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Landslide Analysis Study and Cisewu Countermeasures in District, Garut Regency, West Java

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Abstract. Cisewu-Garut is one of the landslide-prone areas in Indonesia which occurs almost every year, particularly in the rainy season. The landslide in this study takes place in the slope where a BTS tower is located. The peripheral fence is hanging due to ground movement, while housings stay beneath the foot of the slope. This problem could harm its surroundings and needs immediate countermeasures to prevent any hazard. At the initial stage, a survey is conducted to investigate slope condition, soil state (including soil test), and drainage. Based on available soil data, the second stage is slope stability analysis by creating a model corresponding to real condition data using the element method to Plaxis2D software. As for the third stage, a landslide disaster prevention is established by strengthening the foot of slope using gabion and retaining walls. The gabion wall cage dimension would be 5m wide and 2.5m tall. Two retaining walls by the size of 2m high to 1m wide and 1m high to 0.6m wide are build. The result of slope stability analysis is an increase of safety factor by 1.729, which existing factor is 1.244. The countermeasures also involve drainage refinement and water flow diversion so that water will not penetrate to landslide zone.

1. Introduction

According to [1] landslide is a prominent natural disaster in Indonesia, notably in intense rainfall season. Parts of Indonesia archipelago have the form of highlands with steep slopes resulting in frequent landslide disasters. Several factors affecting the incidents are topography, soil and sediment characteristics, rainfall intensity, vegetation, and earthquake [2]. Landslide occurs under three conditions: a steep slope, a slipping zone in the impermeable subsurface, and an adequate amount of water from rains which infiltrate to soil voids above the slipping zone generating escalated force of soil to slope [3].

Landslide often happens in the landscape of steep mountain area and substantial amount deforestation [4]. A shifting slope has an effect on the shear stress of the soil. The greater the slope dipping, the greater the shear stress and also more unstable the slope [5, 6]. If the soil shear stress is smaller than the shear stress along the slipping zone (the increase of water saturation effect), soil erosion would accordingly follow [7].

Cisewu is located in Garut regency, West Java. This area is situated in between the boundary of South Bandung regency, South Garut regency, and South Cianjur regency. The regional forecast map indicates that a ground movement has been detected in West Java on March 2017 [8], Cisewu district is including in the potential zone of ground movement middle-high as depicted in Figure 1, which means a high possibility of ground movement would likely happen in intense rainfall. This has resulted mainly in the adjacent area of river valleys, escarpments, cliffs, or disrupted slope and re-activated ground movement.

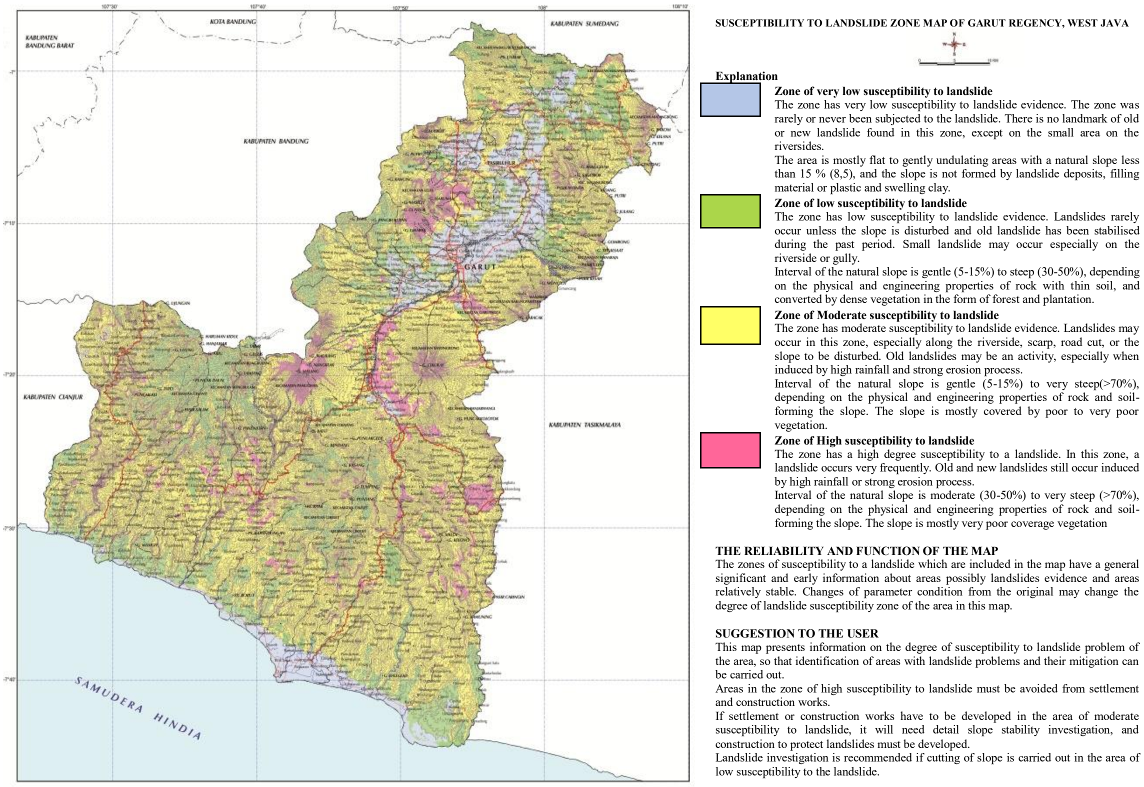

Figure 1. Susceptibility To Landslide Zone Map Of Garut Regency, West Java [8]

The climate and weather in Cisewu district, Garut regency are influenced by three principal factors: monsoonal circulation pattern, mountainous regional topography in the central area of West Java, and topographic elevation in Bandung regency. The average rainfall intensity is normally more than 3500 mm/year, in the El Nino phase the intensity is about 2250-3000 mm/year, and the La Nina phase produces 3000-3500 mm/year [9]. The variety of monthly temperature is the range of 24ºC - 27ºC.

This research is part of a study on the landslide in a building area Base Transceiver Station (BTS) in Cisewu district. The landslide area is located in the south of Cisewu district, Garut regency, west java where there are extreme contour differences. The research scopes are analysis study and an effort to control the landslide effect by building reinforcement and drainage refinement.

Based on visual observation on Figure 2, the tilt of slope is quite steep where the edge of the fence is hanging as the effect of soil movement under construction. The rainfall condition in a normal year, El Nino phase and La Nina phase are high enough [9], whereas the existing water canal in this tower building could not accommodate the rainwater stream resulting water overflow and leaked water into the soil. This condition would reduce the shear strength of soil and rock that would generate ground movement or landslide as in Figure 3.

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Figure 2. Slope failure area in the edge of fence

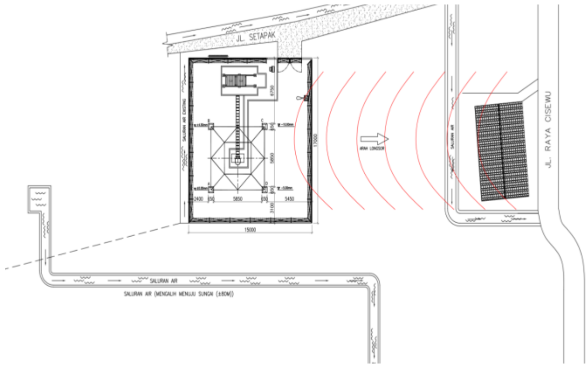


Figure 3. Slope failure direction

Landslide countermeasures include; survey investigation, analysis and slope reinforcement. Appropriate countermeasures shall be selected or designed based on the results obtained from the survey and the analysis [10]. The prevention is established by constructing gabion mesh and retaining walls in the foothills to decrease the slope dipping and to increase safety factor number. Further improvement is to recondition the previous canal and to build the new canal to anticipate rainwater leaked that could lead to the rise of the soil water table and slope failure.

The analysis of site condition is done shortly after the disaster and right after refinement utilising Plaxis2D. The reason for using a finite element method using Plaxis2D approach is that it is being widely used in landslide susceptibility modelling in recent years finite element method [11]. Plaxis is a finite element program, developed for the analysis of deformation, stability and groundwater flow in geotechnical engineering [12]. The finite element method for slope stability analysis has been applied by [13, 14, 15, 16] for further countermeasure.

2. Methods

This study is performed in Cisewu district, Garut regency, West Java. The research location is in the landslide area where a BTS tower building is constructed. The landslide countermeasures are conducted in several stages: survey investigation, slope stability analysis, and an effort to control landslide by applying slope reinforcement and drainage refinement.

2.1 Survey Investigation

This stage includes slope condition survey, soil investigation, and drainage survey. The slope condition survey after soil movement is required to determine the needed test and to formulate the initial hypothesis of landslide cause as well. Furthermore, a description of soil strength could be produced to prevent future landslide disaster. A contour of slope measurement is also depicted in this stage.

The soil test is done using the cone penetration test (CPT) and soil sample collection by hand boring. The penetration test is to recognise the bearing capacity of soil while soil collection by hand boring is conducted to retrieve soil parameters. The soil sample is tested in a laboratory to detect water content, bulk density, particle density, particle analysis, soil consistency limit, and soil shear strength test. These tests also refer to ASTM standards [17, 18, 19, 20].

2.2 Slope Stability Analysis

2.2.1. Model material property. The Mohr-Coulomb model has been used to describe soil material properties. Material shear strength to cohesion, normal stress and angle of internal friction are associated with the criteria of the Mohr-Coulomb model. Table 1 shows soil parameters used as input to Plaxis2D software.

Table 1. Material design parameters in the landslide simulation

Parameter	Name	Layer 1	Layer 2	Gabion dan retaining wall	Units
Material Model	Model	Mohr-Coulomb	Mohr-Coulomb	Elastic Plastis	-
Material Behavior	Type	UnDrained	UnDrained	Non - Porous	-
Unit Weight of Unsaturated Soil	γunsat	10.860	10.110	23.5	kN/m^3
Unit Weight of Saturated Soil	γsat	16.500	16.160	23.5	kN/m^3
Horizontal Direction Permeability	kx	0.000497	0.000916	-	m/hari
Vertical Direction Permeability	ky	0.000497	0.000916	-	m/hari
Young Modulus (contant)	Eref	3428	4000	20.000.000	kN/m^2
Poisson's Ratio	V	0.35	0.35	0.15	-
Cohesion (constant)	Cref	9.270	11.930		kN/m^2
Friction Angle	Φ	23.960	27.920		°
Dilation Angle	Ψ	0	0		°

2.2.2. Slope stability analysis using Plaxis2D.
There are three major aspects that involve in slope stability analysis. The first is about the material properties of the slope forming material. The second is the calculation of factor of safety, and the third is the definitions of the slope failure [21].

The input of material properties is in the form of a graphical geometric model such as soil layering, structure elements, construction stages, burdening, and limit conditions performed using a graphical procedure which is facilitated by Plaxis2D. from the geometrical model, a finite element up to 2D could be easily obtained. Plaxis would automatically generate finite element until random 2D configuration with either global or local choices [12]. Figure 4illustrates initial contour condition after slope failure, and Figure 5 shows slope condition after refinement using gabion mesh and retaining walls as well as soil improvement in the landslide area. The blue area describes Layer 1, whereas the green area shows Layer 2 in the contour design. The slope gains outer loads from both tower weight and building foundation as depicted in these figures. The input for tower load is 52 kN/m^2.

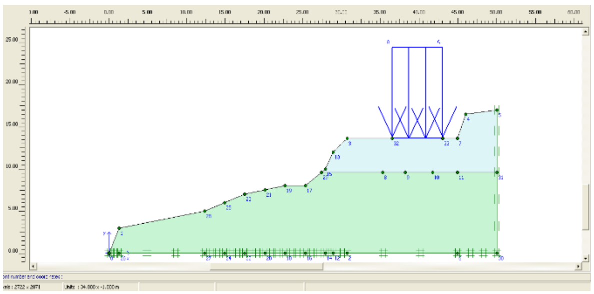


Figure 4. The initial contour design after slope failure.

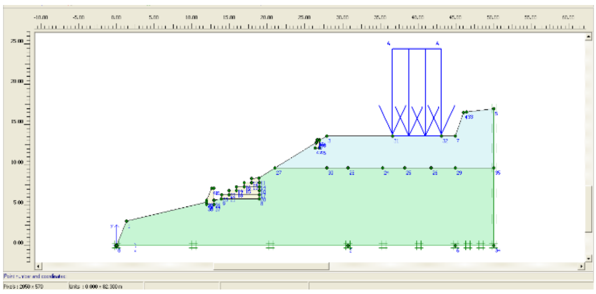


Figure 5. The refined contour design after slope failure.

Calculation of safety factor is obtained by seeking the failure surface (FS) in soil/rocks structure. FS is calculated by subtracting cohesion value to friction angle in the soil gradually until the failure zone produced [14].

Slope failure occurs in case of reduction in shear strength due to saturation and swelling coupled with the condition of seepage, which causes the shear strength equal or less than shear stress [22]. In soil mechanics, it is important to understand the forces acted on slopes, which is the driving force and the resisting force, which prevent from slope failing. The ratio of resisting forces to driving forces is a Factor of Safety (FOS). Slopes with lower FOS means the potential of failing are higher then slopes with higher FOS [23]. Therefore slopes with higher FOS more safer.

2.3 Landslide countermeasures
The countermeasures are performed by applying reinforcement in the foot of slope utilising gabion mesh and retaining walls. These actions also include drainage refinement and constructing new drainage canal to divert the water flow direction heading to the tower building. During heavy rain, the canal should be able to turn the surface water flow from the hill above the tower.

3. Results and discussion
3.1 Survey Investigation
3.1.1. Road shape. The road to the tower area is still accessible enough, however, to reach the residential areas exposed to landslide disaster needs more effort since the road access has been cracked due to slope failure although it can be passed yet as in Figure 6.

Figure 6. The road shape after slope failure

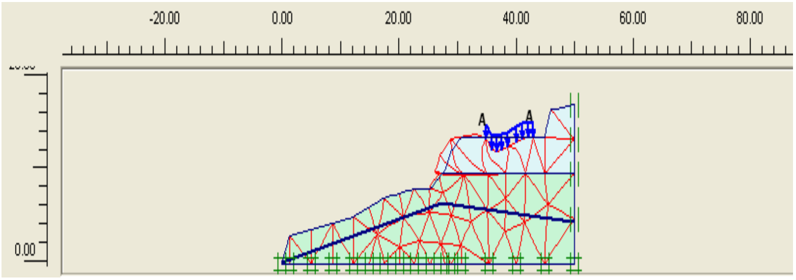
3.1.2. Drainage condition. According to the field survey, the existing drainage condition is not sufficient to accommodate all water flow from the slope as can be seen in Figure 7, this condition triggered seepage to soil and increased the surface water changed to inclining water table and slope failure accordingly.

Figure 7. Drainage condition after landslide

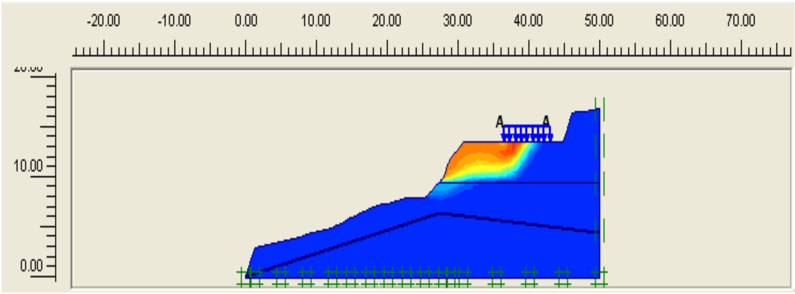
3.1.3. Slope condition. Based on an initial survey result, the slope condition after failure shows muddy, silty clay, with the rise of the water table. The analysis figures that the soil condition is under the safety limit. The safety factor, in this case, is 1.244 while the minimum value is 1.5 in which the failure zone is right under the tower load.

3.2 Analysis and countermeasures

3.2.1. Slope stability analysis using Plaxis2D. The first analysis is done under the condition of after slope failure. The slope receives an outer load in the form of tower weight and building foundation modelled as equal load. In Figure 4, it can be seen that the biggest movement occurs in the tower building area. This movement could be developed since the soil in that area is consists of silty clay or soft soil which could lead to soil displacement in the region. Figure 8 and 9 illustrate the results of numerical analysis by applying the parameters shown in Table 1.



(a)

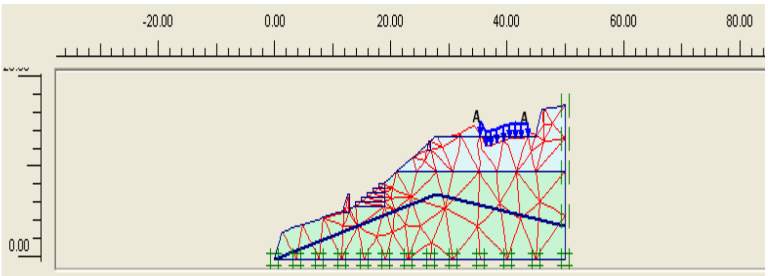


(b)

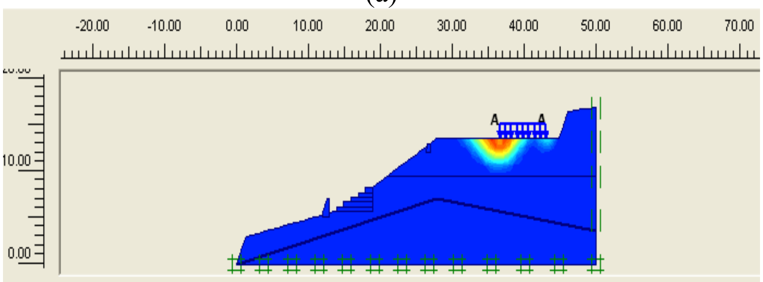
Figure 8. (a) Deformed mesh after the landslide, (b) Failure plane before refinement

The deformed mesh is shown in Figure 8a. The potential slipping zone is described in Figure 8b, which displacement scaling and total regional displacement are depicted as well. Analysis using The Finite Element Method (FEM) could simulate failure plane reaching toe of slope in the current state. FoS, in this case, is 1.244 as in Figure 10a, which shows that slope is very much likely to fail.

The second analysis is obtained by assuming reinforcement in the foot of slope using gabion mesh and two retaining walls. The mesh dimension is 5m wide and 2.5m tall. The size of the first retaining wall is 2m tall and 1m wide, while the second size is 1m tall and 0.6m wide.



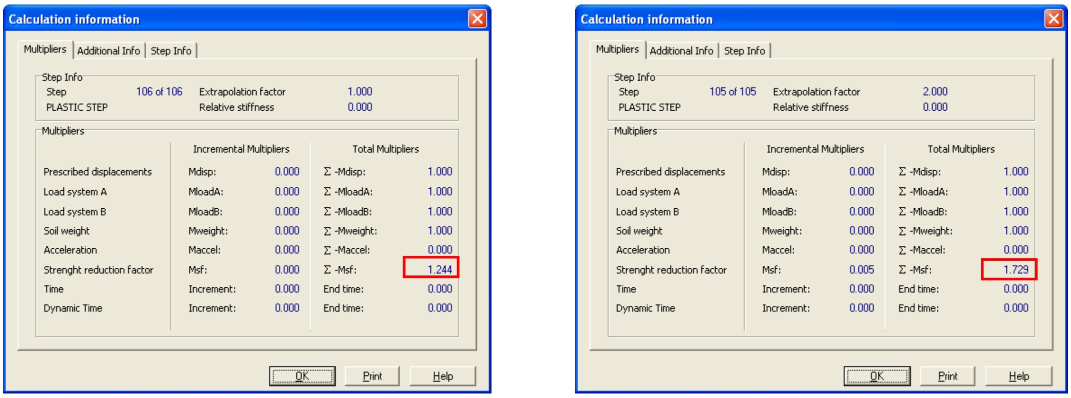
(a)



(b)

Figure 9. (a) Deformed mesh after strengthened, (b) Failure plane condition after reinforcement in the foot of the slope

Figure 9a illustrates deformed mesh after strengthened utilising gabion and retaining walls. The potential slipping zone is described in Figure 9b. The reinforcement could improve the value of FoS in which this case is 1.729 as in Figure 10b, greater than the minimum safety value. Therefore it can be seen that slope condition after reinforcement is under control.



(a) (b)

Figure10. (a) Safety Factor Existing Condition, (b) Safety Factor Strengthening Condition

Further countermeasure is designing drainage canal which is divided into two parts: repairing the existing drainage canal and designing diverted canal dimension that is required to contain rainwater flow from the hill above tower building and to prevent water overflow leaked into the soil (seepage) triggering slope failure. The catchment area and the proposed canal design are described in Figure 11. The diverted canal dimension resulted to accommodate all water flow is 1m wide and 0.9m depth.

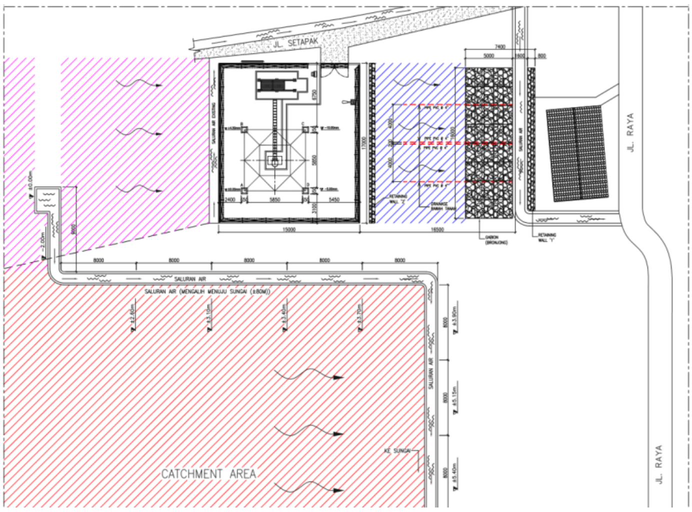


Figure 11. Proposed drainage design

4. Conclusion

According to the data resulted from survey investigation, several tests, and calculations, it can be concluded that landslide countermeasures could be performed in several means: constructing reinforcement using gabion mesh and retaining walls, along with enlarging the existing drainage canal, and building proposed drainage canal. These measures could certainly increase safety factor value to 1.729 greater than the minimum safety value, therefore the safety condition could be reached under the requirement of reinforcement in the foot of the slope.

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