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EDITED BY
Christopher L. Meehan, Ph.D., P.E.
Daniel Pradel, Ph.D., P.E., D.GE
Miguel A. Pando, Ph.D.
Joseph F. Labuz, Ph.D., P.E.

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1801 Alexander Bell Drive
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Preface

The Geo-Institute of the American Society of Civil Engineers (ASCE) has a long history of publishing papers from its annual Geo-Congresses and Specialty Conferences. Since 1986, these conference proceedings have been published in volumes termed Geotechnical Special Publications (GSPs). This volume is GSP 231, and it contains the Proceedings of the 2013 Geo-Congress, entitled *Stability and Performance of Slopes and Embankments III*, which was held March 3-7, 2013 in San Diego, California.

This conference builds upon a distinguished legacy of ASCE Geo-Congresses that have focused on the stability and performance of slopes and embankments, topics that are of critical interest to the geotechnical engineering community. The first conference in this series was held in 1966, and was organized by G.E. Bertram, W.G. Holtz, T.W. Lambe, J.K. Mitchell, H.B. Seed, and R.J. Woodward. The second conference in this series was held in 1992, and was organized by a large group of individuals, many of whom were members of the Embankments, Dams, and Slopes (EDS) committee of the ASCE Geotechnical Engineering Division. Both of these historic conferences included presentations by the most prominent geotechnical engineers of each generation, and the landmark papers from the corresponding proceedings are still widely used and referenced today.

Following this tradition, the 2013 Geo-Congress has brought together the preeminent engineers of today to discuss the many advances in slope and embankment engineering that have occurred over the last two decades. The resulting conference program is both broad and exciting, and includes the honorary Terzaghi, Peck, and Seed Lectures, nine keynote lectures, forty-three technical sessions, five panel sessions, and a wide range of student activities, short courses, and workshops.

In this volume, papers are included from authors presenting in nine plenary sessions, and forty-three focused technical sessions. For the first time, the 2013 Geo-Congress Proceedings have allowed three types of paper submissions: research letters, technical papers, and case study papers. Research letters are 3-4 pages long, and highlight cutting-edge research projects or particularly innovative practice-oriented projects. Technical papers are 6-10 pages long, and detail the findings from research- or practice-oriented projects that are of broad interest to the geotechnical engineering community. Case study papers are 10-15 pages long, and provide more extensive details, photographs, and descriptions about an individual field study.

During the preparation of the conference program, approximately 450 abstracts were considered. From the pool of accepted abstracts, 264 full manuscripts were submitted and reviewed. From this group, 228 papers were ultimately accepted for publication in the Proceedings.

The 43 technical sessions listed in the Table of Contents were proposed and organized by 63 session chairs. In this volume, the reader will find them listed as Members of the Review Board. They were assisted by several hundred professional colleagues in order to guarantee that each published paper received a minimum of two anonymous reviews by experts in the corresponding subject area. The organizing committee grouped the technical sessions into the following five tracks so that papers on common themes would appear side-by-side in the GSP: Exploration and Characterization; Design, Analysis, and Performance; Observation, Monitoring, and Condition Assessment; Inspection, Hazard Assessment, and Management; and Repair and Remediation.

On behalf of the conference organizers and the Geo-Institute at-large, we wish to express our gratitude to all of the session chairs and reviewers for their diligent and tireless efforts to make these Proceedings a reality. We also wish to extend our thanks to Helen Cook, the Geo-Institute's Board and Program Specialist. Ms. Cook's tireless efforts working with authors, session chairs, and members of the conference organizing committee were instrumental in the conference planning process. Finally, we would like to thank the authors for their contributions to the Proceedings. The papers that have been submitted by our colleagues do a great service to the legacy of the two previous ASCE conferences that focused on the stability and performance of slopes and embankments.

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Mechanism of rainfall triggering landslides in Kulonprogo, Indonesia

Agus Setyo Muntohar [1], Jazaul Ikhsan [1], Eko Soebowo [2]

[1] Department of Civil Engineering, Universitas Muhammadiyah Yogyakarta, Jl. Lingkar Selatan, Taman Tirto, Yogyakarta, Indonesia; muntohar@umy.ac.id
[2] Geotechnology Research Center, Indonesian Institute of Sciences, Jakarta, Indonesia

ABSTRACT: A landslide occurred during intense rainfall on 17 to 22 November 2012 in Kulonprogo, Indonesia is evaluated in this paper. The main objective of this work is to investigate the mechanism of rainfall induces landslide and thereby determine the critical time of instability. A finite element seepage analysis was performed to simulate the changes in pore water pressure during the rainfall event. Incorporation seepage model, the limit equilibrium slope stability method was applied to calculate the variations in the factor of safety during the event. Effective stress Mohr–Coulomb failure criterion was applied in the soil failure modeling. For the investigated site, the trend of the factor of safety indicates that the critical time for failure occurs about three days after the intense-rainfall commences. Seepage caused rising of the ground water table, and increased pore water pressure. The slope instability was controlled by the residual shear strength.

INTRODUCTION

Rainfall-induced landslide is a major geotechnical hazard in the world. Hence, landslide is one of the most important disasters in susceptible terrain areas, especially regions that routinely experience heavy rainfall. Some of these landslides occur suddenly and travel at high speeds, posing significant threats to life and property. The occurrence of landslides is becoming more frequent in Indonesia, during rainy season. A landslide occurred in prone area at Kedungrong village in 21 November 2001 after intense rainfall for five days. The landslide destroyed housing, road, and irrigation channel. The landslide area is located at Kulonprogo, Yogyakarta special province (Figure 1). Reconnaissance investigation has been made at the landslide area by Soebowo et al. (2003). The report concluded that the landslide was mostly caused by the geologic formation. Sedimentary rock of breccia pyroclastic is predominantly found in the landslide area. The top layer of slope was covered by residual soil, which was resulted from weathering of breccia. The outcrop observation at the scarp area showed that the slip-plane was at interlayer between breccia and residual soil (Figure 2b). The soil was classified as gravely-silt (Table 1). Other report, Kyi et al. (2007) investigated the influencing factors of landslide at Kalibawang catchment area including Kedongrong. The study confirmed that antecedent and rainfall intensity was determined as influencing factor as well as lithology and geological condition. Previous investigation was less focusing on the mechanism of the landslides. Hence, this paper is aimed to investigate the landslide triggering mechanism by rainfall infiltration. The main objective of this work is to study the effect of rainfall induces landslide and thereby determine the critical time of instability. The study includes both seepage and slope stability analyses.

FIG. 1 Location of the study

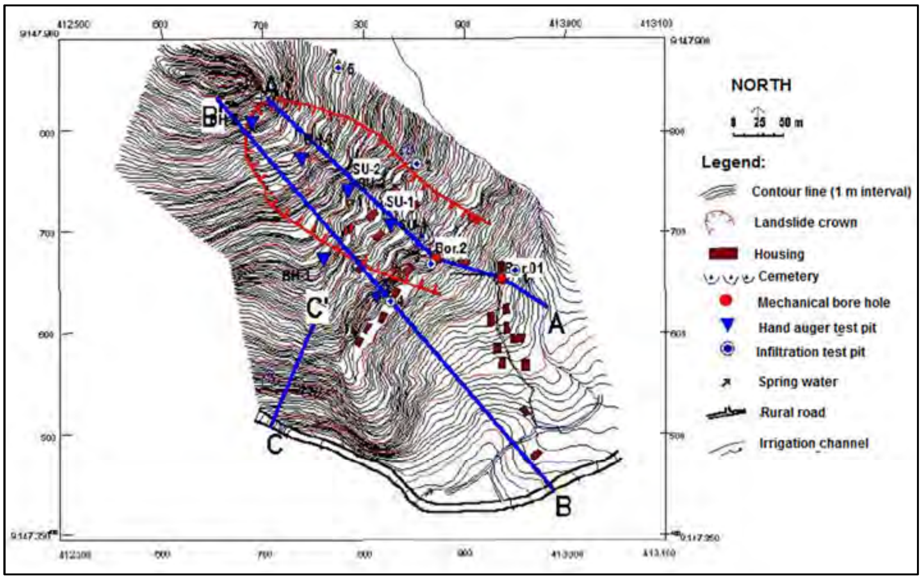
Table 1 Geotechnical properties of the soil and rock

Parameter	**Residual Soil**	**Weathered Breccia**	**Massive Breccia (bedrock)**
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 volumetric water content, θ_s	0.48	0.53	0.50
Saturated permeability coefficient, k_{sat} (m/s)	$1.19\text{x}10^{-4}$	$1.74\text{x}10^{-8}$	-
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	-
Unsaturated friction angle, ϕ^b (_^{o})	15	8	-

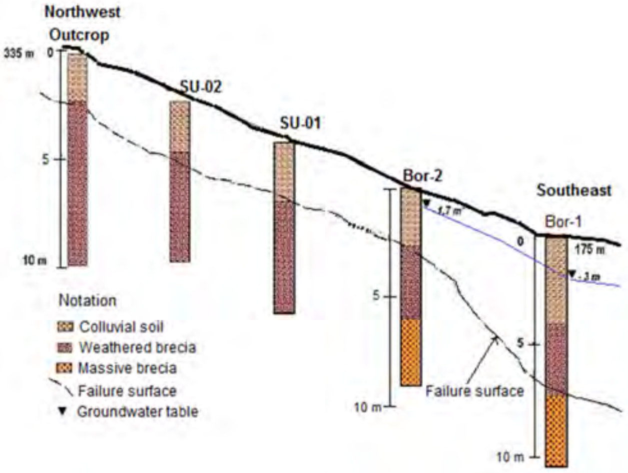
METHODOLOGY

Slope and soil properties

Data input for the slope-stability modeling of the studied area has been taken from topographic and geotechnical investigations. Soil geotechnical parameters were collated from a series of in-situ and laboratory tests, including grain size analysis, measurement of Atterberg limits, and direct shear tests (Soebowo et al. 2003). The soil shear strength parameter was obtained under drained condition. The geotechnical properties of the soil and rock are presented in Table 1. The residual soil can be classified as gravelly-silt which is symbolized with GM according to USCS.



(a)



(b)

FIG. 2 (a) Topographical condition of the slope failures, (b) Cross sectional of the slope (A-A section)

Seepage and Slope Stability Analysis

The seepage analyses are used to investigate how seepage will occur in a slope under a hydrological condition. 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). The hydraulic parameters used in this study were the distribution of rainfall (Figure 3), the saturated coefficient of permeability with respect to water and finally the initial conditions within the slope (Figure 4). Table 1 presents the parameters used in the study. Rainfall was applied as unit flux (*q*) hydraulic boundary on the top soil surface and seepage review was allowed on the slope surface (Figure 4). The left and right edges above the water table were specified as a no flow boundaries (Q = 0), while the edges below the water table were assigned as head boundaries with pressure head equal to the elevation of the water table. These boundaries would allow a reasonale infiltration and seepage condition in an infinite slope (Ng and Shi, 1998; Gofar et al., 2007).

A hydrostatic initial condition was established at the beginning of the transient seepage simulation. The water table below the ground surface was varied from the top to the toe of slope. A very deep water table would certainly produce an unrealistically high negative pore-water pressure near the ground surface in conjunction with hydrostatic condition. Therefore, a limiting negative pore-water pressure was imposed as an initial condition. Based on the field measurement, the initial suction was about 50 kPa. The value was consistent with the findings from other researcher e.g. Gofar et al. (2007), Lu and Godt (2008) who found that the suction stresses of sandy soil and silty soil can reach a maximum of 8 kPa to 50 kPa under no infiltration conditions. These boundary conditions should give reasonable pore-water pressure distribution.

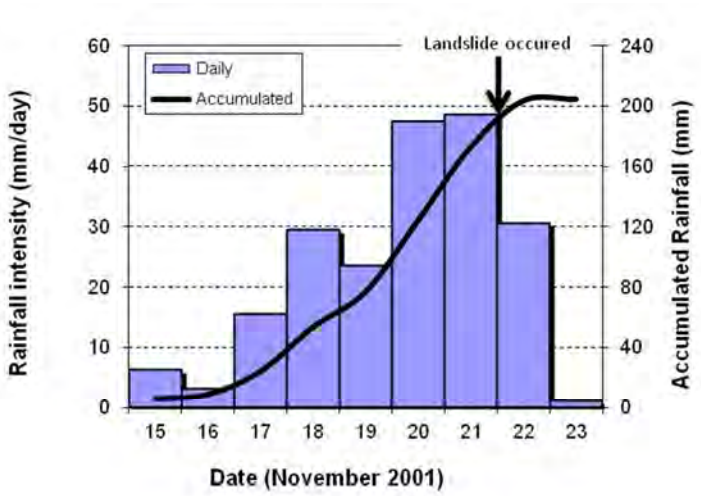


FIG. 3 Rainfall record at the slope failure sites

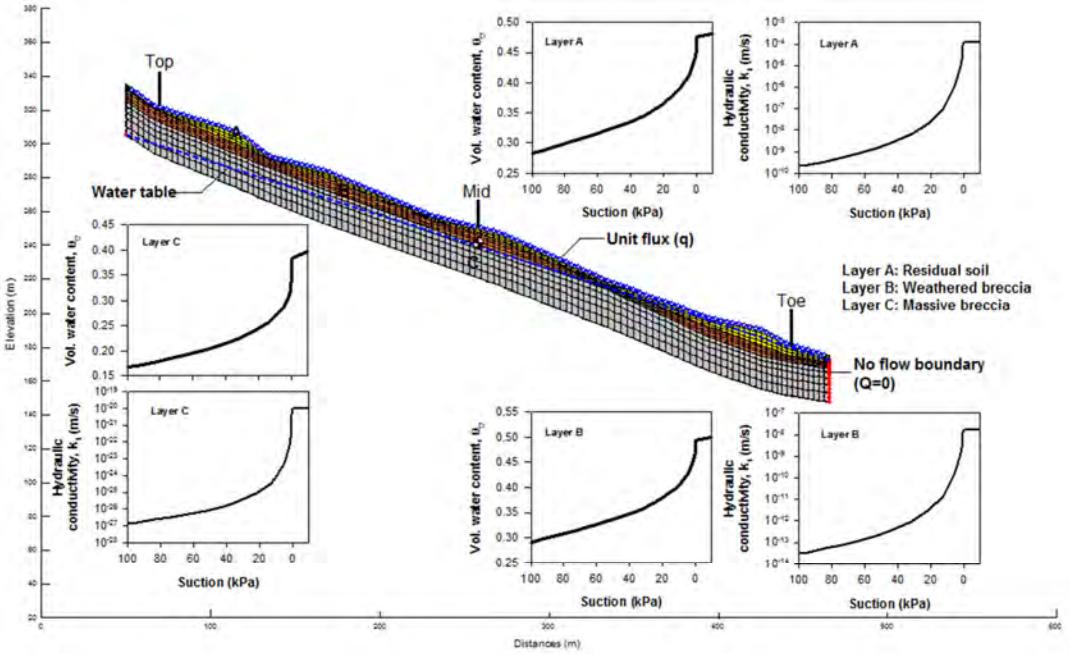


FIG. 4 Slope modeling using finite element, boundary conditions of the numerical model, and hydraulic boundary function for each layer.

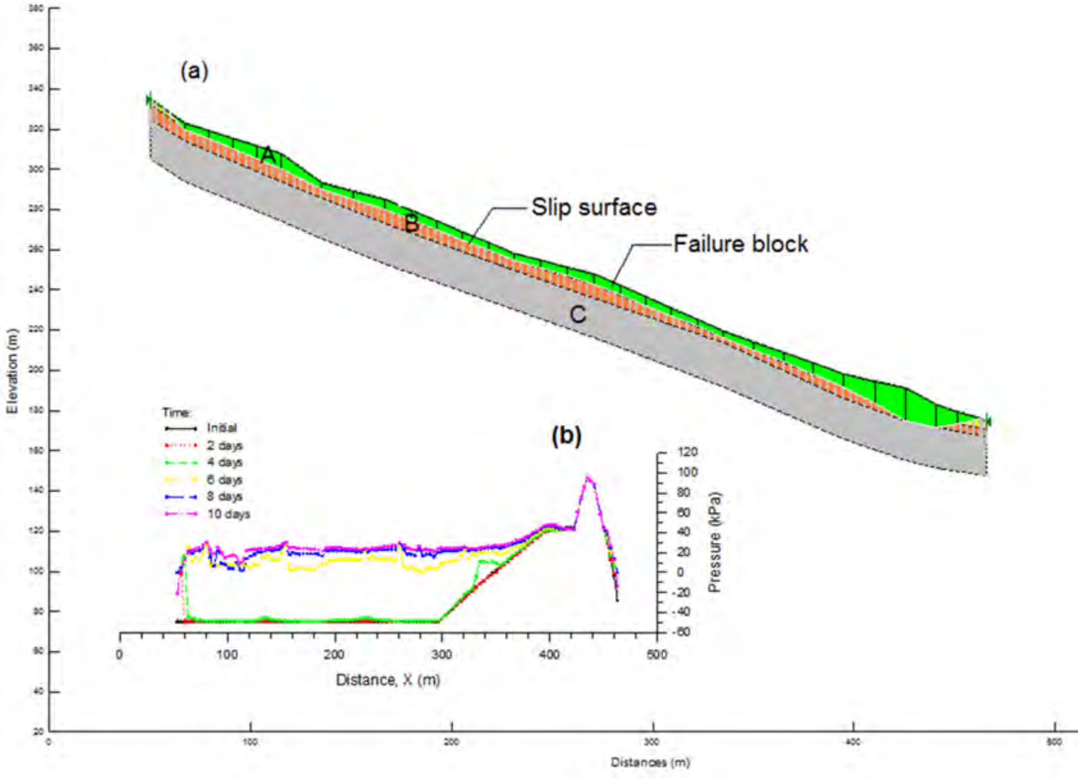


FIG. 5 (a) Modeling the slip surface of the slope, (b) Pore water pressure distribution along slip surface.

The simulated pore water pressure was then be directly linked into the slope stability analysis, SLOPE/W, which imports the slope mesh previously defined in SEEP/W. This model allowed the output from the transient hydrological problem can be used directly in a slope stability model to define the factor of safety with respect to time. The method of analysis was performed based on the limit equilibrium using Bishop's model. The slip surface found from the field (Figure 2b) was fully determined on the model as shown in Figure 5(a). The Mohr–Coulomb criterion was used in terms of effective stress analysis, for positive pore water pressures, and the Fredlund et al. (1978) criterion applied to negative pore water pressures.

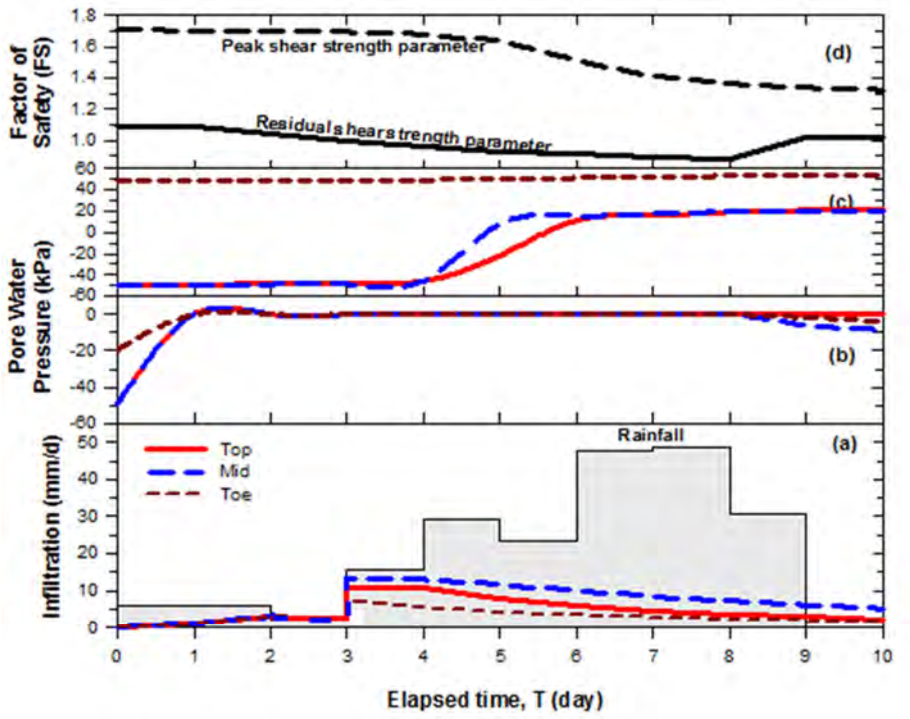


FIG. 6 (a) estimated rain-water infiltration (a), (b) pore water pressure on surface, (c) pore water pressure at failure surface, (d) change of slope stability with elapsed time

RESULTS AND DISCUSSION

Figure 6a shows the variation of rainwater infiltration into the slope. The figure illustrates that the rainwater infiltration is less at the toe area of the slope if compared to the top and mid section of the slope. The result indicates that rainwater infiltrates and flows from the top to down slope. Seepage occurs at toe section of slope. The infiltration rate decreases with the elapsed time of rainfall due to the saturation on the surface. The saturation on surface is shown by increasing of the pore water pressure from negative water pressure to become zero during the rainfall (Figure 6b). Rainwater infiltration advances to the slip-surface after five hours of the rainfall (Figure 6c), and generate pore water pressure at the top and mid section of the slope. This mechanism causes slope instability as shown in Figure 6d. The factor of safety decreases with the elapsed time of rainfall. When the analysis is based on the peak shear strength parameters, the factor of safety varies from 1.7 initially to 1.4 at the end of rainfall. The slope is indicated stable during the rainfall. But, based on the residual shear strength, as the saturated layer rises, the factor of safety decreases and approximately three days after the beginning of the rainfall, it falls to less than 1. This value indicates that the slope fails. The lowest factor of safety is 0.88 which correspond to antecedent rainfall of 173 mm during 8 days precipitation on 21 November 2001. This occurrence time is the same with the reported landslide event.

The result indicates that the residual strength parameter was controlled the slope failures at the studied area. The residual shear strength parameter for landslide analysis results in a reasonable when seepage is obviously occurred during the rainfall event. Residual strength parameter is shown to be the lower bound for mobilized the shear strength on the slip surface. Increase in saturation induced a softening slip surface. At this case, the loss of strength in passing from peak to residual was partly due to an increase in water content. Mesri and Shahien (2003) reported that for many of the first-time slope failures it appears that part of the slip surface was at the residual condition. Selection the residual strength parameter for slope failures analysis was also recommended by Stark et al. (2005).

Along the failure surface the pore water pressure rapidly increase at the toe section of slope (Figure 5b). The result indicates that at the toe of the slope is completely saturated with increases in pore water pressures. The saturation is due to the flow along the interface, which builds up down slope as it receives input from the upper slope sections. The pore water pressure distributions within the slope at top, mid, and toe section are presented in Figure 7. Two days after the rainfall, the rainwater infiltrates, through the soil creates wetting front up to 1.5 m depth with suction near atmospheric pressure (0 kPa). Rainwater infiltrates continuously with the elapsed time and reach wetting front about 3 m, 5 m, and 2 m depth respectively at the top, mid, and toe section of slope. When the wetting front reaches impervious layer, saturation builds up in the layer and rapidly increases the pore water pressure. This circumstance would generate softening on the slip surface. Hence, slope will be in critical state.

After four days of rainfall, the infiltration perches ground water table, which is indicated by positive pore water pressure profiles (Figure 7a and 7b). The ground water table rose to 4–4.5 m below the ground surface at the top and mid slope. It seems that perched water table controls the slope instability. This characteristic agrees with the investigation performed by Rahardjo et al. (1995). At this condition, Egeli and Pulat (2011) stated that the stability of slope was more closely to the soil shear strength behavior follows the ‘saturated’ soil mechanics theory, rather than the ‘unsaturated’ soil mechanics theory.

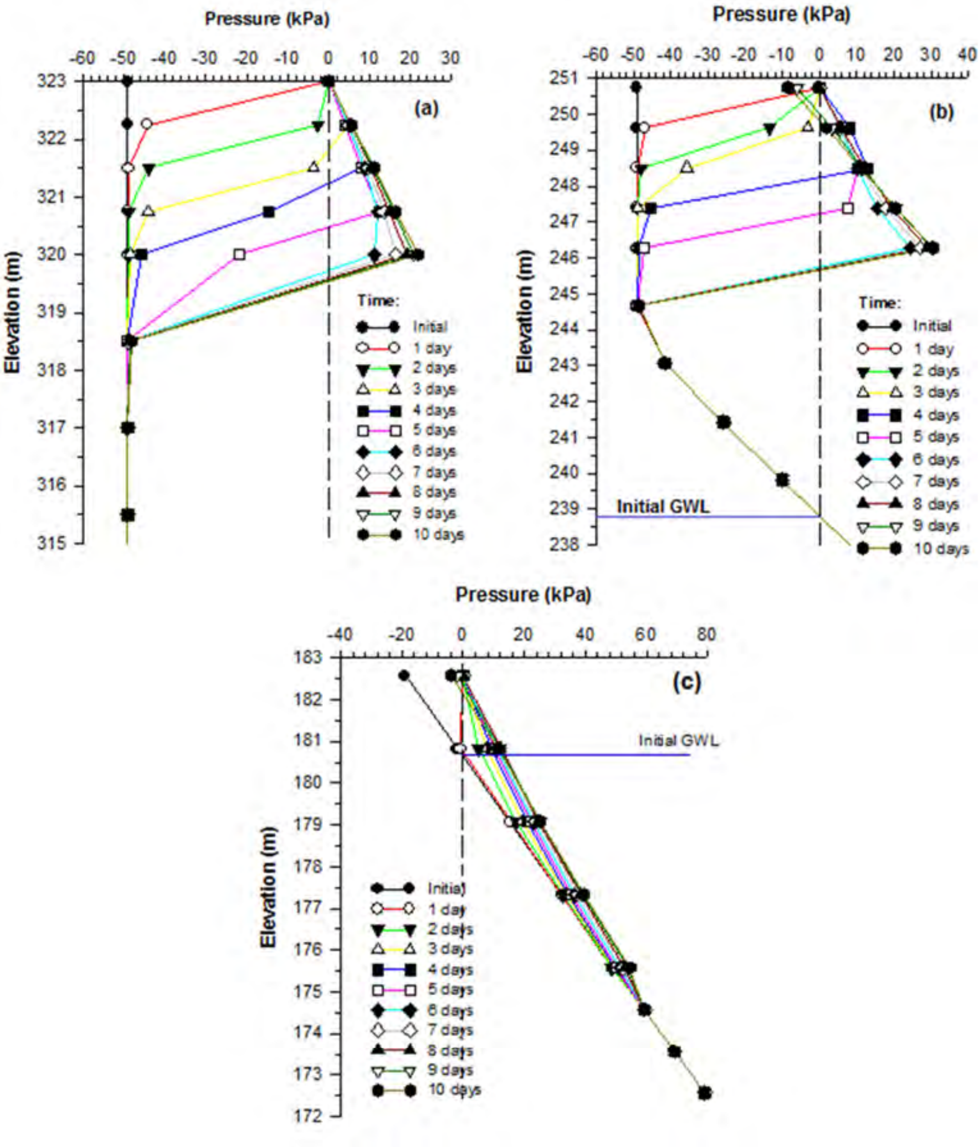


FIG. 7 Pore water pressure distribution during rainfall (a) at the top, (b) at the mid, and (c) at the toe of slope

CONCLUSION

Seepage and slope stability analysis on the Kedungrong landslide has been performed and discussed. The study showed that the slope failure was due to increase in pore water pressure. Selecting the residual shear strength parameter for landslide analysis is recommended when seepage is obviously occurred during the rainfall event. The lowest factor of safety is 0.88 which correspond to antecedent rainfall of 173 mm during 8 days precipitation. Rainwater infiltrates continuously with the elapsed time and reach wetting front about 3 m, 5 m, and 2 m depth respectively at the top, mid, and toe section of slope. Saturation on the top and middle section of the slope caused the infiltrated rainwater flow to the toe section, and then builds up seepage at that section. The results are alluding to conclude that increasing the pore water pressure due to infiltration and perched ground water table, and the residual shear strength of the residual soils were controlled the slope instability during the rainfall event.

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