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RESPONSE OF CLAY SHALE TO THE VARIATION OF MOISTURE CONTENT

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ABSTRACT: Deterioration of shale often occurs in open mining activity because the material is exposed to climate change which causes repetitive change in moisture content and weathering process. Furthermore, the dumping of excavated material caused an accumulation of water and pounding at the intermediate layer and further reduced the shear strength. The increase of water content beyond the infiltration capacity will cause the reduction of inter-particle bonding as well as cohesion of the shale. This research focuses on the effect of water content and creep on both exposed and dumped shale. Direct shear test performed on undisturbed shale and exposed shale showed that creep cause a reduction on shear strength by 60%. Shear strength tests conducted on samples obtained at random from dumped area confirmed that the change in water content significantly affects shear strength. Therefore, the prediction of slope stability should be based on the actual shear strength of both the shale and the dumped material.

Keywords: shear strength, clay shale, moisture content, slope stability

1. INTRODUCTION

Excavation process involved in open coal mining activity causes the exposure of original shale material to atmosphere and climate changes. The weathering process will bring about the change of the material characteristics from rock to soil. For geotechnical engineers, this could be translated to the change in shear strength deterioration. The shear strength and the compressive strength will drastically drop to lower values due to weathering.

Increase in water content has been identified as the dominant factor causing the loss of the shear strength of soil and weak rock. This is due to the alteration of soil state from unsaturated to saturated condition and beyond in which soil looses its shear strength, especially by the reduction of cohesion. The shear strength of the weathered clay-shale may drop to about 33% from that of the fresh one. Large amount of infiltration due to rainfall and pounding-water has been identified as a cause of increasing water content. The shear strength will further reduced once the soil is subjected to wetting and totally loss upon saturation. The mechanism of strength loss due to soaking was discussed by Stark and Duncan (1991).

Besides the loss of shear strength, the change of water content also contributes to swelling and shrinkage of soil volume. Shrinkage or creep of the soil during dry periods after prolonged wet-and-dry cycles lead to the development of tension cracks on the surface of a sloping land. During wet seasons, large amount of water infiltrated through the tension cracks and further seeped into the soil layers. The presence of tension crack initiates a seepage pattern different from those predicted based on the original slope geometry and soil properties.

This paper summarizes research done at Air Laya open Coal Mining area in South Sumatra, Indonesia (Figure 1). Air Laya is one of several mining sites under the auspices of the Bukit Asam Coal Mining Company Indonesia.

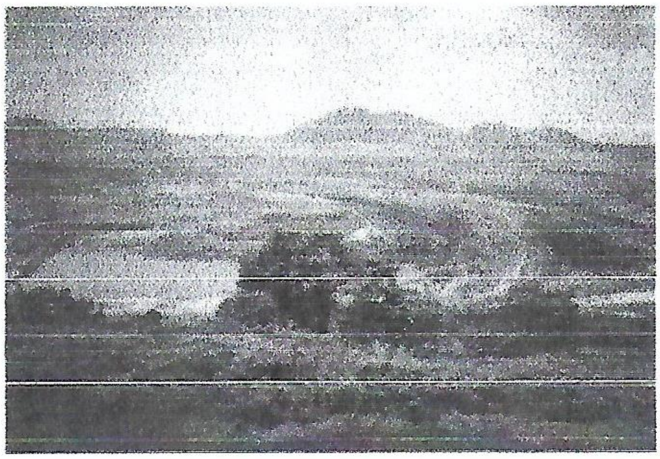

Fig. 1 View of Air Laya open coal mining site

An open coal mining activity involves excavating soil to expose the coal layer and dumping the excavated overburden soil to an assigned dumping site. The subsurface of Air Laya mining site comprises shale and clay shale material. This material is very hard when dry but highly cohesive when wet. During the rainy season, the soil can absorb a large amount of water and because the permeability of the soil is very low, then the water cannot dissipate easily. The soil supposed to swell due to the accumulation of water, but since the swelling pressure in the soil is very low, the soil turn to become very sticky. The soil condition made the mining activity very difficult especially during wet season (Kramadibrata, 1999).

The total area is 1210Ha which currently consists of 560Ha mining area and 650Ha dumping sites. There are two dumping sites namely speader 701 and Spreader 702. The excavation is performed by Bucket Wheel Excavator (BWE). The depth of excavation is 100m with almost vertical angle. The maximum height of fill is 80 m with stepping height of 8 to 10 m and slope of 1:1.5H to 1:3H.

Like any other areas in tropical regions, Air Laya experiences distinctive climatic changes throughout the year. In general, wet weather condition is dominated by North-East monsoon occurs from November to April. The mean annual rainfall for the area is 3,030mm, of which approximately 68.5% fall during wet season. The average ambient temperature is 27°C. The evaporation is limited by high relative humidity, which is about 75% (Gofar *et al.*, 2003).

When the excavated material is dumped on the dumping area, the soil is not compacted and consolidation is expected occur naturally due to the weight of fill. During wet season, rainfall will infiltrate into the soil, causing seepage in fill soil and accumulation of water in the intermediate layer between the original soil and the dumped soil. Increase of water content beyond the infiltration capacity will cause the reduction of inter-particle bonding as well as cohesion of the soil (Rahardjo *et.al.* 2000). In this case, the process occurred at a depth below the ground surface therefore, it is not easily detected.

Slope failures and landslides are common in Air Laya. Most of the slope failures and landslides occurred at the end of wet season. The largest landslide on dumping area, occurred in November 2002, was believed to be caused by the development of tension crack on the surface (Gofar, 2006). From the standpoint of soil strength, the end of wet season is considered as critical because the soil suction which contributes to the shear strength is minimized or eliminated (Fourie, 1996). Infiltration of rainwater into soil will increase the moisture content of the soils, alter the structure of soils and thus reduce or eliminate frictional and cohesive strength. Zhang *et al.* (2005) proposed a relationship between unconfined compression strength of soil with water content.

This research is focused on the evaluation of soil behavior at Air Laya coal mining site and the effect of both creep and the change of water content on the shear strength of clay shale in the dumping area. The understanding on the behavior and the accurate estimation of shear strength is important in the slope stability evaluation.

2. METHODOLOGY

The methodology adopted for this study involved the determination of soil index properties and mineralogy as well as chemical content of the soil found in the dumping area of Air Laya Coal mining. Determination of these characteristics is important to the comprehension on the actual behavior of the soil. Soil properties tests were conducted on samples collected at the dumping site. All tests were performed following the standard procedure suggested by ASTM standards (ASTM, 1995). Mineralogy of the soil was evaluated by x-ray test. Chemical composition was evaluated through gravimetry/ spectrofotometry test.

In absence of laboratory equipment to evaluate SWCC curve, the water retention ability of the soil was evaluated by infiltration and permeability test on falling head permeameter. Infiltration test was performed prior to permeability test and the result was plotted as cumulative infiltration versus time (Green Ampt).

Effect of creep on shear strength was studied based on creep test (Rivai, 2003). The test was performed by direct shear equipment whereby the normal load and shearing was applied until failure was observed. The shear strength at the time of failure was recorded and the data was plotted as shear strength versus time of failure.

Direct shear tests were performed on samples collected at random (in terms of time and location) in the dumping area to evaluate the relationship between the shear strength and water content. In addition, CBR test was performed on both compacted and uncompacted samples to observe the effect of soaking on shear strength.

3. RESULTS AND DISCUSSION

3.1 Soil Index Properties and Composition

The classification test indicated that the soil can be grouped as high plasticity clay or silt (CH or MH). It should be noted that even though the results of Atteberg limit tests indicate that the soil is of high plasticity, the amount of soil passing No. 200 sieve is very low (12.31%) and the amount of colloid is also low (2.35%). This condition explains the behaviour of soil as described in previous paragraph. Activity of the soil can be computed based on plasticity index and the percentage of colloid. For Air Laya soil, the activity is very high i.e 17 which explain the rapid change in the response of soil to water. The properties of the soil are summarized in Table 1.

Table 1 Properties of Soil from Air laya site

Soil parameter	
Specific gravity	2.34
Composition	
Passing sieve No 40	78.14%
Passing Sieve No 200	12.31%
colloid (ø < 0.002 mm)	2.35%
LL (Liquid limit)	65.14%
PL (Plastic Limit)	25.24%
PI (Plasticity index)	40%
SL (Shrinkage Limit)	12%
SR (Shrinkage Ratio)	1.67
Activity	17
Classification (ASTM/UCS)	CH

The mineralogy of the soil, evaluated by X-Ray test, showed that the clay is dominated by montmorillonite (41.50%), kaolinite 33.20%, Siderite (5.20%) and Alpha Quartz (20.20%). The chemical composition is dominated by SiO_2 (53%) and Al_2O_3 (17%) hence, the ion exchange capacity from SiO_2 and Al_2O_3 are high. Based on the mineralogy and chemical composition, the soil can be classified as expansive clay which explains the ability of the soil to absorb a large amount of water.

The results of infiltration-permeability test shows that the response of the soil to the increase of water content is very rapid within the first five minutes, however the water content at saturation 46.15% was only reached after 123 minutes. The volumetric water content at this condition is 52%. Permeability test was performed upon reaching the saturation and the result shows that the permeability of soil in the dumping site Air Laya is 1.39×10^{-7} m/s. This shows that the soil has very low permeability. The results indicate that the soil has a large water retention ability and the findings explain the unique response of the soil to wetting during the excavation, transporting and dumping process. As a fill material, the soil was not compacted and this led to a more complicated mechanism when subjected to rainfall infiltration.

3.2 Effect of water on shear strength parameter

The effect of water content on the shear strength parameters was evaluated by doing direct shear test on samples collected at random (in terms of time and place) from the dumping site. The results shown in Figure 3 indicated that even though the data was very scattered, there is a tendency that the shear strength in terms of cohesion is affected by water content. The scattering of data is due to the heterogeneity of the material found in the dumping area. The cohesion decreases as the water content increases. At saturated water content, the cohesion decreases to as low as 4 kPa. The results also show that water content has very small effect on friction angle as long as the water content is less than saturation.

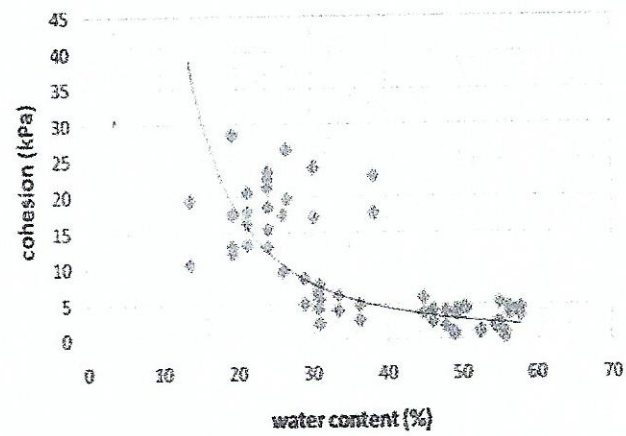

Fig. 3 Effect of water content on cohesion

Figure 4 shows the results of direct shear test on samples at normal water content (about 20%) and at water content near saturation (about 46%).

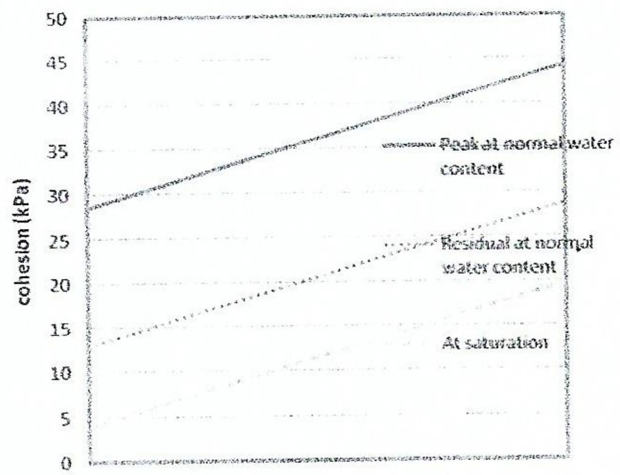

Fig. 4 results of Direct shear test on sample at normal water content and at saturation

Standard Proctor Compaction tests were performed on the soil to evaluate the response of the soil upon soaking and the results shows that the maximum dry density of 16.4 kN/m^3 was achieved at an optimum water content of 17%. For compacted soil, the CBR unsoaked and soaked tests were conducted at the optimum water content results in a CBR unsoaked value of 31% and CBR soaked value of 0.85% with swelling volume of only 0.59%. For soil prepared at water content less than optimum, the CBR unsoaked and CBR soaked are 4.06 and 0.49% respectively with swelling volume of 1.65%. The swelling pressure was very low i.e. 0.2 kPa. It can be seen that he soil has almost no strength upon soaking especially if the soil is not compacted.

3.3 Effect of creep on shear strength parameter

The effect of creep on shear strength parameters were studied by creep test Figure 5 shows the effect of creep on shear strength under three different normal stresses. The figure shows that the shear strength after creep for about 100 days was about 288 kPa as compared to the average original shear strength of 551 kPa. Extension of the logarithmic curve based on these data shows that the shear strength over a long period of time was about 40% of the original strength.

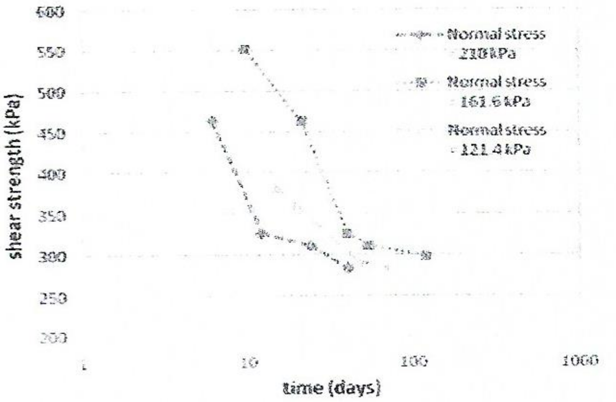

Fig. 5 Strength reduction due to creep

3. CONCLUSIONS

The study explained the unique response of clay shale material obtained in Air Laya mining area to the change in moisture content. The mineral content of the clay cause the soil to absorb a large amount of water and become sticky. However the low swelling pressure made the soil to break up upon saturation and become mud. This has caused the difficulty in the mining activity.

Creep resulted in the reduction of shear strength of shale material by as much as 60% while the increase in water content further reduces the cohesion. Infiltration of water beyond saturation results in the total loss of strength.

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