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Slope stability analysis of landslide in Wayang Windu Geothermal Field, Pangalengan, West Java Province, Indonesia

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Abstract. Large-scale landslide occurred in Margamukti village, Pangalengan, Bandung Regency, West Java Province, Indonesia. The landslide damaged geothermal gas pipeline along 300 m in Wayang Windu Geothermal Field. Based on field observation, landslide occurred in rotational sliding movement. Laboratory analysis were conducted to obtain the characteristics of the soil. Based on the condition of the landslide in this area, the Factor of Safety can be simulated by the soil mechanics approach. Factor of safety analysis based on soil cohesion and internal friction angle was conducted using manual sensitivity analysis for back analysis. The analysis resulted soil cohesion in critical condition (FS<1) is 6.01 kPa. This value is smaller than cohesion of undisturbed slope soil sample. Water from rainfall is the most important instability factors in research area. Because it decreases cohesion in soils and increases weight and pore water pressure in granular media.

INTRODUCTION

Indonesia is a country which has big potential of geological hazard. It also has tropical climate with high intensity of rainfall. Therefore, it is frequently covered by disaster occurrences. One of the occurrences that give many detriments is landslides. In West Java, landslide occurrences have the highest incidence number of all provinces in Java.

On May 5th, 2015, there was large-scale landslide in Margamukti, Pangalengan, Bandung Regency, West Java, Indonesia, which caused the damage of the geothermal gas pipeline along 300 m length, 8 houses buried, and 6 people died. The landslide location is shown in figure 1. The cause of the landslide was triggered by heavy rains from May 2-4th, 2015, that fell during the time in the area and surroundings, then rainfall began to seep into the ground so that the weight of the soil mass was increased. It was exacerbated by the landslide that happened in 2012.

Land use was dominated by elephant-grass plants and erosion on the base-slope, as well as cuts on the bottom of the slope which is used for placement of the pipe. Meanwhile, the weak zone between soil weathering and bedrock, basically can be a sliding plane of mass movement [1].

Based on the condition of the landslide in this area, the Factor of Safety can be simulated by the soil mechanics approach. Factor of safety analysis based on soil cohesion and internal friction angle was conducted using manual sensitivity analysis for back analysis.
GEOLOGICAL BACKGROUND

Based on Alzwar et al., the lithologies of the area (figure 2) from the oldest until the youngest are Waringin-Bedil Andesite, Old Malabar (Qwb) that consists of alternation of lavas, breccia and tuffs, pyroxen andesitic and hornblenda andesitic composition. Undifferentiated Efflata Deposits of Old Volcanics (Qopu) that consists of fine to coarse dacitic crystalline tuff, tuffaceous breccia and old andesitic-basaltic laharic deposits, Malabar-Tilu Volcanics (Qmt) that consists of tuff, laharic breccia contains minor of pumice and lavas.

One of the structural geology which is developed in this area is the faults. The faults are two dip-slip faults with northwest-southeast trending, four strike-slip faults with northeast-southwest trending and north northwet-south southeast trending.

FIGURE 1. Location of the landslide in Pangalengan (modified from Google Earth image)

FIGURE 2. Geology Map of research area (modified from Alzwar et al [2])

In this area, at least there are eight manifestations of geothermal which consists of hot spring, solfatara, fumarola, and spring. Most of manifestations were found around the alignment of fault zones.
PANGALENGAN LANDSLIDE

Geometry

Landslides has 650 m length from crown to toe and the crown width along 160 m. Landslide flows with N280°E trend at the crown and turn toward with N255°E trend (figure 3). It follows the topography gradient of the landslide body. Body width is 200 m based on GPS track of landslide observations on May 9th, 2015. Toe width is estimated 110 m and length of landslide flow is 650 m estimated. Meanwhile, the depth of sliding is about 30 m approximately. The landslide was sketched in figure 4.

![FIGURE 3. Panoramic view of landslide from crown.](image)

Landslide Type

On the landslide, appeared several blocks that were moving toward the sliding plane. The blocks presented the form of vegetation formations which stand still (figure 3). It was indicated that the landslide movement is a sliding type with rotational movement.

Landslide Material

Based on field observation, soil material of the landslide composed by debris of weathered soil of pyroclastic rock and some of altered pyroclastic boulders. Soil sample is classified as silty sand (SC) based on granulometry test. Altered pyroclastic found as boulder and at foot-landing slide area as an outcrop exposed by landslide. This outcrop indicates that the position naturally under the soil layer (figure 6). Classification of soils based on the Unified Soil Classification System (USCS) [3].
METHODS

The samples were carried out in seven spots around the landslide area. Three of the seven samples are in undisturbed part of slope and the rest are samples in disturbed part of slope (soil deposit of landslide). These samples will be tested for density test, granulometry test, Atterberg test, direct shear test and simulation due to the value of Factor of Safety.

The soil density test is conducted to determine natural dan saturated density of soil samples. The granulometry test is conducted to determine soil classification. Atterberg test is conducted to determine liquid limit, plastic limit and shrinkage limit [4]. The Plasticity Index value is calculated by the difference between liquid limit and plastic limit. The angle of internal friction and cohesion are obtained from direct shear test.

RESULT AND ANALYSIS

Soil Density Test

Soil density is determined by ratio of mass and volume. Conducted two measurements of density, natural density from natural water content and saturated density by adding distilled water until saturated condition reached. Average value for natural density from sample of undisturbed slope is 15.56 kN/m³ and saturated density is 16.60 kN/m³.
Granulometry

The granulometry test is used to determine the classification of soils. Based on Unified Soil Classification System (USCS) [3], the test results of granulometry showed that all samples in the landslide location can be classified as SM (silty sand). Concluded that soil properties in this area are relatively similar.

Direct Shear Test

Shear strength parameters (soil cohesion and internal friction angle) of soils were obtained from direct shear test in peak condition. Assumed that slope failure was never occurred in this area. Direct shear test resulted soil cohesion of all samples ranges 3.33-10.47 kPa. The average value of soil cohesion in undisturbed slope is 7.87 kPa and internal friction angle is 34.71° approximately. Internal friction angle in undisturbed slope are used as a ‘known variable’ for sensitivity back analysis.

The Factor of Safety Value

Before back analysis simulation, factor of safety was analyzed by data from laboratory test of soil samples in undisturbed slope. The soil properties have 15.56 kN/m$^3$ density above water table and 16.60 kN/m$^3$ density below water table, 7.87 kPa cohesion, and 34.71° internal friction angle.

The pyroclastic rock layer which lies beneath soil layer has mechanical properties 24.01 kN/m$^3$ density, 17.97 kPa cohesion and 29.10° internal friction angle. Pyroclastic rock cohesion and internal friction angle was obtained from del Potro and Hürlimann [5] research about shear strength parameters of material with argillic alteration in Teide stratovolcano, Tenerife. Density of pyroclastic rock is an average value which was obtained from Masri et al. [6] research about structural permeability in Wayang-Windu, West Java.

Based on simulation, the slope is in stable condition with factor of safety 1.135. The simulation obtained with section that shown in figure 6. Manual sensitivity analysis was conducted to find the condition of material properties when the slope became failure (Factor of safety less than 1). Manual sensitivity analysis conducted to determine the value of cohesion of soil layer (table 1), and assume all other parameters were not changing until the failure of slope.

TABLE 1. Result of sensitivity for back analysis.

| Litology                  | Unit Weight (kN/m$^3$) | Cohesion (kPa) | Angle of internal friction (degree) | Factor of Safety |
|---------------------------|------------------------|----------------|------------------------------------|------------------|
| above water table         | 15.56                  | 7.87           | 34.71                              | 1.135            |
| = natural density         |                        | 7.5            |                                    | 1.109            |
|                           |                        | 7              |                                    | 1.074            |
|                           |                        | 6.5            |                                    | 1.036            |
|                           |                        | 6.1            |                                    | 1.006            |
|                           |                        | 6.09           |                                    | 1.005            |
|                           |                        | 6.07           |                                    | 1.004            |
|                           |                        | 6.05           |                                    | 1.002            |
| below water table         | 16.60                  | 6.03           |                                    | 1.001            |
| = saturated density       |                        | 6.01           |                                    | 0.999            |
|                           |                        | 6              |                                    | 0.998            |
CONCLUSION AND DISCUSSION

The result from sensitivity analysis are the cohesion value = 6.01 kPa (red line in figure 5) and angle of internal friction = 34.71°. Water from rainfall is the most important instability factors in research area. Because it decreases cohesion in soils and increases weight and pore water pressure in granular media [7]. This was confirmed with the report from Geological Agency [1], that there was high intensity rainfall in research area a few days before the landslide event. Some fractures zone which found around the slope also accommodate water penetration into ground.

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