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EFFECTIVENESS OF HORIZONTAL DRAIN FOR SLOPE STABILITY OF COAL MINING, CASE STUDY OF SLOPE FAILURE IN TAMBANG GUNTUR, SOUTH KALIMANTAN

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Abstract

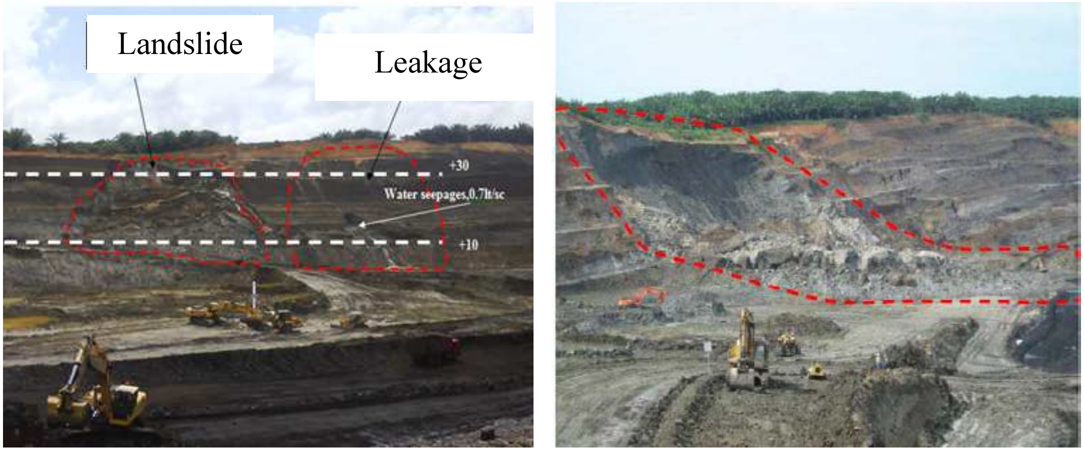
Slope failure occurred in Tambang Guntur PT. Borneo Indobara in Tanah Bumbu, South Kalimantan results in not only technical problems but also a financial problem. The mining operation was terminated. An investigation was conducted to determine the cause of the landslide and obtain methods to prevent further landslides. This study focused on the inquiry into the slope failure occurred in the location mentioned above. Several boreholes were performed to determine detail sub-soil layers and soil properties especially the shear strength of soils. A piezometer was installed and used to obtain the pore-water pressure data located close to the landslide. Additional data such as rainfall data and topography data is also used. A calculation using computer program was also used to model and obtain the safety factor of the slope. The result shows that the landslide occurred due to extremely high rainfall and extended period of rain. A horizontal drain was installed to reduce pore-water pressure as a method of slope stabilization. This paper presents and discusses the effectiveness of the horizontal drain in the field to stabilize the slope.

Keywords: landslide; coal mine; horizontal drain; rainfall; slope stability

1. INTRODUCTION

Landslide is a disaster that resulted not only damage to infrastructure but also casualties. Djamal (2002) reported that from 1990 to 2002 more than 800 slope failure occurred in Indonesia that claimed more than 1000 dead and hundreds injured. It also results in damage to more than 500 infrastructure and dozens of kilometers of roads. In 2016, National Disaster Management Authority of Indonesia (BNPB) reported that there were 625 incidents of landslides in Indonesia (BNPB, 2016). The landslides occurred not only on natural slopes that are close to public property but also in the excavation work for example in open pit mines.

Tambang Guntur is active block coal exploitation in the district of Tanah Bumbu, South Kalimantan. Mining activities have been carried out by the open pit mine system with a ladder on each slope. Although the slopes of the pit have been designed very well with a safety factor of more than 1.3, landslide with a diameter of approximately 30 meters, and 20 meters high occurred (Figure 1.a). The landslide coincided with the very high rainfall. Seepage of 700 ml/s was observed close to the first landslide. After a month, at the same location, a larger landslide with a diameter up to 60 meters and a height of 30 meters happened (Figure 1.b).



(a) (b)

Figure 1. Slope failure at Tambang Guntur (a) first landslide, and (b) further landslide

In Indonesia, many slope failures coincided with or followed an extremely high rainfall (Djamal, 2002; Apip et al., 2010; Hirnawan, 2010; Liao, 2010; Arifin, 2010; Prayuda, 2012; Sumaryono, 2014; Zakaria, 2015). In other countries, some studies have also presented the effect of rainfall on landslides. For example, Singapore (Rahardjo et al., 2002; Rahardjo et al., 2003), Malaysia (Ng et al., 2015; Ismail et al., 2016), Thailand (Kanjanakul et al., 2016), and Philippine (Orense, 2004). During periods of rain, water infiltrates into the soil to raise the water table, increase the pore-water pressure, and subsequently enhance the risk of landslides. According to Rahardjo et al. (2002), prolonged heavy rain destroyed matric suction that plays a significant role in the stability of earthworks.

One method commonly used to decrease the ground water level on the slopes is the use of horizontal drain that is defined as holes drilled into a cut slope or embankment and equipped with a perforated metal or slotted plastic liner (Royster, 1980). Some studies have been done to examine the effectiveness of horizontal drain application (Rahardjo et al., 2003; Carrol et al., 2011; Jude et al., 2014; Ng et al., 2015; Ismail et al., 2016; Mukhlisin and Aziz, 2016). The effectiveness of the horizontal drainage system is affected by the location, length and spacing, soil properties, and slope geometry (Ismail et al., 2016). Horizontal drains should be placed as low as possible in the slope for lowering the water table since horizontal drains located in the upper regions of the slope are unnecessary in the long term (Rahardjo et al., 2003). By mean parametric study, Ismail et al. (2016) concluded that horizontal drains might effectively decrease the groundwater level for cut slopes with high groundwater level by installing it sufficiently deep into the slope to intercept the groundwater from the fractured rock. Ng et al. (2015) and Ismail et al. (2016) suggested that the use of geophysical resistivity to identify the best location and the length of the horizontal drain by analyzing the delineation of high water content zone and the possible seepage flow path. Jude et al. (2014) used value-engineering analysis to define the inclination of slope and horizontal drain material.

Due to the successful design and utilization of horizontal drain in slope stabilization are often governed by local experience, the information about the application in the field yet required. This paper presents the effectiveness of horizontal drain use at Tambang

Guntur Mine in Tanah Bumbu District, South Kalimantan. The effectiveness is described regarding the increase in slope factor of safety as compared to the element of security for the case without horizontal drains.

2. SOIL INVESTIGATION AND INSTRUMENTATION

The study of subsoil and sampling was conducted using a drilling machine Jakro 200 types of wireline systems with penetration capability of 200 m. The points of the drill locations are shown in Figure 2. Soil as a result of drilling with a diameter of 89 mm was placed in core boxes, for example as illustrated in figure 3(a). Samples were taken at intervals of 5 m and adjusted to rock lithology before being sent to the laboratory.

The pore-water pressure was measured using a vibrating wire piezometer. The piezometer was installed at a depth of 47 m in BH12 after the core drilling process has been completed. The drilling and installation were conducted in Desember 2013 to respond to the seepage on the slopes. The pore water pressure reading was carried out efficiently on 1st January 2014. The data was collected daily. Figure 3(b) shows the photo of the pore-water pressure measurement in the field.

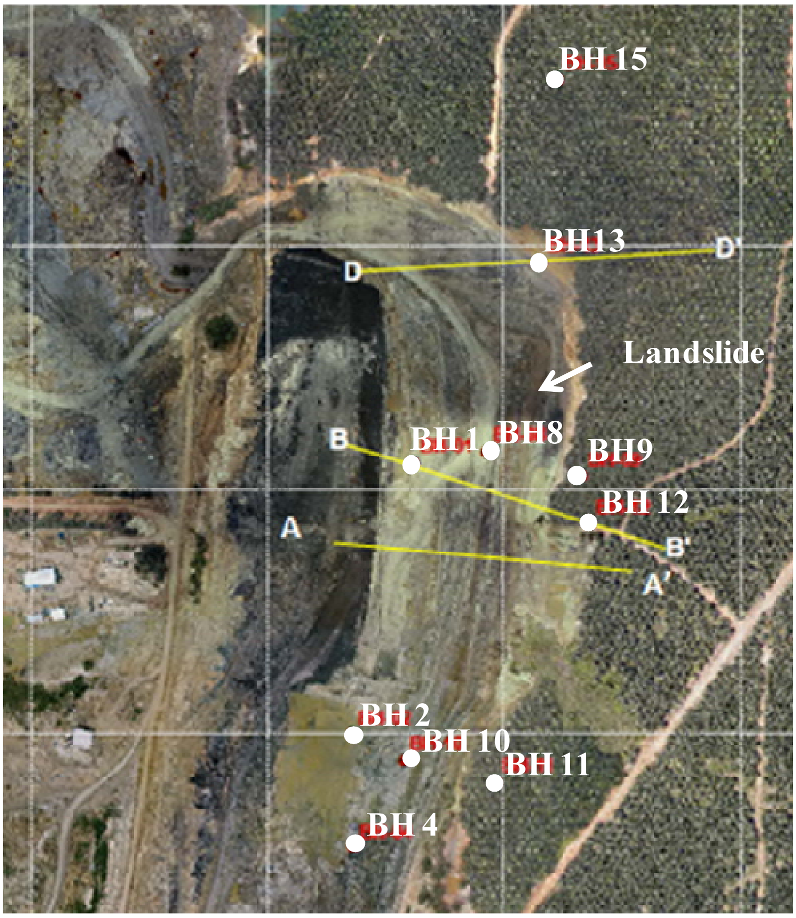


Figure 2. Bore hole locations

(a)

(b)

Figure 3. (a) Example of core box, and (b) pore-water pressure measurement

The research was focused on bore holes BH1, BH8, BH9, and BH12, and a cross-section B-B because it is the nearest location to the first landslide (Figure 4). As shown in the figure, BH8 has a depth of 60 m placed approximately 15 m over the toe, and BH12 has 77-m deep with an inclination of 40^o placed in the top of the slope. Figure 4 also shows the surface of the slope before and after the landslide occurred. Before landslide, the ground surface has a slope of 40^o. The landslide changed the slope to be 21^o.

Based on the borehole profiles, it was determined that the soil being studied was eight layers of mudstone namely ms-1 to ms-8 (Figure 4). The volumetric weight of the material and unconfined compression test (UCT) results vary from 21.00 to 23.06 kN/m^3 and from 0.18 to 0.87 MPa, respectively. The mudstone was brittle and easily broken. By strength, the material is classified as very low strength rock (Deere and Miller, 1966) or fragile (Brown, 1981; Marinos and Hoek, 2000).

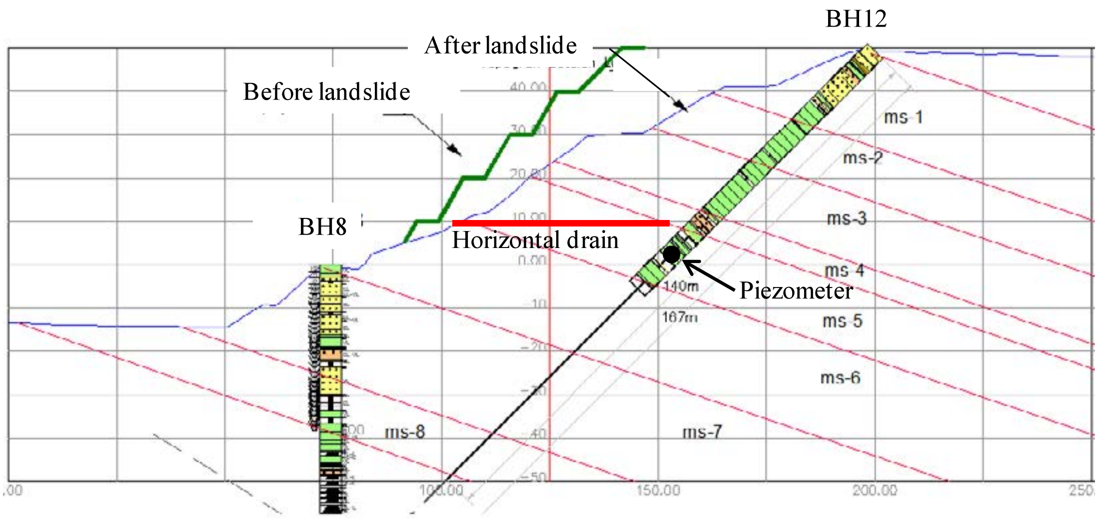


Figure 4. Cross section B-B

3. HORIZONTAL DRAIN INSTALLATION

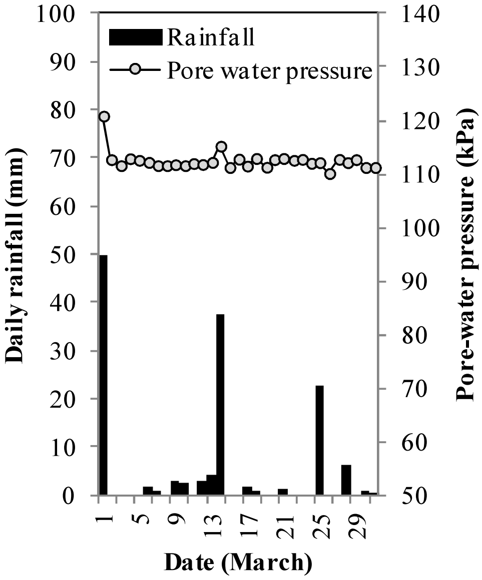
On June 1st 2014, a horizontal drain was installed to reduce pore-water pressure in the slope at the bottom of the slopes. Drilling horizontally was carried out to a length of 50 m using the crawler drill-type with a maximum capacity of 100 m. Figure 5(a) shows horizontal drilling process. As shown in the figure, a little water flows out of the borehole. The problems faced during the drilling process were stuck rod, water loss, rain, and puddles. A perforated galvanized pipe was installed in the hole after drilling has been completed. Immediately after the pipe was installed, the water flows through the pipe as shown in Figure 5(b). The debit was measured manually using a plastic bucket and a stopwatch. The highest debit recorded after pipe installation reaches 1200 ml/s.

4. RAINFALL EFFECT ON PORE-WATER PRESSURE IN THE SLOPE

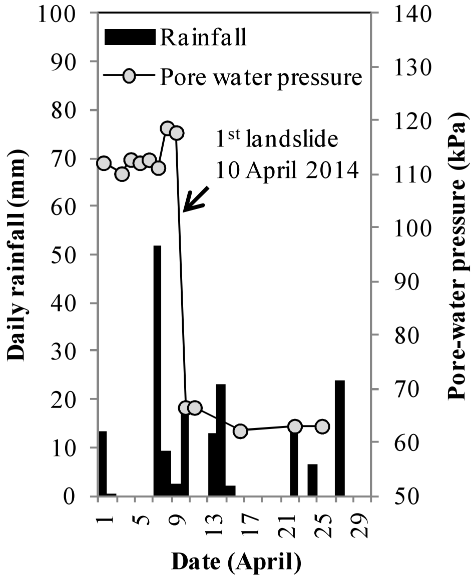
Figure 6 shows pore-water pressure and rainfall data at monitoring period March and April 2014. As shown in Figure 6(a), the pore-water pressure data is almost constant at 112 kPa with a slight change in response to rainfall condition. For examples, on 1 and 14 March, the pore-water pressure increased to reach pressures of 121 and 115 kPa in response to rainfall of 50 and 37 mm/day, respectively. It appears that the pore water pressure increases due to rainfall higher than 30 mm/day. In addition, the pore water pressures are controlled by relatively high existing groundwater level and seepage that occurs on the slopes. In April, pore-water pressure rose to 120 kPa to respond four days rain with maximum rainfall of 50 mm/day. It resulted in a landslide on 10 April 2014 with a diameter of 30 m and 20-m high as shown in Figure 1(a). After the landslide, pore-water pressure decreased gradually. A Similar trend occurred in May that larger landslide coincided with extremely long and high rainfall on 13 Mei 2014.

(a) (b)

Figure 5. (a) Horizontal drilling process, and (b) installation of the perforated galvanized pipe



(a)



(b)

Figure 6. Pore-water pressure reading and rainfall data (a) monitoring period: 1-31 March 2014, and (b) monitoring period: 1-30 April 2014

Figure 7 shows a 9-month data set of average rainfall and pore-water pressure. The figure also shows the times of events (i.e., landslides and installation of the horizontal drain). From January to March, pore-water pressure increased from 105 to 112 kPa. In April and May when the landslide occurred, the pore-water pressure decreased to 74 and 71 kPa, respectively. It was because of the water flowed out through fracture and slide surface formed by the landslide. In June, the horizontal drain was installed. Increase in pore-water pressure in response to high rainfall and extended period of rain in July has not ever resulted in the landslide. This was one proof of the effectiveness of horizontal drain to prevent a landslide. Pore-water pressure decreased in August and September in response to rainfall and the use of the horizontal drain.

5. EFFECT OF HORIZONTAL DRAIN ON SAFETY FACTOR OF SLOPE

Another way to observe the effectiveness of horizontal drain on slope stability is to consider the factor of safety. The slope stability analysis was performed using the limit equilibrium slope stability software (i.e., Slide). Several simplifications were made to analyze slope safety factors. (1) The slopes with the soil layers were modeled with the features present in the Slide software. (2) The horizontal drainage hole was not directly applied to the model. (3) the changes in pore water pressure due to horizontal drain were converted to the height of ground water level (GWL) in the slope. (4) Only slope safety factors were obtained from this calculation.

Figure 8 is an example of slope stability analysis performed in this study at the condition before the first landslide. Based on computation result, a safety factor of slope on March with the pore-water pressure of 112 kPa converted to the ground water level of 11.4 m under ground surface was very close to 1 (i.e., 1.058). In the field, a landslide occurred.

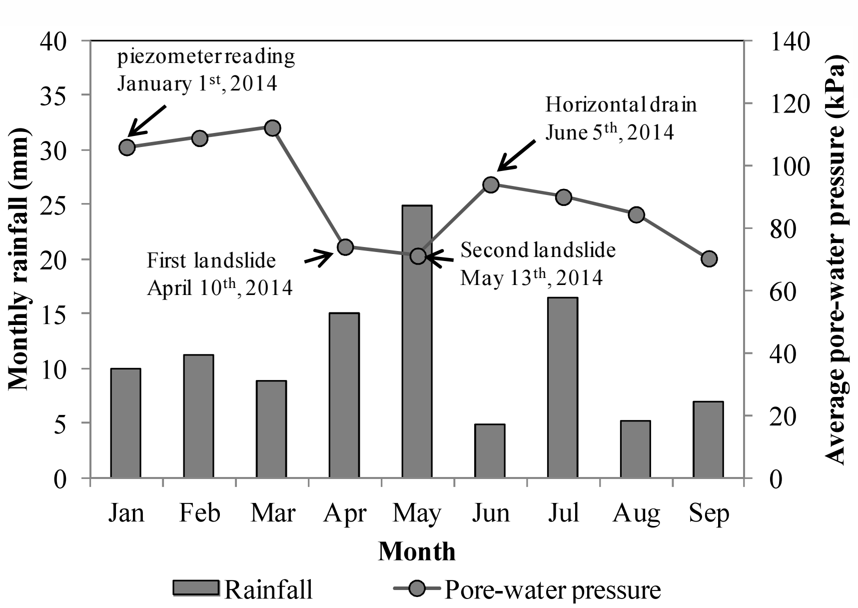


Figure 7. Average rainfall and pore-water pressure from Jan-Sep 2014

In July where the horizontal drain has been installed, the safety factor of slopes with an inclination of 20^o and pore-water pressure of 90 kPa (i.e., GWL of 13.18 m) was 1.3. The safety factor increased by decreasing pore-water pressure in August and September. For long-term mining exploitation, deeper excavation is planned to a depth of 65 m. Stability of slope with a depth of 65 m, the inclination of 20^o, and pore-water pressure of 120 kPa (i.e., assumed as the highest pore-water pressure occurred in the slope) was conducted using Slide. The safety factor obtained was 1.0. Higher safety factor (i.e., >1.3) can be reached by maintaining the pore-water pressure at a maximum of 70 kPa. The result reveals that another horizontal drain at the location as low as possible in the slope should be installed to increase the stability of the slope.

Besides height of ground water level, pore-water pressure influences the shear strength of the rock. Positive pore-water pressure results in decreasing the shear strength of saturated rock (Mesri et al., 1972). Its variation affects alteration in the stresses and the behavior of rock and soil thus triggering rupture and deformation of the crust (Mohammed, 1997). The cohesive and frictional properties of rock mass were significantly reduced from drained to the undrained condition. Since horizontal drain that allows water to flow out from rock mass can be equated with the drained condition, its presence in the slope will maintain the shear strength of rock mass forming the slope.

Mudstone which is dominant in the slope being studied is another reason of landslide due to its sensitivity to water absorption and desorption. The strength of mudstone decreases significantly when it is in contact with water (Lee et al., 2007). Jiang et al. (2014) found that rapid crack growth occurred in the first 72 hours of water infiltration. Moreover, the presence of discontinuity in mudstone as shown in Figure 3 provides channels for water to intrude the mudstone. The longer time mudstone in contact with water, the wider its crack and cause a new fracture in the material. In the field, high pore-water pressure drives water to penetrate into the discontinuity of mudstone. The decrease in shear strength of mudstone due to in contact with water was not considered in safety factor calculation using Slide.

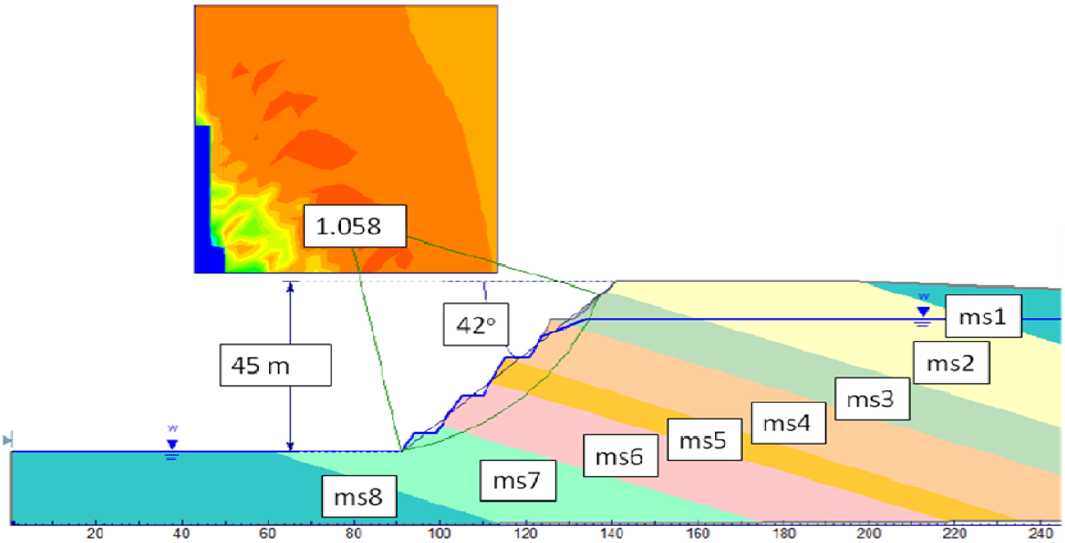


Figure 8. A model using the limit equilibrium slope stability software.

6. CONCLUSION

The effectiveness of horizontal drain for slope stability of coal mining has been analyzed using pore-water pressure data in the field and computer program. The landslide at Tambang Guntur coincided with or followed not only extremely high rainfall but also an extended period of rain. The horizontal drain installed in the slope has been successful to reduce the pore-water pressure that is highly influenced by rainfall. In the field, increase in pore-water pressure in response to high rainfall and extended period of rain during the term of study has not ever resulted in a landslide.

The safety factor of slope obtained using a computer analysis increases by decreasing the pore-water pressure. For long-term mining exploitation, another horizontal drain located as low as possible in the slope is required.

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