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Slope stability analysis for landslide mitigation in Satui, Tanah Bumbu, South Kalimantan

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Slope stability analysis for landslide mitigation in Satui, Tanah Bumbu, South Kalimantan

A Salimah

Civil Engineering Departement, Politeknik Negeri Jakarta, Prof. Dr. G.A. Siwabessy, UI Depok, Jawa Barat. 16425

Corresponding author: aisyah.salimah@sipil.pnj.ac.id

Abstract. Satui is a Tanah Bumbu sub-district that is in the territory of South Kalimantan yielding mainly coal. The illegal and uncontrolled coal mining formed a steep slope in this area. The slope was exactly shaped close to a telecommunication tower building and other buildings. The excavation in this area provoked an eroded and imbalanced slope thus triggering a landslide. This research is aimed to deal with erosion prevention and disaster risk reduction to mitigate the environmental impact. The investigations of slope and soil conditions are used to obtain soil data as the first stage of research. The second stage is analyzing the slope stability toward soil data. A stable slope condition is indicated by existing analysis with FoS 1.66. Yet to avoid future disaster risk, slope reinforcement by employing Geo-Anchor is performed. The last stage is executed by implementing the proposed drainage and slope surface formation.

1. Introduction

Landslides are mass ground movements, causing deaths and infrastructural damage around the world every year, and important to understand what triggers them to reduce future losses [1], [2]. Landslides have occurred regularly in Indonesia, especially in the intense heavy rainy season. Plateaus with steep slopes result in frequent landslides [3]. Landslides mostly occur when the ground on a slope becomes unstable. Several factors affecting the destabilization of the ground are a variety of natural and human causes, most commonly rainfall but also seismic activity, mining, or changes to vegetation affecting soil composition [4]. The presence of vegetation plays a great role to retain the ground from subsidence on a precipitous hilly area [5]. However steep slopes can be formed from human activities such as mining. Shear stress is highly affected by ground movement in a slope. The shear stress will be bigger as the dipping of the slope increases causing the unstable condition of the slope [6]. If the shear stress along the slipping zone higher than the soil (increased saturation of water), resulting in their downward and outward movement by gravity such as landslides, debris flows, mudslides, rock falls, earth flows, and other mass movements [7,8].

Satui sub-district is in the region of Tanah Bumbu, South Kalimantan holding about 881.73 km^2 as wide [9]. Tanah Bumbu topographically includes littorals, lowlands, and hills, while Satui owns the scope of the plain and beach area in the southern part. According to Koppen climate classification, the climate in Satui, commonly in Tanah Bumbu, is clustered into isothermal tropical wet-dry climate (Af-Aw) with the dry season in high temperature [10]. In which area occupied this climate type has a long dry season. The rain intensity in the wet season could not compensate for the rain deficit in the dry season and lack vegetation in the region [11]. Soil type and it is characteristics rely on soil formation factors such as temperature, climate, parent material, organisms, and time. The soil type in Tanah Bumbu is dominated by Red-Yellow Podzolic soils (RYP) as wide as 161,028 Ha (31.78%). Following [12], podzolic soil experienced weathering in a tropical and subtropical climate. Red-Yellow Podzolic soils are more susceptible to erosion than others, being less permeable on the whole. The predominant characteristic of podzolic is a thin surface horizon, accumulated clay layer under the surface horizon, and a rather acidic type of soil. The podzol itself is quite humid in which the highest soil moisture is obtained in boulder shaped. Figure 1 shows the susceptibility ground movement map of South Kalimantan that Satui sub-district, Tanah Bumbu belongs to the zone of very low susceptibility. Therefore, Satui is basically safe from landslide natural hazards.

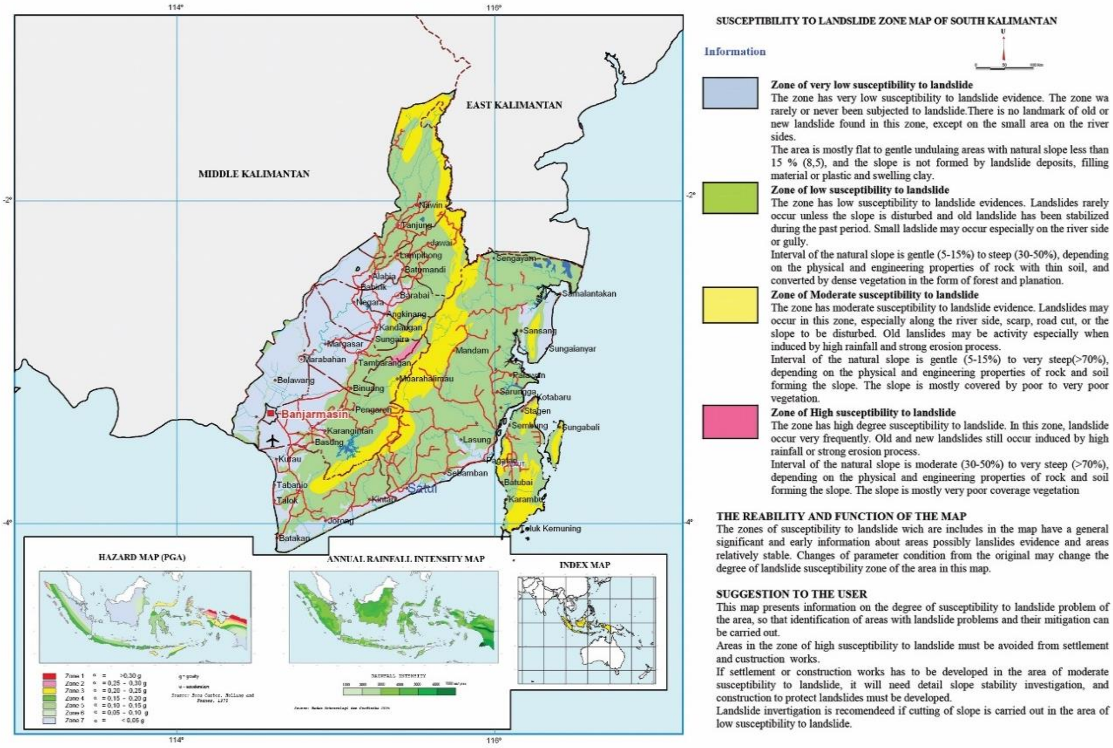


Figure 1. Landslide zone map of South Kalimantan[13]

Tanah Bumbu also has the highest coal reserve in Kalimantan, this includes Satui. In 2018 South Kalimantan coal production reached 150 million tons and is recorded as the second highest coal mining area in Indonesia after East Kalimantan [14]. However, some coal mines in South Kalimantan are illegal. These illegal mine excavation, which is uncontrolled and without rehabilitation, involved excessive environmental disasters such as the change of soil structure and instability of slope, in the form of direction shift and high loss of stress in the slope base from a rock block. An extra load on the slope could be caused by high intensity of rain leading to slope erosion particularly in the surface layer of the slope. The continuous slope erosion could induce lessening of slope stability and triggering ground subsidence. Therefore, several countermeasures are needed to tackle the disaster risk endangering the surroundings. This study is located on the illegal mining site in which the excavation has reached 7 m in depth, thus the erosion could not be neglected and the probability of slope failure has risen particularly in rainy seasons. This research focused on the study of the landslide mitigation in a structure area of Telecommunication Tower in Satui, Tanah Bumbu, South Kalimantan. The slope area is located in the south of Satui, Tanah Bumbu, South Kalimantan where extreme contour due to illegal coal mining is taken place. The scope of research is the study of slope stability analysis and efforts to prevent landslides by building reinforcement and improving drainage.

Figure 2. Slope condition after eroded

As can be seen, Figure 2 shows the steepness of the slope is adequately high and the edge of the original land getting eroded approaching the tower building as the effect of illegal coal mine excavation. Accordingly, prompt and precise mitigation is needed to prevent the continuity of erosion. Landslide mitigation includes; investigation survey, analysis, and reinforcement of the slope. The results from the survey and analysis will be considered in risk mitigation planning [15]. The countermeasure involves the construction of Geo-Anchor as slope surface reinforcement. Further improvements are to recondition the previous drainage. The new drainage is built to anticipate the absorption of rainwater into the pores of the soil which has the potential for raising the groundwater table and risk of slope failure.

Slope stability analysis using Plaxis 2D could generate a finite element method. The application of this method has been commonly utilized to model landslide susceptibility in the past years [16]. The groundwater flow, stability, and deformation analysis are performed by finite element program in Plaxis for geotechnical engineering purposes [17]. Has also engaged this method for this slope analysis for further efforts [18-21].

2. Methods

This research performed in Satui, Tanah Bumbu, South Kalimantan, in the area of tower telecommunication building is threatened by landslides due to the excavation of illegal coal mining. Several stages are carried out to mitigate landslides: survey condition, slope stability analysis, applying slope reinforcement using GeoAnchore, and drainage refinement.

2.1. Survey condition

This stage includes a survey of current slope conditions, an investigation of soil, and a survey of drainage. A Survey of slope conditions is also carried out after soil movement to decide the required tests and to initiate the hypothesis of slope failure cause. Also, this stage generates slope measurement contour and illustrates the soil strength to dodge the slope failure in the future.

A Cone penetrometer test (CPT) was applied to identify the soil bearing capacity. Meanwhile, the hand boring method is used to compile the soil samples to obtain the parameters of soil. These samples are then examined in the laboratory to discover density and analysis of particle, soil water content, the limit of soil consistency, bulk density, and soil shear strength according to the standard by ASTM [22-25].

2.2. Stability analysis of the slope

2.2.1. Material design property. To obtain material properties of soil, this study employs the Mohr-Coulomb model which criterion of the material model refers to normal stress, material shear strength, cohesion, and internal friction angle. The input parameters for this model in Plaxis2D software are represented in Table 1.

Table 1. Existing material design parameters

Parameter		Layer 1	Layer 2	Units
Material Model	Model	Mohr-Coulomb	Mohr-Coulomb	-
Material Behaviour	Type	UnDrained	UnDrained	-
Unsaturated unit weight	γ_{unsat}	15.575	21	kN/m^3
Saturated unit weight	γ_{sat}	17.350	22	kN/m^3
Horizontal Direction Permeability	k_x	0.00864	0.00864	m/day
Vertical Direction Permeability	k_y	0.00864	0.00864	m/day
Young Modulus	E_{ref}	1200	10000	kN/m^2
Poisson's Ratio	V	0.35	0.35	-
Cohesion (constant)	C_{ref}	6.121	58.86	kN/m^2
Friction Angle	Φ	21.872	38	°
Dilation Angle	Ψ	0	0	°

2.2.2. Plaxis2D to analyze slope stability. The slope stability analysis holds three principal aspects, those are slope formation material properties, FoS calculation, and slope failure interpretation [26]. The graphical geometric model is used as the input for material properties in Plaxis2D. This model occupies burdening, construction stages, structure elements, soil layering, and limited conditions provided by the software which then simultaneously results in a finite element and the 2D configuration. This configuration is obtained by constructing the finite element into the 2D arbitrary configuration in local or global choices [12]. Figure 3 illustrates the contour condition after erosion caused by illegal coal mining. Layer 1 is shown in the blue area, whereas green areas describe layer 2 in the contour design. The load received by the slope comes from the weight of the tower and the foundation of the tower building was depicted in these figures. Tower load input is 55 kN/m^2.

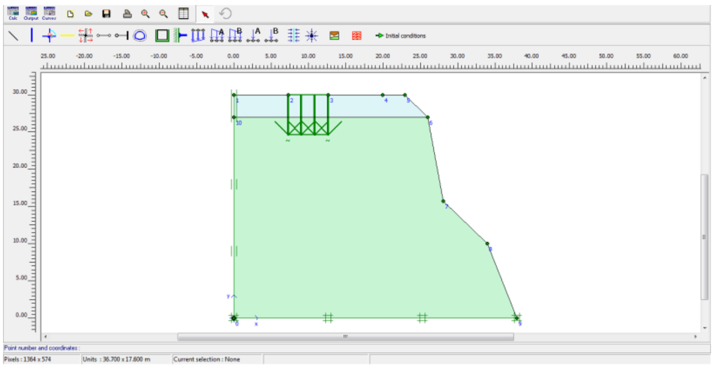


Figure 3. The contour design after eroded

FoS is calculated by detecting the slipping zone in the soil generated from the subtraction of cohesion angle to friction angle constantly until this area is obtained [15].

The failure surface is developed when the resistance of shear strength is a change to lower since the presence of pore water and seepage condition affect the shear stress become similar or more than the shear strength [27]. To understand the stability of slope determination, the friction force and cohesion forces that resist the slope from failing are considered in slope mechanics. FoS is a comparison between resisting (summation of friction and cohesion) force and driving force. Slopes with higher FoS mean lower failure potential than slopes with lower FoS [26]. Therefore, slopes with higher FoS are safer.

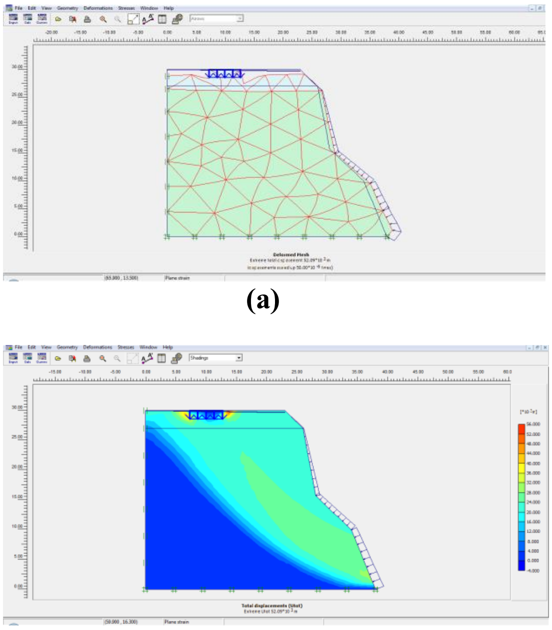
2.3. Landslide mitigation
The mitigations are performed by applying Geo-Anchor for reinforcement in steep slope and drainage refinement. Geo-Anchor is a soil reinforcement system that consists of an anchor head applied on a secured anchor head position, thus shaping a cone plane. This plane provides resistance transmitted subsequently to the head plate by the wire connecting the anchor head and the head plate. The tensile strength received by the head plate is distributed equally by Geogrid or wire mesh to the entire slope surface to escalate the slope stability. To finalize this process, Geo-Anchor could complete it in two manners; shotcrete and sodding. Yet, due to infertile soil conditions to vegetate, sodding would be inapplicable, therefore shotcrete is considered a better option. This mitigation also incorporates drainage repair and novel drainage canal construction to switch the direction of water flow which leads to the surrounding tower. Altering the surface water from the heights should be the role of the canal.

3. Results and discussion

3.1. Survey condition
The road around the building area is still accessible enough, yet reaching the tower building area needs more caution since part of the pathway has been eroded due to slope failure even though it is still accessible as shown in Figure 4.

Figure 4. Pathway and edge of the fence after eroded

3.2. Analysis of existing condition
The next stage is analysis completed under the condition of erosion. The slope gains outer load from the weight of the tower and foundation of the building as equal load. As can be seen in figure 5, no significant movement occurs in the area building of the tower. The parameters of existing material design in Table 1 generates the numerical analysis as represented in Figure 6.



(a)

(b)

Figure 5. (a) Displacement for an existing condition, (b) Condition of failure

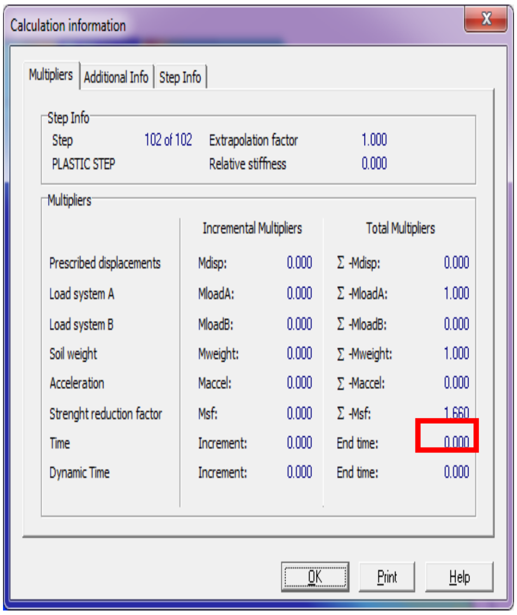


Figure 6. FoS for an existing condition

Figure 5a shows the existing displacement condition. The area potential of the slipping zone is depicted in Figure 5b which total regional displacement are described as well. The result using Plaxis2D could describe the slip surface from crest and hill slope to foot slope at the existing condition. FoS in this case is 1.66 as seen in Figure 6 which describes that slope condition is quite stable because the FoS calculated is more than required (FoS>1.5). The critical point on the failure plane is yet within the safety margin.

This safe slope stability involves a soil layer under 3 m of depth which is a coal seam and a dense soil layer. Nevertheless, noticing the slope condition formed in the building area and preventing a constant erosion, slope reinforcement is necessary by applying GeoAnchor.

3.3. Slope reinforcement stages

This measure consists of several interconnected phases. Before installing GeoAnchor, drainage refinement, slope surface configuration, and Geogrid assembly should be finished. Geo-Anchor is then finalized using shotcrete.

The first stage is drainage refinement which divides the canal design into several parts: the first is by fixing the drainage existing, the second is designing proposed drainage, required to contain rainwater flow and prevent absorption of rainwater into the pores of the soil are triggering the failure of slope (seepage). The proposed drainage design is drawn in Figure 7. The resulting drainage dimension to accommodate all water flows is 0.6m wide, 0.4m depth with a drainage length of 91.8m.

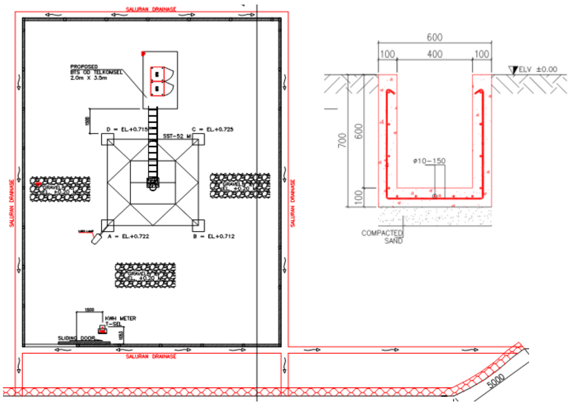
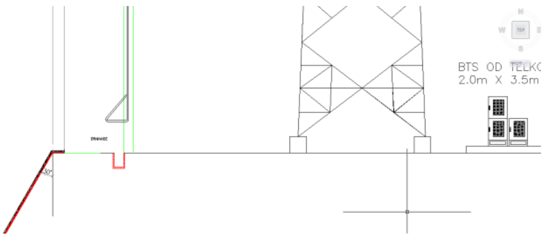
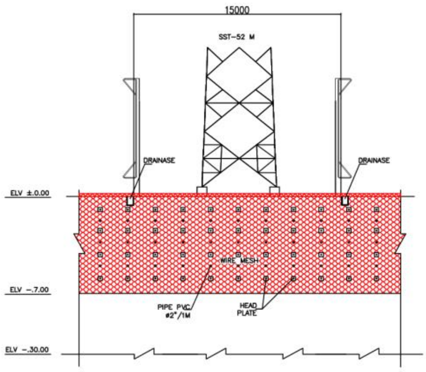


Figure 7. Proposed Drainage Design



(a)



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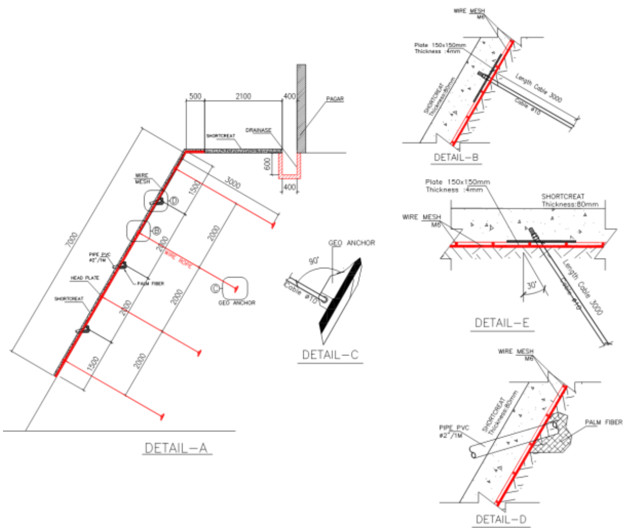
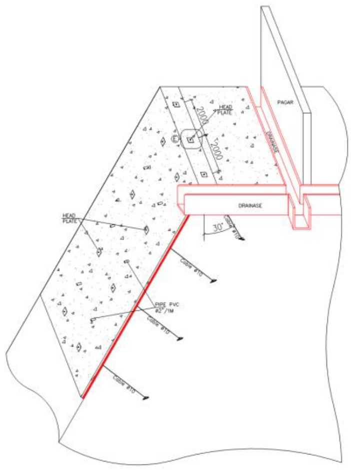


(c)



(d)

Figure 8. Detail consruction; (a) Slope surface configuration, (b) Geogrid assembly, (c) Detailed GeoAnchore installation plan, (d) Shotcrete finalization

The slope surface configuration is done as the second stage by adjusting the slope surrounding the tower building to tilt by a local contour in 7 m depth pictured in Figure 8 (a). The next stage is

Geogrid or wire mesh installation in the diameter of 6 mm, 40 m long, and 7.5 m depth as in Figure 8 (b). Geo-Anchor acts as the last stage completed with shotcrete. The direction of the Geo-Anchor head is perpendicular towards the slope surface. Figure 8 (c) shows a detailed GeoAnchore installation plan, while detailed shotcrete finalization is described in Figure 8 (d).

4. Conclusion

The result of FoS is obtained after field survey, laboratory tests, and calculations in which this study produces 1.66 of safety value which is more than the requirement (FoS > 1.5). This signifies the stable and safe condition of the slope. The result is highly caused by the layers of coal and hard soil under 3 m depth. However, to mitigate the risk of future slope failure, the slope reinforcement is necessarily done using GeoAnchor. Due to this stable condition, the slope stability analysis is not considered yet after Geo-Anchor installation. Furthermore, slope reinforcement is engaged to prevent erosion adequately from destabilization.

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