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INFLUENCE OF GEOLOGICAL CONDITION TOWARDS SLOPE STABILITY ON LANDSLIDE: CASE STUDY IN TENGKLIK VILLAGE, TAWANGMANGU DISTRICT, KARANGANYAR REGENCY, CENTRAL JAVA PROVINCE, INDONESIA

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Abstract

A rain-induced landslide has occured in Guyon Village, Tengklik Tawangmangu District Karanganyar Regency, Central Java Province, Indonesia on February 2009. The movement was initiated by crack occurrence, 30 cm in depth and 2 meter in length. Such crack continuously developed in depth, extention and numbers, until then it resulted in land subsidence up to 260 cm in depth. Accordingly, ten houses were damaged and ten of families must be evacuated. This subsidence is very potential to further grow and create more consequences for human life and houses / land damage. Therefore, this research is carried out to understand the influence of geological factors and rainfall to the landslide phenomena. This research conducted engineering geology investigation such as mapping, drilling, insitu test, XRD test, soil mechanic test and slope stability analysis by limit equilibrium method i.e. Seep/W and Slope/W. By those research activities, the cause and mechanism of landslide can be understood. Rainfall characteristics which triggered such landslide can also be identified.

Based on those investigations, it is found that the landslide occurred in slow rate sliding (creep) due to the control of slope stratigraphy conditions and gentle slope inclination, which is induced by rainfall. Stratigraphy condition that plays important role in landslide mechanism are the permeable layers consisted of sandy silt (shear strength 12 kPa) and silty sandstone (shear strength 18 kPa) overlaid above impermeable andesite breccia (shear strength 104 kPa). Undulating slope may induce landslide in creep rotational type. Based on slope stability simulation, it is known that rainfall triggered landslide is rainfall 20 mm/ day average precipitation in 55 days and rainfall 20 mm/ day average precipitation in 49 days followed by one day with 178 mm/ day average precipitation.

Keywords: *Landslides, slope stability*

1 Background

Karanganyar regency is located in Central Java province known has potential landslide. This region is located in slope of Lawu Mountain. The topography is predominated by hilly area with high soil layer fertility and relatively thick soil. This condition is prone to landslide.

Based on the landslide mapping by Geological Engineering research team in 2002, Karanganyar area is divided into several zones of landslide susceptibility from low susceptibility to high susceptibility. One of area that

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included in high zone of susceptibility level is Tengklik village, Tawangmangu district.

On February 2009, a landslide occured in Tengklik village. The movement was initiated by crack occurrence, 30 cm in depth and 2 meter in length on February 2009. Such crack continuously developed in depth, extention and numbers, until then it resulted in land subsidence up to 260 cm in depth. Accordingly, ten houses were damaged and ten of families must be evacuated. This subsidence is very potential to further grow and create more consequences for human life and houses/land damage.

Therefore, this research is carried out to understand influence of geological factors and rainfall which affected to landslide in Tengklik.

2 Research Methods

This research method is devided into two steps : Field and Laboratory Investigation. The former are geological investigation, core drilling, and field testing. The latter are X-Ray Diffraction test, engineering rock/soil characteristics test and analysis of slope stability using limit equilibrium method (Slope/W and Seep/W program).

Field investigation consists of field reconnaissance and detail survey. The former survey was conducted to understand general condition of area. The latter survey was carried to collect morphology data, geology, soil, hidrology condition, land use and landslide data. Core drilling was carried in order to obtain subsurface condition and at the same time also conducted field testing such as permeability test and standard penetration tests (SPT). Besides, hole drillings were also used to observe water table fluctuation before, during, and after raining season.

The result of rock and soil drilling core tested in laboratory was then used to analyzed engineering soil and rock properties. Testing of soil engineering properties were including grain size, spesific gravity, atterberg limit, water content, porosity, pore value and shear strength (cohesion and internal friction angle). Testing of rock engineering properties were including spesific gravity, water content, porosity, pore value and shear strength. Those data was used for landslide and slope stability analysis. Moreover, X Ray Difraction test was also conducted to determine type of the clay.

Table 1: Kinds of field and laboratory investigation in this research

FIELD INVESTIGATION	PURPOSES
Geological investigation	morphology data, geology, soil, hidrology condition, land use and landslide data
Core drilling	- subsurface condition - observe water table fluctuation
field testing	permeability test and standard penetration tests (SPT)
LABORATORY INVESTIGATION	**PURPOSES**
drilling core testing	engineering soil and rock properties
X Ray Difraction test	type of clay
SEEP/ W dan SLOPE/ W program	To analyse the flow of groundwater in the slope and Factor of Safety (FS)

Finite Element Method (FEM) is used for analyzing the flow of groundwater in the slope and Factor of Safety (FS) computed based on Limit Equilibrium Method. Those analyses adopted SEEP/ W and SLOPE/ W program (Geostudio 2004 program, V.6.01). SEEP/ W program used finite element to simulated rainfall infiltration and counted the time from pore water pressure distribution in the slope. SLOPE/ W computed FS from limit equilibrium analysis in the different pattern from pore water pressure distribution resulting from SEEP/ W. In the Geostudio 2004 program (SEEP/ W and SLOPE/ W) several parameters were needed as listed in the Table 2.

Table 2: Parameters that were used in SEEP/ W dan SLOPE/ W program

SEEP/W	SLOPE/W
VWC function or SWCC (Soil Water Characteristics Curve)	Effective strength of soil / rock
Hydraulic conductivity from rainfall characteristic	Pore Water Pressure (PWP) distribution
Initial condition of slope	Unit weight of soil / rock on the slope
	Slide plane

3 Result and Discussion

3.1 Landslide Condition

On early February 2009, landslide happened in Tengklik affected land subsidence up to 260 centimeter in depth and 5-30 centimeter in width (Figure 1). This landslide affected infrastructures such that street, 27 houses and 33 families must be evacuated.

Based on The Laser Distance measurement, the length of landslide from the crown until the toe is approximately 173,9 meter in length and 94,5 meter in width. On the crown part of landslide, lithology was settling around 80 centimeters – 260 centimeters. Direction of cracks on the crown is N 333° E and the direction of landslide is N 2600 E. The cracks in the body of landslide generally have direction N 255° E.

According to the type of landslide movement, this area has a rotational creep. This type is recognized on its soil mass movement (Hardiyatmo, 2006). Creeps generally happen on slope with 20°, controlled by plasticity of soil or rock layer such as silt, clay, claystone or tuff (Karnawati, 2005). In Tengklik, landslide happened which is slope 10-20° and montmorillonite found in silty sandstone as sements.

3.2 Slope Stability Analysis

SEEP/ W analysis was undertaken by creating meshing on the landslide section. It is divided into two layers, i.e sandy silt and silty sandstone. Andesite breccia did not undergo meshing due to assumption of it as impermeable layer. Both of those layers gave values of hydraulic function (hydraulic conductivity (K), volumetric water content (VWC) and grain size. K value of sandy silt is 1.44×10^{-7} m/sec and its VWC is 0,35.

K value of silty sandstone is 1.03×10^{-6} and its VWC is 0,65. Grain size measurement is based on hydrometer analysis result. SEEP/ W program used steady state and transient analysis in which the boundary fuction used unit flux (q) vs Time boundary. Step function is used in the particular time of raining as happened in the field. For instance, in the type of rain e.g. antecedent type, in the first day rain lasted for 8 hours then water infiltrated to the ground in 16 hours. Hence, the second day rainfall condition was the same first day. This condition happened continuing up to several days or weeks based on the planning of simulation.

Antecedent rainfall was made to be 20 mm/day intensity and the peak of rainfall in one day was made to be 178 mm/ day intensity. Those values are based on previous research by Karnawati (2000a) and data of rainfall intensity in Tawangmangu area before landslide happened. Assumption of 8 hours is based on daily rainfall in the field that the type of rainfall is antecedent and the intensity is low (around 20 mm/ day). Assumption of the peak of rainfall happened in 16 hours is based on daily rainfall in the field that thas type of heavy rain with the high intensity of rainfall (more than 100 mm/day). The initial condition before rainy season is obtained by using groundwater table in Oktober 2009. Furthermore, a simulation conducted on antecedent rainfall had condition of 20 mm/day rainfall intensity in 8 hours. In the 7th day, over half of the slope was in saturated condition up to the middle of the slope. In 14th day, the change of groundwater table is relatively stable. In the 21st day, upper part and middle of slope was in saturated water condition. All of the slope was wholly

Figure 1: Crown of landslide (dash-line). (a) Cracks rose on 2 February 2009; (b) subsidence on 9 February 2009

saturated with water in 39th day. The critical slope condition was happened in 56th day. Simulation of 178 mm/day in 18 hours only made the half of slope in saturated condition. If the simulation combined rainfall in 20 mm/day continued with rainfall 178 mm/day intensity, critical slope condition would happened in 49th day.

Modelling in SLOPE/ W simulation by using Mohr Coulomb model determined entry and exit model for slide plane. Engineering properties used unit weight (γb), cohesion (c) and internal friction angle (see Table 3). Afterwards, result of SEEP/W simulation is combined with SLOPE/ W simulation and the results are shown in Table 4.

Table 3: Data of soil /rock engineering properties based on laboratory test, simulation and literatures

Type of soil/ rock	Rock/ soil Engineering properties		
	γ_b (gram/cm^3)	c (kg/cm^2)	ϕ (^{0})
Sandy silt	18,5	0,12	37,39
Silty sandstone	21,6	0,18	15
Andesite breccia	25,4	1,04	36,87

3.3 Inducement of Landslide

3.3.1 Slope Stratigraphy

According to the engineering geological map (Figure 2), the research location is divided into three soil/rock units, i.e. sandy silt unit, silty sandstone unit and andesite breccia unit. The youngest unit is sandy silt with thickness 5 – 7,5 meter and up to 7,5 meter in depth. Based on its physical properties, the unit of soil is intermediately weathered up to residual soil condition (based on weathering classification, Wyllie and Mah, 2004). The second unit is silty sandstone with thicknes around 3 – 5, 5 meter and 4 - 13 meter in depth. It has physical properties of highly weathered, intermediate – rather loose compactness and intermediate hardness. In this rock unit, andesite fragment is found in 7,5 meter depth (BH-2) – 12,5 meter (BH-1). Andesite breccia is the oldest rock unit which has thickness of 7 meter and 8 meter (BH-2) – 13 meter (BH-1) in depth. Fragments of this unit are andesites which have size from pebble to gravel and of volcanic sand matrix.

Based on the stratigraphy strata and physical properties of rock / soil (SPT test and permeability test result), soft rock or soil (sandy silt and silty sandstone) onto hard rock (andesite breccia). Water was infiltrated and filled into those rock units. When the water flew onto andesite breccia unit, it could not emerge this rock and finally created slide plane.

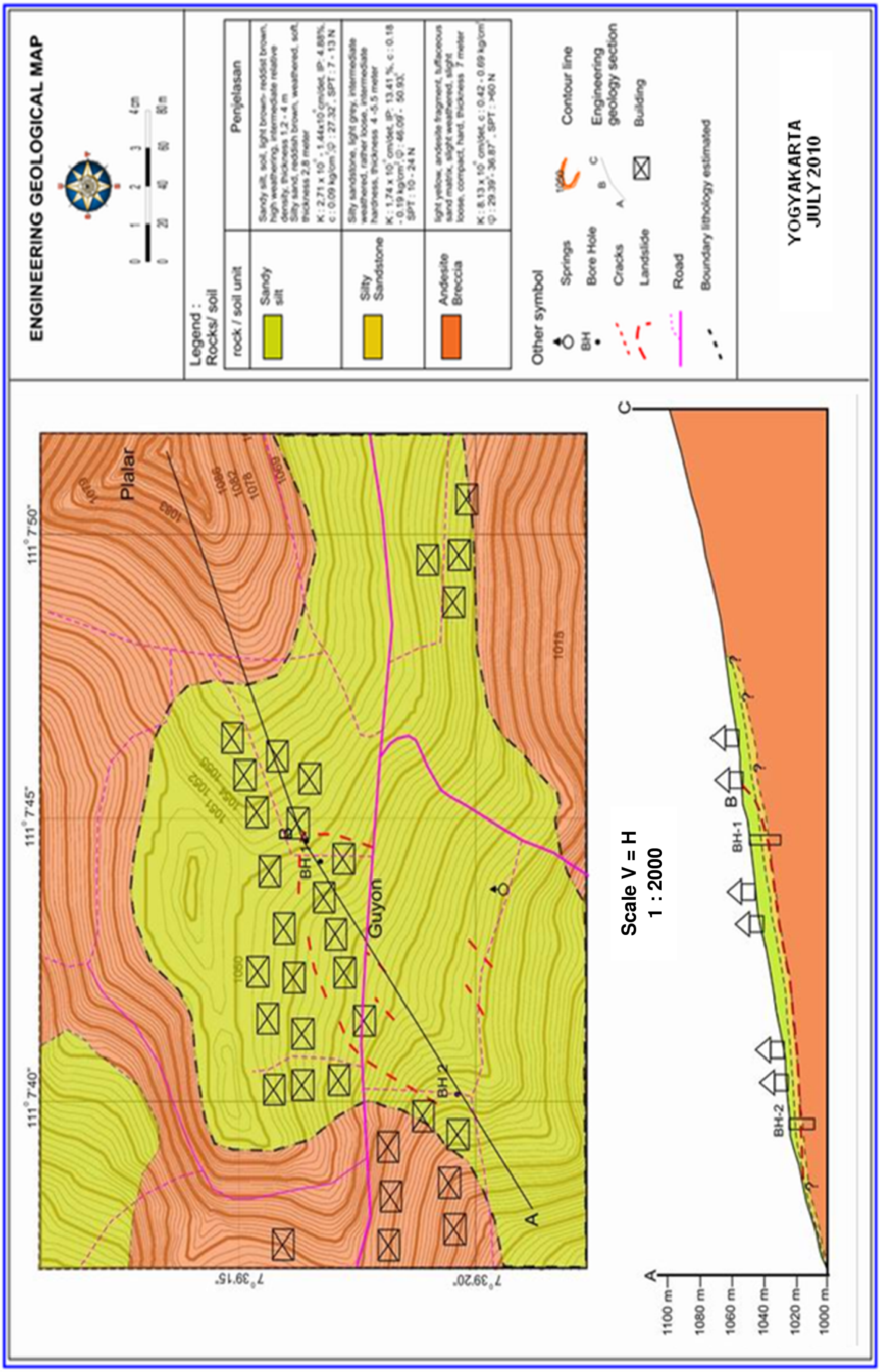

Figure 2: Engineering geological map

Table 4: Changing of FS based on rainfall intensity and duration of rain

No.	Factor of Safety (FS)	Amount of rain day	Esplanantion
1.	1,898	-	No rain
2.	1,485	1 day	20 mm/ day rain fall intensity
3.	1,616	7 day	20 mm/ day
4.	1,403	14 day	20 mm/ day rain fall intensity
5.	1,480	21 day	20 mm/ day rain fall intensity
6.	1,288	30 day	20 mm/ day rain fall intensity
7.	1,144	55 day	20 mm/ day rain fall intensity
8.	1,593	1 day	178 mm/ day rain fall intensity
9.	1,144	49 day and 1 day (peak of rain)	20 mm/ day rain fall intensity and 178 mm/ day rainfall intensity

Furthermore, sandy silt and silty sandstone contain fine mineral (based on XRD test the mineral is montmorillonite). That mineral is capable to adsorb enormous water and swell easily. Those condition mostly affected the lost of shear strength (cohesion and internal friction angle) which created landslide (Karnawati, 2005). Likewise, cracks in silty sandstone made water infiltrates easily to soil and then water accumulated onto andesite breccia layer. This condition created slide plane.

3.3.2 Engineering properties of soil / rock

Based on rock/soil engineering properties test, each unit has different engineering properties. Sandy silt has engineering properties such as specific gravity value (Gs) is 2,61, cohesiveness of intermediate – low plasticity level, high water content, low permeability value, low kPa value (2 – 9 kPa) and has unit weight around 17,3 - 18,5 Kg/m^3.

Silty sandstone has Gs value from 2,65 until 2,73. This value includes cohesive soil (but not the organic matter content). Based on plasticity index, this unit is cohesive soil with intermediate plasticity. From water content test, its value is approximately 45.05 % to 60,35 %. Based on those values, this unit has high water content. This unit also has low permeability, high porosity (44.74 % - 56.93 %), low shear strength (8 - 12 kPa), with unit weight around 18,5 - 19,5 Kg/ m^3.

Andesite breccias have specific gravity around 2,64 - 2,65. This value is for cohesive soil. In addition, this unit has a very low water content (1,9 % to 2,27%), low permeability, low porosity (5,3 % - 6.3 %), high shear strength 104 kPa and with unit weight from 25,4 to 25,5 Kg/m^3.

Based on engineering properties above, sandy silt and silty sandstone are possible to move (i.e. have low shear strength) which lay onto andesite breccias (high shear strength).

3.3.3 Slope

Creep happened in slope 10-20°. This slope condition created creep type. Generally, creep and subsidence happen in slope which has $\leq$ 20° inclination controlled plasticity or sensitive rock or soil (Karnawati, 2005).

In Tengklik, landslide happened in slope with inclination 10-20° and the thickness of soil is approximately 4 – 7 meters. This soil is the result of material deposition from upper part of source rock or hidrotermal alteration. That alteration is based on the soil thickness and the location is in the slope of Lawu Mountain. It has formed in Quaternary and altered intensively. Such thickness of the soil would not possible if it is a result from mechanical weathering on an account of long time period.

In addition, soil of tropical region will be influenced by changing of season. Landslide can be of creep type, however the motion is slow (Broms,1975 dalam Hardiyatmo, 2006). The rapid creeping will have range between 1 mm up to 10 meter each year (Summerfield, 1991 vide Hardiyatmo, 2006). Creeping in Tengklik has been going on more than one year until recent with the depth of subsidence until February 2009 achieves 2, 6 meter.

Based on SLOPE/ W simulation, loading

triggered by buildings with undulating slide plane would not influence the FS. If it is put in the toe of landslide, it will add the retaining of the slope (i.e. *FS* value will increase).

3.3.4 Rainfall

In rainy season, rain happens continuously with low or high rainfall intensity. This phenomena is then followed by infiltration of water into soil or rocks. Hence, groundwater table increases in the slope, heightens pore water pressure and lower shear strength. Then, creeping will occur (Gostelow, 1991 vide Hardiyatmo, 2006).

Groundwater infiltrates sandy silt and silty sandstone and afterwards it is occupied above the impermeable layer (the andesite breccia). The more the rainfall intensity (i.e. higher or longer), the more water infiltrates to the permeable layer and become saturated.

Except the infiltration of water that enhances groundwater level, infiltration of water rises the unit weight of the soil/rock (heighten load mass of soil / rock). It vanishes the stress suction between andesite breccias and rock unit above on it and intensifies pore water pressure in the soil/ rock as well.

Based on the combination between SEEP/W and SLOPE/W, normal rainfall (around 20 mm/day) that happens in several weeks will extremely influence factor of safety. When the slope was not influenced by groundwater table, value of *FS* is high (FS=1.898). When the slope was influenced by groundwater table fluctuation (rainfall intensity is 20 mm/ day in several weeks and rainfall intensity in178 mm/ day in one day), the value of *FS* decreased from 1.268 – 1.288. When the groundwater table nearly reached ground surface, value of *FS* was in critical condition (*FS* = 1.121 – 1.144, see Figure 3 and 4). It can be concluded that a slope will be in critical condition if the groundwater table increase significantly. The rapidness of infiltration and increasing of groundwater table into the soil/ rock is controlled by stratigraphic conditions.

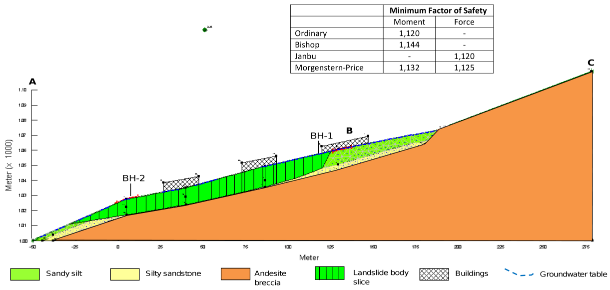

Figure 3: *SLOPE/W* and *SEEP/W* simulation with 20 mm/day rainfall in 55 days

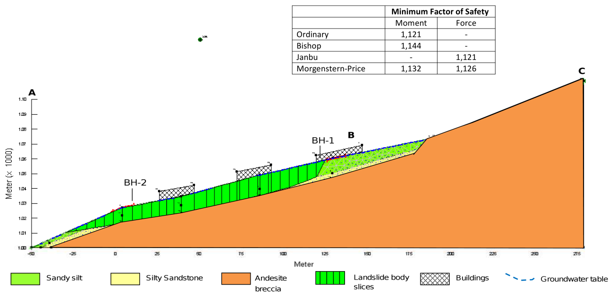

Figure 4: *SLOPE/W* and *SEEP/W* simulation with 20 mm/day rainfall intensity in 49 days and continuing raining 178 mm/day rainfall intensity in 1 day

4 Summary

4.1 Conclusions

Based on the result, it can be concluded that:

1. A stratigraphic condition that controls landslide is permeable unit rocks/soil type, consisted of sandy silt and silty sandstone and laid above impermeable layer (andesite breccias).

   (a) Undulating slope does not significantly induce landslide, but causes kind of landslide in the location, i.e. a rotational landslide.

   (b) Engineering properties which are different among units (the shear strength of sandy silt is 12 kPa and the shear strength of silty sandstone is 18 kPa) lay onto andesite breccias (shear strength is 104 kPa) and effect unstable slope.

2. Based on SLOPE/ W and SEEP/ W simulation, rain that can induce landslide is the rain with rainfall intensity close to 20 mm/ day in 55 days and rain with rainfall 20 mm day in 49 days, continued by one day of peak rain if 178 mm/ day rainfall intensity.

4.2 Suggestion

Reducing landslide effects can be held in Tengklik by closing cracks with the cement or impermeable materials, installing impermeable material on footstep ways, installing drainage ditch and closing cracks on ditchs; all of the above will reduce infiltration to the landslide.

References

Anonim (2002) Inventarisasi Daerah Rawan Tanah Longsor di Kabupaten Boyolali, Wonogiri, Karanganyar dan Sragen, Jurusan Teknik Geologi Fakultas Teknik Universitas Gadjah Mada, Jogjakarta

Abramson,L.W.,Lee, T.S., Sharma,S.,and Boyce, G.M, 2002, Slope stability and stabilization methods, 2nd Edition, John Wiley and Sons, N.Y

Craig, R.F. (1987) Soil mechanic, fourth Edition, Department of Civil Engineering University of Dundee, Chapman and Hall

Cronin, V.S. (1992) Compound Landslides; Natur and Hazard Potential of Secondary Landslides within Host Landslides, Landslide Mitigation, Geological Society of America Volume IX, Colorado.

Deere, D.U., and patton, F.D. (1971) Slope Stability in Residual Soils, In Proc.4th Panamerican Conference on Soil Mechanics and Foundation Engineering, vol.1. Caracas.

Gasmo, J.M, Rahardjo,H., and Leong, E.C. (2000) Infiltration Effects on Stability of a residual soil slope, Computers and Geotechnics 157, pp.145-165

Hardiyatmo, H.C (2006) Penanganan Tanah Longsor dan Erosi,Gadjah Mada University Press, Jogjakarta

Karnawati, D. (2005) Bencana Alam dan Gerakan Massa Tanah di Indonesia dan Upaya Penanggulangannya, Jurusan Teknik Geologi Fakultas Teknik Universitas Gadjah Mada, Jogjakarta

Krahn, J. (2004) Stability Modeling with Slope/W – An Engineering methodology, Geo Studio 2004, Geo-slope International, Ltd.

Moore, D.M., Reynolds, R.C. (1997) X-Ray Diffraction and The Identification and Analysis of Clay Minerals, Oxford University Press,New York

Surono,B.Toha, I. Sudarno (1992) Peta Geologi Lembar Surakarta-Giritontro, skala 100.000, Pusat Penelitian dan Pengembangan Geologi, Bandung

Rogers, J.D. (1992) Recent Developments in Landside Mitigation Technique, landslides/ Landslide Mitigation, Landslide Mitigation, Geological Society of America Volume IX, Colorado.

Terzaghi, K dan Peck, R.B (1967) Soil Mechanics In Engineering Practice,2nd Edition, John Willey and Sons, New York.

Wyllie D.C, Mah C.W (2004) Rock Slope Engineering, Civil and Mining 4th Edition, Spon Press, London.

