# The effects of evaporation flux boundary condition on pore water pressure in hillslope

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## Abstract

Pore water pressure is main parameter for analysis slope stability problem or landslide problem. The situation of pore water pressure depends on net moisture flux boundary conditions. In the surfaces boundary, evaporation is the processes that remove water from the top soil layer. Hillslope soil increases negative pore water pressure and might increases stability of the hillslope. It is very useful to understand about evaporation effect on the pore water pressure. The study focuses on simulation of pore water pressure under evaporation process. The numerical analysis models were used to study the effect of evaporation on pore water pressure of hillslope at Doi Pui research station of Kasetsart University, Chiang Mai, Thailand. The results of numerical analysis with no flow condition show a good agreement with those obtains from the field monitoring data. On other hand, the pore water pressure results in unit gradient condition disagreement with field monitoring at Doi Pui.

**Keywords:** evaporation, numerical analysis, climate, flux boundary

## 1. Introduction

In order to understand the safety behavior of slope, It is necessary to evaluate of moisture transfer between the soil layer and the atmosphere. A flux boundary refers to moisture transfer across soil - atmosphere interface. The parameters relating with flux boundary condition are infiltration, evaporation, transpiration, evapotranspiration and runoff. The infiltration of rainfall into hillslope increases the pore water pressure. It leads to decreases the stability of the hillslope. On the other hand, the evaporation, transpiration and evapotranspiration are process that remove water from hillslope. The negative pore water pressure increases as the soil dries, hence risk for the occurrence of landslides to be down.

[9]. show the effect of evaporation flux on factor of safety of slope and found that the factor of safety can be increased 34% due to evaporation. However the rainfall occurred, the factor of safety was decreased by 27%.

The mechanism leading to extreme rainfall-induced slope failures is well-understood. When a slope is subjected to pore pressure or ground water table increase due to infiltration, total stresses and shear stresses remain constant, but the soil matric suction and shear strength on the failure plane decrease [10]. In contrast, the influence of evaporation on hillslope is difficult to study because it depends on several factors, such as net solar radiation, wind speed, air temperature, and the difference in the behavior of evaporation between water surface and soil. This paper presents the negative pore water pressure distribution as a result of numerical analysis base on the evaporation process.

## 2. Soil-atmosphere coupling

The condition of ground depends on net moisture flux boundary conditions. The evaluation of net moisture flux needs to know the water balance in each site. The water balance is the net of moisture exchange between ground surface and atmosphere. Rainfall enters the ground through the infiltration process. When leaves the ground by actual evaporation (AE) or transpiration (T). It may be flows from the ground surface by runoff process (R). The components of net moisture flux at the ground can be written in the following form and shows in Fig.1.

$$I = P - AE - T - R \tag{1}$$

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Where I is Net infiltration flux, P is precipitation flux, AE is actual evaporation flux, T is transpiration flux, and R is runoff flux.

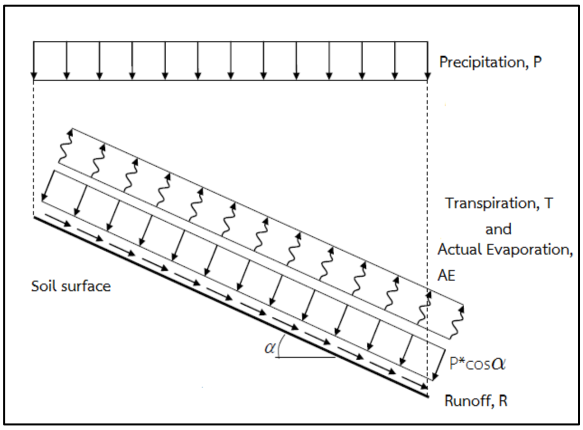


**Fig.1.** Soil-atmosphere moisture flux components [after 4].

## 3. Partial differential equations for water and heat flow

Fredlund and Gitirana Jr. (2005) combined the equation of conservation of mass for the water phase, Darcy´s law for the flow for liquid water, Fick´s law for the flow of water vapor, and Lord Kelvin's relative humidity equation that it is simplifications of the general equations for water and heat flow. The PDE of heat flow and water can be written as follows:

$$\frac{\partial}{\partial x}\left[k^{w}\frac{\partial}{\partial x}\left(\frac{u_{w}}{\gamma_{w}}+y\right)+\frac{k^{vd}}{\gamma_{w}}\frac{\partial u_{w}}{\partial x}-\frac{k^{vd}}{\gamma_{w}}\frac{u_{w}}{(T+273.15)}\frac{\partial T}{\partial x}\right]$$
$$+\frac{\partial}{\partial y}\left[k^{w}\frac{\partial}{\partial y}\left(\frac{u_{w}}{\gamma_{w}}+y\right)+\frac{k^{vd}}{\gamma_{w}}\frac{\partial u_{w}}{\partial y}-\frac{k^{vd}}{\gamma_{w}}\frac{u_{w}}{(T+273.15)}\frac{\partial T}{\partial y}\right]$$
$$= m_{2}^{w}\frac{d\left(u_{a}-u_{w}\right)}{dt} \qquad (2)$$

## 4. Field site description and climate condition

The slope is located in the residual soil that weathering from the Granite Triassic group (Doi Pui soil series) at Doi Pui research station of Kasetsart University. The Doi Pui research station of Kasetsart University is located in Doi Suthep - Pui national park, Chiang Mai, Thailand. The research station position is approximately 2079845.83N and 487848.14E, in addition, above mean sea level 1,250 meter. The slope geometry and soil profile as shown in Fig.2.

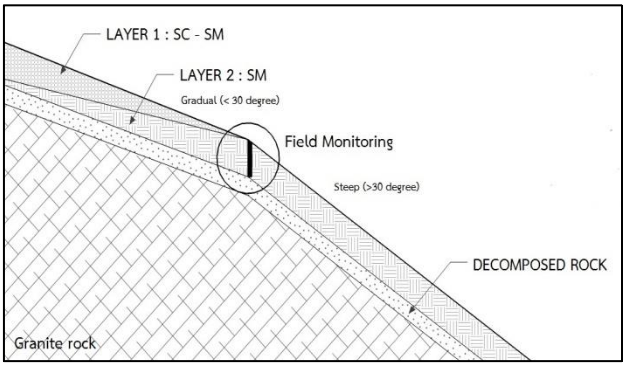


**Fig.2.** Field site location at Doi Pui, ChiangMai, Thailand

In 2013, Geotechnical Engineering Research and Development center (Department of civil engineering, Kasetsart University) collaborative Research with OYO Corporation under the Landslide Monitoring Induced by Local Intensive Rain Project at Doi Pui, Chiang Mai, Thailand. The project studied and monitored the hillslope at Doi Pui where the same area with department of Mineral Resources project [Fig.4.]. The project installed rain gauge, tensiometer, in-place inclinometer and debris flow detection sensor [Fig.3.].

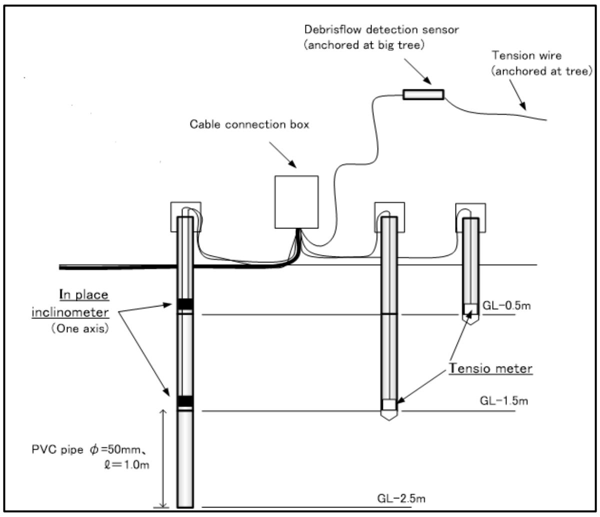


**Fig.3.** Installation of the monitoring instruments

The climate condition in Doi Pui is cool year round. Average temperature is approximately 20 degree Celsius. Average relative humidity is between 56.7 % – 89.3 %. Average wind speed is 7.7 km/hr. The rainy season peaks in August and September. Rainfall is about 2000 mm/year. Evaporation rate is 1165 mm/year.

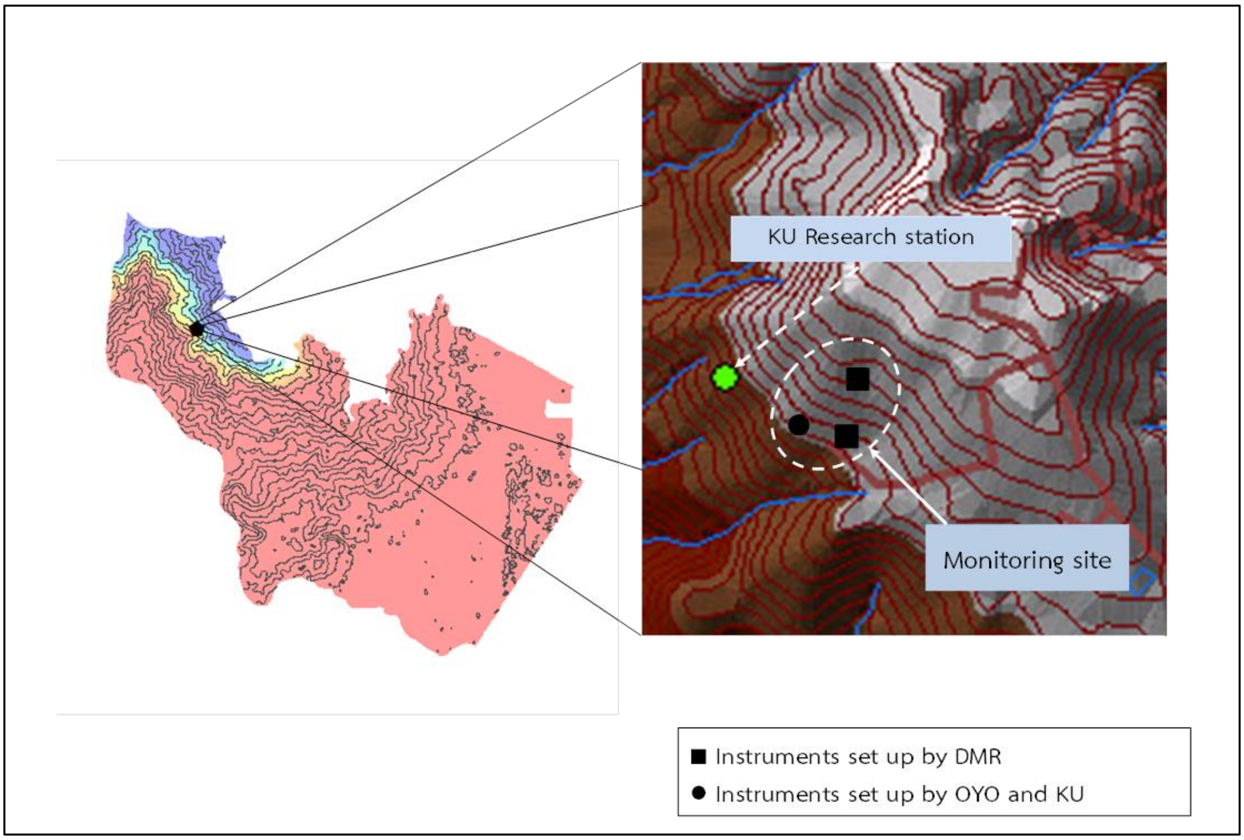


**Fig.4.** Location of monitoring installation in Doi Pui Research Station

## 4. Soil – water characteristics curve and Hydraulic Function

The soil-water characteristic curve (SWCC) and permeability function are the most important properties for unsaturated soils analysis including infiltration, evaporation and prediction of unsaturated shear strength. SWCC of a soil is provides a relationship between water content and soil matric suction. In this study, SWCC is determined using miniature KU-tensiometer for suction 0 to 100 kPa [Fig.5.]. Permeability function estimated by Van Genuchten equation (1980). The saturated permeability of soil at Doi Pui site was 6.903 x 10-5 cm/sec. The permeability function of residual soils at Doi Pui site is shown in Fig.6.

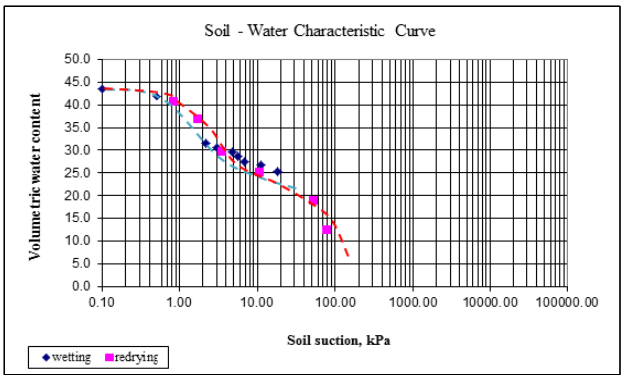


**Fig.5.** Soil – Water characteristics curve of residual soil at Doi Pui

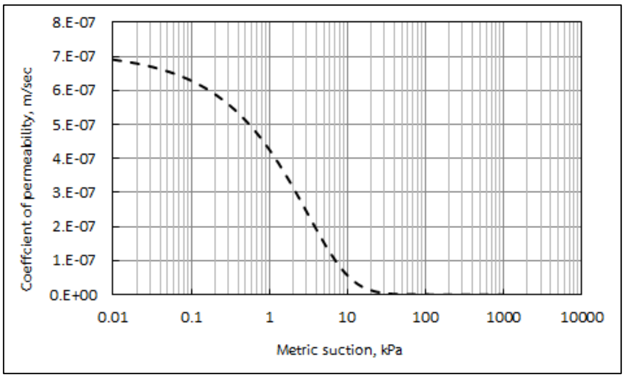


**Fig.6.** Permeability function of residual soils at Doi Pui

## 5. Evaporation modeling of residual soil slope

The numerical model used finite element software, Vadose/W (Geoslope International Pte Ltd., 2007). The model analyzed the effect of evaporate flux boundary on the negative pore water pressure at Doi Pui. The model used only drying soil–water characteristic curve because the evaporate process removes moisture from the ground. The permeability function used SWCC data for estimate the functions. The initial condition for the slope model was generated using spatial function based on the initially measured pore-water pressures from the tensiometer data at Doi Pui. The initial pore water pressure was -12.6 kPa that tensiometer reading at depth 0.5

meter. Spatial function is a function in Vadose/W to assist the users in setting up the initial condition of the model [8]. The climate data and pore water pressure data were the periodically collected from 4 January 2015 to 9 January 2015. The climate data used to input the finite element model, shown in Table 1.

Table 1. Climate data for the numerical model

| Date | Max Temp (°c ) | Min Temp (°c ) | Max. RH (%) | Min. RH (%) | Rainfall mm. |
|---|---|---|---|---|---|
| 04/01/15 | 36.1 | 14 | 58 | 56 | 0 |
| 05/01/15 | 37.4 | 15.3 | 58 | 56 | 0 |
| 06/01/15 | 37.5 | 16.2 | 58 | 56 | 0 |
| 07/01/15 | 37.2 | 15.7 | 58 | 56 | 0 |
| 08/01/15 | 21.6 | 18 | 58 | 57 | 0 |
| 09/01/15 | 18 | 16.3 | 57 | 56 | 0 |

The boundary condition of the analysis consists of two main parts include top boundary and bottom boundary. The top boundary is surface mesh that they are used to input the climate data. The bottom boundaries were done in two cases. In the first case, bottom boundary condition was no flow condition. In the second case, the bottom boundary was unit gradient condition. This study used both cases because the weathered rock properties could not found. The mesh and boundary condition are shown in Fig.7.

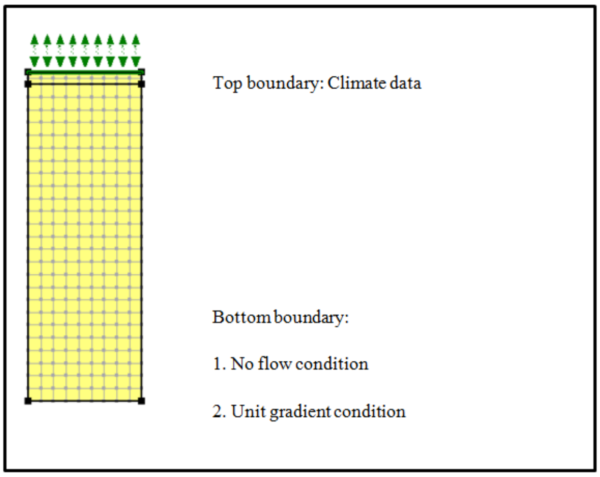


**Fig.7.** Top and bottom boundary condition for model

Fig.8. shows negative pore water pressure distribution with time at depth 0.5 m. from the ground surface. During the first days of the analysis, it is found the analyzed negative pore water pressure distribution is closed to the field monitoring and both numerical analysis. Next period, the result of negative pore water pressure in second condition continuously decreased and no concurs with the field monitoring. Therefore, the negative pore water pressure results in no flow condition show good agreement with those obtain from field monitoring.

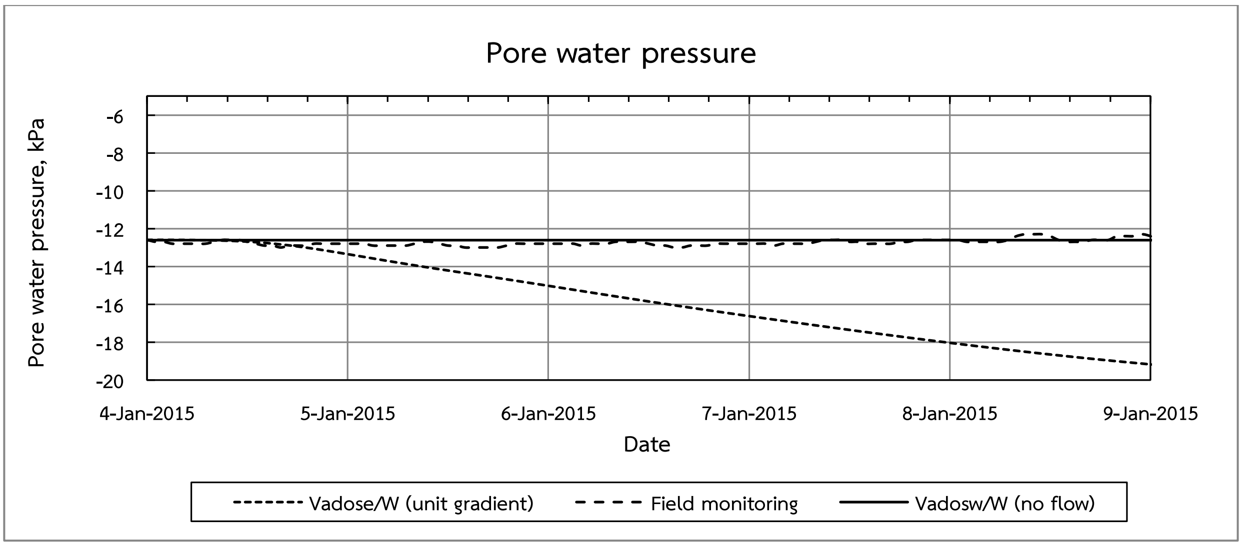


**Fig.8.** negative pore water pressure as result of numerical analyses

## 6. Conclusions

1. The characterization of climatic data is necessary for quantifying evaporation flux boundary conditions. Therefore, the weather station in field site should be full option for weather observation.

2. The pore-water pressure distribution from no flow boundary show a reasonably good agreement with those obtained from field monitoring data.


## Acknowledgement

The author would like to thank Department of Mineral Resources, Geotechnical Research and Development Center (GERD), and Geotechnical Innovation Laboratory (GIL) Department of civil engineering, faculty of engineering, Kasetsart University


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