Estimating Unsaturated Hydraulic Properties by Transient Evaporation Method in Soft Rock in Rokkasho Area, Japan

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Abstract

As sedimentary soft rock has a potential to store hazardous nuclear waste, several countries utilize it as a possible and safe way of hazardous nuclear waste disposal. Therefore, precise estimation of unsaturated hydraulic properties is needed on the unsaturated flow of this type of rocks to assure the safety of the disposal. In this study, Tertiary sedimentary soft rock samples were collected from Rokkasho Low Level Waste Disposal site in Japan. Applicability of an empirical model; Campbell (CB) model, which use commonly for soil hydraulic property estimation was studied. This model was applied to one dimensional flow induced by evaporation in three Pumice Tuff specimens and three Sandstone specimens. The inverse estimation technique was used to select the best parameter in each model by adopting Genetic Algorithm (GA) as an optimization tool. From the results it was clearly found that the unsaturated hydraulic properties could be easily estimated by CB model and the measured evaporation change could be well analyzed. According to the results the CB model is robust for unsaturated flow analysis in soft rock.

Key words: Unsaturated flow, Sedimentary soft rock, Inverse estimation, Genetic algorithm

Introduction

The sedimentary soft rock (mudstone, sandstone, tuff, etc.) is considered as one of the preferable types of host rock for hazardous waste disposal as it has generally low hydraulic conductivity and it contains clay minerals which have high ability to absorb the radionuclide. Therefore, these wastes are isolated in tunnels excavated in deep underground of sedimentary soft rock. However, the safety of the disposal must be assured because there may be many fractures around the tunnel and form the 'fractured zone' due to many reasons such as the unsaturated zone created during the excavation, the change of stress in the tunnel wall and the settlement of waste under the ventilation conditions. Because of the many fractures created in this 'fractured zone', the tunnel wall becomes highly permeable. Due to that, the groundwater and the hazardous waste flow easily through this zone. Therefore, it is very important to estimate the unsaturated hydraulic properties of this zone precisely. For the estimation, the relationship among the relative hydraulic conductivity, saturation and suction pressure should be well estimated.

Many studies have been conducted to evaluate the unsaturated properties of soil, but the suitable model for soft rock has not been clarified yet. Therefore it is crucial to study in detail on a proper model suitable for soft rock. Campbell model which is mostly used for hydraulic property estimation in soil was evaluated based on the measured and calculated transient evaporation data from three Sandstone samples and three Pumice Tuff samples. The estimation of parameters of the above model was used by adopting the Genetic Algorithm in inverse estimation technique as an optimization tool. The objective of this study is to examine the applicability of CB model for the soft rock samples.

Methodology

The closed form Campbell (CB) model adopted in this study is summarized as follows.

$$k(\theta) = k_{sat}\left(\frac{\theta}{\theta_{sat}}\right)^{m} \quad \text{if } \varphi < \varphi_e \quad (1)$$

$$\theta(\varphi) = \theta_{sat}\left(\frac{\varphi_c}{\varphi}\right)^{1/b} \quad \text{if } \varphi < \varphi_e \quad (2)$$

where, θ (m^3m^{-3}) is the volumetric water content, θ_{sat} is the saturated water content (m^3m^{-3}). φ (Jkg^{-1}) is the matric potential, φ_e (Jkg^{-1}) is the air entry potential, k (ms^{-1}) is the unsaturated hydraulic conductivity and k_{sat} (ms^{-1}) is the saturated hydraulic conductivity. b is a shape parameter related to the pore size distribution of the porous media.

This model has a threshold value φ_a which indicates the pressure for entering air into the soft rock. Two parameters were selected in this model and by simulating the evaporation change using inverse estimation technique these parameters were optimized. Three Sandstone samples and three Pumice Tuff samples were collected from Rokkasho Low Level Waste Disposal site in Japan. The properties of these specimens are shown in Table 1. Using the transient evaporation change one dimensional unsaturated flow was generated by disk shaped specimens. First, the samples were fully saturated by submerging in a distilled water container and then sucking water by a vacuum pump. Then, the samples were completely sealed except the upper surface which allows the evaporation. The evaporation rate was determined considering the weight change of the sample. When the weight is less than 0.01g/hour, the experiment was terminated. This experiment was done in a constant temperature (25°C) and constant humidity (40%) chamber.

Campbell (1985) has proposed an equation to estimate one dimensional upward flow induced by the evaporation (E_v).

Table 1 : Physical properties of soft rock specimens

Sample Name	L (cm)	D (cm)	ρ_b (gcm^{-3})	? (%)	k_s (cm/sec)
Sandstone-1	3	9	1.81	0.42	4.0E-7
Sandstone-2	2	6	1.61	0.46	6.5E-7
Sandstone-3	2	6	1.56	0.46	7.5E-7
Pumice Tuff-1	3	9	1.70	0.52	4.2E-6
Pumice Tuff-2	2	7	1.46	0.58	4.8E-6
Pumice Tuff-3	2	7	1.53	0.52	3.6E-6

L= Length, D= Diameter, ρ_b=Bulk density,
ϕ= Porosity k_s= Saturated hydraulic conductivity

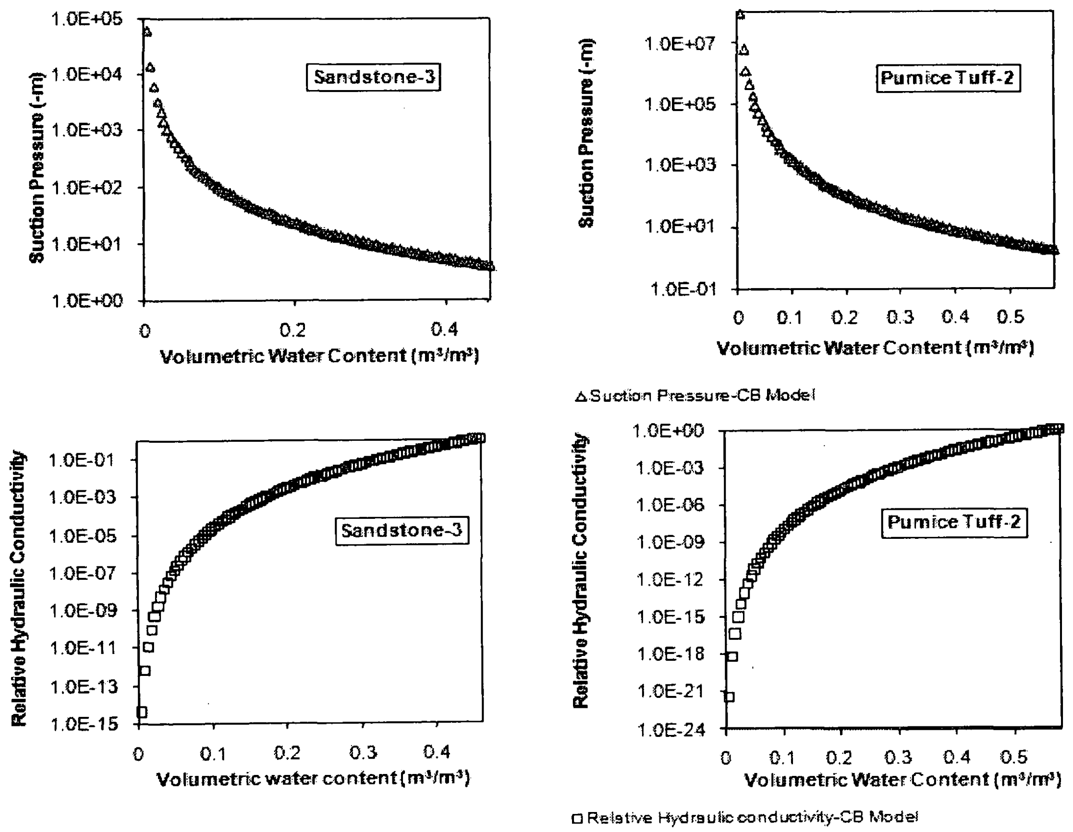

Figure 1 : (a) Retention curves for sandstone-3 and pumice tuff-2 specimens (b) Relative hydraulic conductivity curves for sandstone-3 and pumice tuff-2 specimens

$$E_v = E_p \frac{(h_s - h_a)}{(1 - h_a)} \qquad (3)$$

where h_s is the soil/rock surface humidity and h_a is the atmospheric humidity. According to this equation evaporation is a function of h_s under constant h_a. E_p is the potential evaporation. To estimate the model parameters, the inverse technique was applied considering both liquid flow and vapour flow (Campbell, 1985). To avoid the problems occur in this technique the Genetic Algorithm (GA) was adopted (Amarasinghe et al., 2011).

Results and Discussion

The measured evaporation change was simulated using the CB model. The measured and calculated evaporation change for the soft rock samples was plotted using the best combinations of the model parameters and the compatibility was checked. According to those fitted curves the CB model gave good accordance in both soft rock samples. It was observed that the measured evaporation rates for sandstone specimens are nearly constant (~ 12 mm/day) in the initial evaporation conditions. However, initial evaporation rate varies (12-18 mm/day) due to the variation of pumice distribution in those samples.

The relationship between the relative hydraulic conductivity, saturation, and suction pressure were obtained by applying the optimized parameters of the CB model to this model equation. These relationships obtained by this model for a sandstone specimen and a pumice tuff specimen are shown in **Fig.1**. According to this figure, the trends of the unsaturated hydraulic property curves of the soft rock specimens are not so different. The reason may be that the properties of soft rock samples (both pumice tuff and sandstone) are almost same (see Table 1). Therefore, the relationships can be estimated precisely using CB model as it has a threshold value which shows the entering air into the rock sample.

The selection of a proper model to estimate unsaturated hydraulic properties in soft rock is very important. In this study, the performance of Campbell model was investigated by estimating the best parameters in each model.

By the results obtained it is clear that the transient evaporation change can be well estimated and the model parameters can be obtained precisely by Campbell model. Therefore, the unsaturated flow in soft rock can be well analyzed by the Campbell model.

References

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