Effect of the Initial Suction Boundary on the Slope Failure of Volcanic Residual Soil

Agus **Setyo** Muntohar[1]
[1]*Department of Civil Engineering, Universitas Muhammadiyah Yogyakarta, D.I. Yogyakarta, Indonesia*
E-mail: muntohar@umy.ac.id

ABSTRACT: Rainfall-induces slope failure has been intensively investigated to obtain the failure mechanism and its affecting and controlling factors. This paper presents a numerical analysis of the rainfall and limiting pore water pressure on the slope instability of volcanic residual soil. The slope was natural slope where was located in Kedungrong, Kulonprogo Regency. The slope was modeled using 2D finite element method to anlayze the rainfall infiltration and slope stability. In this study, the initial suction at the surface was limited from 1 to50 kPa with initial groundwater depth up to 20 m below the slope surface. In general, a higher initial suction induces a delayed rainwater infiltration and result in delayed slope failure. When the initial suction was generated from ground water table, limiting the initial suction in the numerical analysis can provide a reasonable result to evaluate the slope failure
Keywords: initial suction, rainfall, slope stability, infiltration, pore water pressure, volcanic soil.

1. INTRODUCTION

Many landslide cases in Indonesia occurred in rainy session during November to February. At this period, the rainfall continuously precipitated and triggered the slope failures. Indonesia receives significant rainfall year-round but experiences a wet season that peaks in January and a dry season that peaks in August (Hendon, 2003; Lee, 2015). Evaluation of the rainfall triggering slope instability shows complexity in the numerical model. Several studies indicated that slope stability was affected by the boundary on the slope surface and initial condition such as flux, initial suction, rainfall intensity and duration (Tsaparas et al., 2002; Rahardjo et al., 2013; Muntohar et al., 2013). The researcher also investigated the controlling parameter on the rainfall-induced slope failures. Rainfall characteristics and hydraulic properties of the soil were the most controlling parameter that should be paid attention to the numerical model (Tsaparas et al., 2002; Rahardjo et al., 2007).

In the 2D numerical analysis for infiltration or seepage requires the initial conditions of pore-water pressure at the soil surface. Through this initial condition, then pore pressures are calculated for each change in volumetric water content during infiltration. Many researchers (e.g. Ng and Shi, 1998; Tsaparas et al., 2002; Lee et al., 2009; Rahardjo et al., 2010) suggest that initial negative pore water pressure at the soil surface needs to be restricted, especially when very deep groundwater is encountered. In a very deep groundwater table, when the initial conditions of pore water pressure are based on hydrostatic pressure, they tend to produce unrealistic pore pressures.

A landslide case in Kedungrong village occurred in November 2001 after five days of intense rainfall (see Figure 1). This landslide is interested to be studied since the area is populated. Figure 2 shows the location of landslides in District of Kulonprogo, Yogyakarta. This paper is addressed to investigate the effect of limiting of initial pore water pressure on the rainfall-induced slope instability.

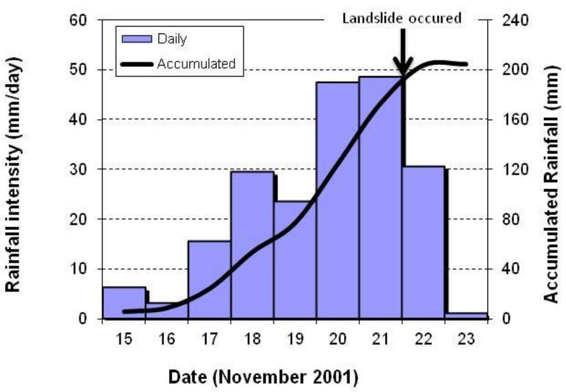


Figure 1 Rainfall record at the landslide area

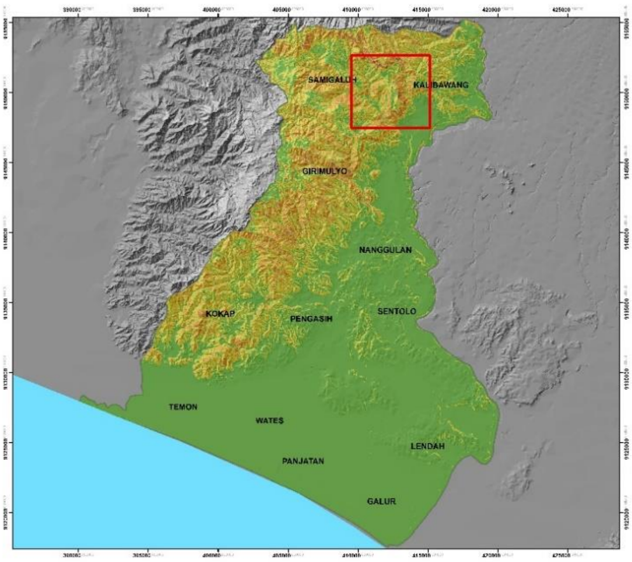


Figure 2 Location of Kedungrong landslide

2. RESEARCH METHOD

2.1 Soil and Slope Properties

Both field and laboratory tests were carried out to obtain the soil layers and the geotechnical properties. Figure 3 shows the slope profile which was interpreted from hand-auger work. The slope was covered with residual soil of tuffs, weathered-breccia, and breccia-rock at the lowest layer. The geotechnical properties of each layer are presented in Table 1. The soil-water characteristic curve and hydraulic conductivity – suction relationship are shown in Figure 4.

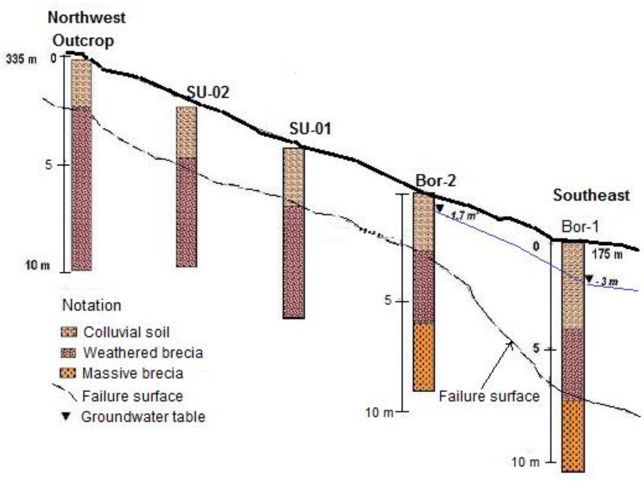


Figure 3 The sectional area of the slope and soil layers

Table 1 Geotechnical properties of the soil layers

Parameter	Residual Soil (Layer A)	Weathered Breccia (Layer B)	Massive Breccia (Layer C)
Natural moisture content, w_N(%)	33.2	39.4	40.2
Bulk unit weight, γ_b (kN/m^3)	17.7	15.1	14.8
Unit weight above water table, γ_d (kN/m^3)	13.4	12.1	11.7
Degree of saturation, S_r (%)	90.1	64.8	41.9
Saturated permeability coefficient, k_{sat} (m/s)	1.19x10^{-4}	1.74x10^{-8}	-
Cohesion at failure (peak), c' (kPa)	16	48	-
Residual cohesion, c'$_r$ (kPa)	12	36	-
Internal friction angle at peak, ϕ' (_o)	24	10	-
Internal friction angle at residual, ϕ'$_r$ (_o)	18	9	-

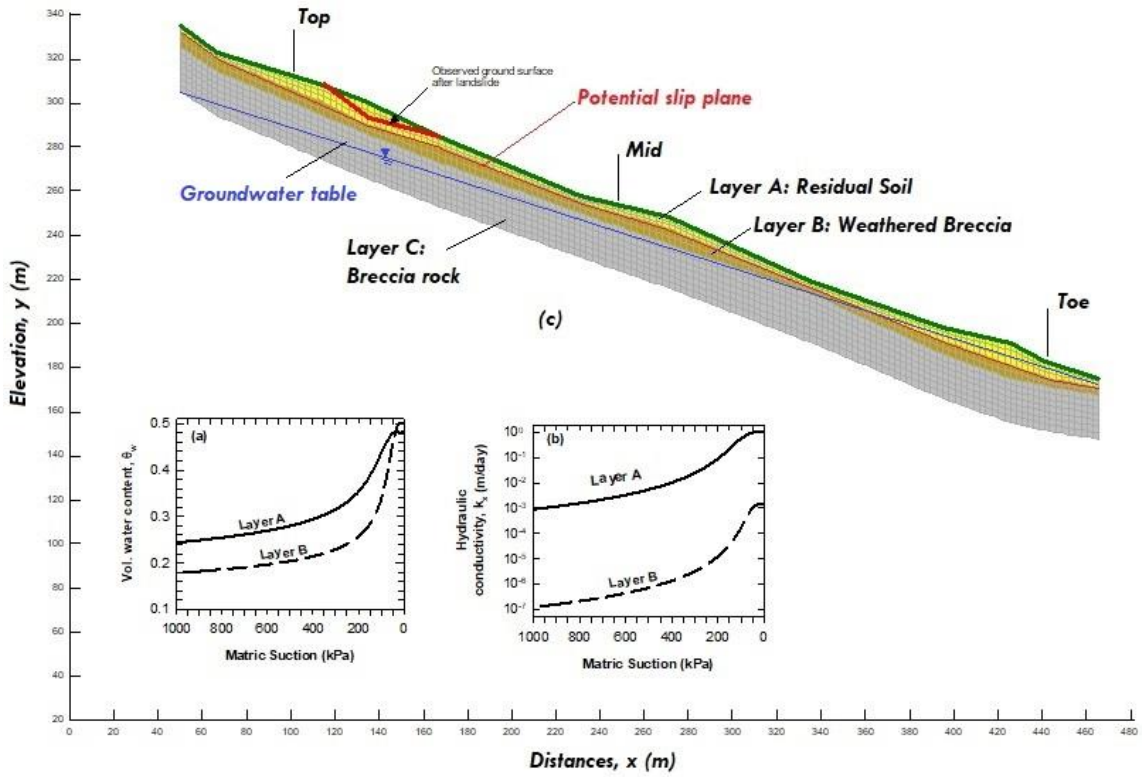
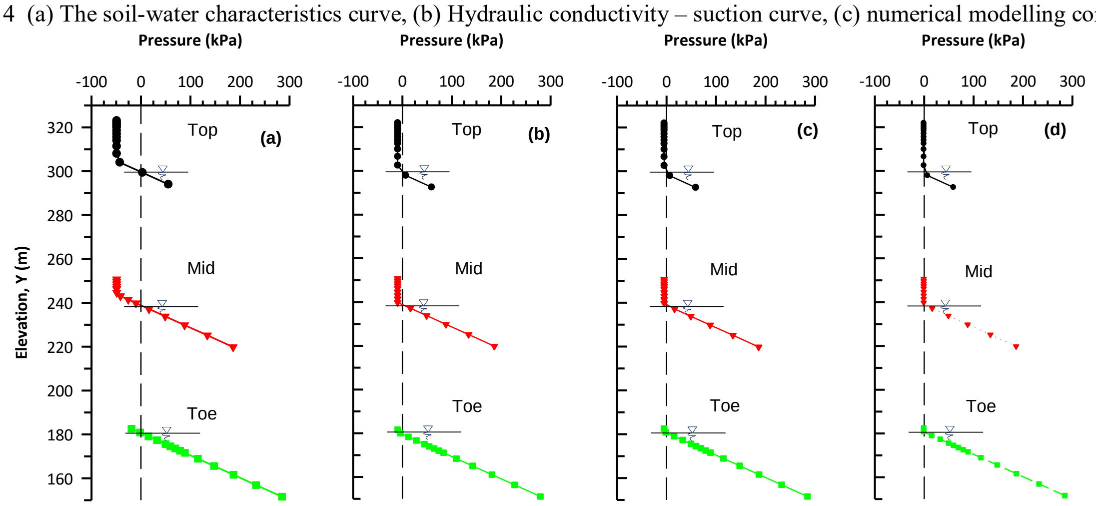


Figure 4 (a) The soil-water characteristics curve, (b) Hydraulic conductivity – suction curve, (c) numerical modelling condition



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and (d) u_a-u_w = 1 kPa

2.2 Numerical Analysis

Figure 4c illustrates the idealization of the slope for numerical analysis. The finite element used quadrilateral meshes of 3 m size. This size was suitable to obtain numerical convergence result. For these analyses, a finite element software SEEP/W was used (GeoStudio, 2004a). The slope stability analyses were used to study the effect of seepage conditions on the factor of safety of the slope. The analysis was conducted by SLOPE/W (GeoStudio, 2004b).

In this study, the initial suction at the surface was limited from 1, 5, 10, and 50 kPa with initial groundwater depth up to 20 m below the slope surface (see Figure 5). The rainfall was applied on the slope surface as unit flux (q) and the seepage review was allowed on the surface. The pore water pressure are reviewed at the top (top), middle (mid) and toe slopes (toe). The pore water pressure obtained from SEEP/W analysis was then directly linked to SLOPE/W analysis. The factor safety (FS) was calculated according to limit equilibrium Bishop method. This analysis allowed the factor of safety varied with the elapsed time as the pore water pressure changed.

3. RESULTS AND DISCUSSION

The typical pore pressure profile of the numerical simulation is presented in Figure 6 and 7 for initial suction 1 kPa and 50 kPa respectively. The pore water pressure profile clearly shows the

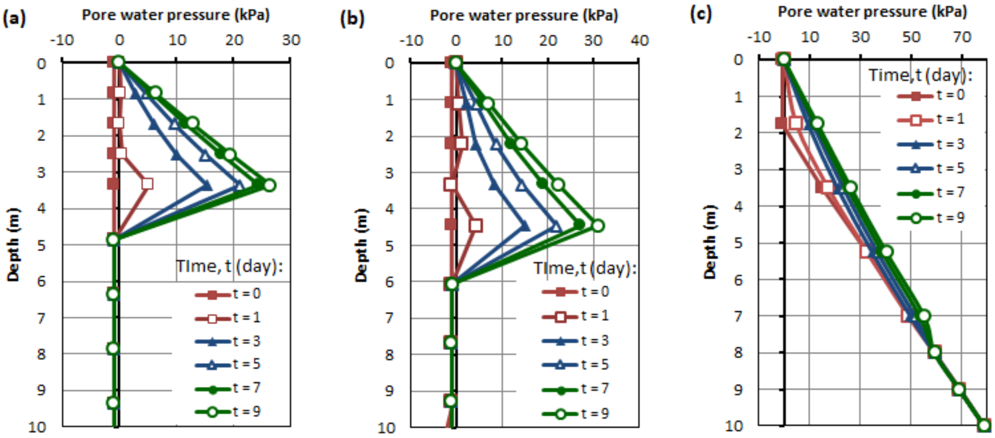
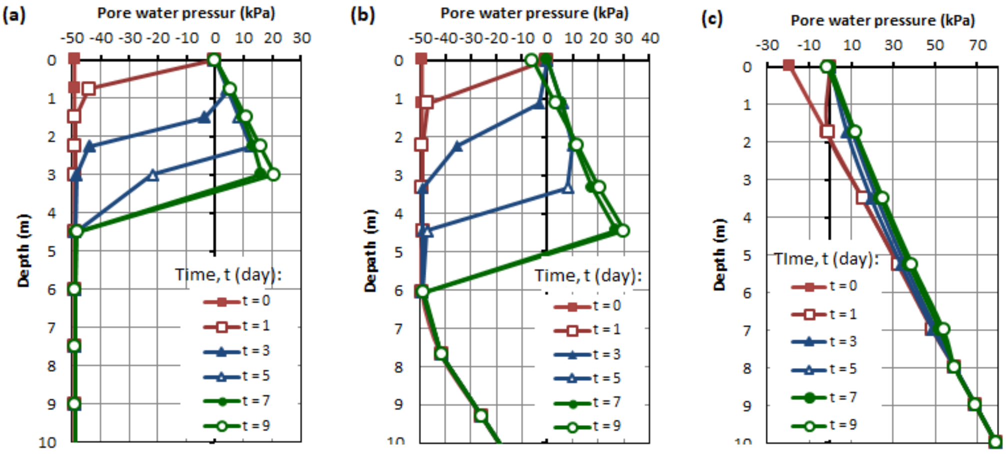


Figure 6 Pore water profiles for limiting suction 1 kPa (a) at top, (b) mid, and (c) toe slope



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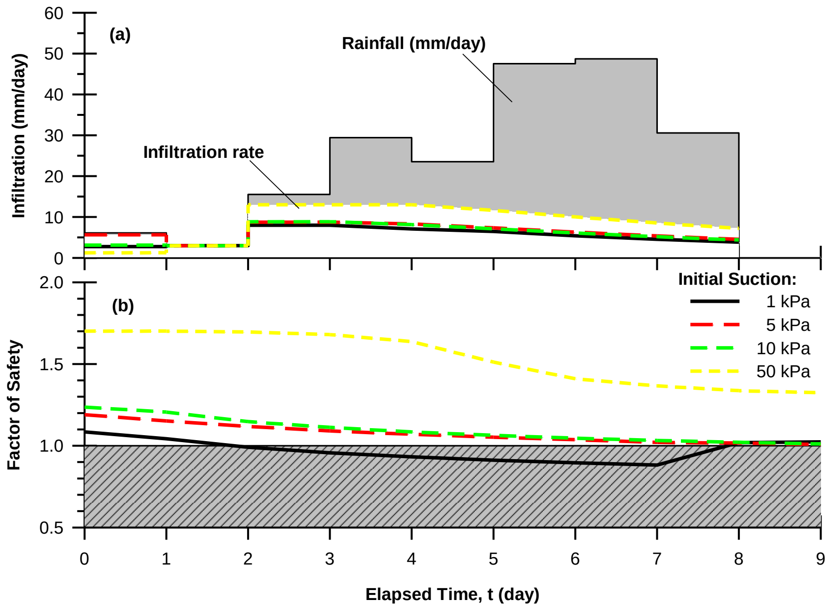

Figure 8 (a) Variation of infiltration rate, and (b) Variation of the factor of safety with elapsed time.

change in pore pressures against the initial conditions of suction on the slope surface. After a day of rainfall (t = 1 day), it was observed that the surface was saturated for all initial suction condition. The saturation advanced to a deeper depth with the elapsed time of rainfall. Positive pore water pressure was build up on the interface of the Layer B and Layer C, because of the Layer C is almost impervious. It allows the rainwater to flow along the interface and induced seepage at the toe of slope (see Figure 6c and 7c). This mechanism was introduced in Muntohar and Soebowo (2013).

At low initial suction (Figure 5), the wetting front zone is rapidly achieved at low rainfall intensity and shorter duration. In contrast to a higher initial suction (Figure 6), it takes longer to form a wetting zone. During infiltration, rainwater displaced the air in unsaturated zone and delaying infiltration was induced. In contrast at a lower initial suction, the soil is nearly saturated. Thus, the rainfall infiltration rate is slower. At the observed point at the mid slope, infiltration rate tends to increase with increasing initial suction (Figure 8a). This condition generally explains that slope surfaces with a higher suction values tend to be near dry or dry. Thus, rainwater can rapidly flow into the slope subsurface. However, the depth of the wetting zone achieved is relatively shallow depending the rainfall intensities.

It can been seen in Figure 8b that the factor of safety decreases as the rainfall intensity increases. The decrease of the factor of safety was attributed to the increase in pore water pressure (see Figure 6 and 7). Ng and Shi (1998) explained that increase in pore water pressure reduce the shear strength of the soil according to the Mohr-Coulomb failure criterion for unsaturated soils. Slope with a higher initial suction result in delayed slope failure because of delayed infiltration and build up pore water pressure. The result was also explained by Rahardjo et al. (2010). A shallower initial groundwater table generated a lower initial suction. As a result, the combination constituted to a worst factor of safety of slope (Rahardjo et al., 2007). Thus, the determination of the initial conditions of suction greatly affects the stability of the evaluated slopes.

4. CONCLUSION

A numerical analysis has been successfully performed to investigate the effect of limiting initial suction on the rainfall-induced slope failure. A remarkable results and discussion conclude that the initial conditions of suction greatly affect the stability of the evaluated slopes. In general, a higher initial suction induces a delayed rainwater infiltration and result in delayed slope failure. When the initial suction was generated from ground water table, limiting the initial suction in the numerical analysis can provide a reasonable result to evaluate the slope failure.

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