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Determination of unsaturated soil properties and slope deformation analysis due to the effect of varies rainfall

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Abstract

Recently, landslides often occurs in natural slope in Indonesia, which is associated with the coming rainy season. The increment of ground water level caused by rainfall has affected the properties and behavior of soil especially the unsaturated soil. Generally, the stability of slope is evaluated based on safety factor, but the deformation occure at the soil can also be a good interest in asses the stability of slope. This research is focused to observe the change of pore water pressure and associate deformation considering the hydro-mechanical properties of unsaturated soil due to the effect of varies rainfall. In this research, numerical simulation was carried out to analyze the deformation of the slope affected by pore water pressure change due to rainfall using software-based Finite Element Method of SIGMA/W and SEEP/W from GEO-SLOPE 2004. Unsaturated soil properties, such as Soil Water Characteristic Curve (SWCC) and Hydraulic Conductivity function are obtained from laboratory test and also predicted based on grain-size distribution using psycho-empirical method in SOILVISION Database. HAVARA is used to help rainfall data analysis using statistic approach. Rainfall model is used to vary the moisture content to model unsaturated soil condition. There are six rainfall models, consists of one steady state model and followed by five transient model to accommodate the pore water pressure changes due to rainfall. The results show that rainfall with intensity near saturated permeability of soil gives more significant influence in increasing pore water pressure and deformation than normal rainfall even with long duration. Proposed countermeasure by providing counterweight and sub drain do not significantly take effect the deformation, but it could improves the safety factor significantly, so that the slope is more in stable condition.

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Keywords: landslide, unsaturated soil properties, pore water pressure, slope deformation, numerical simulation, finite element method, countermeasures.

1. Introduction

Indonesia is a tropical country that has two seasons: the rainy season and dry season. The season changes have significant influence on natural phenomena. The influence of natural events such as evaporation (evaporation and evapotranspiration) and precipitation (rainfall) that result in ground water level fluctuations. Rising groundwater levels due to rainfall influence the nature and behavior of the soil in response to the pressure / load occurs. Lately, frequent landslides in Indonesia, which is associated with the arrival of the rainfall season. As happened at the gas station building Sambipitu located in the Yogyakarta-Wonosari Km 13 Sambipitu Wonosari, Yogyakarta who have been severely damaged by the collapse and embankment slopes suffered landslides after several days of rainfall.

Events known as landslides or mass movement of soil, rocks, or a combination of both, often occurs in the slopes of the natural or artificial, is actually a natural phenomenon where a natural look for a new balance due to a disturbance or the factors that affect and cause a reduction in shear strength as well as increased shear stress [12]. Unfortunately, in an attempt to understand the phenomenon of the above, the necessary field and laboratory testing for unsaturated soil that takes a long time and cost a bit. But along with the theory and technology in the field of geotechnical particular problem of unsaturated soil, the technical properties of unsaturated soil can be obtained through empirical approach that is based on the basic physical properties of the soil such as the grainsize distribution and weight-volume relationship of soil [3].

This study aims to determine the technical nature of unsaturated soil with predictions based on the basic physical properties of the soil (grainsize distribution and weight-volume relationship of soil) and examine the slope deformation caused by the influence of variations in rainfall. Limits used in the scope of this research is the analysis of stress and strain on the slopes reviewed in two-dimensional (plane strain) and the soil is modeled as elastic-plastic with effective stress parameter type and using criteria Mohr-Coulomb extended collapse.

2. Unsaturated Soil

Unsaturated soil generally has three phases, namely solid, water and air phases, in contrast to saturated soil which only has two phases (solid and water) which give rise to the presence of the two types of pore pressure namely pore water pressure u_w and pore air pressure u_a which resulted in a boundary (interface) between the water and the air, known as contractile skin [3]. The difference between u_w and u_a called the matric suction. Because of the presence of the contractile skin and matric suction, the interaction between the solid, water and air causes a complex hydro-mechanical behavior of the unsaturated soil element [8]. The relationship between the amount of water in the soil and suction drawn on a curve called Soil Water Characteristic Curve (SWCC). The amount of water here can be a gravimetric water content (w), volumetric water content (θ) or the degree of saturation (S) [14].

3. Rainfall Induced Landslide

Rainfall is expected as the main cause of the landslide [7]. Increasing the water content in the soil can be caused by rainfall during a certain period, so that the effective stress decreases and the resulting shear stresses in the soil decreased as well [11]. Bemmelen (1949) in Saroso (2002) states, triggered landslide can occur due to high rainfall is 70mm / h [6]. Karnawati [6] conducted a study using the slope of hydrodynamic numerical modeling to identify the characteristics of rainfall induced landslide. Based on these studies, a relatively low rainfall (25 mm/day) can trigger landslides on the slopes of the permeability cover 2.51×10^{-6} m/sec. The characteristics of rainfallfall induced landslide controlled by the level of permeability of the soil cover slopes and groundwater. Prasetyowati and Subiyanti [8, 10] states that a normal rainfallfall with long duration is the most influenced rainfallfall on changes in pore water pressure and movement or deformation on the slopes.

4. Research Methodology

4.1. Soil materials

This study uses two types of soil, ie clay and silt, which is obtained from Wates area, while the silt soil obtained from Sambipitu area. Location of the study was on the slope below Sambipitu gas station building located in the Yogyakarta-Wonosari Km 13 Sambipitu Wonosari, Yogyakarta. From the measurement results can be known the location's coordinate using GPS coordinates is at 7 ° 53 '20 730 " South Lattitude and 110 ° 32' 17 180" East Longitude.

4.2. Research stage

The first step of this research is to collect secondary data necessary. Soil data obtained based on previous research conducted by Suryolelono and Rifa'i [13] and the results of physical properties testing and testing of filter paper method and direct shear conducted Hidayah and Yuniar [5,15]. Testing of filter paper was conducted in order to obtain the relationship between the water content in the soil suction. Direct shear testing is done with water content variation aims to get a suction effect on the increase in value of shear strength. Further laboratory testing is done to obtain a water-saturated soil parameters such as water saturated soil permeability coefficient (k_{sat}) obtained based on the type of falling head permeability test, effective cohesion (c ') and the effective friction angle (φ') are obtained by direct shear testing (consolidated drained) [2].

The next step is to determine the properties of unsaturated soil that predict SWCC based on grain size distribution (GSD) and volume-weight relationship soil. The SWCC along with saturated soil permeability coefficient of water is then used to obtain a prediction function unsaturated soil permeability. These results will then be compared with the direct measurement performed by Hidayah and Yuniar [5, 15] and by matching with a database system ground in Soil Vision conducted by Handoko [4].

The next step is the analysis of rainfall data obtained from four rainfall stations around the study site were considered to represent the characteristics of rainfall at the site because the study was not conducted direct rainfall measurements in the field with a 16-year observation period (1993-2008). Then analyzed to determine the length of the incidence of the most frequent rainfall and rainfall distribution-clock era.

The final step is a numerical simulation that begins with geometry profiling slopes and soil layering based on topographic maps, observations and results of drilling the ground. Furthermore, the determination of the required input parameters both in the analysis of pore water pressure in the slope using SEEP/W and stress-deformation analysis of slopes using SIGMA/W.

5. Results and Discussion

5.1. Soil properties and clasification

Soil physical properties and classification of clay and silt samples were investigated by Hidayah and Yuniar [5,15] and the results are shown in Table 1.

Coefficient of permeability in water saturated conditions obtained by $3.86x10^{-4}$ cm/sec for MH and CH for $5.78x10^{-4}$ cm/sec and concluded that both the semi-impermeable layer (semi-pervious layer). Direct shear test results show that the cohesion effective CD for MH is 4 kPa and CH at 15.39 kPa, whereas the effective friction angle of 32° for MH and 15.63° for CH, and φb obtained by 5.6° for MH and 5.43° for CH.

Table 1. Soil properties and classification

Parameters	Clay (CH)	Silt (MH)	Parameters	Clay (CH)	Silt
Specific Gravity, G_s	2.594	2.551	Dry density, γ_d (g/cm^3)	1.21	1.01
Liquid limit, L_L	86.34%	87.69%	Porosity, *n*	0.53	0.60
Plastic limit, P_L	30.03%	42.74%	Void ratio, *e*	1.144	1.52
Plasticity index, P_I	56.31%	44.95%	% passing no.200 (fines)	85.78%	95.45%
Shrinkage limit, S_L	9.26%	16.92%	% retained no.200 (coarse)	14.22%	4.55%
Natural water content, *w*	36.36%	58.20%	USCS	CH	MH
Bulk density, γ_b (g/cm^3)	1.65	1.6			

5.2. Determination unsaturated soil properties

To estimate SWCC obtained by grainsize distribution analysis and volume-weight relationship of soil by using methods of estimation contained in SOILVISION for MH and set using SWCC generated by Fredlund and Wilson PTF. SWCC estimation results are then plotted together with the results of direct measurements SWCC [16] and the results matching with a database system [4]. Similarly to the soil CH, seen in predicting the SWCC, clay CH considered more difficult than the silt soil MH indicated by none curve SWCC offensive point filter paper test results.

Having established the estimated result Fredlund's SWCC and Wilson PTF as SWCC is chosen, the next is getting saturated soil permeability function in part by the value of water saturated soil permeability coefficient (k_{sat}) and SWCC was selected as shown in Figure 1 which shows a graph of the function of unsaturated soil permeability to the suction value for land MH and CH.

5.3. Rainfall analysis

From the data available from the 4 rainfall stations during 16 years of observation, it shown that the average rainfall which is often occured in each interval is 3 hours/day and 4 hours/day, each of which occurred in 3 intervals of rainfall. In this study the average long period rainfall set at 4 hours/day with consideration because it has a longer duration of rainfall and rainfall intensity is higher. To determine the distribution of hourly rainfall-era, made the curve relationship between the percentage of rainfall depth and duration of rainfall percentage of all data that has rainfall duration of more than 1 hour (1532 rainfall event) in order to obtain measurable rainfall distribution curve (observed pattern) consisting of an observed pattern-1 are based on the average value (mean) and the observed pattern-2 are based on the mean (median).

Based on observations of precipitation with 16-year observation period (1993-2008) in the study area, the rainfall plan used in this study defined as shown in Table 2 below.

Table 2. Rainfall models scenario

Rainfall Model	Type of Rainfall	Rainfall Duration	Purpose
1	No rain	0	Steady seepage analysis for intial condituion
2	Heavy rain (120.4 mm/day) for 4 hours duration	4 hours	Observation of slope deformation analysis due to the effect of heavy rain with short duration
3	Normal rain (10 mm/day) for 10 days + heavy rain (120.4 mm/day) for 2 days	288 hours (12 days)	Observation of slope deformation analysis due to the effect of the beginning rainy season
4	Heavy rain (120.4 mm/day) for 2 days + no rain for 3 days + normal rain (40 mm/day) for 3 days	192 hours (8 days)	Observation of slope deformation analysis due to the effect of the middle rainy season
5	Normal rain (30 mm/day) for 4 days + no rain for 3 days + normal rain (10 mm/day) for 8 days	360 hours (15 days)	Observation of slope deformation analysis due to the effect of the ending rainy season
6	Normal rain (10 mm/day) for 20 days	480 hors (20 days)	Observation of slope deformation analysis due to the effect of normal rain with long duration

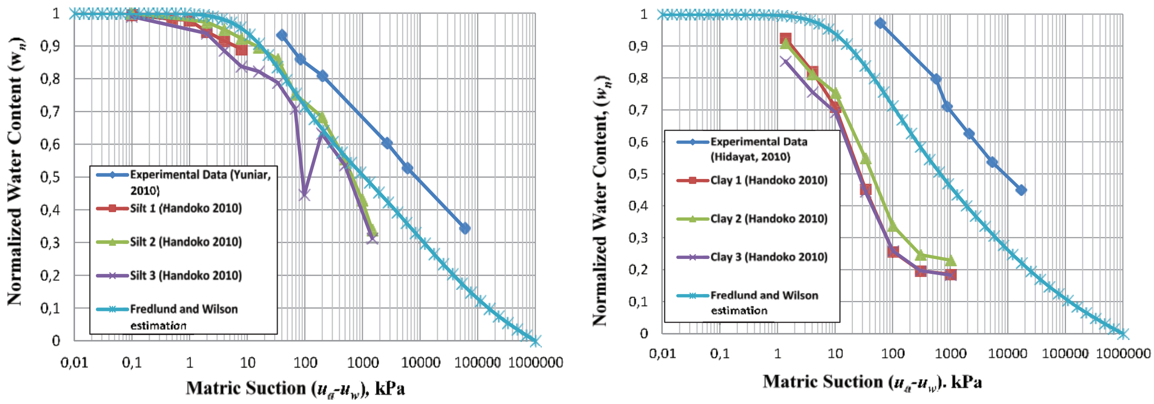

Fig. 1. (a) the SWCC for MH soil ; (b) the SWCC for CH soil.

5.4. Slope deformation analysis using finite element method

Shape and soil parameters and boundary conditions of the slope geometry used in the numerical simulations are the cross section B-B from bore log results as shown in Table 3 below. Based on the results of this study concluded that the changes in pore water pressure and the greatest deformation occurs in rainfall conditions on the 5th model and cross section B-B, namely a row of 33.2 kPa and 25.1 mm for pore water pressure and horizontal deformation as shown in Figure 2 below.

Table 3. Soil parameters for numerical simulation using finite element method

Parameters	Bedrock	Silt MH layer	Fill layer	Retaining Wall
Soil model	elastic-plastic	elastic-plastic	elastic-plastic	linier-elactic
Elastic modulus, E (kN/m^2)	50000	7319	10000	100000
Poison ratio, υ	0.3	0.35	0.3	0.2
Effective cohesion, c’ (kN/m^2)	50	4	5	0
Effective friction angle, φ (°)	15	32	30	0
Friction angle related to matric suction changes, φ_b (°)	0	23.66	5	0
Bulk density, γ (kN/m^3)	20	16	20	24
Permeability, k_{sat} (m/hour)	3.6 x 10^{-10}	1.368 x 10^{-2}	7.2 x 10^{-1}	1 x 10^{-13}

Furthermore, the slope stabilization efforts by placing counterweights in the form of soil deposits at the foot of the old fill aimed enlarge style erode resistance to the force that comes permeable layer (sand soil) with a 50 cm thickness and 15 cm diameter perforated drain pipe at the base of the counterweight [1] which aims to evacuate some of the water, especially rainfall water infiltrating into the soil, so the soil does not become a slope forming in water saturated conditions and plus installation of a retaining wall as shown in Figure 3.

It is seen that the effect of slope stabilization effort made it less effective when viewed from the deformation caused by the 5 th rainfall model, but in terms of the safety factor of slope stability analysis results using SLOPE/W is done Handoko [4], results of operations undertaken slope stabilization show enhancement of safety factor significantly from 1.085 at condition without counterweight to 1.417 at the condition with counterweight so that the slope can be said to be in stable condition as shown in Figure 4.

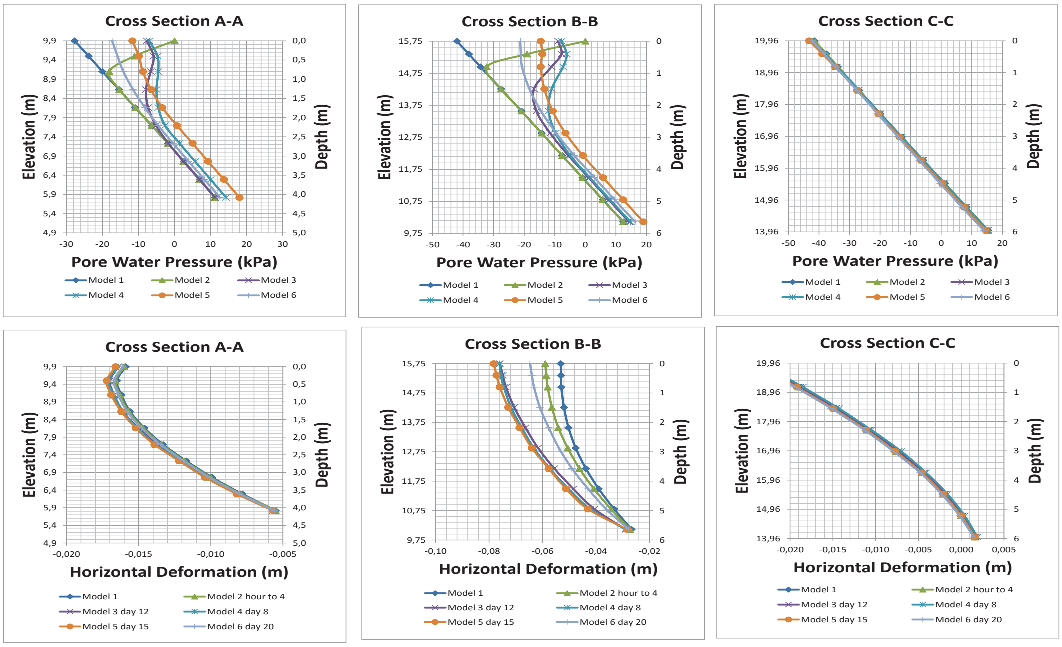

Fig. 2. Pore water pressure and horizontal deformation of cross section A-A, B-B and C-C

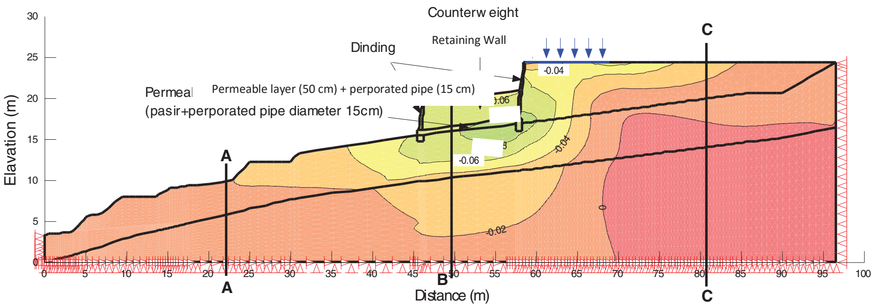

Fig. 3. Horizontal deformation of the slope after placing counterweight.

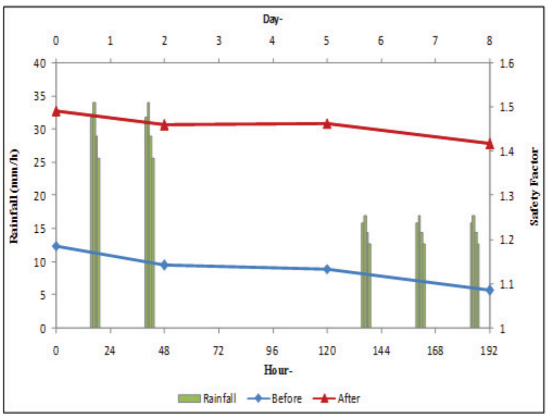

Fig. 4. The safety factor of slope stability before and after using counterweight.

6. Conclusions

The conclusion that can be drawn from this study are: (1) Silt soil derived from Sambipitu is High Plasticity Silt (MH), whereas clay of Wates is High Plasticity Clay (CH). (2) Effective cohesion is 4 kPa for MH and for CH is 15.39 kPa, whereas the effective friction angle of MH is 32° and for CH is 15.63°. (3) φb parameter values for CH is 5.43° and for MH is 5.6° in matric suction under 450 kPa. (4) On the slope deformation analysis with matric suction occurring below 50 kPa, the parameter value for MH φb obtained by 23.66°. (5) The average period of rainfall at the study site was set at 4 hours/day. (6) Changes in pore water pressure and the greatest deformation occurs in rainfall conditions on the 5th model and pieces of the cross section B-B, namely a row of 33.2 kPa and 25.1 mm for pore water pressure and horizontal deformation. (7) With the countermeasures of landslides in the form of the counterweight and sub drain, visible results of countermeasures that do show increased safety factor significantly from 1.085 at condition without counterweight to 1.417 at condition with counterweight.

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