected to be appropriate and effective since the SWCCs in high suction range is in a relatively narrow range and the trend of the a parameter value does not seem reasonable when the m parameter is used as a fitting parameter.

Total of 20 data sets obtained by the tests on weathered granite soils were evaluated by the neural network in this study. Fig. 2 shows the 4-2-1 structure of the neural network selected in this study. The 4-2-1 structure has 4 nodes in the input layer, 2 nodes in the hidden layer, and 1 node in the output layer. The transfer function adopted in this study is a log-sigmoid type $[\alpha=(p+e^{-q})\text{-}p]$ in the first layer, and the second (output) layer transfer function is a linear function $[\alpha=q]$.

4.2 *Training of ANN model*

The ANN model was trained for 13 data sets using Bayesian regularization as a generalization technique with 4 input parameters in the input layer. Fig. 3(a), (b) and (c) show the results simulated by the neural network analysis and those obtained by the tests in regard to the parameters, (Δs, a, n), respectively.

4.3 *Testing of ANN model*

7 data sets which were not included in the training stage were used to check the applicability of the trained network model. The comparison of the predicted parameter values with the measured values are shown in Fig. 4. The results of ANN model were also compared with the other estimation methods of SWCCs (Fig. 5); Vereecken (1989), Tyler & Wheatcraft (1989), Rawls et al. (1985), Scheinost (1996), Arya & Paris (1981) and Fredlund et al. (1997). These 6 results were obtained from SoilVision (1996) which is a knowledge-based database system for soil properties.

From the results shown in Fig. 5, the network model proposed in this study produced reliable predictions, and the precision of the prediction results was relatively high, in comparison with the prediction results of other prediction methods. The main reason may be that these prediction methods were based on the data obtained from different soil types. It is inferred from these results that the SWCCs are affected by the soil type. Accordingly, it is appropriate to apply the prediction method merely based on the weathered granite soils to the prediction of SWCCs of the related type of soils.

The connection weights and biases trained to obtain 3 parameters for the network models were summarized in Table 1.

Table 1. Connection weights and biases trained for the network models

Parameters		1st layer		2nd layer
Δs	Weights	0.8048 0.9527 -0.6533 0.1659	-0.4158 -0.6697 0.8949 1.1596	1.5504 -1.7029
	Biases	0.4288 0.7346		0.0828
a	Weights	0.1286 0.9527 -0.6205 -0.0549	-0.1593 -1.0254 0.6908 0.0096	1.2722 -1.4060
	Biases	-0.0295 0.0327		-0.0434
n	Weights	0.4030 0.9451 -0.1751 -0.1208	-0.4216 -0.9794 0.1777 0.1269	1.1540 -1.2198
	biases	0.1368 -0.1530		-0.0286

Table 2. Soil properties of the slope

Water content (%)	Void ratio	Gravel percent (%)	Sand percent (%)	Silt & Clay percent (%)
18.7	0.79	0.9	93.7	5.4

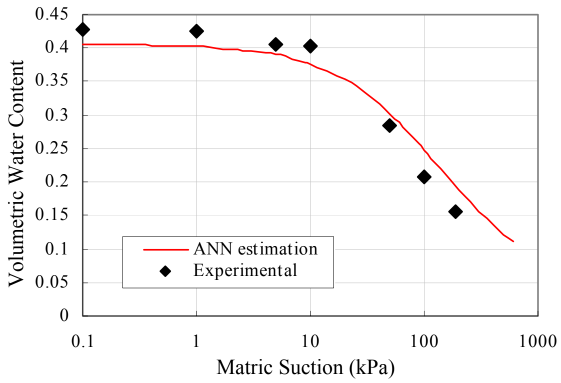


Figure 6. Estimated and experimental SWCCs for the cut slope design constructed in South Korea

5 APPLICATION TO A SLOPE DESIGN

The ANN technique to estimate the SWCC of a given soil was applied to the design of unsaturated cut slopes constructed in South Korea. The SWCC was required for the seepage analysis of the rainfall induced infiltration into the slope. The SWCC of the undisturbed specimen from the field slope was tested by the volumetric pressure plate extractor. The SWCC was also estimated from the basic soil properties summarized in Table 2. Fig. 6 shows the comparison of the estimated and test results. We could find that the ANN technique gives a similar SWCC to the test results.

6 CONCLUSIONS

The SWCC is a fundamental and important soil property in the unsaturated soil engineering. However the tests are time-consuming and costly. Thus a method reasonably predicting the SWCC for Korean weathered granite soils was suggested based on the test results obtained from the experiments. In other words, a method to estimate the parameters (Δs, a, n) used in Fredlund & Xing's SWCC equation was proposed using an ANN.

The summary of the results obtained in this study is as follows ;

1) The m value among the parameters used in the SWCC equation could be set to 1.7 for Korean weathered granite soils.
2) The PSD, compacted water content and void ratio were used as input data in the ANN model for predicting the parameters since it was confirmed that the basic soil properties were affecting parameters in view of the test results and the fitting results.
3) From the comparison results with other prediction methods, the network model proposed in this study resulted in more reliable predictions, and the precision of the prediction results was high.
4) Further experimental researches on the SWCC for the weathered granite soils would improve the precision of the estimation results.

The application of this kind of ANN technique to the design practice of the slope would make the unsaturated soil engineering be used easily and practically to the other general geotechnical engineering field in a near future.

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