Effects of soil porosity on rain-water infiltration and slope stability

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1. Introduction

Slope failure caused by rainwater infiltration into a slope is widely recognized. Many studies were performed and all confirmed that rainwater infiltration into a slope has a great effect to slope instability. Rainwater infiltrate into soil increasing unit weight of soil with an increase in moisture content and decreasing effective stress in soil and thus reduces the soil shear strength, which can eventually result in slope failure. Modeling infiltration in unsaturated soil slopes is important for illustrating slope failure caused by heavy rainfall. In this study, a numerical model which is combined with circular analysis of simplified *Bishop's* method was used to analyze rainwater infiltration on unsaturated soil and its effect on slope stability by the variation of effective soil porosity (ESP).

2. Soil Data

Figure 1a shows relationship between saturated soil water content θ_s and saturated hydraulic conductivity K_s on 2 layers of granite soil. The data for the first and second layers were obtained from 34 and 18 observations, respectively. The figure shows a scatter plot of the relationship, which means these are not so clear correlation between θ_s and K_s. On the other hand, Figs. 1b and 1c showed relationship between water capacity function $f(\psi)$ and soil capillary pressure ψ, included observed data, average, calculation, as well as multiply 1.5 and 0.5 of ESP for the first and second soil layers, respectively. The multiply factor of calculation are used as variations of the ESP which are independently to hydraulic conductivity (see Fig. 1a).

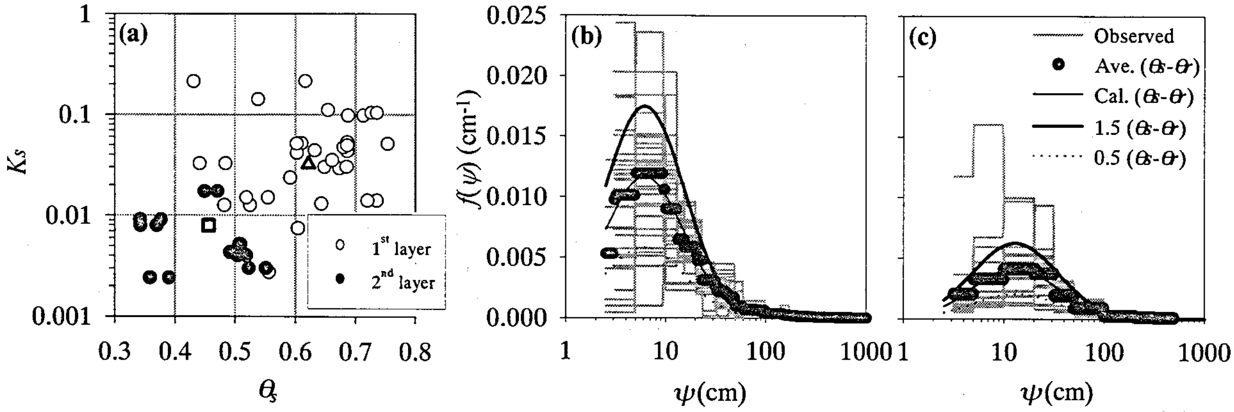


Figure 1. (a) Relationship between θ_s and K_s observed data soil, (b) First and (c) Second layer curve of $f(\psi)$ - ψ

3. Simulation Model

Two-dimensional numerical model of finite element method for saturated-unsaturated soil water flow (*Kosugi, 2004*) was used for illustrate a typical process of rainfall infiltration. In this analysis, we assumed 2 layer soil slopes with 50 cm depth of each layer, 20 m of length and 35° of slope gradient. Moreover for soil parameter used the average soils data of estimated parameter of Log Normal 2 (LN2) Model (*Kosugi, 1999*) as follows.

Tabel 1. Average value of the estimated parameters of the LN2 model

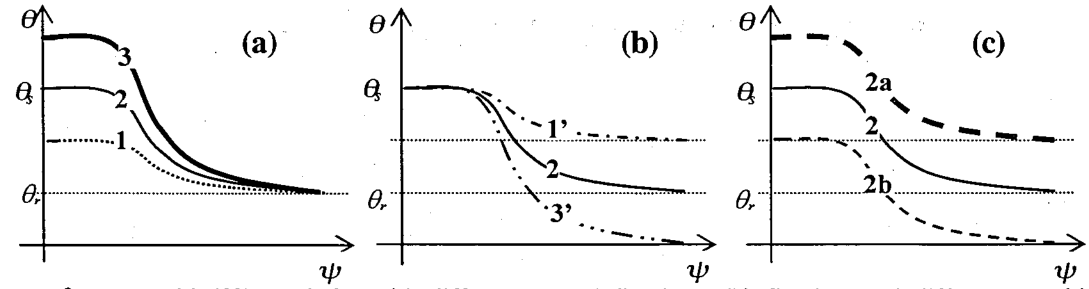
Soil type	Structure	Num. data seat	θ_s	θ_r	ψ_m	σ	Ks	α	β
Forest	Granite 1st layer	34	0.621	0.370	-14.3	0.92	0.0322	-0.747	2.899
Forest	Granite 2nd layer	18	0.456	0.242	-33.8	0.98	0.079	-1.258	2.964

Hougawachi rainstorm event which caused a large landslide occurred on July 21, 2003 was used as rainfall input data. For initial condition, 50 % of the Hougawachi rainstorm with 48 h drainage as antecedent rainfall (i.e. the rainfall prior to major rainfall event) was applied to the soil slope, and then it was continued with 100 % of the Hougawachi rainstorm as major rainfall. Output of this model is used as input data for the slope stability analysis which formula of safety factor, *F*, proposed by *Bishop's* (1954), is used to the analysis of slope stability.

$$F = \frac{1}{W \sin\alpha} \sum \left[\{c'b + (W - ub)\tan\phi'\} \frac{\sec\alpha}{1 + \frac{\tan\phi' \tan\alpha}{F}} \right]$$

where, W is the total weight of the slice of soil, c' is cohesion, ϕ' is internal friction angle, u is pore pressure, b is width of the slice of soil, α is the angle between the bottom slice boundary and the horizontal. In this case we used $c' = 30$ and $\phi' = 20°$.

We analyzed effect variations of the effective soil porosity (as shown on Figs. 2a, b, and c based soil data on Figs. 1b and c) concerning change on discharge, pore water pressure in soil bed layer and soil water content when safety factor, *F*, is smaller than 1.



Figue 2. ψ - θ curve with ESP variation, (a) different θ_s and fixed θ_r, (b) fixed θ_s and different θ_r, (c) different θ_s and θ_r

4. Result and Discussion

Figures 3a and b show rainstorm event, discharge outlet and pore water pressure at 181 cm from lower end of the soil slope. Increment of the discharge and pore water pressure are affected by the maximum rainstorm event. It is noted that the same result of the discharge and pore water pressure was obtained when the same ESP (θ_s - θ_r) was used regardless of the differences in the absolute values of θ_s and θ_r.

Figures 3c and e show safety factor with respect to the variation of ESP. The Figures present that the initial safety factor is similar between Case 1 and 2b, between Case 2a and 3, and among Case 1', 2 and 3'. This result indicates that θ_s is the dominant factor for the magnitude of initial safety factor which was computed after the 48 h drainage, because the weight of soil solid part increases as θ_s becomes small. Although the magnitude of initial safety factor was similar, the time when safety factor became smaller than 1 was different (Fig. 3c and e).

On the contrary, the time when safety factor became smaller than 1 was similar between Case 1 and 1', between Case 3 and 3', and among Case 2, 2a and 2b instead of the differences in the initial safety factor. This result indicates that ESP is the dominant factor to decide the time of land slide occurrence; when ESP is larger, the soil has a larger capacity to absorb rain water which results in the slower increase in of pore water pressure (Fig. 3b).

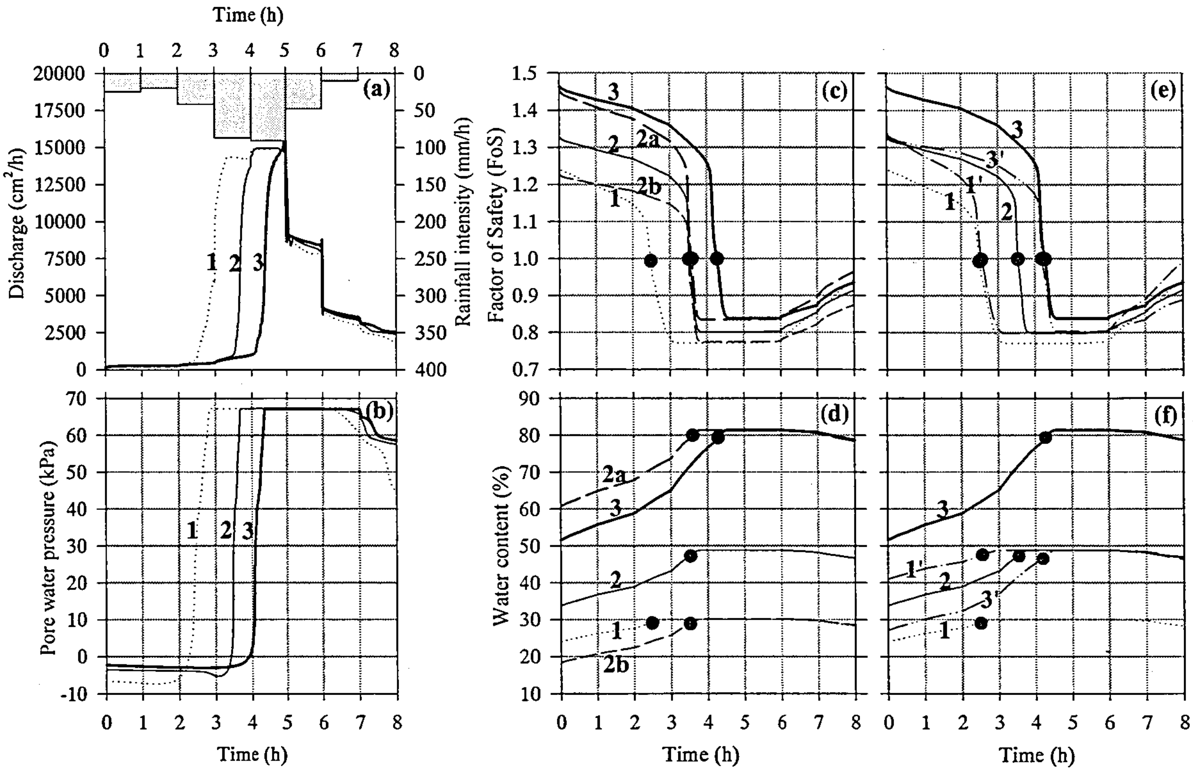


Figure 3. (a) Hougawachi rainstorm hyetograph and computed discharge rate, (b) pore water pressure, (c), (d), (e), and (f) safety factor and water content for cases summarized in Fig. 2

Figures 3d and f show the increment of water content in the sliding segment of the slope. The figures present that the safety factor became smaller than 1 when the soil slope is close to the saturated condition. Case 1 and 2b, Case 2a and 3, as well as Case 1', 2 and 3' have similar water content when safety factor became smaller than 1, because of the same θ_s. The comparison among Case 1, 2, and 3 shows that the larger ESP value results in the greater soil water content in the slope when the landslide happens, because the large ESP value increases not only the initial water content but also the increment in water content because of the delayed initiation of the landslide. It is likely that the larger water content in the sliding segment increases the probability of debris flow initiation which may increase damage in the downstream region.