Seepage and Pore Water Pressure Behavior: A Case Study of Landslide Triggering Mechanism in Uttaradit, Thailand

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ABSTRACT: This paper reports on the study of seepage behaviour in terms of pore water pressure variation with relation to landslide in Tambon Maepoon, Umper Laplae, Uttaradit province. The soil-water characteristic curve (SWCC) and permeability function were directly tested in the laboratory on undisturbed samples. These properties were subsequently used in Finite Element analysis of 1D rainfall infiltration into a hypothetical soil profile in order to investigate the pore water pressure distribution which was also compared with the field monitoring results. The pore water pressure distribution was used to calculate the Factor of safety variation with time of 45 deg. slope using infinite slope model. Influences of various parameters such as soil thickness, drainage condition at soil-rock interface and soil weathering degree, on stability were studied. For this hypothetical slope, the triggering rainfall can vary from 75 to 300 mm indicating other influential parameters for slope instability, including impeded drainage at the base and reduced permeability with depth and degree of weathering.

1 INTRODUCTION

At present, many landslide warning systems usually employ rainfall amount as practical criterion for quantifying likelihood of slope failure and its severity (e.g. Kay, 1998, Mairaing et al., 2012). The warning criteria or critical rainfall envelopes were normally based on historical records of rain patterns during past landslides. Nevertheless, landslides initiation mechanism is known to depend also on various other factors such as slope gradients, geology, soil type, antecedent soil moisture, shear strength, permeability, water retention behaviour, etc.

Interaction between these factors is complex and consequently means that the critical rain criteria are mostly site-specific. This paper focuses on a study of infiltration behaviour using numerical analysis (SEEP/W) which is based on laboratory-determined unsaturated soil behaviour and calibrated against field measurement of pore-water pressure. This was to shed some light on the issue of landslide trigger mechanism.

The materials used in this study are undisturbed residual silty soils (classified as ML) derived from sedimentary rock in landslide area of Uttaradit province, Northern Thailand, which suffered shallow type failure in 2005, due to prolonged and intense rainfall. Saturated & unsaturated direct shear behaviour as well as water retention behaviour of this material has been investigated and reported in details by Jotisankasa & Tepparnich (2010). The tests have been performed on undisturbed samples collected from depths of 0.3-1m. The shear strength of the soil has been shown to increase with depth, yet its cohesion however appeared to be destroyed by a couple of cycles of extreme wetting/drying or weathering process. Further results of the numerical infiltration analysis part from the study by Tepparnich (2010) are reported in this paper.

2 SOIL PROPERTIES

Infiltration analysis requires two parts of information on soil hydraulic properties, namely, Soil-water characteristic curves and Permeability function. In this study, the instantaneous profile (IP) method was employed to determine both properties on undisturbed sample collected from depths of 0m (ground surface), 0.3m and 0.8m. Experimental setup for the IP tests is shown in Fig. 1 and the detailed testing procedure has been explained by Jotisankasa et al. (2010). The method involved gradually wetting or drying a soil sample whereby its weight and suctions along sample height were continuously monitored.

Fig. 2 shows the SWCC and permeability functions as obtained from IP tests. It should be noted that for SWCC, the degree of saturation at zero suction (for soaked sample) was still 80-90%

which means that there were still some occluded air present in the void. It was then assumed that this occluded air would disappear (S_r = 100%) once the pore-water pressure reached 20 kPa as shown in Fig. 2a. The saturated permeabilities were obtained from field infiltration tests and have values of 1E-5, 5E-6, and 5E-6 m/s for soil at depths of 0m, 0.3m and 0.8m, respectively.

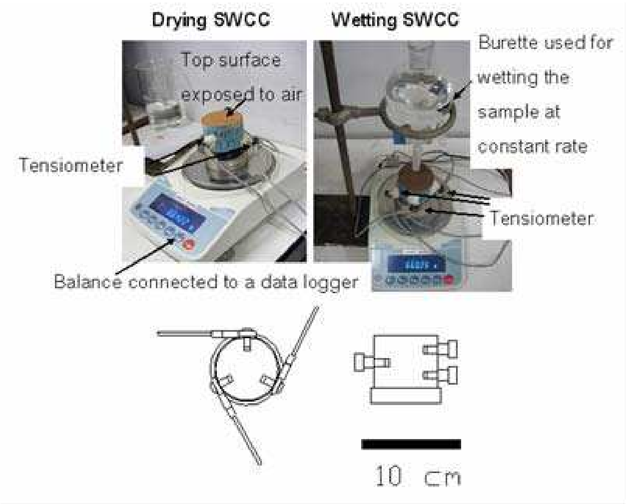


Fig. 1 Experimental setup for instantaneous profile tests of continuous SWCC and k-functions

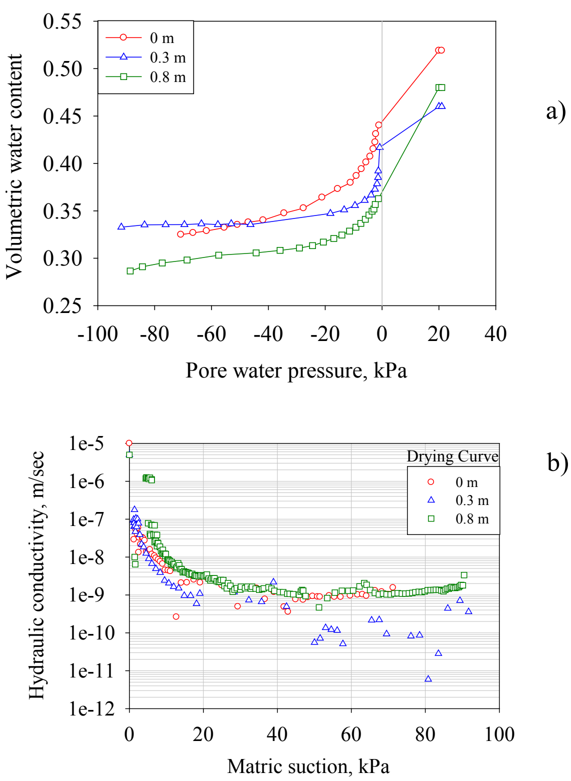


Fig. 2 Soil-water characteristic curves and permeability functions of the residual silty soils

Table 1 summarises the effective strength parameters as obtained from direct shear tests on saturated and unsaturated undisturbed samples. Shear strength (τ) equation for variably saturated soil can be expressed as (1);

$$\tau = c' + \sigma_n \tan\phi' - u_w \tan\phi'' \qquad (1)$$

where, c'= effective cohesion intercept, σ_n= normal stress, ϕ' = effective angle of shearing resistance, u_w= pore water pressure (positive or negative), ϕ'' = angle of shearing resistance due to pore water pressure or suction (for unsaturated case,u_w<0, and$\phi'' = \phi^b$, but for saturated case, u_w>0, then ϕ''=ϕ'). Also shown in Table 1 are the values of reduced cohesion to take account of effect of weathering that will be used in subsequent analysis. This assumption was based on direct shear test results by Jotisankasa & Tapparnich (2010) which demonstrated that cycles of wet & dry of sample tended to reduce its cohesion and not the friction angle.

Table 1. Strength parameters used in stability analyses

Depth (m)	ϕ'	c' (kPa)	Reduced cohesion by 20%, c' (kPa)
0	17.6	22.8	18.2
0.3	40.4	4.6	3.7
0.8	32.0	13.7	11.0

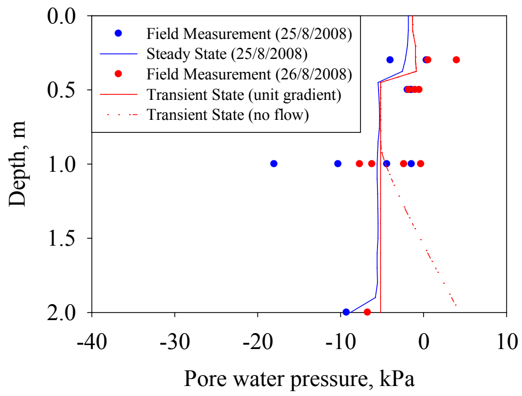


Fig. 3 Pore-water pressure profile from field measurement compared with numerical analyses

3 ONE-DIMENSIONAL INFILTRATION AND STABILITY ANALYSIS

In this study, 1-dimensional seepage analysis (SEEP/W) was performed in order to obtain the variation of pore-water pressure with depth and time, in response to different accumulated amount of rain. Soil thickness of 2m and 0.5m overlying bedrock was assumed in the analysis. The pore-water pressure profiles were subsequently used in calculating stability using infinite slope model.

Infiltration behavior was studied using Richard's and continuity equation as shown in (2).

$$\frac{\partial}{\partial x}\left[k_x \frac{\partial h}{\partial x}\right] + \frac{\partial}{\partial y}\left[k_y \frac{\partial h}{\partial y}\right] + Q = m_w \left[\frac{\partial u_w}{\partial t}\right] \qquad (2)$$

where, k_x and $k_y$was the permeability in x and y direction respectively, h = total hydraulic head, Q = applied boundary flux, u_w = pore water pressure, and m_w = gradient of the soil-water characteristic curve.

3.1 *Steady-state analysis*

The first step of the infiltration analysis involved calibrating the initial condition of pore-water pressure with the field measurement, reported by Jotisankasa & Tapparnich (2010). This initial condition of pore-water pressure was calculated from steady-state analysis as shown in Fig. 3. In this analysis, a constant unit flux was assumed at top surface as the average monthly rainfall (300 mm/month or 1.077E-7 m/s). The pore-water pressure at 2m depth was fixed at the value of -9 kPa, the same as obtained from field measurement.

3.2 *Transient seepage and stability analysis*

Transient seepage analysis was then performed assuming the flux at top surface of 1.39E-5 m/s or 50mm/hr using the steady-state analysis results as the initial condition. The boundary conditions at the base in transient analysis were assumed to be either no-flow (impeded drainage) or unit-gradient (free-draining).

Figs. 4 and 5 show the variations of pore-water pressure for different rainfalls from the analyses, for both types of boundary conditions. Evidently, for soil section with poor-drainage at base (Fig. 4), the increase in pore-water pressure was more significant which resembled perched water tables at 0.2 and 2m depth. The pore-water pressure reached the maximum value of 11.8 kPa at 2m depth after 350mm of rain. On the contrary, for the soil section with good drainage (Fig. 5), only minimal pore-water pressure developed at the base even after 350mm of rain. This thus highlights the importance of realistic specification of base boundary condition.

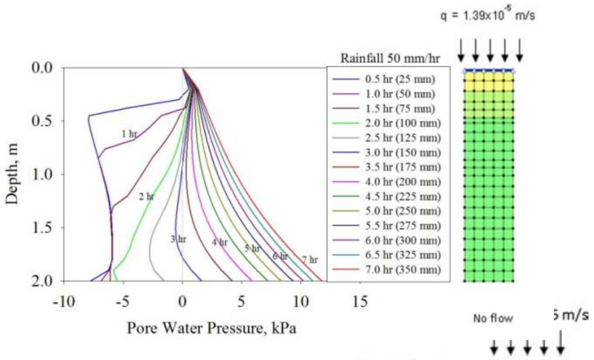


Fig. 4 Pore-water pressure profiles for different rainfalls from transient analyses (No-flow conditions at base)

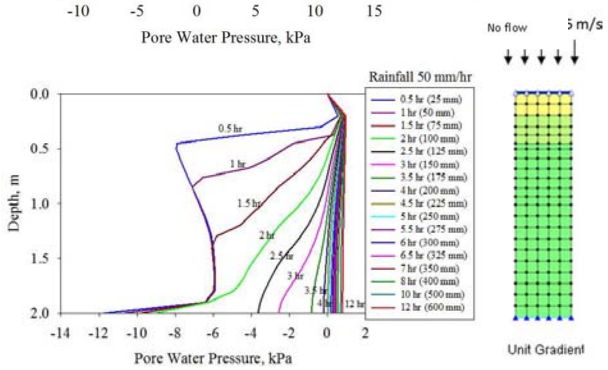


Fig. 5 Pore-water pressure profiles for different rainfalls from transient analyses (Free-draining or unit-gradient conditions at base)

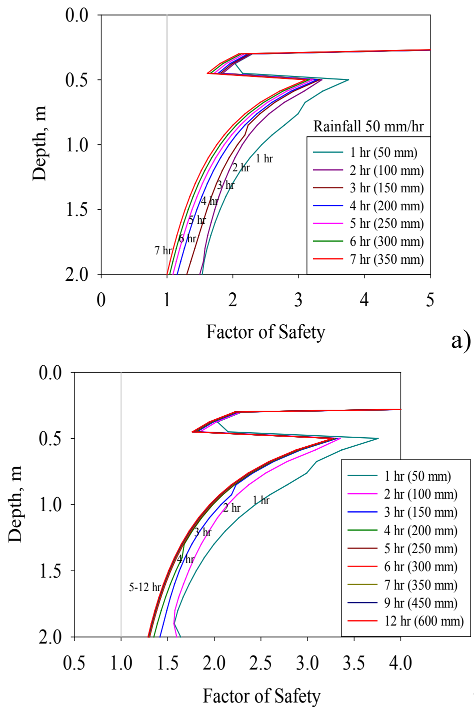


Fig. 6 Factor of Safety for different rainfalls from infinite-slope and infiltration analysis for Case (a) No-flow condition at base and (b) Free-draining at base

These pore-water pressure profiles were then used to calculate the stability of 45^{o} slope using infinite slope model as shown in Fig. 6. It can be seen that the slope would fail at the depth of 2m if the rain lasted about 7 hours and reached the amount of 350mm only if the drainage condition at the base was impeded (i.e. no flow condition).

Another set of analyses was carried out on soil section assuming soil thickness of 0.5m with no-flow condition assumed at the base. Fig. 7 shows pore-water pressure profile for different rainfall amounts. Evidently, the pore-water pressure appeared to increase rapidly within 1 hour (50mm of rain) and tended to be relatively unchanged thereafter at 4.9kPa at 5m depth.

In terms of stability, the safety factor was calculated using infinite slope model (Eq. 3) for the case of 1:1 slope (β =45^{o}) having shear strength from laboratory tests and the case with reduced cohesion at different depths,z, (γ~18.4 kN/m^3)

$$F = \frac{c' + \gamma z \cdot \cos^2\beta \tan\phi' - u_w \tan\phi''}{\gamma z \sin\beta \cos\beta} \quad (3)$$

Fig. 8 shows the factor of safety with time and depth. Evidently, the slope with original strength parameters would remain stable (FS >1) even after 1.5 hour (75mm of rain) while the slope with 20% reduction in cohesion would fail at depth of 0.5m when rain exceeded 75mm.

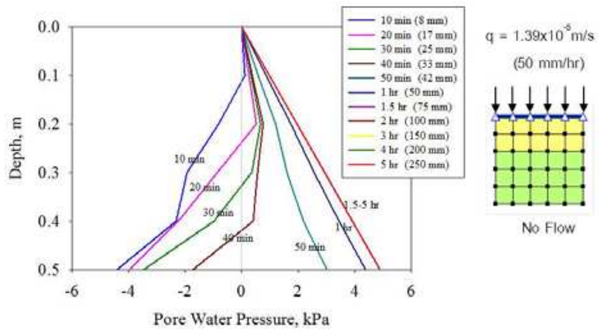
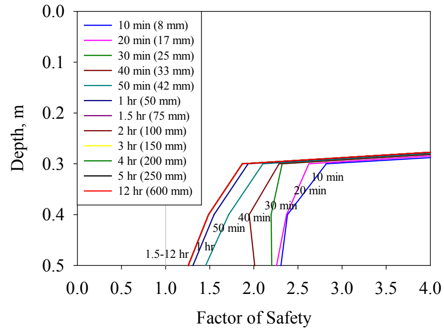
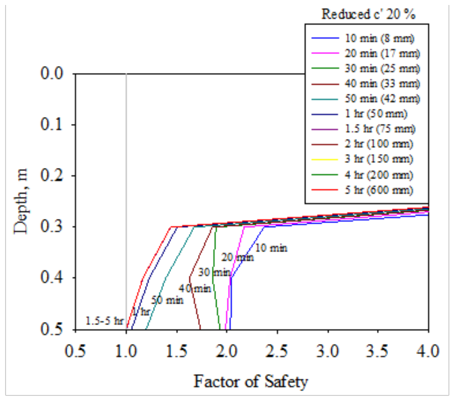


Fig. 7 Pore-water pressure profiles for soil thickness of 0.5 m from transient analyses (No-flow conditions at base).



a)



b)

Fig. 8 Factor of Safety for slope assuming no-drainage basefor Case (a) Original shear strength has tested and (b) Reduced cohesion - 20%

4 CONCLUSIONS

Landside initiation mechanism is complex and involves various factors. This paper focuses on a numerical study of 1-D infiltration and stability using infinite slope model, with emphasis on base-drainage condition and soil thickness. It appeared from these simple analyses that the range of critical rainfall amount can vary from 75 to 300mm even for the same antecedent rainfall. This large variation in the critical rain originated from differing base drainage condition, soil-thickness and weathering degrees.

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