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Characterization of landslide and its earthwork solutions

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Abstract. A slope has a high tendency to slide due to many factors. In any construction design, two things should be taken into account are stability and settlement. In case of landslide, a slope is not stable which mobilizing stress is higher than allowable stress. In order to reach target slope stability, earthwork solutions can be conducted. This study has the objective to characterize landslide and propose some properly alternative earthwork solutions. In order to realize the objective, field observation, literature review, laboratory test, and landslide modeling are performed. In field observation and literature review, it is obtained the geometry before and after landslide, and surrounding area condition. In this experiment, tested soil is taken from the location of landslide in Jepara, Central Java. The soil test aims to investigate index and engineering properties used as an input. In order to model earthwork in slope and to obtain its safety factor, application program Plaxis is used. From the result of tested material, the soil is dominated by granular soil with the amount of cohesive soil more than 5%. As for mechanical properties of the soil, the friction angle is and the cohesion quite high, classified as Silty Sand (SM). From modeling with Plaxis, the existing slope has safety factor (SF) 0.61 and 1.01 without reinforcement and with reinforced respectively. However with modification of slope into 5 terrace model having slope 1:1 each terrace, the SF increases 1.56.

1. Introduction

Naturally, plateau having steep slope is potentially sliding due to its overburden pressure. Landslide occurs owing to combination of internal soil strength and external load. Landslide can be from many factors such as type of soil, soil density, slope angle, vegetation, building load, rain water (when drainage is not well managed), and vibrations. Since external load is increasing, mobilized stress (from external force) can be higher than allowable stress from internal soil thus landslide emerges. According to The National Agency for Disaster Countermeasure (BNPB), landslide in Brebes, Central Java on 22 February 2018 has caused 11 loss of life and 7 missing people [1]. In the period January 2010 until February 2018 as many as 3.753 landslides have appeared and caused loss of life 1.661 people [2]. The Region Agency for Disaster Countermeasure (BPBD) of Central Java stated that in the year of 2014 landslide was the second highest number disaster among others reaching 82,85% [3]. According to [4] in the period 2011 until 2015, as many as 2.425 landslides have occurred in Indonesia. From that number, landslides mostly happened in the province of Central Java, West Java, East Java, West Sumatera, and East Kalimantan. These disasters have caused loss of life 1.163 people, 112 missing people, 973 wounded people, and around 48.191 people evacuated.

Some researchers have performed study on slope stability for instances [5-9], and [10]. In [5] using Plaxis, comparison between counterfort wall and bored pile to increase safety factor (SF) of slope was performed. In the perspective of safety factor, both alternative methods result SF > 1.5 however bored pile is preferred since more efficient. Study conducted by [6] and [7] resulted that slope soil in saturated condition due to rain infiltration has SF lower than that of soil in unsaturated condition. Additionally, SF of slope which is steeper is lower than that of gentle or shallow slope [6]. Performed by [8], counterfort of retaining wall can increase SF. Beside retaining wall, soil nailing can be used also to increase SF like performed by [9] and [10].

In the beginning of 2019 a landslide hit village Kunir, Subdistrict Keling, District Jepara, Central Java with the area of landslide is 60 meters in length and 20 meter in height. Some houses located just in the toe of slope were in damaged but no victims since the residents were aware and evacuated before huge landslide occurred. From the field observation in the top of slope is the only one road connecting one village to another which is class III road, only light vehicles can pass by. This study aims to characterize landslide occurred in the village Kunir and propose properly alternative earthwork solutions to avoid landslide.

2. Research method

This study is conducted by using application program Plaxis v8.2 to model landslide and earthwork solution for landslide. In order to model landslide properly, some parameters are required as inputs in Plaxis program such as the geometry of existing slope, soil properties of slope, and condition of surrounding area of landslide. Field observation was carried out to picture the condition of landslide area. As for the geometry of existing slope, it is difficult to obtain the existing geometry since it was carried along with the landslide. The secondary data was conducted by interviewing the residents and collecting video and information from internet to complete data on existing geometry before landslide. Tested soil is taken from the area of landslide with sampling was conducted by taking landslide soil from edge part of slope. General standard soil test for index and engineering properties were performed in Laboratory of Geotechnics, Civil Engineering Department Universitas Islam Sultan Agung. Condition of surrounding area of landslide is taken into account as factors causing failure of slope for instance building load and condition of drainage. When drainage is not well managed, water infiltrates into soil thus it becomes burden to the slope.

3. Result and Discussion

3.1. Geometry of slope before and after landslide

In the first part, condition of before - after landslide, road condition, and drainage are explained. Fig. 1 and Fig. 2 present before and after landslide condition, and the drainage respectively. The height of slope from the toe to the road is around 20 meters. From Fig. 1 left-side condition before sliding, the counterfort (gravity wall) constructed has steep slope almost vertical (approximately 1: 0.1).

Figure 1. Before and after landslide condition

The existing slope before sliding is taken from video on internet. After landslide, the slope is around 1:1 which the landslide reaches the houses. The road using flexible pavement is 3 meter wide, only light vehicles can pass by. It is impossible for two cars standing side by side due to the width of the road. Fig.2 displays the drainage condition. It seems that drainage is not well managed since water infiltrates to the soil. Landslide occurred when it rained.

Figure 2. Drainage condition

3.2. Tested material

Table 1 presents the result of tested material of landslide. It appears that the soil is dominated by granular soil (72.25%) rather than cohesive soil (27.75%). However the amount of cohesive soil which is quite lots more than 5% can influence the behavior of whole soil. As for mechanical properties of the soil, the friction angle is high (45.86°) classified as dense soil and the cohesion is medium (42.7 kPa). In short, the slope is composed of fairly good soil, classified as Silty Sand (SM) but it needs to check whether it can stand without failure if it is cut near - vertical gradient.

Table 1. Index and engineering properties of tested material

Gs	W %	c (kg/cm^2)	ϕ (°)	Atteberg Limits LL	PL	PI
2.587	25.902	0.427	45.86	41.00	26.88	14.12

Gravel %	Sand %	Silt %	Clay %	Proktor Modified γ_d max	w opt	SL
35.88	36.37	27.00	0.76	1.20	31.5	53.007

3.3. Modeling landslide with Plaxis

The next step is modeling the landslide using Plaxis program. Geometry of slope with all external loads and soil properties are inputted. Firstly, the existing slope before landslide is modeled to discover how landslide happened. Then to increase the stability of slope in order to avoid failure (landslide), only a few alternative earthworks are attempted. Fig. 3a displays the geometry of the slope with external loads. The soil consists of two layer soil with the ground layer is denser. The slope is modeled in near-vertical gradient without reinforcement to check whether it can stand without failure. The slope soil is modeled as saturated soil. Two kinds of distributed load in the surface represent road load (15 kPa) and building load (10 kPa). From Plaxis, it results that the SF is only 0.61 less than 1. After the slope is reinforced with gravity wall (Fig. 3b), the SF is only 1.01. For long period, the SF 1.01 is not enough for slope stability since it is less than 1.5. From this findings, it seems that the reinforcement cannot bear the loads coming from infiltrated water, road and building loads. With the slope height is 20 meters without a terrace, installing gravity wall is not good choice.

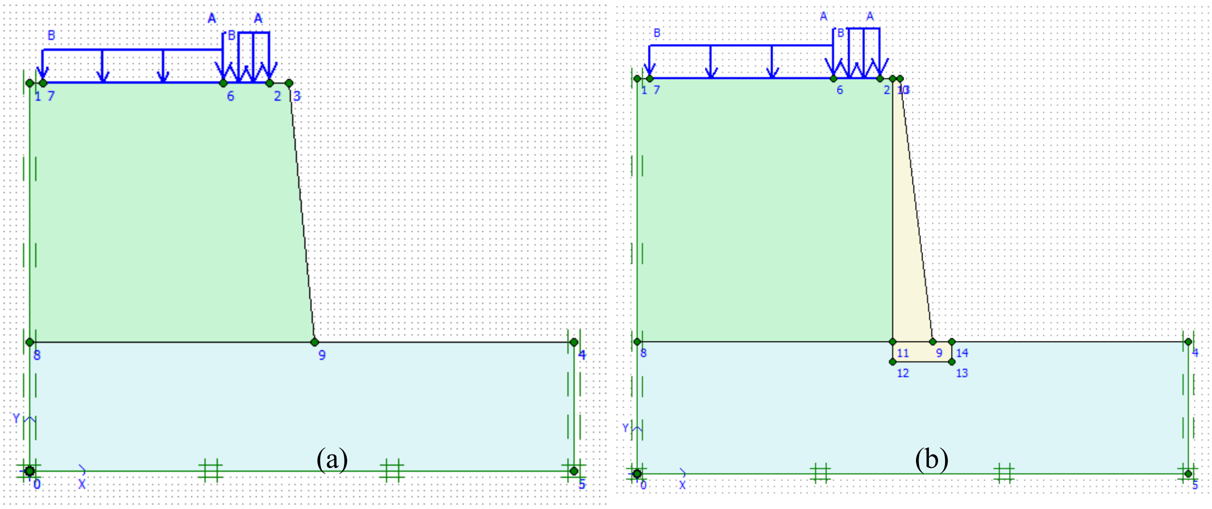

Figure 3. Estimated existing slope: a) natural slope b) with gravity wall reinforcement

Some earthwork solutions which propose sufficient stability can vary. However, for economical purpose, available space, and the easiness of construction they cannot be applied since they are very costly. Compared soil reinforcement to modification of slope angle, the latter is somewhat more efficient. Like displayed in Fig. 4, slope is modified into 5 terrace model having slope 1:1 each terrace. This modification results SF 1.56 more than 1.5. The deformation presented in Fig. 5 reaches highest on the horizontal surface (red color) not in slope. However this model requires large space to construct soil embankment.

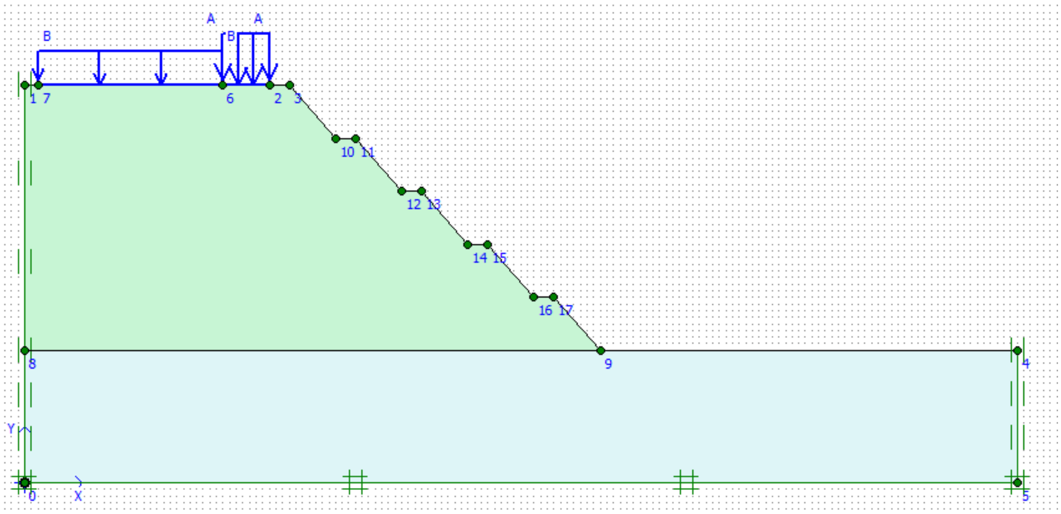

Figure 4. Terrace earthwork solution without reinforcement

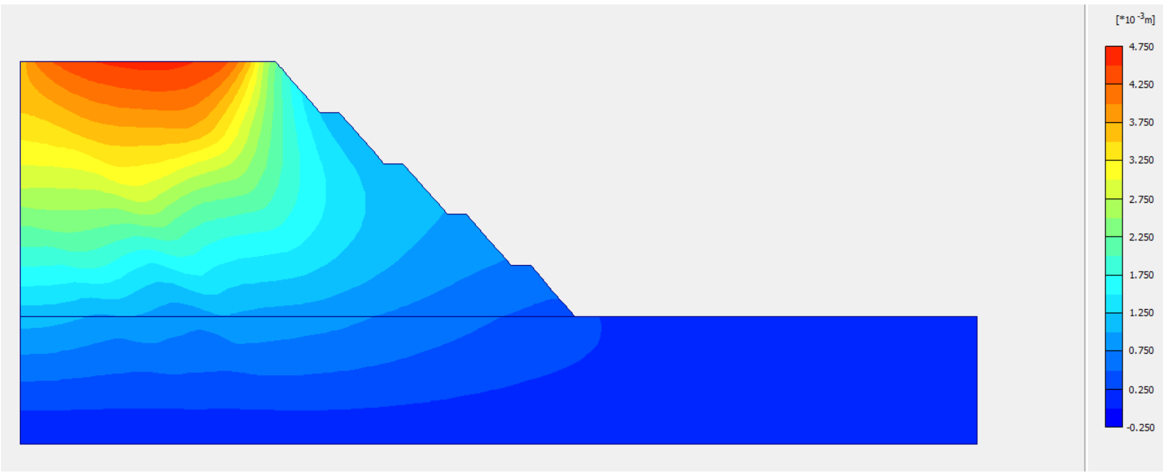

Figure 5. Deformation of slope

3.4. Alternative earthwork solutions

Here are proposed earthwork solutions that can increase stability of slope:

1) Compaction of soil embankment every 20 cm in dense condition according to optimum field soil density (90% laboratory proctor standard). This can increase shear strength of soil (c and ϕ). If soil is denser so that soil bearing capacity is also higher and settlement is lower. In order to reach target compaction, proper instrument (such as pad foot roller) and compaction method are required. Embankment soil is layered every 30 cm and water content ± 2-4 % OMC can be added. The number of laps to compact the layer is based on a trial embankment.
2) The angle of slope is made more shallow or gentler. When the existing slope encounter failure, the change of slope angle gentler can increase stability for instance slope 1:3 can resulted higher stability than slope 1:2. If a slope consisting of some flat surfaces or platforms but the overall slope angle is not different from a slope without flat surface, the stability will be the same.
3) Construction of counterweight of gravity wall or cantilever wall. Cantilever wall is better than gravity wall due to its tensile strength but more costly. Counterweight also functions to avoid erosion in the toe of slope. The construction of gravity wall works well if the height of soil countered is less than 4 meters.
4) Geosynthetics which counts on its tensile strength also can increase slope stability. The same with cantilever wall, it is costly. The price reaches Rp. 18.500 per m^2.
5) Soil nailing can produce effective stability. However soil nailing cannot be utilized in any condition of soil, only in dense or stiff soil or soil which can stand without any reinforcement for 2-3 hours, soil nailing can work well. In addition, soil nailing is also costly.
6) In order to quickly flow rain water on and in slope, drainage is able to be installed vertically every 10 meters in slope surface and drainage pipe diameter 2 inch is installed every 1 meter on the surface of slope.
7) To protect a slope from surface erosion and to avoid rain water infiltrates to slope, *Vetiver* grass can be installed. Compared to the price of shotcrete, it is lower-cost.

4. Conclusion

Landslide normally occurs just after earthquake or raining. In the case of village Kunir, Jepara the landslide happened after raining. However it is not only one factor inducing landslide in village Kunir but many factors such as geometry of slope, type of soil, external load, and drainage system.

1) The height of slope is very high around 20 meters with angle of slope near - vertical gradient. With such height, the gravity wall type counterfort constructed has steep slope almost vertical (approximately 1: 0.1) and without flat surfaces or platforms. Drainage is not well managed causing water easily infiltrates to the soil. The slope is composed of fairly good soil with consistency Silty Sand (SM) with high friction angle. However mobilized stress coming from external loads was higher so that landslide occurred. From this findings, the reinforcement of gravity wall cannot bear the loads coming from infiltrated water, road and building loads. The slope with height is 20 meters without a terrace, installing gravity wall is not good choice.
2) In order to have a stable slope, firstly external loads should be taken into account in existing condition to find out whether landslide occurs or not. Soil is modeled as saturated soil not as dry soil. From Plaxis, the SF of slope without reinforcement is only 0.61, then after the slope is reinforced with gravity wall, the SF is 1.01 less than 1.5. For economical purpose, earthwork solution can be proposed by modification of slope angle. With the slope contains 5 terraces having slope 1:1 each terrace, the SF 1.56 more than 1.5.

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