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Factors Causing Landslides on Highways in Ogan Komering Ulu Regency, South Sumatra Province

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Abstract

This research focuses on the study of a slope's Factor of Safety (FOS) in the context of landslides. The slopes under study are located on the outer bend of a river and feature differences in groundwater levels on the slope and outside the slope. This research was conducted on Jalan Kol. Burlian STA 429+312 (case 1) and connecting road IV STA 194+420 (case 2) in OKU Regency, South Sumatra Province, Indonesia. The analysis was carried out using the Slope/W program to obtain the FOS to discover the cause of the landslide. The results of the Slope/W program (Fellenius method) provided an initial condition FOS value for case study 1 of 1.70, and a FOS value after scouring of 1.12. For case study 2 the initial condition FOS value was 1.68, and after scouring 1.05. Based on the results of the analysis, it can be concluded that the cause of the landslide is the occurrence of scouring and the presence of GWT.

Keywords: Landslide, Road, Slope/W, Factor of safety, Ground water table.

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1. Introduction

Landslides are the most frequent natural events in Indonesia and are among the natural disasters that claim the most victims [1]. Landslide problems in Indonesia are generally caused by a combination of topography, high rainfall, and geological conditions. South Sumatra Province has many areas that are very vulnerable to landslide hazards. During the rainy season, landslides often become a serious problem that almost every border area must deal with.

The terrain conditions in South Sumatra Province generally take the form of lowlands and sloping areas with an average land height of +12 m above sea level, with swamps in the eastern and partly central areas, while the central region to the west consists of undulating hills. The national road network passes through the terrain. Due to the condition of the area, the roads are vulnerable to landslides, both those that have occurred and those that have the potential to occur.

Based on BP2JN data for the South Sumatra Region from the Center for National Road Implementation V, Directorate General of Highways, Ministry of Public Works and Public Housing, landslides in the South Sumatra Region were quite frequent. The landslides occurred in multiple areas, such as the cross-link II landslide, covering the Sekayu-Mangun Jaya area at KM. 110+100, KM. 161+000, KM. 161+570, KM. 172+580, and KM. 251+990. The landslide covered the third cross-link area of the Lahat-SP Air Cold KM. Road Section 222+850, KM. 227+700, KM. 229+000, KM. 254+100. Cross-link IV was covered in the area of Jalan Baturaja-Bts Kab.Oku, KM. 190+250, KM. 190+250, KM. 193+000, and KM. 194+420. Figure 1 illustrates (a) the location of the landslide and (b) the geological map of cross-link III [2].

The results of the analysis by BP2JN for the South Sumatra Region, on the issue of connecting Roads II, III, and IV, explained that the cause of the landslide was the fact that the road was at a bend in the river channel. This causes river water to scour the road slopes until it eventually reaches its critical slope. In addition, the landslides can be explained by the increase in pore water pressure when rainfall continues to reach its critical water level, as well as the fact that the road embankment is on slippery shale claystone which is very susceptible to landslides when there is groundwater infiltration in the shale clay. It is very easy for a decrease in shear strength to occur due to poor road drainage systems and the vibration of vehicles crossing the road.

Therefore, it is necessary to analyze the situation of areas that are prone to landslides. Research in the form of case studies of the locations where landslides have occurred, such as the examples above, is expected to reduce the number of landslides through the analysis of the factors that cause landslides in predetermined locations, in this case in Ogan Komering Ulu Regency, South Sumatra Province.

Anucharn and Dasananda [3] used Weighted Linear Combination (WLP) and Analytical Hierarchy Process (AHP) methods to study landslide maps. Their research concerned the area of Khao Phanom Bencha Watershed in Krabi Province, southern Thailand. The results of the map analysis were used to describe how landslides could be mitigated. The research conducted by Zhang [4] compared the results of numerical analysis with limit equilibrium theory slope stability analysis and concluded that a great deal of knowledge about the factors that contribute to landslides is necessary. In addition, Pourkhosravani and Kalantari [5] examined the methods used for slope stability analysis. These are Limit Analysis (LA), Limit Equilibrium (LE), Numerical Analysis (NA), and Artificial Neural Networks (ANN).

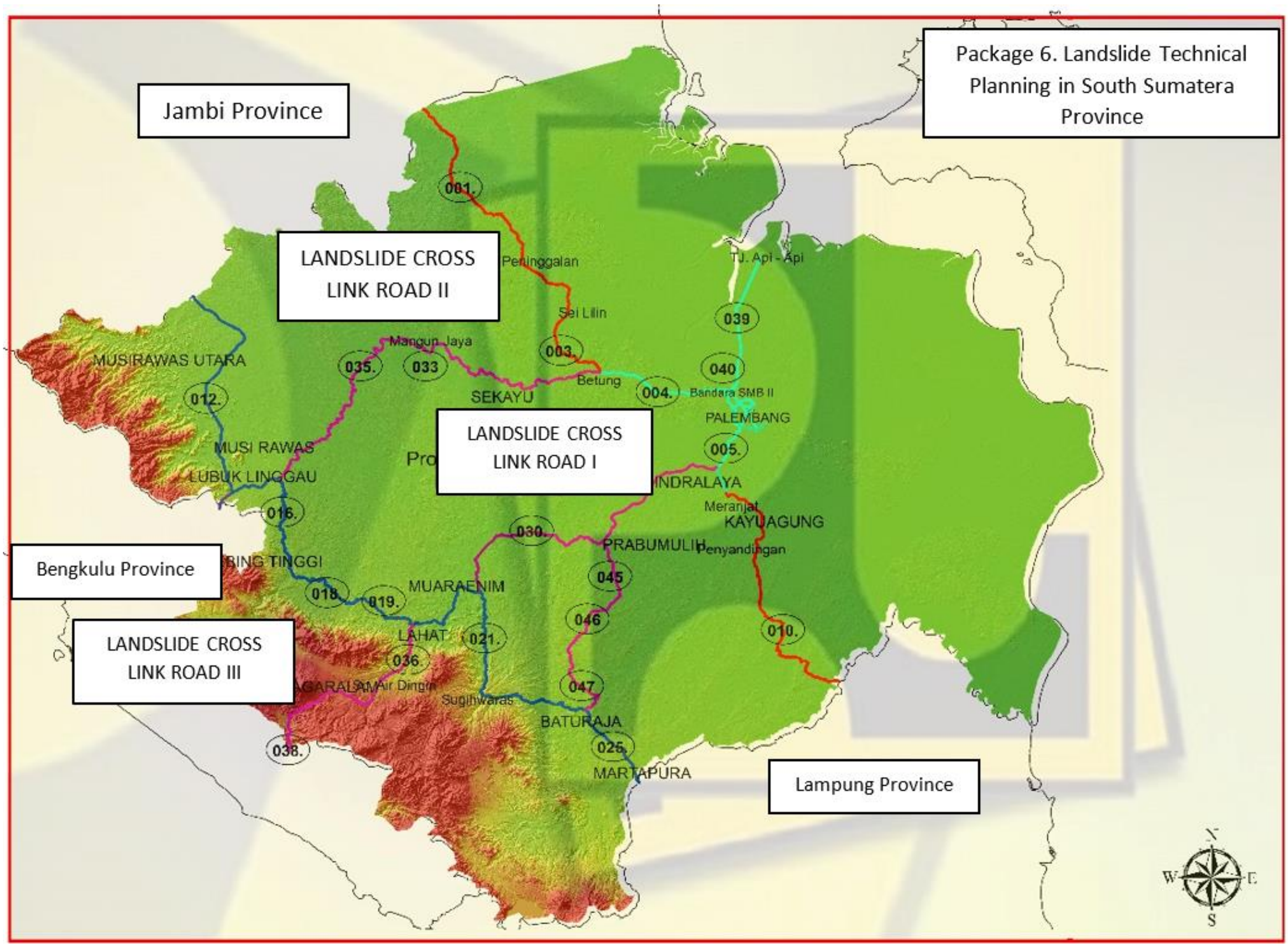

Figure 1.
Landslide location in South Sumatra region and geological map of cross-link road III.

Given the large number of locations that are considered prone to landslides, a method is needed to simplify and speed up the results of accurate calculations on slope stability for each location. One method to achieve this is with the help of a computer program, such as the Slope/W program. Slope/W is a software program that uses boundary balance theory to calculate the safety factor of a slope [6]. The analytical methods used in the Slope/W program are the slice method, the Fellenius method, Bishop Simplified, Morgenstern-Price, Spencer, Generalized Limit Equilibrium (GLE), and Janbu Simplified methods.

The Factor of Safety (FOS) of slope stability is outlined in Table 1 [7]. A Factor of Safety (FOS) equal to 1 indicates that a slope is in critical condition. A Factor of Safety (FOS) value of 1.5 can be used to design a model for slope stability analysis.

Table 1.
The factor of safety (FOS) value of slope stability.

Factor of Safety (FOS)	Condition of Slope
Factor of Safety < 1.07	Unstable
1.07 < Factor of Safety ≤ 1.25	Critical
Factor of Safety > 1.25	Stable

The objectives of this research are as follows: (1) To analyze the factors that cause landslides in Ogan Komering Ulu Regency, South Sumatra Province (Case Study: Jalan Kol. Burlian and Jalan Lintas Connecting IV); (2) To analyze slope stability in Ogan Komering Ulu Regency, South Sumatra Province (Case Study: Jalan Kol. Burlian and Jalan Lintas Connecting IV) in areas where landslides have occurred with the Slope/W program; and (3) To determine the slope's Factor of Safety (FOS) value before and after slope reinforcement is carried out. Erosion can be classified based on geological material, speed of movement, and failure mechanism. Different types of erosion require different mitigation and planning considerations. Figure 2 shows the various types of landslides. Craigh [8] explained that landslides depend on soil type, soil composition, groundwater, seepage, and slope geometry. The failure of natural and artificial slopes is usually caused by activities that increase shear stress or decrease shear strength. Reale et al. [9] studied railway infrastructure across Europe. The results show that the case study involves a steep slope of about 38º, with a reliability value of 3. To analyze the slope stability we must consider the type of landslide and also the real weather.

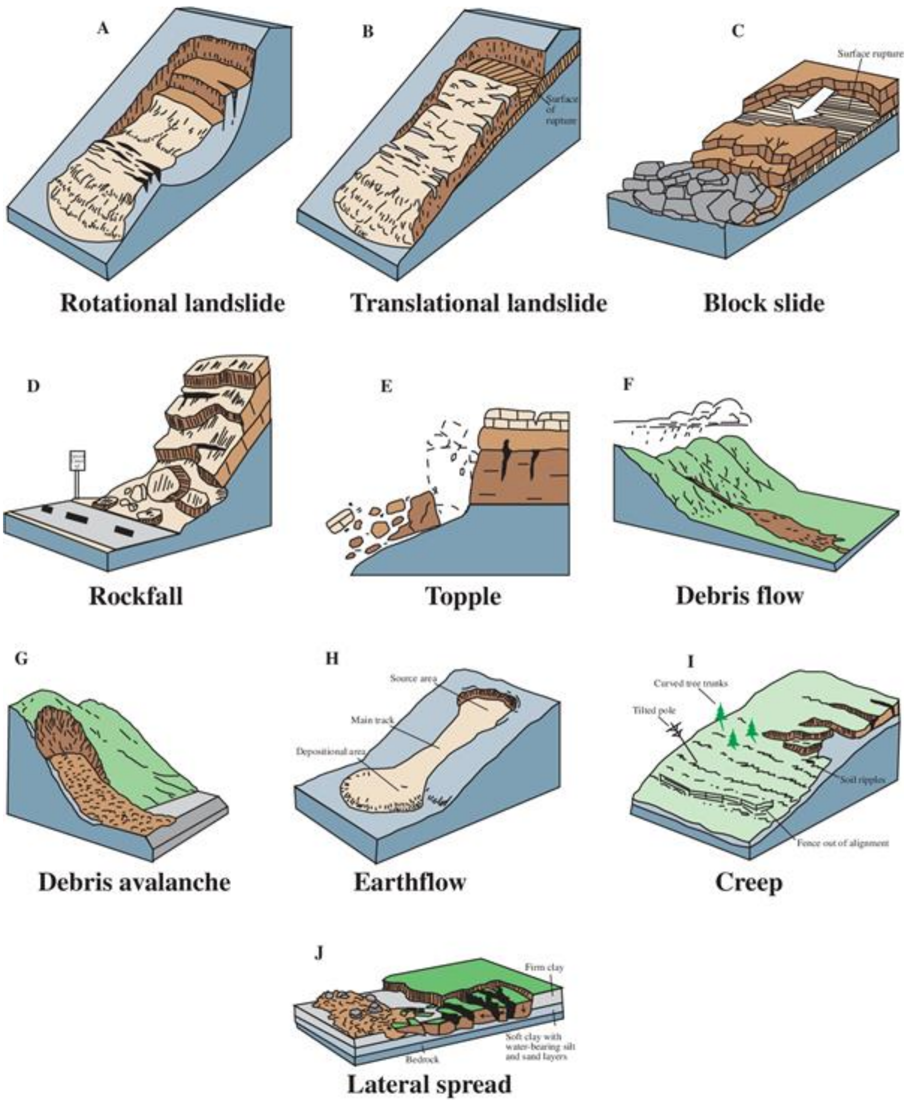

Figure 2.
Types of landslides.

2. Materials and Methods

The research methodologies utilized in this study include a literature review, field studies, experimental studies, and analysis of landslide locations. The study began by collecting data from the prior literature as well as information from the field. The literature review stage involved collecting and studying material related to the problem under study. The information obtained from books and journals on soil mechanics, slope stability, and related subjects was used as a reference to conduct the next stage of research.

The field study comprised the collection of primary and secondary data regarding landslides that have occurred in landslide-prone areas of Ogan Komering Ulu Regency, South Sumatra Province. Observations were also made on the works that had been carried out in the area.

The secondary data collected were (1) data on landslide-prone locations in Ogan Komering Ulu Regency, South Sumatra Province from the Public Works Department of Highways of Ogan Komering Ulu Regency; (2) data on the geological conditions of Ogan Komering Ulu Regency from the Mining Service of South Sumatra Province; (3) topographic maps and slope profile data; and (4) data on landslide events that have been previously researched and landslide news from newspapers.

The experimental studies carried out were laboratory testing of the index properties of the soil, soil classification, as well as the parameters of the shear strength of the soil. Then we proceeded with the identification of areas that are prone to landslides to determine the factors that cause landslides. Slope stability analysis was carried out using the Slope/W computer program. By carrying out several analyses, a minimum Factor of Safety (FOS) was obtained, along with the surface of the landslide area. The sampling locations were based on two research case studies, namely Jalan Kol. Burlian (STA 429+312) and cross-link Road IV (STA 194+420) in Ogan Komering Ulu Regency, South Sumatra Province.

Soil samples from the landslide site were tested at the Laboratory of the Department of Civil Engineering, Faculty of Engineering, Sriwijaya University, Inderalaya. The laboratory tests were used to identify and classify the properties of the soil using ASTM, USCS, and AASHTO standards. The physical properties of the soil tested included: water content (Wn) ASTM D4718-15, specific gravity (G_s) ASTM C 127, wet volume weight (γ_b) ASTM D4718-15, dry volume weight (γ^d) ASTM D4718-15, weight saturated volume (γ_{sat}) ASTM D4718-15, Atterberg limits ASTM D4318, and sieve analysis ASTM D422. After testing for the index properties and soil classification, the technical properties of the soil were also investigated by testing the soil shear strength (Triaxial Test, ASTM ASTM D-2850-89). The parameters obtained are the angle of shear in the soil (ϕ) and the value of cohesion (C). This test was conducted at the Laboratory of the Civil Engineering Department, Faculty of Engineering, Sriwijaya University, Inderalaya.

Figure 3 and Figure 4 [2] describe the cross-sectional shape of the two research case studies. They also show the stratification of the land. Based on the figures, analyses were carried out using the Slope/W computer program. This model relates to geometric representation and input soil parameters, such as cohesion (c), shear angle (ϕ), soil density (γ), and groundwater level. The locations and photos of the landslides in this study are shown in Figure 5 [2]. The stages of calculating slope stability using the Slope/W program are as follows: (a) slope modeling; (b) determining soil parameters such as (soil density, kN/m^3), c (cohesion, kPa), and (shear angle, ^{o}); and (c) determine the ground water table (GWT).

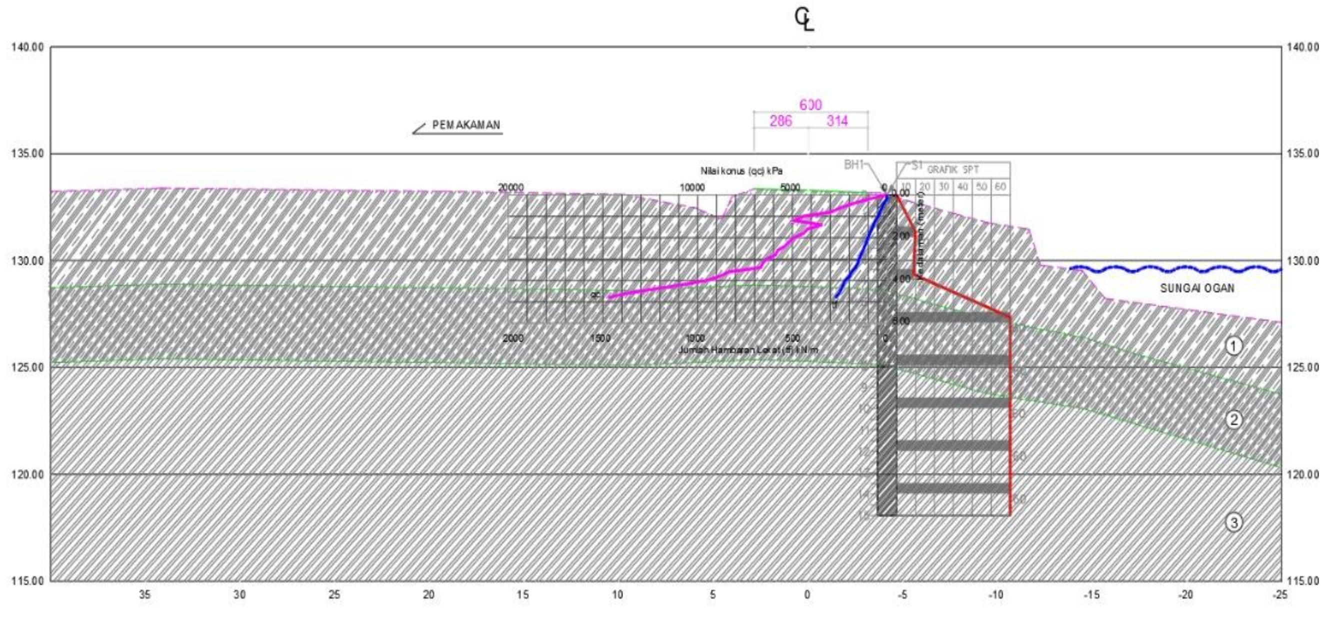

Figure 3.
Soil stratification for case 1.

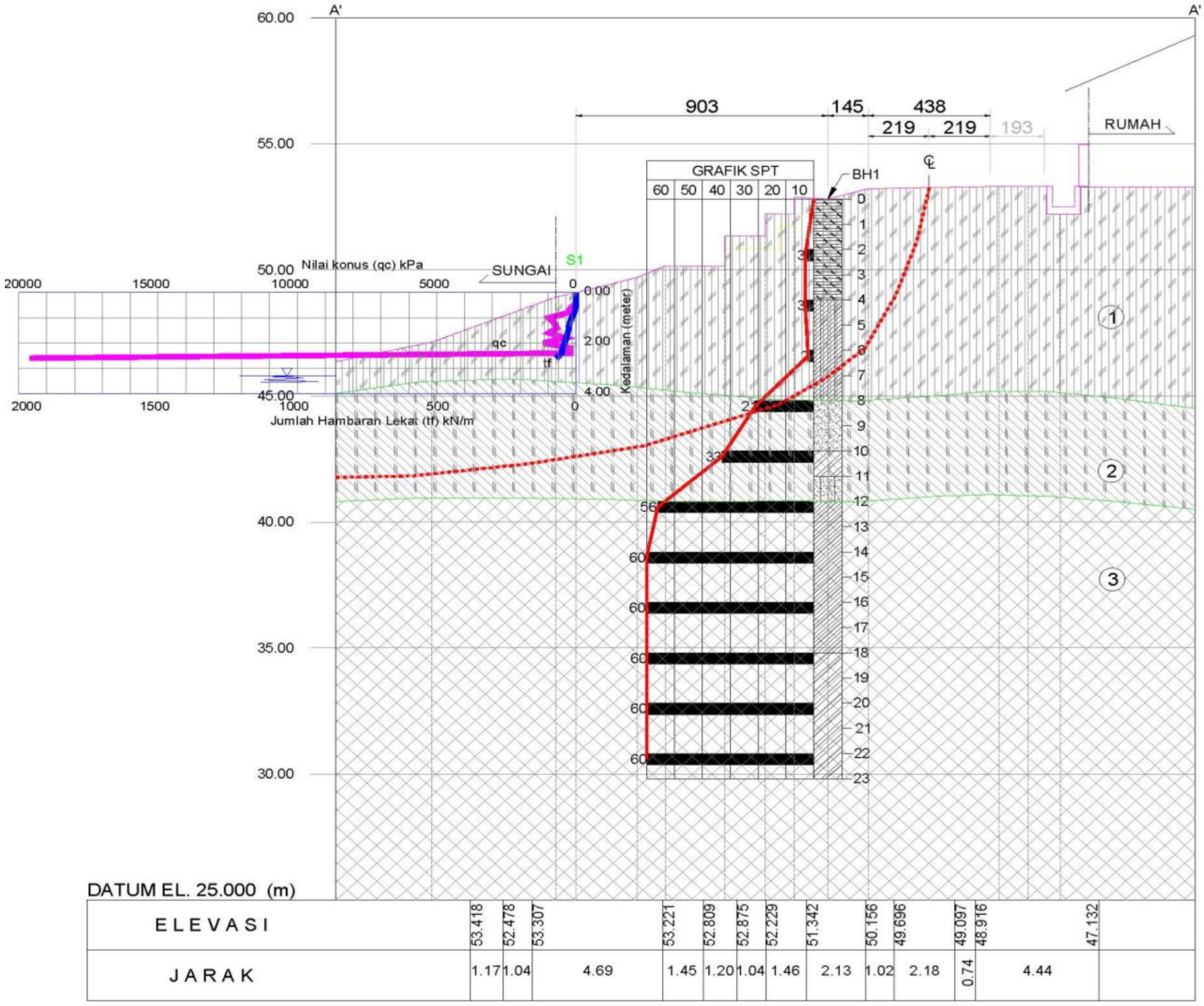

Figure 4.
Soil stratification for case 2.

(a) Case 1

(b) Case 2

Figure 5.
Landslide location.

3. Results and Discussion

3.1. Test Results of Soil Properties and Classification

The results of the laboratory testing concern soil samples from two research locations. The location for case study 1 is Jalan Kol. Burlian Canal Village STA 194+420 East Baturaja District, Ogan Komering Ulu Regency. The location for case study 2 is Jalan Lintas Connect IV Desa SP. Sugih Waras STA 429+312 Ogan Komering Ulu Regency. The samples were taken using a drill and tested at the soil mechanics laboratory of Sriwijaya University.

Soil samples were taken in the form of undisturbed soil samples and disturbed soil samples. The tests carried out in this research were of two types, namely testing soil physical properties (soil properties) and testing soil mechanics. Tests on the physical properties of the soil consisted of measuring the soil moisture content, sieve analysis, Atterberg limits in the form of liquid limits (LL) and plastic limits (PL), as well as testing the specific gravity of the soil. Meanwhile, soil mechanical testing, in this case, consisted of the Triaxial Unconsolidated Undrained (UU). The results of the tests for physical properties and soil classification are summarized in Table 2.

From the results of the laboratory tests, it was found that the original soil water content (Wn) of the village of Terusan STA 194+420 (case 1) was 52.888 %, and the water content (Wn) of the village of SP. Sugih Waras STA 429+312 (case 2) was 39.049 %. Based on the AASHTO classification, the soil sample from the village of Terusan STA 194+420 (South Sumatra) was classified as expansive clay, and the soil sample from the village of SP. Sugih Waras STA 429+312 was classified as sandy loam. Furthermore, the soil sample from the village of Terusan STA 194+420 was classified as clayey (CH), and that taken from the village of SP. Sugih Waras STA 429+312 was classified as clay soil (MH).

3.2. Test Results of Mechanical Properties

The test of the mechanical properties of the soil that was carried out was the Triaxial Test for Unconsolidated Undrained Conditions. This triaxial test was carried out 3 times with cell pressure stresses of 1kg/cm2, 2 kg/cm2, and 3 kg/cm2, respectively. Each location for soil sampling consisted of 2 points. Therefore, 12 samples were tested in total. The test object was 7 cm high with a diameter of 35 cm. The results obtained from the triaxial testing are shown in Table 3. The graphs of the results of the triaxial testing for the 2 research case studies are shown in Figure 6.

The results of the triaxial test in case study 1 (STA 194+420) are a cohesion (c) value of 19.18 kPa, and an internal shear angle (ϕ) of 19.6°. In addition, in case study 2 on the interconnecting road IV Desa SP. Sugih Waras STA 429+312, a cohesion (c) value of 19.60 kPa was obtained, and an internal shear angle (ϕ) of 8°. The parameter data from the triaxial UU test was used to input soil data in the slope/W program.

Table 2.
Physical properties and soil classification.

No	Soil Test Type	Case 1 STA 194+420	Case 2 STA 429+312
1	Optimum of Water Content (Wn_{opt}) (%)	52.89	39.05
2	Specific Gravity (G_s)	2.65	2.69
3	Soil Passes Sieve No. 40 (<0.425) (%)	90.87	44.50
4	Soil Passes Sieve No. 200 (<0.075) (%)	81.80	89.60
5	Liquid Limit (LL, %)	57.54	58.59
6	Plastic Limit (PL, %)	31.89	28.41
7	Plastic Index (IP, %)	25.64	30.19
8	Soil Classification According to AASHTO	A-7-6	A-7-5
9	Soil Classification According to USCS	CH	MH
10	Cohesion (c) (kPa)	19.60	19.18
11	Internal Friction (ϕ) (°)	9°	8°
12	Weight of Soil (γ) (kN/m^3)	1.28	1.51

Table 3.
Triaxial test results UU (unconsolidated undrained).

Location	Case 1 STA 429+312		Case 2 STA 194+420	
	Cohesion (c kPa)	Internal Friction (ϕ°)	Cohesion (c kPa)	Internal Friction (ϕ °)
Point A	18.92	19.75	19.75	8
Point B	19.45	19.45	19.45	8
Average	19.18	19.60	19.60	8

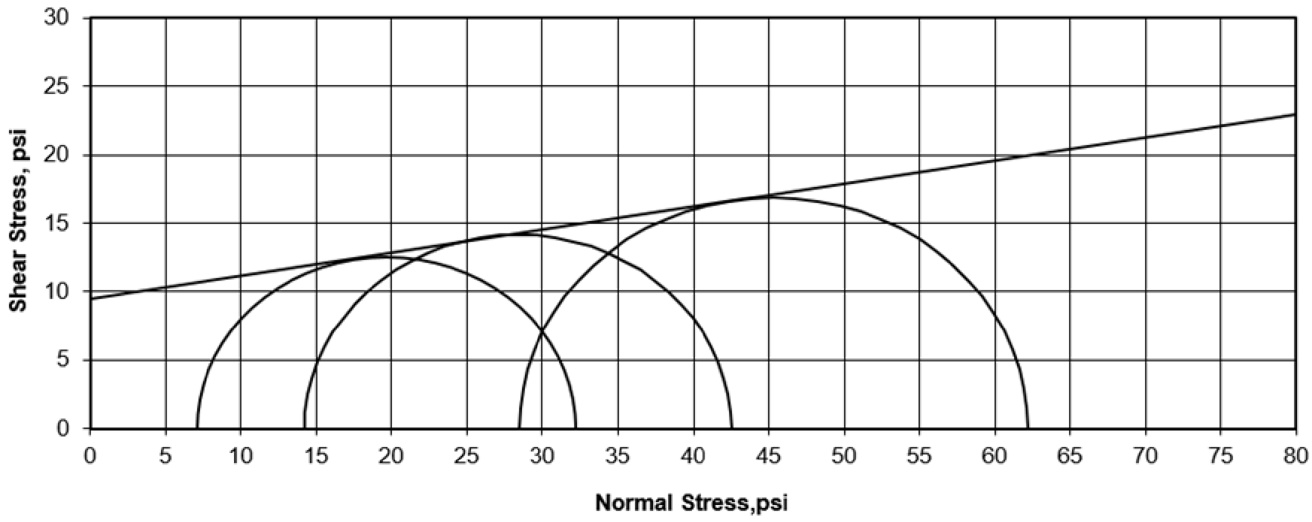

Figure 6.
Triaxial test results.

The road segment Sp. Sugihwaras – Bts. Baturaja City Km. 429+312 is the location of the landslide in case study 1 due to the movement of material in the form of clay with gravel inserts, clay, and claystone. The cause of this landslide is that there is a bend in the river channel, so that water continuously scours the slopes of the road, and the subgrade of the road ends up gradually descending. In addition, the soil material in this location is intercalated clay with gravel, clay, and claystone, meaning that the material is easily saturated and erosive. An illustration of the causes of landslides in this location is shown in Figure 7.

Case study 2 concerns the location of Jalan Batu Raja – Bts. Regency. Oku Km. 194+420, which is a landslide location due to the movement of materials in the form of sandy clay, clay, and claystone. The cause of this landslide is that the location is right at a bend in the geometry of the river. It is thought that the road landslide begins with continuous scouring of river water during flooding, such that the slope of the road reaches a critical point when a landslide occurs (Figure 8). The road embankment is on slippery shale claystone, which is very susceptible to landslides when there is groundwater infiltration in the material because it is very easy to bring about a decrease in shear strength in this material.

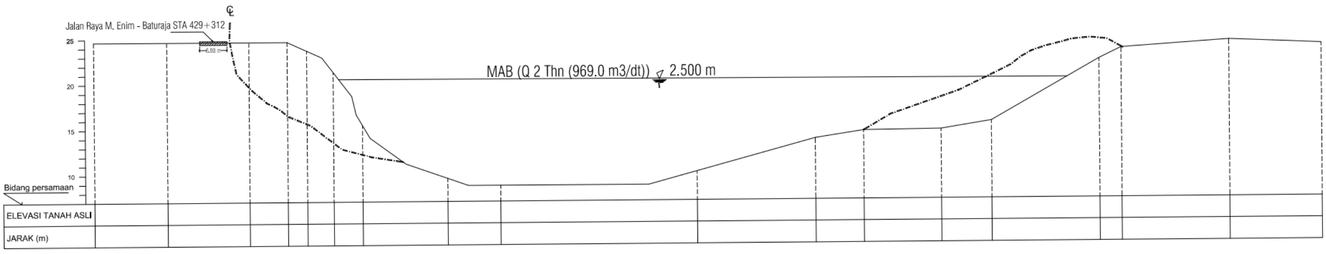

Figure 7.
Cross-sectional of case study 1.

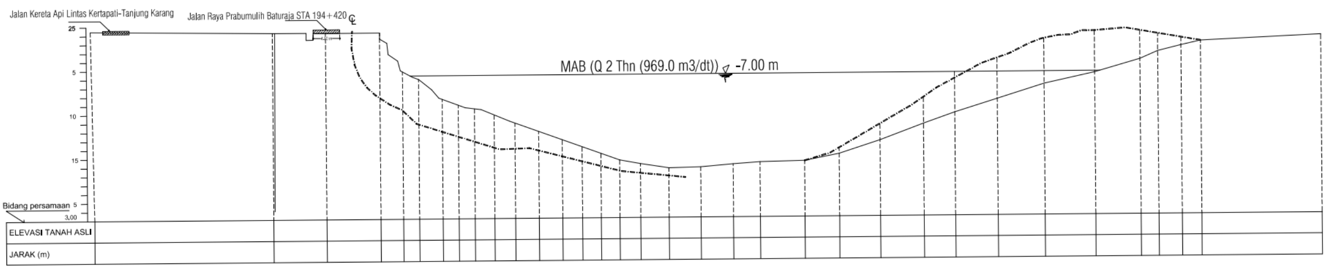

Figure 8.
Cross-sectional of case study 2.

Table 4 shows the results of the calculation of the Factor of Safety (FOS) using the Slope/W program on the slopes that have experienced failure. Based on Table 4, in case study 1 (Village of SP. Sugih Waras STA 429+312) the initial FOS value using the Fellenius method was 1.68. After scouring, the slope's FOS value decreased to 1.05. Likewise, the results of the calculation of the FOS due to the ground water level are displayed. In the initial profile of the -4m, -2m water level slope, the FOS value is 1.22. At the water level -2 m and -1 m, FOS values of 0.76 and 0.49 were obtained.

In case study 2 (Desa Terusan STA 194+420), based on the results of the Slope/W program using the Fellenius method, the following FOS values were obtained: (a) the initial FOS was 1.70; (2) scouring FOS = 1.19; (3) at water level -2 m and -1 m, FOS = 1.43; (4) at water level -2 m, FOS = 1.08; and (5) at -1 m water level, FOS = 0.69. The analysis of the FOS values in the two research case studies shows that scouring and ground water levels can reduce the value of FOS. At the beginning of the slope conditions, the FOS value is still > 1.25, but due to the influence of scouring and ground water level, the FOS value becomes < 1. This is what causes landslides. The FOS results from the Slope/W analysis for case studies 1 and 2 are shown in Figure 9 and Figure 10. Figure 11 and Figure 12 show the FOS graph for case study 1.

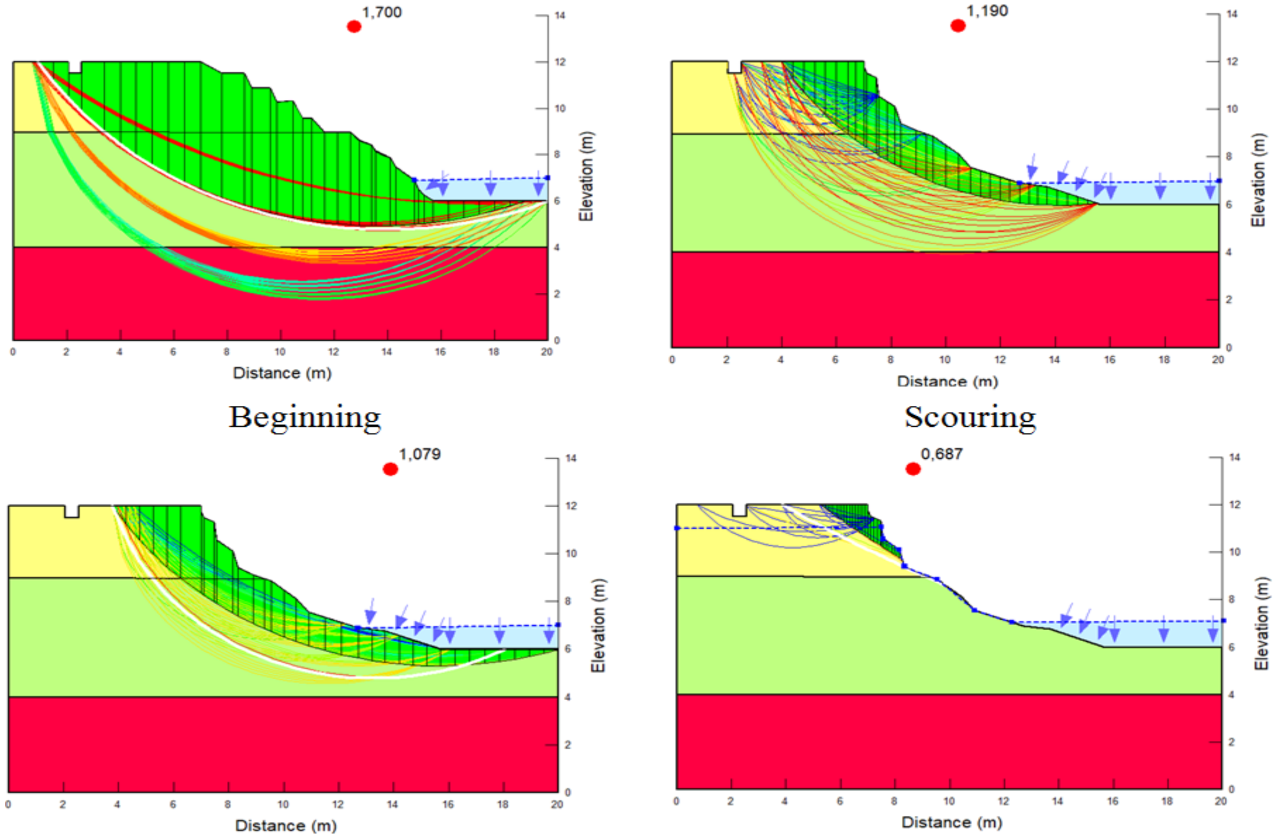

Figure 9.
FOS results of the slope/W program case study 1.

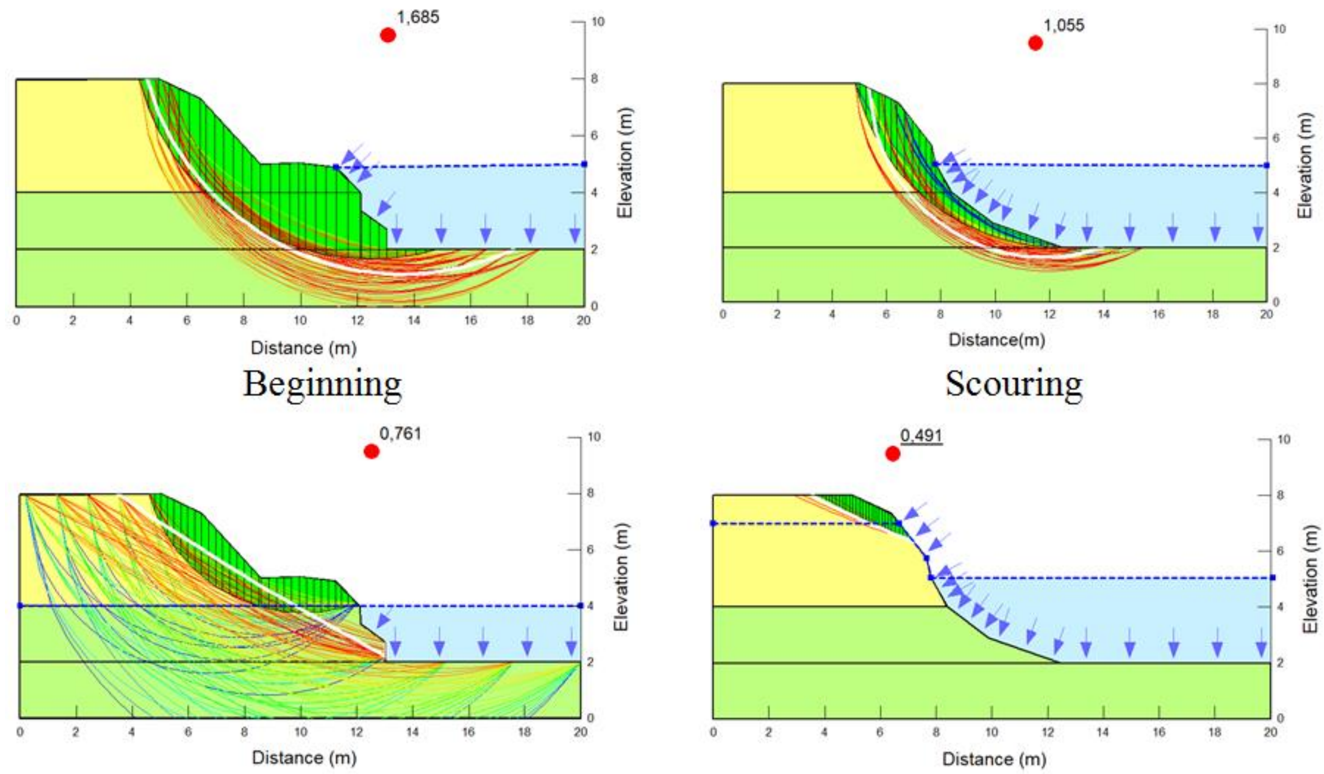

Figure 10.
FOS results of the slope/W program case study 2.

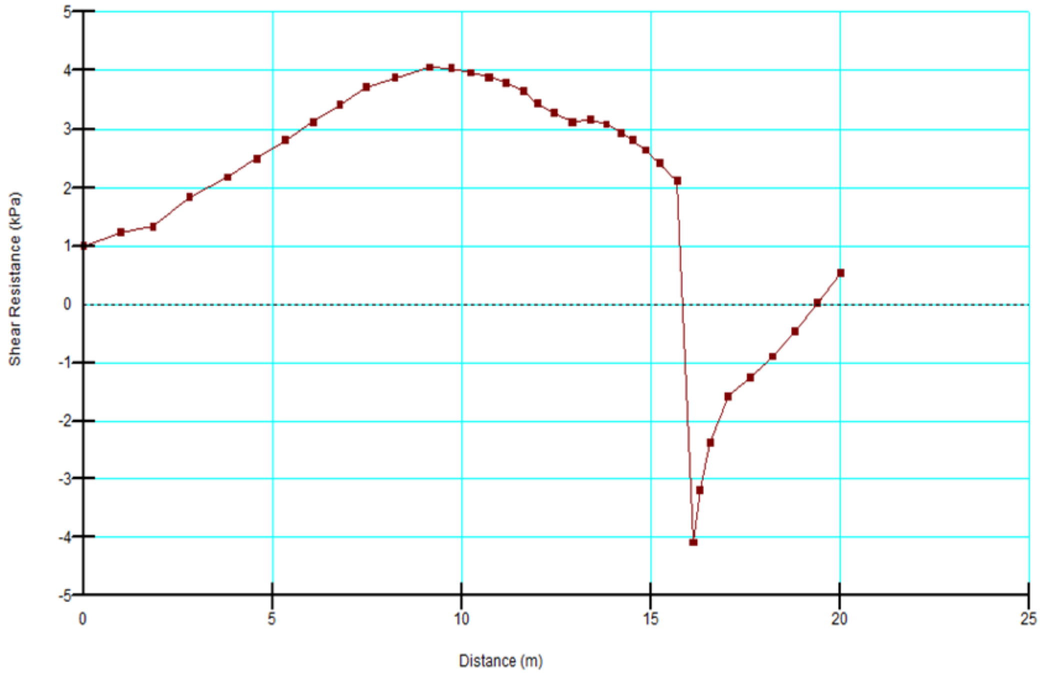

Figure 11.
The graph of FOS for case 1 (1.700).

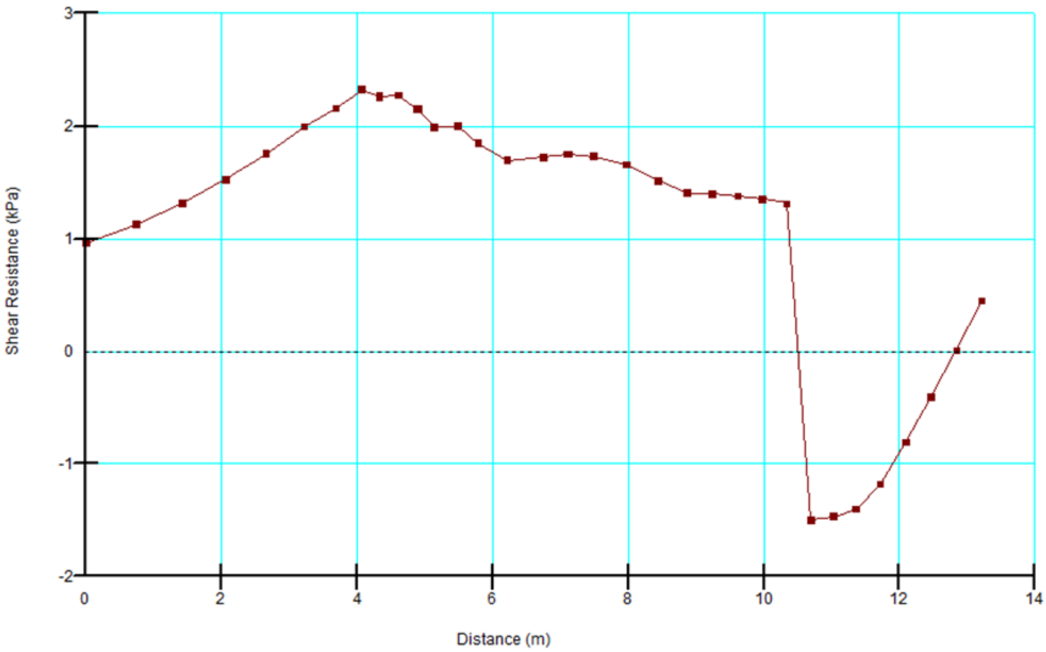

Figure 12.
The graph of FOS for case 1 (1.190).

Table 4.
Calculation of factor of safety (FOS).

No	Location	Calculation of Factor of Safety (FOS)				
		Beginning	**Scouring**	**Initial profile of GWT slope-4m, -2m**	**GWT -2m**	**GWT -1m**
Case 1	SP. Sugih Waras village STA 429+312	1.68	1.05	1.22	0.76	0.49
Case 2	Terusan village STA 194+420	1.70	1.19	1.43	1.08	0.69

Table 5 shows the results of the Factor of Safety (FOS) calculation using several methods from the Slope/W program. The methods used are Morgensten-Price, Fellenius/Ordinary, Bishop, Janbu, and Spencer. At the case study 1 research location, SP Village. Sugih Waras STA 429+312, the largest initial FOS value is 1.729, based on the Bishop method. And the smallest initial FOS value is 1.651, based on the Janbu method. After scouring, the FOS values became 1.058 (Bishop method) and 1.001 (Janbu method). The results of this research are consistent with previous studies in showing that the FOS value decreases.

The study of Sutejo and Gofar [10] analyzed the stability of natural slopes. They used the Bishop method to obtain FOS values and found FOS 1.51-2.30 (θ= 55º) and FOS 1.28-2.08 (θ = 70 º). Juliantina et al. [11] researched the factors that cause natural slope landslides in Muara Enim regency, Indonesia. Using the Slope/W program and the Bishop method, they obtained the following FOS values: case study 1 (Sugihwaras-Muara Enim) = 1.104 and case study 2 (SP. Sugihwaras-Baturaja) = 1.186.

Table 5.
Results of calculation of factor of safety (FOS) with several methods.

Methods	Case Study Research Location 1 STA 429+312		Case Study Research Location 2 STA 194+420	
	Beginning	Scouring	Beginning	Scouring
Morgensten-Price	1.728	1.003	1.554	1.153
Fellenius/Ordinary	1.685	1.055	1.700	1.190
Bishop	1.729	1.058	1.702	1.191
Janbu	1.651	1.001	1.500	1.144
Spencer	1.727	1.055	1.701	1.191

Meanwhile, other studies [12] have investigated the factors that cause landslides. The location of this study was road embankments in East Java, Indonesia. Varied soil depth was found to be one of the factors that causes landslides. In addition, Aprilia and Indrawan [13] analyzed the slope stability of rock in landslides in West Sumbawa, at the Batu Hijau open mine. Their methods of analyzing the slope were GLE (General Limit Equilibrium), LE (Limit Equilibrium), Bishop, and Janbu. Using each of these methods, the FOS values were nearly identical. However, a Plane Failure (PF) analysis led to a higher FOS value than the GLE, LE, Bishop, and Janbu methods.

Ariyanto and Joni [14] researched landslides based on a geoelectric survey in Waru Kabupaten Pamekasan, Madura, East Java, Indonesia. The results of their research show that the factors that cause landslides include faults, cracks, and high slope. Furthermore, the research [15] at Pomendi cutting (km 208/738) by means of geotechnical investigations including CSMRS and slope reinforcement found that one factor that causes landslides is rain. Finally, a study carried out east of the Jordan Rift Valley [16] involved a slope stability analysis that found that the causes of landslides include deep sliding and excessive loads.

4. Conclusion

The conclusions of this research are:

1. The landslides at the 2 research sites (Sugih Waras Village STA 194+420 and SP. Sugih Waras STA 429+312) were caused by scouring at the foot of the slope, differences in the ground water table (GWT) on the slopes, and river water levels.
2. The results of the FOS calculation at location 1 Desa Terusan STA 194+420 using the manual Fellenius method showed an initial slope condition of 1.701; the FOS calculation using Slope/W was 1.700. Applying the conditions after scouring, the manual calculation of the Fellenius method gave 1.171, and the FOS calculation using Slope/W gave 1.190. At location 2, SP Villages. Sugih Waras STA 429+312, the initial condition of the slope gave a manual calculation of FOS using the Fellenius method of 1.669, and the calculation of the FOS using Slope/W gave 1.689 (a difference of 1.1 %). The FOS calculation of the condition after scouring gave a manual result of 1.052 and a computed result of 1.055.
3. The results of the calculation of FOS considering the differences in water level on and outside the slope demonstrate how the risk of landslide is increased. For location 1, in the Village of Terusan STA 194+420, the initial condition of the slope is 1.433, the condition after scouring is 1.079, and when the water level on the slope body is increased, the FOS is 0.687. At location 2, SP Villages. Sugih Waras STA 429+312, the initial condition of the slope is 1.220, the condition after the scour is 0.761, and when the ground water table on the slope body is raised, the FOS is 0.491.

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