Analysis of slope slip surface case study landslide road segment Purwantoro-Nawangan/Bts Jatim Km 89+400

Joko Sidik Purnomo¹, Yusep Muslih Purwana and Niken Silmi Surjandari

¹Civil Engineering Department of Post Graduate Program Sebelas Maret University
Jl. Ir. Sutami 36A Kentering Jebres Surakarta Postal Code 57126, INDONESIA

E-mail: jokosidikp@yahoo.com ,ymuslih@yahoo.com, niken.silmi.surjandari@gmail.com

Abstract. Wonogiri is a region of south eastern part of Central Java province which borders with East Java and Yogyakarta Province. In Physiographic its mostly undulating hills so that the frequent occurrence of landslides, especially during the rainy season. Landslide disaster that just happened that on the road segment Purwantoro-Nawangan / Bts Jatim Km 89 + 400 were included in the authority of the Highways Department of Central Java Province. During this time, Error analysis of slope stability is not caused by a lot of presumption shape of slip surface, but by an error in determining the location of the critical slip surface. This study aims to find the shape and location slip surface landslide on segment Purwantoro - Nawangan Km 89 + 400 with the interpretation of soil test results as well as modeling use limit equilibrium method and finite element method. Processing contours of the slopes in the landslide area resulted in three cross section that slopes A-A, B-B and C-C which will be modeling the slopes. Modeling slopes with dry and wet conditions at the third cross section slope. It was found that the form of the slope slip surface are known to be composite depth 1.5-2 m with safety factor values more than 1.2 (stable) when conditions are dry slopes. But its became failure with factor of safety < 0.44 when conditions are wet slopes.

1. Introduction
Wonogiri is a region of south eastern part of Central Java province which borders with East Java Province and Yogyakarta Province. In Physiographic region of Wonogiri mostly undulating hills so that the frequent occurrence of landslides, especially during the rainy season. Landslide disaster that just happened that on the road Purwantoro-Nawangan/Bts Jatim Km 89 + 400 were included in the authority of the Highways Department of Central Java Province. The location of a provincial road that connects Wonogiri Regency of Ponorogo, so that the existence of these roads is vital to support the transportation flow of goods and services for both regions. The main problem in the stability analysis is to determine the slip surface landslides [1]. During this time, error analysis of slope stability is not caused by a lot of presumption shape slip surface, but by an error in determining the location of the critical slip surface [2]. This paper aims to find the shape and location slip surface landslide on segment Purwantoro - Nawangan Km 89 + 400 with the interpretation of soil test results as well as modeling use limit equilibrium method and finite element method.
2. Slip surface location with CPT test
To determination of the positions of landslides in the field is not conducted directly, but attributed to determining the shear stress was drained soil based on the correlation value of the cone \( q_c \) from CPT testing whose value is directly proportional. The collapse of the slope can be caused by the disruption of stability, when the shear stress is greater than the allowable shear strength in the ground, then the process of land mass movement will occur. Based on test results of CPT at some point in parallel directions landslide, slope pieces obtained by positioning of points conical low value. When these points are connected will be seen a field that is a collection point or a weak point called the slip surface. Slip surface of depth was predicted by the test results of CPT in study area according to the method Suryolelono is modeled as interface element [3]. In addition with this method the potential for further sliding to predict in case of disturbances on the slope. Slopes will adjust to the new shape of the slope with the slope angle is smaller than the natural slope angle of the slope forming soil type.

3. Layout and location slip surface
Landslide is one type of soil or rock mass movement that generally occurs on a slope of 20°-40° to the moving masses in the form of residual soil, sediment colluvial and weathered volcanic rocks. Colluvial residual soil and soil are generally a loose and can store water. As a result, the shear strength is relatively weak, especially if the water contains more saturated and pressing. Increased water saturation can occur if the land is gone in the top layer of soil or rock that is more cohesive and impermeable. So that the water that seeped into the soil difficult to penetrate a layer of soil or rock beneath it, and only accumulate in the soil is relatively loose. Contact between layers of soil or rock that is impermeable to the mass of soil on top is often a slip surface of ground movement.

Slip surface can also be the zone that is the boundary the level difference of rock weathering, field discontinuity rock, and the rock layers such as clay stone, silt stone, shale and tuff. Masses of soil and rock that does not move the soil or bedrock that is more compact and more massive example andesite and andesite breccia rocks. The emergence of permeation or springs on the slopes generally occurs at the contact zone between the water impermeable rock masses or layers of soil/rock that passes water. This contact zone is often a slip surface movement.

Landslide on residual soil, especially on steep slopes, slip surface not like the type of landslide in the circular shape. On residual soil slip surface of a relatively shallow depth, often with a slightly curved or nearly planar (Figure 1). Nevertheless, the volume of landslide material is still very large [4].

![Figure 1. Landslide on soil residual mechanism](image_url)
The mechanism of landslides through higher groundwater levels often occur in residual soil slopes and colluvial. Colluvial residual soil layer or serves as a free aquifer and aquifer were hanging (perched aquifer) with the condition of the ground water level fluctuates depending on the amount of infiltration of rainwater. Free aquifer (phreatic aquifer) is the flow of water in the saturated condition that occurs in the aquifer that has a water level that is not pressurized. While hanging aquifer is a layer saturated with water that is above a layer of soil or rock that is less watertight than the main aquifer.

The presence of a layer of relatively less impervious causes the water caught in it and form a layer of water-saturated. The aquifer that hanging is not too wide and only contains water only during the rainy season. Besides resulting rise in groundwater levels, the pervasive rain water into the slope can also lead to a) increase the weight volume of soil and rock, b) reduction in pore water pressure is negative (suction) in the zone is not saturated (unsaturated), c) an increase in the positive pore water pressure, d) internal erosion and e) changes in the mineral content of constituent masses of soil and rock on the slope. The effectiveness of rain in triggering landslide depends on the amount of rainfall and the long rains, the graduation rate of water in the soil and water saturation in the slope before the rain [5].

4. Slip surface location process
In the plane strain problem, the slip surface is assumed to be a circular arc in many existing LEM. However, numerical analysis has revealed that the shape of the slip surface might be a combination of a straight line and a circular arc or a combination of a straight line and a logarithmic spiral. Optimisation techniques have been shown to be the most efficient means of locating non circular slip surfaces [6–10].

In the SRM, the critical slip surface is found automatically from the increase in the shear strain due to the reduction of the shear strength. Typically, the critical slip surface is approximated using technical measures, mesh deformation plots [11], velocity fields [12], etc. Cheng et al. [13] defined the critical slip surface as a wavy line that connects the maximum shear strain increment. Zheng et al. [14] similarly defined the critical slip surface as a wavy line that connects the maximum equivalent plastic strain, where the wavy line is smoothed using the least squares method.

5. Research methods
In this study, the data used is secondary data such as bore log data, soil properties, the data shear strength of soil investigation soil mechanics laboratory Faculty of Engineering, Sebelas Maret University. Photo documentation and the results on location surveys in the form of coordinates of ground cracks are taken directly from location. Land contour data downloaded free from website www.tanahair.indonesia.go.id with form of shp. Land contour is processed with the help of software and performed to obtain the land cracks plotting area landslide. Landslide areas are plotted coordinates of any point soil cracks, and then determine the 3 cross-sectional area slopes that represent landslide. Interpretation of the results on the CPT test 4 point parallel directions landslide, cross section obtained by positioning points conical low value. When these points are connected will be seen a field that is a collection of weak points called slip surface. Processing contours of the slopes in the landslide area produce three cross section that slopes A-A, B-B and C-C which will be modeling. This research method is with the interpretation of CPT test and bore hole combined with a cross section of slope and modeling shape of slip surface using limit equilibrium method and finite element method. Modeling slopes with dry and wet conditions at the third cross section slope.

6. Result and discussion
Soil samples will drill test results conducted laboratory tests to determine the physical properties of soil, one of which is the shear strength.
### Table 1. Soil test result

| No. | Sample | type of investigation | w (%) | Gs (%) | grainsize | Atteberg | \( \gamma_B \) (gr/cm\(^3\)) | C (kg/cm\(^2\)) | \(\phi\) (°) | Classification |
|-----|--------|-----------------------|-------|--------|-----------|---------|-----------------|----------------|-----------|---------------|
| 1   | BH 1 04.00 - 04.50 M (UDS) | Gravel | 45.15 | 2.64 | 0.18 | LL | 48.60 | 1.722 | 0.459 | 10.84 | SC = Sandy Clay |
|     |        | Sand |            |       |       | 69.25 | PL | 37.75 | 12.83 |          |               |
|     |        | Silt & Clay |            |       |       | 30.57 | PI | 10.85 |          |               | Layer 1 |
| 2   | BH 1 6.50 - 7.00 M (UDS) | Gravel | 42.96 | 2.66 | 0.85 | LL | 46.98 | 1.652 | 0.262 | 12.83 | SC = Sandy Clay |
|     |        | Sand |            |       |       | 53.57 | PL | 38.65 |          |               |               |
|     |        | Silt & Clay |            |       |       | 45.58 | PI | 8.33 |          |               |               |
| 3   | BH 1 14.50 - 15.00 M (DS) | Gravel | 2.67 | 2.67 | 2.87 | LL | 42.42 |            | - | - | Compact rocks Layer 2 |
|     |        | Sand |            |       |       | 35.42 | PL | 35.37 |          |               |               |
|     |        | Silt & Clay |            |       |       | 61.72 | PI | 7.05 |          |               |               |

From processing and plotting the contours of soil cracks, then the resulting landslide areas. The next step is to perform the the interpretation of the data results CPT test in the third cross section slope so is known composition of soil forming slopes.

**Figure 2. Landslide area to determine the cross section**

In figure 3-5 that the results CPT on S1, S2, S3, and S4 show that the hard soil (\(q_c = 250 \text{ kg/cm}^2\)) is located at a depth between 3-9 m. On the soil drill test results have N-SPT value greater than 50 (N-SPT > 50) is located at a depth of over 7 m (hard soil). The test results CPT at 4 point in parallel directions landslide, cross section obtained by positioning points conical low value. Based on this, a cross-section of A-A, B-B and C-C are synchronized to CPT results by connecting the weakest points will form a slip surface symbolized by dashed lines. Prediction calculation depth slip surface as figure 3-5 showed that depth which occurred between 1.5-2 m.
Figure 3. Composition of the soil forming slopes A-A

Figure 4. Composition of the soil forming slopes B-B

Figure 5. Composition of the soil forming slopes C-C
Modeling slopes with LE and FE methods produces that slopes in wet conditions make the slope becomes unstable with a safety factor of less than 0.44 with LE methods and less than 0.33 with FE methods. Shape critical slip surface at the time of wet conditions is shaped composite. By knowing the shape and location of slip surface proper, then handling the strengthening of the slope can be done appropriate. Comparison shape slip surface and safety factor of slope are shown in the figure 6-8.

**Figure 6.** Slip surface slope A-A (a). Limit Equilibrium (b). Finite Element

**Figure 7.** Slip surface slope B-B (a). Limit Equilibrium (b). Finite Element

**Figure 8.** Slip surface slope C-C (a). Limit Equilibrium (b). Finite Element
The comparison shape of slip surface and safety factor between limit equilibrium and finite equilibrium method can be known that the shape resulting from both methods have a slip surface which shape almost the same. Figure 4-6 (a) search the slope slip surface using the LE method where this method uses the principle of equilibrium forces and moments. Shape slip surface in wet conditions produces composite shape (combination of circular and flat shape). The occurrence collapse of the slope in figure 4-6 (b) using strength reduce method (SRM). In SRM, the strength parameters of soil will be decreased until the slope fails and the factor of safety will be the ratio between the actual strength parameters of the soil and the critical parameters, therefore on the finite element method does not recognize shapes slip surface.

The definition of factor of safety in SRM is exactly same as in limit equilibrium method [15]. Safety factor in wet condition between the two methods have small differences. The results factor of safety in wet conditions with LE and FE methods are shown in table 2.

| Table 2. Factor of safety |
|---------------------------|---------------------|---------------------|---------------------|
| Cross Section             | Limit Method        | Finite Method       | Description         |
| Slope A-A                 | Dry 3.812 Wet 0.444 | - 0.294             | Safety Failure      |
| Slope B-B                 | Dry 3.135 Wet 0.408 | - 0.290             | Safety Failure      |
| Slope C-C                 | Dry 2.957 Wet 0.359 | - 0.336             | Safety Failure      |

7. Conclusion
Interpretation of the results of soil tests on roads Purwantoro-Nawangan/Bts Jatim Km 89 + 400 indicated that slip surface consist of more than two flat surfaces connecting points of the lowest cone (weakest point) and the shape of slip surface with a depth 1.5-2 m. In interpretation of the slip surface with two-dimensional modeling using limit equilibrium method and finite element method in wet conditions on the slopes of a cross section A-A, B-B and C-C produce a composite (combination of circular and flat shape) slip surface.

References
[1] Bardet J P and M M Kapuskar 1989 Computers and Geotechnics Journal Vol. 8 No. 4 pp 329 – 348
[2] Bowles E 1984 Physical and geotechnial properties of soil (New York: McGrawHill)
[3] Suryolelono K B 1993 Civil Engineering Forum No. 11/1 August 1993.
[4] Wesley L D 2010 Geotechnical engineering in residual soils (New Jersey: John Wiley & Sons, Inc)
[5] Karnawati D 2005 Land Mass Movement of Natural Disasters in Indonesia and Handling Efforts. (Yogjakarta: Geology Engineering Gadjah Mada University)
[6] Arai K and Tagyo K 1985 Soils Found. 25(1) 43-51
[7] Greco V.1996 J Geotech Eng 122(7) 517-25
[8] Malkawi A,Hasan W and Sarma S 2001 J. Geotech. Geoenviron. Eng 127(8) 688-98
[9] Zolfaghari AR, Heath AC and McCombie PF 2005 Comput Geotech 32(3) 139-52
[10] Cheng YM, Li , Chi S C and Wei WB 2007 Comput Geotech 34(2) 92-103
[11] Kim J Y and Lee S R 1997 Comput. Geotech 21(4) 295-313
[12] Dawson E M,Roth W H and Drescher A 1999 Geotechnique 49(6) 835-40
[13] Cheng Y M, Lansivaara T and Wei W B 2007 Computers and Geotechnics 34(3) 137-150
[14] Zheng H, Sun G and Liu D 2009 Comput. Geotech.2009 36(1-2) 1-5
[15] Griffiths D and Lane P 1999 Geotechnique 49(3) 387-403