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Landslide potential is reviewed from the characteristics of the physical properties and strong shear of the avalanche material on the Arso-Waris National Road.

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ABSTRACT

Keywords: slope/w, bishop, fellenius, landslides.

There are many landslide points on the Arso-Waris National road, so it is necessary to conduct research on the potential for landslides from the physical and shear strength properties. The analysis method uses Slope/W software from GeoStudio, using the Bishop and Fellenius analysis method. The results of the study on 4 points along the Arso-Waris section, showed that with a decrease in the value of the shear strength parameter, both the cohesion value (average decrease of 69.91%) and the value of the shear angle (average decrease of 92.77%) in the reverse analysis resulted in a decrease in the value of the safety factor score by 71.5% (Bishop Method) and 71.11% (Fellenius Method). The value of the smallest (critical) safety factor is 0,498, located at point 4 KM.105+193 in combination loading, by using the Fellenius method. Changes in physical properties and shear strength have the potential to reduce safety factors so that there is potential for landslides.

Introduction

The Arso-Waris national road is one of the sections in the Trans Papua Jayapura-Wamena segment, which is one of the government's plans to improve infrastructure in the eastern region of Indonesia. Not only connecting Jayapura and Wamena, but this intention is also to open the isolation of areas that have great potential to develop. The connectivity built is expected to stimulate economic growth and expand access to education and health. Thus it can improve the quality of life of the local community. The threat of natural disasters and road instability is a problem that can cause damage to the road body and can even result in the sudden disconnection of the road body, so that road performance is reduced. The occurrence of the movement of the soil mass that makes up the slope or so-called landslide, is a common geological phenomenon that occurs to find natural balance (Bokko et al., 2019). Avalanches that occur on road bodies can cause discomfort for road users and can even take lives.

Based on data collected from the Jayapura National Road Implementation Center from 2019 to 2023, it is known that the stability of the Arso-Waris national road section increased in 2023 by 81.34%. One of the reasons why the stability has not been able to reach 100% is that there are still several avalanche points in the form of shallow avalanches in the embankment layer.

The Terrain shape of the Arso-Waris road section is a bumpy area ranging from light to heavy with its relief dominated by hills to mountains. Based on the Geological Map sheet 3413-Jayapura (*Peg Cyclops*) and sheet 3412-Taritatu (Keerom), issued by the Center for Geological Research and Development, it can be known that this area is included in the geological formations QTu (UNK formation), Tmm (Makats formation) and Toma formation (Auwea formation). The UNK formation is in the form of Grewak interspersed with claystone, siltstone, napalm, conglomerate sandstone, and lignite inserts. The Makats Formation is in the form of sandstone interspersed with silt and well-coated claystone.

The types and physical properties of the soil in each region are different because they are influenced by climate, vegetation, geology, and morphology. Each of these factors plays an important role in determining the type and physical properties of the soil that can be found in an area. Soil is a natural resource that is very important for human life, so it is important to understand how the type of soil in each region can be different. Physical properties can be known using various testing methods, and Indonesia already has its standard, namely the Indonesian National Standard (SNI).

Based on the above, it is necessary to conduct research related to the analysis of slope stability on the Arso-Waris road section, through the physical properties of the soil and the strength of the shear of the avalanche material from the slope at the research site.

Method

The location of the research is on the Arso-Waris national road, precisely in the administrative area of Keerom Regency. Soil samples at four points of the study site were collected for testing the physical properties and engineering of landslide potential materials in the laboratory. The distribution of sample location points is at point 1 KM 66 + 327, point 2 KM 80 + 725, point 3 KM 88 + 335, and point 4 KM 105 + 193.

Soil samples were collected for physical property testing and triaxial testing in the laboratory, based on Indonesian National Standards (SNI). The soil parameters tested for soil physical properties are in the form of moisture content (SNI 1965:2008), specific gravity (SNI 1964:2008), content weight (SNI 03-3637-1994), grain analysis (SNI 3423:2009), Atterberg boundaries consisting of liquid limits (SNI 1967:2008), plastic limits and soil plasticity index (SNI 1966:2008), soil shrinkage limits (SNI 3422:2008). Meanwhile, the triaxial test for cohesive soils in an unconsolidated and non-drained state (UU) is based on SNI 4813:2015, SNI 03-2455-2004 for soils in a consolidated state, not drained (CU) and consolidated drained (CD). Slope stability analysis using the GeoStudio Slope/W program version 2021.4 to obtain safety factor values.

Results and Discussion

Interpretation of Physical and Mechanical Properties Test Results

Table 1
Recapitulation of laboratory test results of soil physical and mechanical properties

DESCRIPTION	UNIT	TEST RESULTS			
		DATA PRIMER	DATA SECONDS		
Sample Location		KM.66+327	KM.80+725	KM.80+725	KM.105+193
Sample Depth	m	1.00 – 1.50	1.50 – 2.00	1.50 – 2.00	1.50 – 2.00
GRADATIONS					
Gravel	(%)	6.1	2.88	0.09	0.33
Pasir	(%)	25.2	36.22	29.58	32.96
Lanau	(%)	52.17	57.37	61.33	60.17
Lampung	(%)	16.53	3.53	9.0	6.54
ATTERBERG LIMITS					
Liquid Limit	(%)	19.60	18.85	22.11	24.5
Plastic Limits	(%)	12.41	10.98	11.69	13.89
Plasticity Index	(%)	7.20	7.87	10.42	10.61
Shrink Limit	(%)	24.13	20.75	31.41	26.18
Specific Gravity	Gs	2.62	2.652	2.657	2.657
Contents Weight	gr/cm3	1.58	1.644	1.749	1.749
Up Air	(%)	19.25	25.99	46.76	46.76
TRIAXIAL (UU)					
Kohesi	kg/cm2	0.5	0.29	0.27	0.4
Sliding Angle	degree	21.0	8.3	8.46	6.98

Source: Analysis results

Table 2
Recapitulation of interpretation of laboratory test results

Description	**Interpretation Results**				**Conclusion**
	Data Primer	**Data Seconds**			
Sample Location	**Km.66+327**	**Km.80+725**	**Km.80+725**	**Km.105+193**	
Sample Depth	1.00 – 1.50	1.50 – 2.00	1.50 – 2.00	1.50 – 2.00	
Gradations	Sandy Silt	Sandy Silt	Sandy Silt	Sandy Silt	Sandy Silt
Atterberg Limits					
Liquid Limit	Low	Low	Low	Low	Low
Plastic Limits	Low	Low	Low	Low	Low
Plasticity Index	Keep	Keep	Keep	Keep	Keep

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Shrink Limit	Tall	Tall	Tall	Tall	Tall
Specific Gravity	Keep	Keep	Keep	Keep	Keep
Contents Weight	Keep	Keep	Keep	Keep	Keep
Up Air	Low	Keep	Tall	Tall	Low S/D High
Triaxial (Uu)					
Cohesion	Keep	Keep	Keep	Keep	Keep
Sliding Angle	Keep	Low	Low	Low	Low to Medium

Source: Analysis results

Layout dan Cross Section

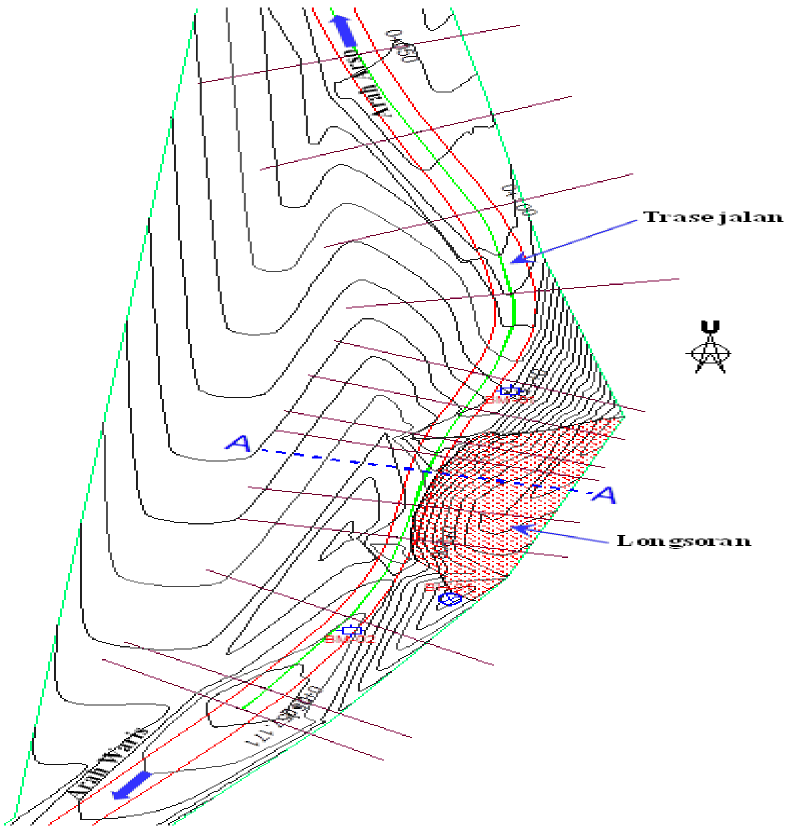

Figure 1
Layout Longsoran KM 66+327

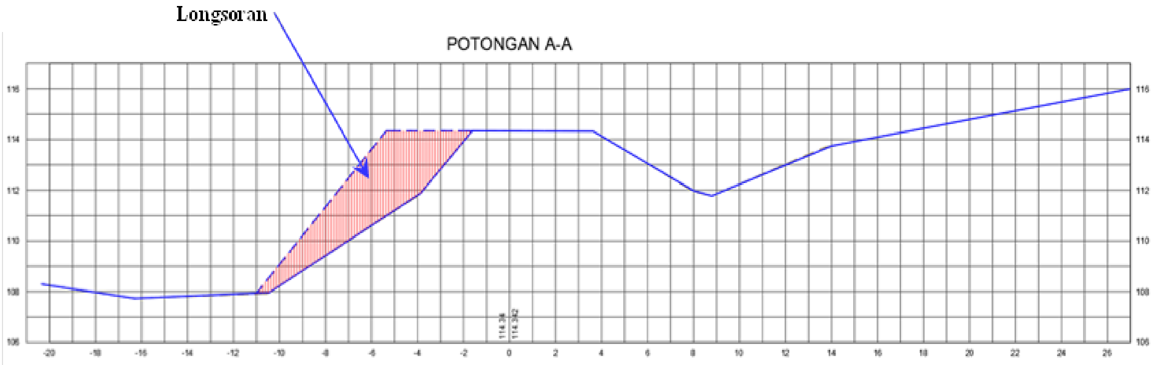

Figure 2
Cross Section Longsoran KM 66+327

The avalanche at KM.66+327 is on the left side of the road towards Waris. The area of the avalanche is 956.91 m2 with a slope of 88.14%.

Stratification of Slope Cross Sections

Based on the results of soil investigation in the form of core drills, SPT, and laboratory test results, in each landslide location, the slope stratification is obtained as follows:

The following is soil stratigraphic data based on the results of analysis and correlation of field data at the KM.66+327 avalanche site.

Table 3
Soil stratigraphic data at KM.66+327

Layer	N-Spt	γ (Kn/m3)	ϕ (^{O})	C (Kpa)	Classification
Layer 1	5	15.54	21	49.03	Lanau Sedang
Layer 2	20	21	30.43	60	Lanau Kaku
Layer 3	7	19	29.64	42	Medium Clay

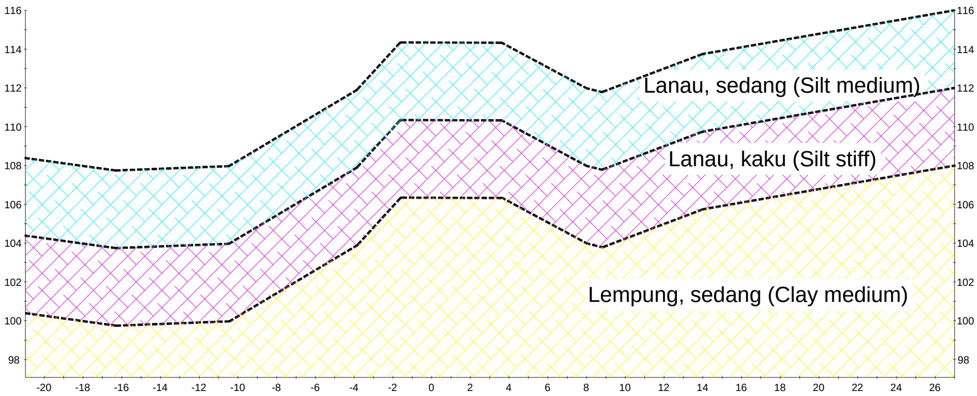

Figure 3
The soil profile of the location of the landslide KM.66+327

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Modeling with Slope/W Computer Programs

Table 4
Soil parameter data used for modeling analysis at KM.66+327

Condition	c (kPa)	ϕ (degrees)	Contents Weight (kN/m3)
Excision	49.03	21	15.54
Back-Analysis	13	0.9	15.54

Method Bishop

1) No Burden

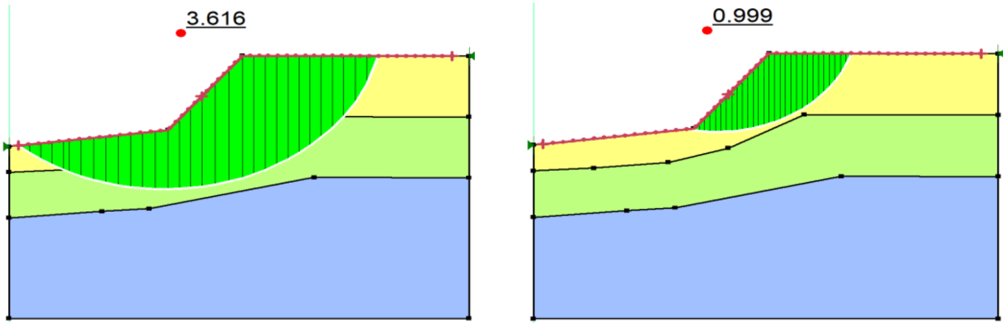


Figure 4
Results of Slope/W Modeling Under No Loading Conditions, with Bishop Method at KM.66+327

In the existing analysis, the values of c=49.03 kPa and ϕ=21° were used, with the conditions without loading as shown in Figure 4. a which depicts the slip plane with the lowest safety number of 3.616. Meanwhile, in the reverse analysis, after the c parameter was lowered to the value of c=13 kPa and ϕ=0.9, ° it showed a decrease in the value of the safety number to 0.999 (figure 4. b). A safety figure value of 0.999 indicates that there was a collapse (SF<1).

2) Pore Water *Pressure* Load (Groundwater Table)

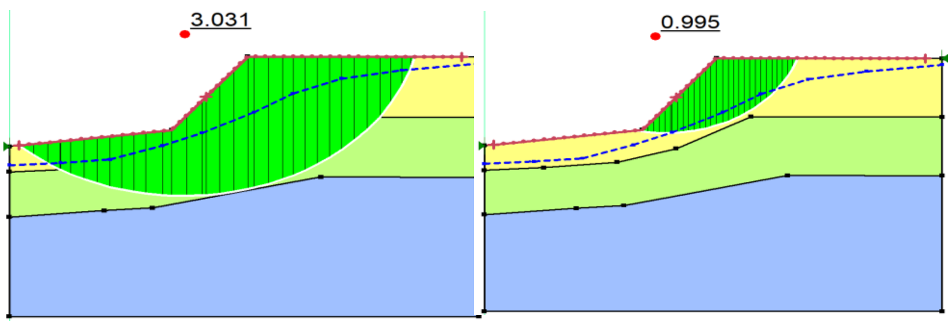
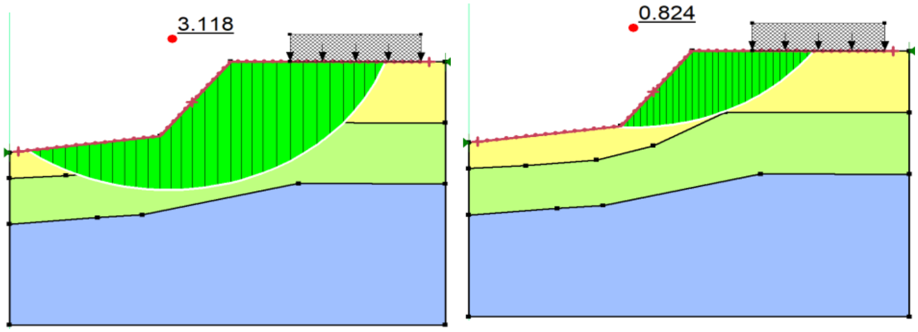


Figure 5
Slope/W Modeling Results

Under the influence of MAT, with the Bishop Method at KM.66+327

In the existing analysis, the values of c=49.03 kPa and ϕ=21° were used, with the *pore water pressure* loading condition as shown in Figure 5. a which depicts the slip plane with the lowest safety number of 3.031. Meanwhile, in the reverse analysis, after the c parameter was lowered to the value of c=13 kPa and ϕ=0.9, ° it showed a decrease in the value of the safety number to 0.995 (figure 5. b). A security number value of 0.995 indicates that there has been a collapse (SF<1).

3) Traffic Load



Excision Back-Analysis

Figure 6 Results of *Slope/W* Modeling in Traffic Load Conditions, with Bishop Method at KM.66+327

In the existing analysis, the values of c=49.03 kPa and ϕ=21° were used, with the traffic loading conditions as shown in Figure 6. a which depicts the slip field with the lowest safety number of 3.118. Meanwhile, in the reverse analysis, after the c parameter was lowered to the value of c=13 kPa and ϕ=0.9, ° it showed a decrease in the value of the safety number to 0.824 (figure 6. b). The security number value of 0.824 indicates that there has been a collapse (SF<1).

4) Seismic Load

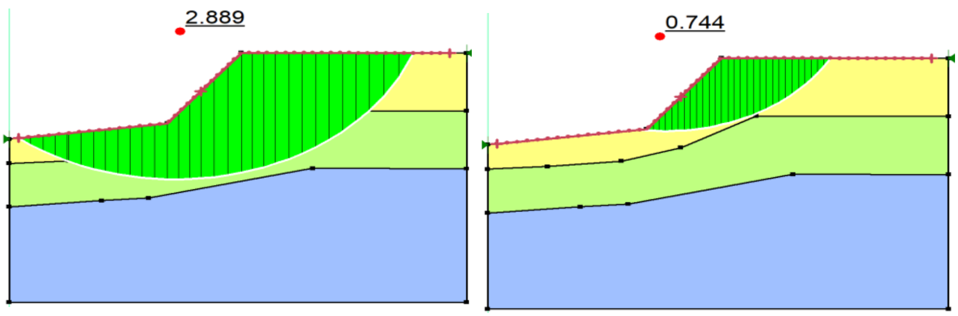


Figure 7
Results of *Slope/W Modeling* under Seismic Load Conditions, with Bishop Method at KM.66+327

In the existing analysis, the values of c=49.03 kPa and ϕ=21° were used, with seismic loading conditions (earthquakes) as shown in Figure 7. a which depicts the slip plane with the lowest safety number of 2.889. Meanwhile, in the reverse analysis, after the c parameter was lowered to the value of c=13 kPa and ϕ=0.9, ° it showed a decrease in the value of the safety figure to 0.744 (figure 7. b). A safety figure value of 0.744 indicates that there has been a collapse (SF<1).

5) Combination of Loading

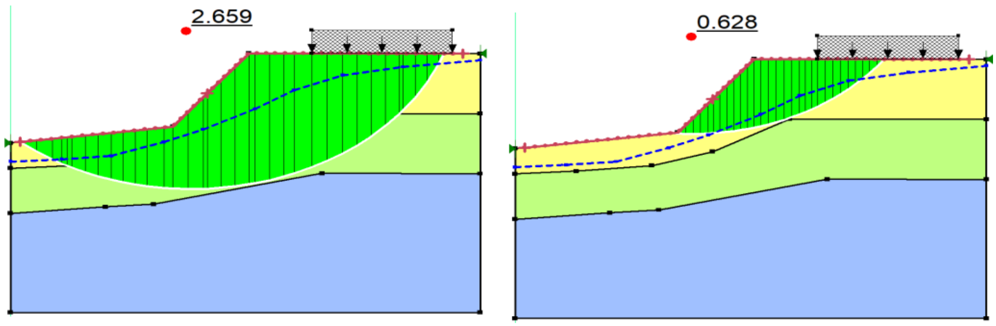


Figure 8
Results of *Slope/W Modeling* under Combined Load Conditions, with Bishop Method at KM.66+327

In the existing analysis, the values of c=49.03 kPa and ϕ=21° were used, with the combined loading conditions as shown in Figure 8. a which depicts the sliding field with the lowest safety number of 2.659. Meanwhile, in the reverse analysis, after the c parameter was lowered to the value of c=13 kPa and ϕ=0.9, ° it showed a decrease in the value of the safety figure to 0.628 (figure 8. b). A security number value of 0.628 indicates that there has been a collapse (SF<1).

Recapitulation of Slope/W Modeling Results

The following is a recapitulation of the modeling results with Slope/W.

Table 5
Recapitulation of the results of 1 KM point modeling. 66+327

Loading Conditions	Security Number (SF)			
	Excision		Back-Analysis	
	Bishop	Fellenius (Ordinary)	Bishop	Fellenius (Ordinary)
Unencumbered	3.616	3.407	0.999	0.998
Influence Mat	3.031	2.948	0.997	0.995
Traffic Load	3.118	2.909	0.824	0.822
Seismic	2.889	2.718	0.744	0.743
Combination	2.659	2.552	0.628	0.627

Source: Analysis results

Table 6
Recapitulation of 2 KM point modeling results. 80+725

Loading Conditions	Security Number (SF)			
	Excision		Back-Analysis	
	Bishop	Fellenius (Ordinary)	Bishop	Fellenius (Ordinary)
Unencumbered	2.748	2.739	0.999	0.998

Influence Mat	2.528	2.433	0.989	0.979
Traffic Load	2.612	2.601	0.923	0.922
Seismic	2.062	2.055	0.745	0.741
Combination	1.853	1.847	0.659	0.654

Source: Analysis results

Table 7
Recapitulation of 3 KM point modeling results. 88+335

Loading Conditions	Security Number (SF)			
	Excision		Back-Analysis	
	Bishop	Fellenius (Ordinary)	Bishop	Fellenius (Ordinary)
Unencumbered	2.723	2.287	0.997	0.833
Influence Mat	2.729	2.318	0.998	0.850
Traffic Load	2.316	1.967	0.815	0.696
Seismic	1.956	1.907	0.717	0.603
Combination	1.690	1.467	0.597	0.525

Source: Analysis results

Table 8
Recapitulation of the results of modeling the 4 KM point. 105+193

Loading Conditions	Security Number (SF)			
	Excision		Back-Analysis	
	Bishop	Fellenius (Ordinary)	Bishop	Fellenius (Ordinary)
Unencumbered	7.345	7.315	0.984	0.980
Influence Mat	7.242	7.211	0.970	0.966
Traffic Load	5.697	5.675	0.775	0.772
Seismic	4.617	4.610	0.629	0.628
Combination	3.674	3.660	0.500	0.498

Source: Analysis results

Relationship of Safety Numbers with Sliding Strength Parameters

At avalanche point 1 at KM.66+327, the landslide occurred at a decrease in the cohesion value from 49.03 kPa to 13 kPa or a decrease of 73.49%, while the shear angle decreased from 21° to 0.9° or a decrease of 95.71%. The decrease in the value of the sliding strength parameter results in a decrease in the safety figure.

At the landslide point 2 at KM. 80+725, the landslide occurred at a decrease in the cohesion value from 28.44 kPa to 11.33 kPa or a decrease of 60.27%, while the shear angle decreased from 8.3° to 0.7° or a decrease of 91.57%. The decrease in the value of the sliding strength parameter results in a decrease in the safety figure. The following is a table of security number value decreases:

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Table 9
Decrease in the value of the security number at Point 2 KM. 80+725

KONDISI PEMBEBANAN	ANGKA KEAMANAN (SF)				PENURUNAN NILAI ANGKA KEAMANAN (%)	
	EKSISTING		ANALISIS BALIK			
	BISHOP	FELLENIUS (ORDINARY)	BISHOP	FELLENIUS (ORDINARY)	BISHOP	FELLENIUS (ORDINARY)
Kondisi Tanpa Dibebani	2.748	2.739	0.999	0.998	63.65	63.56
Pengaruh MAT	2.528	2.433	0.989	0.979	60.88	59.76
Beban Lalu Lintas	2.612	2.601	0.923	0.922	64.66	64.55
Seismik	2.062	2.055	0.745	0.741	63.87	63.94
Kombinasi	1.853	1.847	0.659	0.654	64.44	64.59

Source: Analysis results

At the 3rd avalanche point at KM. 88+335, the landslide occurred at a decrease in the cohesion value from 26.48 kPa to 10.75 kPa or a decrease of 59.40%, while the shear angle decreased from 8.46° to 0.4° or a decrease of 95.27%. The decrease in the value of the sliding strength parameter results in a decrease in the safety figure. The following is a table of security number value decreases:

Table 10
Decrease in the value of the security number of Point 3 KM. 88+335

KONDISI PEMBEBANAN	ANGKA KEAMANAN (SF)				PENURUNAN NILAI ANGKA KEAMANAN (%)	
	EKSISTING		ANALISIS BALIK			
	BISHOP	FELLENIUS (ORDINARY)	BISHOP	FELLENIUS (ORDINARY)	BISHOP	FELLENIUS (ORDINARY)
Kondisi Tanpa Dibebani	2.723	2.287	0.997	0.833	63.39	63.58
Pengaruh MAT	2.729	2.318	0.998	0.850	63.43	63.33
Beban Lalu Lintas	2.316	1.967	0.815	0.696	64.81	64.62
Seismik	1.956	1.907	0.717	0.603	63.34	68.38
Kombinasi	1.690	1.467	0.597	0.525	64.67	64.21

Source: Analysis results

At the 4th avalanche point at KM. 105+193, the landslide occurred at a decrease in the cohesion value from 39.23 kPa to 5.3 kPa or a decrease of 86.49%, while the shear angle decreased from 6.98° to 0.8° or a decrease of 88.54%. The decrease in the value of the sliding strength parameter results in a decrease in the safety figure. The following is a table of security number value decreases:

Table 12
Decrease in the value of the security number at Point 4 KM. 105+193

KONDISI PEMBEBANAN	ANGKA KEAMANAN (SF)				PENURUNAN NILAI ANGKA KEAMANAN (%)	
	EKSISTING		ANALISIS BALIK			
	BISHOP	FELLENIUS (ORDINARY)	BISHOP	FELLENIUS (ORDINARY)	BISHOP	FELLENIUS (ORDINARY)
Kondisi Tanpa Dibebani	7.345	7.315	0.984	0.980	86.60	86.60
Pengaruh MAT	7.242	7.211	0.970	0.966	86.61	86.60
Beban Lalu Lintas	5.697	5.675	0.775	0.772	86.40	86.40
Seismik	4.617	4.610	0.629	0.628	86.38	86.38
Kombinasi	3.674	3.660	0.500	0.498	86.39	86.39

Source: Analysis results

One thing about the results of the analysis using the Bishop and Fellenius method is that the value of Bishop's security number is always greater than that of Fellenius. This is due to a difference in approach to calculating the interaction of forces on the soil. Bishop's method considers the normal force and shear force between each slice, providing a more comprehensive and accurate picture of the slope's stability. On the other hand, the Fellenius Method does not take into account the interaction of forces between slices, which results in a more conservative estimation. In addition, Bishop used the balance of moment and force in his calculations, while Fellenius only used the balance of forces. Bishop's more detailed approach results in more accurate and usually higher results.

The higher the safety score, the farther the slope is from the possibility of landslides. The lower the safety score, the greater the possibility of landslides.

Conclusion

After connecting various parameters and conducting a series of analyses, the following conclusions were obtained. Based on the results of drilling, N-SPT values, laboratory testing, and the USCS classification system on samples from a depth of 1 to 2 meters, the characteristics of the physical properties of the avalanche material on the Arso-Waris road section are known. The soil along this section, according to the USCS classification, is included in the category of silt with low plasticity or Mud-Low Plasticity (ML). The liquid limit and plastic limit of the soil are at a low level, while the shrinkage limit is high. This low plasticity property is indicated by a moderate plasticity index value, but the soil has a considerable tendency to change volume, which is indicated by a high shrinkage limit value. Its plasticity index is medium, while the moisture content varies from low to high.

In addition, it was found that the relationship between the safety number and the shear strength showed that when the shear strength parameters (c and φ) decreased, the safety number also decreased, thus increasing the potential for landslides. The value of the smallest or most critical safety figure was found to be 0.498 at point 4 KM.105+193 under the combined loading condition, which was obtained through the Fellenius method.

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