Slope Stability Analysis to Evaluate Slope Failure in Northern Thailand by Standard Penetration Test

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Abstract

Highway embankments constructed on high mountain areas usually have a problem of slope stability in the rainy season that can have a great impact on road users because it is often limited in terms of boundaries. The purpose of this study was to analyze the stability of slope by using the Standard Penetration Test (SPT). The SPT is an in-situ of soil testing that can be collected data while boring. N-Value from SPT gives shear strength parameters of soil that can analyze the factor of safety. A total of 30 samples were collected from slope failure locations along the highway in Northern Thailand that had boring data in the area or nearby distance between slope failure area and borehole, not more than 30 km. N-Value can compare the relationship with the effective friction angle of coarse grains (sand) or the cohesion of fine gains (clay). Friction angle and cohesion have analyzed the factor of safety under a critical period of rain and normal traffic volume. The factor of safety is between 0.108-1.471 and displayed the results of the analysis in "Factor of Safety Map in Northern Thailand".

Keyword: Slope stability/ Standard penetration test/ Factor of safety

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1. Introduction

The problem of landslide or slope failure along the roads constructed in a mountainous area is often found frequently when entering the rainy season. Because the construction in these areas is often limited space constraints. The terrain has steep slopes and land use. Damage caused by the failure of the slope will affect the road user and people who live nearby. This requires budget and staff to solve problems and manage areas after a disaster. Therefore, if there is a way to assess the stability of slope before a disaster occurs, responsible agency will be prepared to prevent damage or mitigate any damage that may occur can alert the people who use to route as well as coordinating with people in the management of land use area or even pre-construction planning such as road expansion or construct a new road.

The evaluation of slope stability can be done in a number of methods [1]. This research is studied by the geotechnical method. Studying the factor affecting the failure of slope using data from soil drilling with the Standard Penetration Test (SPT) method to analyze the factor of safety (F.S.) of the area along the road. The Standard Penetration Test is one of the popular methods of testing soil properties in the field (In-situ test) and gives shear strength parameters without using more laboratory [2]. It is used widely because of its simplicity and is not expensive [2].

Assessment of the slope stability, a factor of safety will be taken into consideration [3]. For stable slope embankment, a factor of safety is greater than 1.5 and critical when F.S. is equal to 1 [4]. N-Value from SPT is a blow count. The tester will count the number of times the cylinder is hammered into the ground at a distance of 15 cm in 3 intervals. The value of the Standard Penetration Test (N-Value) is the number of hammer times to achieve a distance of 30 cm (2 times after). The first 15 centimeters are not taken into account because the soil in this period is considered to be disturbed by the drilling process. In general, the SPT is not suitable for soils with an N value less than 4 [4]. N-Value have been used to the shear strength parameter are cohesion and friction angle of soil that can be calculate to factor of safety. In this research, the relationship between N-Value and factor of safety have been discussed to ensure that N-Value affect to factor of safety.

2. Previous work

In mountainous areas, highways construction in these areas is often damaged in the rainy season. Because when it rains, rainwater will seep through the soil layer, which will increase the moisture in the soil mass. It makes the attraction between a grain of soil loosening. The shear strength is reduced by moisture. As a result, the stability of slope embankment is decreasing, and there is an increased likelihood of landslide or slope failure [5]. Several methods of assessment of slope stability have been studied by many researchers. One of them is the method of studying the geotechnical factors by analyzing the shear strength parameter of soils. Obtaining shear strength parameters can be done in many methods both in the field (in-situ test) and in the laboratory.

Dechpatungwesa and Chairatanangamdaj, 2019 studied and analyzed the cause of slope failure of highway embankment no.1194 Mae Sariang - Mae Samlaep route sta.21+150 [6]. And Muntathong et. al., 2017 studied the cause of slope failure of highway embankment no.1349 Samoeng – Wat Chan route sta.34+450 [7]. The research has collected soil samples to test shear strength by the Direct Shear Test method under normal moisture and high moisture conditions. The data analysis is base on the principle of Limit Equilibrium. Analysis factor of safety of the soil in the study area. In normal moisture conditions, the slope will be stable. But in high moisture conditions and earthquakes, the slope will be unstable.

Yousof and Zabidi, 2018 [2] studied the reliability of using standard penetration test (SPT) in predicting properties of soil. SPT is one of the methods that can be done with the shear strength parameters. It is used widely because of its simplicity, inexpensively, and gives a chance to obtain these parameters without using laboratory tests. The research had studied the reliability of SPT in predicting Atterberg limits and shear strength parameters; cohesion, and angle of friction in the State of Pahang, Malay. The simple correlation between SPT and soil parameters is performed by using a simple regression method. The results show the shear strength of the soils affects the SPT number.

Marques and Lukiantchuki, 2015 [8] evaluated of the stability of a highway slope through numerical modeling in Sao Paulo, Brazil. This research is to assess the stability of the slope from the factor of safety. N-value from Standard Penetration Test was used in this study for estimation of shear strength parameter of soil. Stability analysis based on Morgenstern-Price method and 20 kPa of surcharge load. The result shows a factor of safety of 1.16 that is below the minimum recommended by the Brazilian Technical Standard. After that, the stability of the slopes was analyzed during the critical period. The result shows the factor of safety of 0.78 that a decrease of 33% from normal conditions. Then, the reliability of the analysis results was determined. The factor of safety can vary between 0.74 and 1.59. The standard deviation was 0.11 and the reliability index 1.44, resulting in a probability of failure of 7.7%. From the analysis, the stability of the section to be unsatisfactory.

3. Present Work

The efficient method in geotechnical engineering for analyzing slope stability is the Direct Shear Test but it is very difficult to collect samples, test in the laboratory, and people who test samples should a specialist in geotechnical engineer. So in this research, the Standard Penetration Test is an interesting method because it is easier than the Direct Shear Test. Standard Penetration Test can test in the field and people who test samples are not required to the specialist in geotechnical engineering. However, this research wants to analyze the factor of safety for evaluating the stability of slope in an easy method but the accuracy of analysis results must be within acceptable criteria or not very inaccurate.

The purpose of this study was to analyze the stability of slope along with the road construction in a mountain area of Northern Thailand by using the N-Value obtained from the Standard Penetration Test.

4. Methodology

4.1 Data preparation

Preparing data for this research use of secondary data from the Bureau of Materials, Analysis, and Inspection, Department of Highways, and related other agencies for analyzing the Factor of Safety (FS). The data used are as follows:

4.1.1 Boring data in 2016 – 2020.

4.1.2 Cross-section of landslide or slope failure embankment in each location along the mountainous roads in 2016 – 2021.

4.1.3 Shape file: Boundary of Province (in Northern Thailand), Highway route, Geology and etc.

Boring data in 2016-2020, In the soil survey, there will be a Standard Penetration Test which is following the Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils D1586-11 [9]. The test drives the weight to transfer the force to the hollow inside the slitting cylinder to penetrate the layer where the soil sample will be collected. The tester will count the number of times the cylinder is hammered into the ground at a distance of 15 cm in 3 intervals. The value of the standard penetration test is the number of hammer times to achieve a distance of 30 cm (2 blocks). The first 15 centimeters are not taken into account because the soil in this period is considered to disturb by the drilling process. But in general, the SPT test is not suitable for soils with an N value less than 4 [4]. However, the conditions for stopping hammering depend on the type of foundation work to be constructed. The results of this drilling survey were shallow foundation surveys. So stop hammering at N = 50. The N-value obtained from the test must be revised to N with a standard energy efficiency of 60%. Because soil parameters that interpreted from SPT testing and the geotechnical engineering knowledge database was developed based on the N_{60} value. However, these adjustments are not welcome because of difficulties and complexity. In practice, it is assumed that the value of N measured in the field is equal to N_{60}.

The sample drilling results (Boring Log and Field Log) will contain various information that can compare to the relationship between the N value and the shear strength parameter. This can apply in the analysis of the factor of safety. An example of the boring data and field log are shown in Figure 1 and Figure 2.

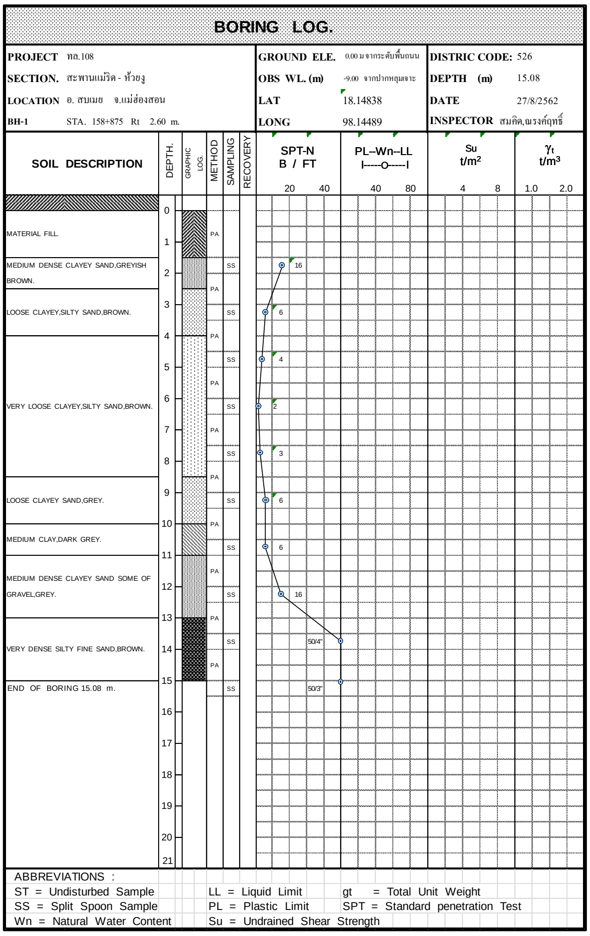

Figure 1. Boring log results show the depth and N values in each soil type.

The relationship between N-value and soil parameters was used to calculate the safety factor are:

- *Effective Friction Angle, Ø*

The relationship between N and the effective friction angle has been shown in the form of a comparative table in several studies. For this research, the relationship between N-values and the effective friction angle of coarse-grained soils of Wisutmethanukul, 2015 as shown in Table 1.

FIELD LOG

PROJECT.	ทล.108	**DATE.**	27/8/2562
SECTION	สะพานแม่ริด - ห้วยงู	**DISTRIC CODE:**	526
LOCATION	อ.สบเมย จ.แม่ฮ่องสอน	**INSPECTOR.**	สมคิด,ณรงค์ฤทธิ์
COOR.	LAT = 18.14838 LONG = 98.14489	**GROUND ELE.**	0.00 ม. จากระดับพื้นถนน
BH-1	STA. 158+875 Rt 2.60 m.	**OBS WL.**	-9.00 ม

NO.	DEPTH. FROM (M.)	DEPTH. TO (M.)	METHOD	STANDARD PENETRATION TEST 6"	6"	6"	N	SAMPLING SOIL DESCRIPTION
1	0.00	1.50	PA					
2	1.50	1.95	SS	7	9	7	16	MEDIUM DENSE CLAYEY SAND,GREYISH BROWN.
3	1.95	3.00	PA					
4	3.00	3.45	SS	2	3	3	6	LOOSE CLAYEY,SILTY SAND,BROWN.
5	3.45	4.50	PA					
6	4.50	4.95	SS	2	2	2	4	VERY LOOSE CLAYEY,SILTY SAND,BROWN.
7	4.95	6.00	PA					
8	6.00	6.45	SS	1	1	1	2	-DITTO.-
9	6.45	7.50	PA					
10	7.50	7.95	SS	1	1	2	3	-DITTO.-
11	7.95	9.00	PA					
12	9.00	9.45	SS	3	3	3	6	LOOSE CLAYEY SAND,GREY.
13	9.45	10.50	PA					
14	10.50	10.95	SS	2	3	3	6	MEDIUM CLAY,DARK GREY.
15	10.95	12.00	PA					
16	12.00	12.45	SS	3	7	9	16	MEDIUM DENSE CLAYEY SAND SOME OF GRAVEL
17	12.45	13.50	PA					GREY.
18	13.50	13.95	SS	33	50/4"	-	50/4"	VERY DENSE SILTY FINE SAND,BROWN.
19	13.95	15.00	PA					
20	15.00	15.45	SS	503"	-	-	50/3"	-DITTO.-
								END OF BORING. (15.08 m.)

PA= POWER AUGER ST=SHELBY TUBE SS=SPLIT SPOON WO=WASH OUT

Figure 2. The number of times that the hammer was hammered into each interval of 15 cm in 3 test intervals.

Table 1. The relationship between N-values and the effective friction angle of coarse-grained soils. (Wisutmethanukul, 2015)

N	N_{60}	Describe	γ_t (kN/m³)	D_r (%)	∅' (degree)	X (degree)
0 – 5	0 – 3	Very Loose	11 – 16	0 – 15	26 – 28	0
5 – 10	3 – 9	Loose	14 – 18	16 – 35	29 – 34	0
10 – 30	9 – 25	Medium	17 – 20	36 – 65	35 – 40[a]	$\phi'_p - \phi'_{cs}$
30 – 50	25 – 45	Dense	19 – 22	66 – 85	40 – 45[a]	$\phi'_p - \phi'_{cs}$
> 50	> 45	Very Dense	> 20	86 – 100	> 45[a]	$\phi'_p - \phi'_{cs}$

- *Estimation of undrained shear strength of fine-grained soils*

The determination of the undrained shear strength of clays (C_u) is usually tested in a laboratory. However, Cu can be estimated from the SPT test that has adjusted the incident energy N60: as shown in Table 2.

In this research, N-value had converted to the effective friction angle in the soil or the undrained shear strength by the rule of three in arithmetic. Using the N-value data obtained from the SPT test, it is necessary to classify the soil type: clay or sand. Because of the selection of a comparison table, only one of the tables will be used. But in reality, there will be silt soil, which is soil whose grain size is between clay and sand. In selecting the table, the relationship of coarse-grained soil was used. Together with the cohesion cost of soil grains in the rainy season, that is the average value in the engineering soil group of Thailand (Sornralump et al., 2018) [10], as shown in Figure 3. The type of rock or soil origin can be determined by overlapping the coordinates of the slope failure location with the geology map shapefile as shown in Figure 4.

Table 2. The relationship between the N60 value and the undraining shear strength of clay soils. (Visutmethanukul, 2015)

N_{60}	Describe	γ_t (kN/m^3)	C_u (kPa)	Pressed with the thumb
0 - 2	Very Soft	< 15.7	< 10	Sink more than 1 inch (2.5 cm.)
3 - 5	Soft	15.7 – 18.8	10 - 25	Sink about 1 inch
6 - 9	Medium	15.7 – 20.4	25 - 50	Sink when using moderate force
10 - 15	Stiff	18.8 – 20.4	50 - 100	It is about 0.8 cm deep.
15 - 30	Very Stiff	18.8 – 22.0	100 - 200	Not a deep mark but you can use your fingernail to press it to make a mark.
30 - 50	Hard	> 20.4	200 - 300	Not a deep mark when using a fingernail, it is still difficult to scratch.

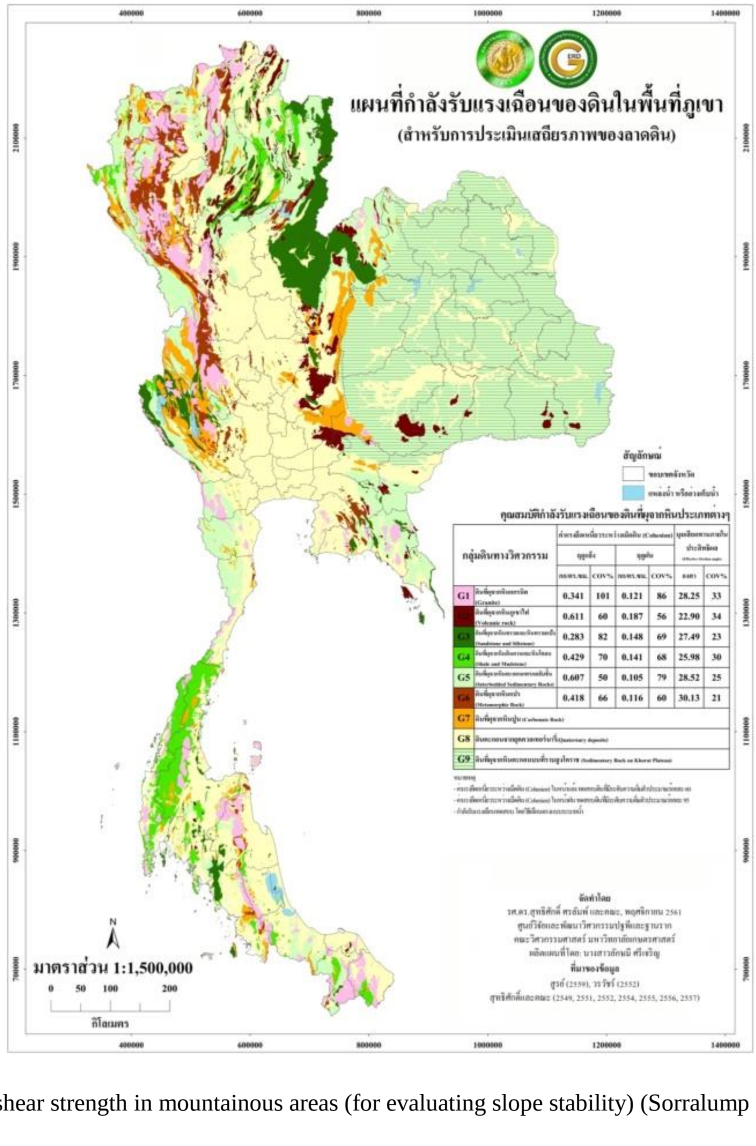

Figure 3. Map of soil shear strength in mountainous areas (for evaluating slope stability) (Sorralump et al., 2018)

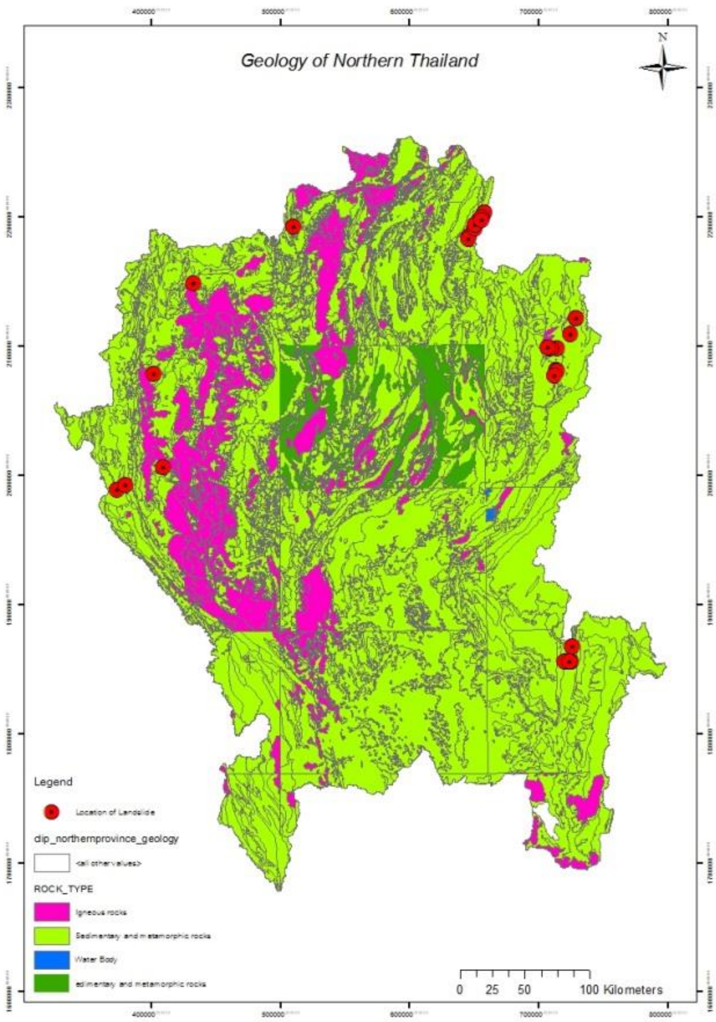

Figure 4. The location of slope failure in different rock types

The location and cross section of slope failure in 2016-2021, cross-section data will know the slope angle that failed. Cross section data as shown in Figure 5. Slope Angle is one of the factors used to calculate the factor of safety and can also take distances both horizontally and vertically to be plotted in the Geo Studio 2007 program to create a sloped model as well.

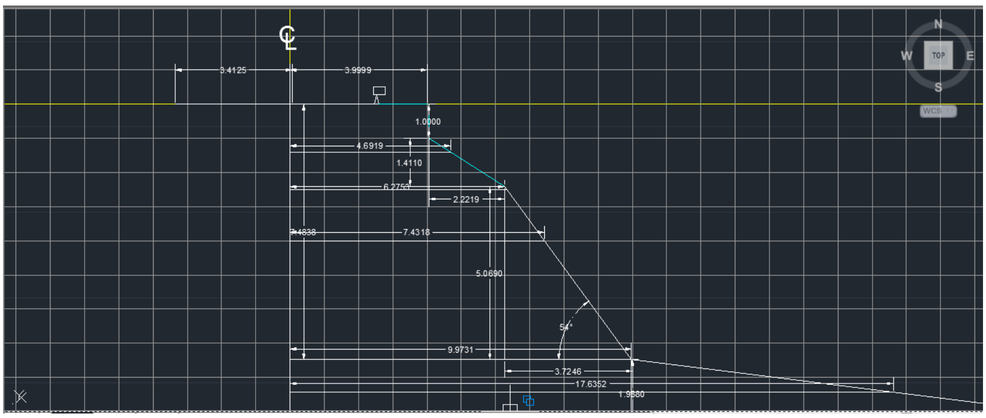

Figure 5. The example of cross section at the site of the slope collapse.

When the data is collected, boring data is taken into account together with the location of the slope failure. The courtesy of the drilling data, there are many objectives of exploration. In this research, the study only the borehole data corresponding to the failure site or nearby area was selected from 30 areas as shown in Figure 6. (In the distance between the borehole and the site of the failure, not more than 30 kilometers because the greater distance, the more information will be inaccurate at that location.).

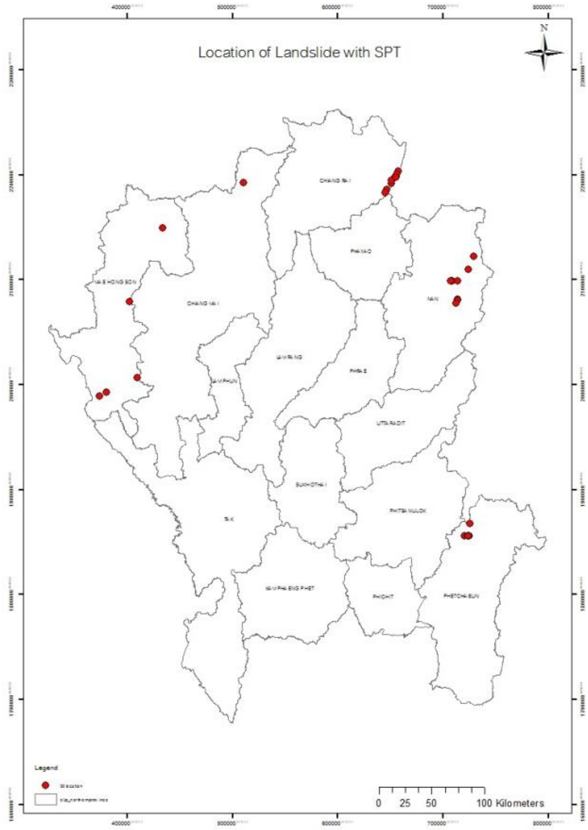

Figure 6. Slope failure location with nearby borehole data

4.2 Classified type of slope failure

There are several formulas in the factor of safety analysis according to the erosion characteristics of the slopes. Therefore, it is appropriate to choose a formula for calculating the factor of safety. This research classifies the characteristics of failure into two major types:

4.2.1 Erosion failures as shown in Figure 7 are based on the Infinite Slope stability analysis equation.

$$F.S. = \frac{c'}{\gamma z \sin\alpha \cos\alpha} + \left[\frac{\tan\emptyset'}{\tan\alpha} - m\left(\frac{\gamma_w \tan\emptyset'}{\gamma \tan\alpha}\right)\right]$$

Figure 7. Show the area and nature of the failure of a slopes in Highway No.1263, section Khun Yuam - Pang Ung, at about 18+580 km LT.

4.2.2 Circular failure as shown in Figure 8 using Bishop's Simplified Method slope stability analysis equation.

$$F.S. = \frac{\sum_{n=1}^{n=p}(cb_n + W_n \tan\emptyset + \Delta T \tan\emptyset)\frac{1}{m_{\alpha(n)}}}{\sum_{n=1}^{n=p} W_n \sin\alpha_n}$$

Figure 8. Show the area and nature of the failure of a slopes in Highway no. 108, section Mae Rid Bridge-Huai Ngu at km. 158+865 - km.158+923 RT.

4.3 Slope stability analysis

Once the erosion characteristics have been classified, the above two equations have been applied appropriately. Substituting variables were obtained by comparing the relationship of the N-Value with the effective friction angle and undrained shear strength in combination with the slope angle obtained from cross-section data. For substituting other variables as follows:

- The unit weight of soil was determined at approximately 18 kN/m^3 [11].
- The weight of the backfill according to the report data from the Bureau of Materials,

Analysis, and Inspection, Department of Highways at approximately 20 kN/m^3.

• Moisture condition based on the highest moisture conditions (m = 1) (Saturated Soils).

• The external force is the weight of the vehicle being transferred into the pavement, which may increase the forces causing the embankment slide down recommended by Standard Truck and Lane Loads according to AASHTO: Standard Specification for Highways Bridge is 9.3 kN/m^2 (this research uses 10 kN/m^2) [12].

Because Bishop's Simplified Method is a rather detailed and complex computational method, Geo Studio ver.2007 was used for stability analysis as shown in Figure 9.

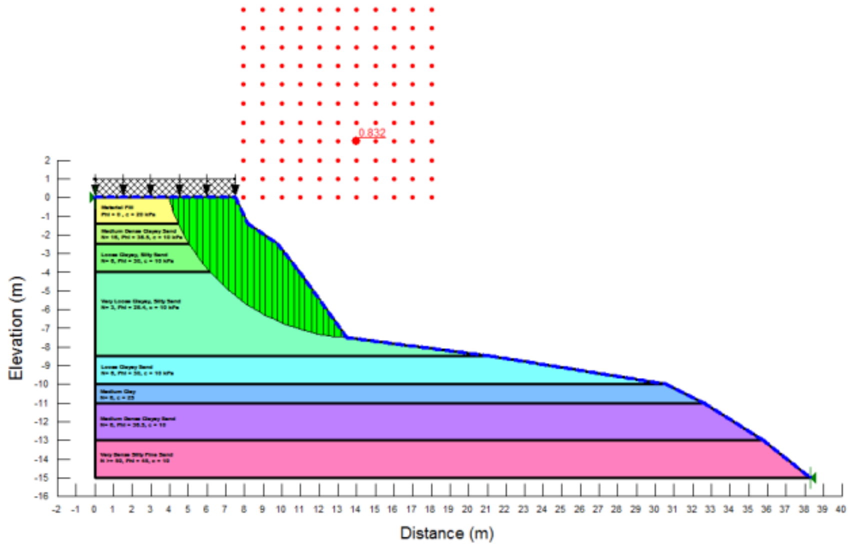

Figure 9. Model of failure characteristics and factor of safety results in Highway no. 108 at km. 158+865-km.158+923 RT.

Then the values of these variables are calculated for slope stability in the form of factor of safety, which is the factor of safety is the comparative ratio between soil power to the unit of resistance while balancing. The safety ratio was used to assess the stability of the sliding slope. as shown in Table 3.

Factor of Safety = (Shear Strength)/(Shear Stress)

5. Result

After analysis, the type of slope can be classified into 2 major types. Erosion slope in 8 areas and circular failure in 22 areas. And type of country rock as shown in Table 4.

Table 3. Factor of Safety for the stability of sliding slopes. (Visutmethanukul, 2015)

Stability	Analysis	Factor of Safety
Temporary excavation work and embankment	Analyzed with non-drained shear strength. (C_u)	1.1 - 1.3
Permanent excavation work	Critical Friction Angle Analysis (ϕ'_{cs})	1.2 - 1.4
Foundation of the embankment	C_u or ϕ'	1.2 - 1.5
Embankment (or compacted soil)	ϕ'	1.2 - 1.4
Soil filling on the old disaster plane	Analyzed by the angle of residual friction (ϕ'_r)	Natural value

Table 4. The location of the slope failure, type of slope failure, and country rock

No.	High way no.	Section	Km. – Km.	Lane	Location		Type of failure	Country rock
					X	Y		
1	1249	Mae Ngon – Nong Tao	Km.14+620.000 - Km.15+050.000	RT	510441.6020	2192928.501	Circular failure	Shale/Sandstone
2	108	Mae Rid Bridge – Huai Ngu	Km.158+865.000 - Km.158+923.000	RT	409740.4321	2006780.649	Circular failure	Shale/Metamorphic rock
3	2331	Jowo – Phu Hin Rong Kla Nation Park	Km.8+300.000 - Km.11+000.000	LT, RT	725880.7811	1868081.261	Infinite slope	Sandstone
4	1095	Mae Na – Tha Krai	Km.112+007.000 - Km.112+035.000	RT	433359.8463	2149395.779	Circular failure	Granite
5	1263	Khun Yaum – Pang Oung	Km.18+580.000	LT	402360.7991	2079167.396	Infinite slope	Granite
6	1093	Khun Huai Krai – Pha Tung	Km.48+650.000 - Km.48+675.000	LT	646527.7069	2186278.469	Circular failure	Phyllite
7	1093	Khun Huai Krai – Pha Tung	Km.44+250.000 - Km.44+280.000	RT	645471.0827	2183520.320	Infinite slope	Phyllite
8	1093	Khun Huai Krai – Pha Tung	Km.59+300.000 - Km.59+500.000	LT, RT	651024.1710	2192067.360	Infinite slope	Phyllite
9	1093	Khun Huai Krai – Pha Tung	Km.72+687.500 - Km.72+787.500	LT	654071.0426	2197577.897	Circular failure	Phyllite
10	1225	Pang Chang – Na Bua	Km.19+500.000 - Km.19+785.000	RT	714020.7632	2081848.327	Circular failure	Tuff
11	1225	Pang Chang – Na Bua	Km.20+290.000 - Km.20+325.000	RT	714192.9263	2081230.692	Circular failure	Tuff
12	1225	Pang Chang – Na Bua	Km.25+135.000 - Km.25+325.000	LT	712334.3665	2077796.603	Circular failure	Sandstone
13	12	Wang Thong – Kek Noi	Km.110+330.000 - Km.110+405.000	LT	725098.0616	1856120.143	Circular failure	Sandstone/ Shale
14	1081	Don Moon – Lak Lai	Km.37+025.000 - Km.37+095.000	LT	714095.7693	2099171.977	Circular failure	Shale
15	1081	Don Moon – Lak Lai	Km.30+900.000 - Km.30+970.000	LT	709047.9233	2099010.546	Infinite slope	Shale
16	1081	Don Moon – Lak Lai	Km.28+650.000 - Km.28+725.000	RT	707129.3827	2099390.562	Circular failure	Shale
17	1194	Mae Sariang – Mae Samlaep	Km.37+700.000 - Km.37+750.000	RT	373988.6972	1989716.407	Circular failure	Sandstone/Shale
18	1194	Mae Sariang – Mae Samlaep	Km.26+775.000 - Km.26+900.000	LT	380361.3980	1993211.504	Circular failure	Sandstone/Shale
19	1081	Lak Lai – Bo Kluea	Km.62+090.000 - Km.62+350.000	RT	724413.2560	2110316.617	Infinite slope	Sandstone/Shale
20	1093	Khun Huai Krai – Pha Tung	Km.64+215.000 - Km.64+250.000	LT	651064.1253	2195039.456	Circular failure	Phyllite
21	1093	Khun Huai Krai – Pha Tung	Km.80+800.000 - Km.80+900.000	LT	656381.0114	2200871.125	Circular failure	Phyllite
22	1093	Khun Huai Krai – Pha Tung	Km.88+720.000 - Km.88+760.000	LT	657915.9465	2204127.663	Circular failure	Phyllite
23	1093	Khun Huai Krai – Pha Tung	Km.88+742.000 - Km.88+777.000	RT	657916.4104	2204145.954	Infinite slope	Phyllite
24	1093	Khun Huai Krai – Pha Tung	Km.80+270.000 - Km.80+410.000	RT	656031.5364	2200637.095	Circular failure	Phyllite
25	1093	Khun Huai Krai – Pha Tung	Km.74+800.000 - Km.75+200.000	LT	655648.2625	2198084.994	Circular failure	Phyllite
26	1081	Lak Lai – Bo Kluea	Km.78+523.000 - Km.78+533.000	LT	728960.5745	2122457.578	Circular failure	Sandstone/Shale
27	1081	Lak Lai – Bo Kluea	Km.78+475.000 - Km.78+505.000	RT	728941.8534	2122426.736	Infinite slope	Sandstone/Shale
28	12	Wang Thong – Kek Noi	Km.103+880.000 - Km.103+960.000	LT	720630.5130	1856061.568	Circular failure	Sandstone/Shale
29	12	Wang Thong – Kek Noi	Km.108+570.000 - Km.108+635.000	LT	723611.4762	1856466.669	Circular failure	Sandstone/Shale
30	12	Wang Thong – Kek Noi	Km.108+890.000 - Km.108+940.000	LT	723839.9794	1856426.495	Circular failure	Sandstone/Shale

5.1 The result of factor of safety

From the analysis of the factor of safety totaling 30 areas in the northern region of Thailand. Both with Erosion and Circular Failure models. The result of the factor of safety totaling 30 areas in the northern region of Thailand was approximately 0.108-1.471, as shown in Table 5.

Table 5. The result of factor of safety

no.	Highway no.	Section	Km. - Km.	Lane	Factor of Safety
1	1249	Mae Ngon – Nong Tao	Km.14+620.000 – Km.15+050.000	RT	0.923
2	108	Mae Rid Bridge – Huai Ngu	Km.158+865.000 - Km.158+923.000	RT	0.832
3	2331	Jowo – Phu Hin Rong Kla Nation Park	Km.8+300.000 - Km.11+000.000	LT, RT	0.500
4	1095	Mae Na – Tha Krai	Km.112+007.000 - Km.112+035.000	RT	0.195
5	1263	Khun Yaum – Pang Oung	Km.18+580.000	LT	0.430
6	1093	Khun Huai Krai – Pha Tung	Km.48+650.000 - Km.48+675.000	LT	0.874
7	1093	Khun Huai Krai – Pha Tung	Km.44+250.000 - Km.44+280.000	RT	0.600
8	1093	Khun Huai Krai – Pha Tung	Km.59+300.000 - Km.59+500.000	LT, RT	0.444
9	1093	Khun Huai Krai – Pha Tung	Km.72+687.500 - Km.72+787.500	LT	0.917
10	1225	Pang Chang – Na Bua	Km.19+500.000 - Km.19+785.000	RT	1.471
11	1225	Pang Chang – Na Bua	Km.20+290.000 - Km.20+325.000	RT	0.767
12	1225	Pang Chang – Na Bua	Km.25+135.000 - Km.25+325.000	LT	0.398
13	12	Wang Thong – Kek Noi	Km.110+330.000 - Km.110+405.000	LT	0.549
14	1081	Don Moon – Lak Lai	Km.37+025.000 - Km.37+095.000	LT	0.286
15	1081	Don Moon – Lak Lai	Km.30+900.000 - Km.30+970.000	LT	0.326
16	1081	Don Moon – Lak Lai	Km.28+650.000 - Km.28+725.000	RT	0.349
17	1194	Mae Sariang – Mae Samlaep	Km.37+700.000 - Km.37+750.000	RT	0.849
18	1194	Mae Sariang – Mae Samlaep	Km.26+775.000 - Km.26+900.000	LT	1.287
19	1081	Lak Lai – Bo Kluea	Km.62+090.000 - Km.62+350.000	RT	0.755
20	1093	Khun Huai Krai – Pha Tung	Km.64+215.000 - Km.64+250.000	LT	0.908
21	1093	Khun Huai Krai – Pha Tung	Km.80+800.000 - Km.80+900.000	LT	0.949
22	1093	Khun Huai Krai – Pha Tung	Km.88+720.000 - Km.88+760.000	LT	0.915
23	1093	Khun Huai Krai – Pha Tung	Km.88+742.000 - Km.88+777.000	RT	1.330
24	1093	Khun Huai Krai – Pha Tung	Km.80+270.000 - Km.80+410.000	RT	0.953
25	1093	Khun Huai Krai – Pha Tung	Km.74+800.000 - Km.75+200.000	LT	0.976
26	1081	Lak Lai – Bo Kluea	Km.78+523.000 - Km.78+533.000	LT	0.957
27	1081	Lak Lai – Bo Kluea	Km.78+475.000 - Km.78+505.000	RT	0.600
28	12	Wang Thong – Kek Noi	Km.103+880.000 - Km.103+960.000	LT	0.514
29	12	Wang Thong – Kek Noi	Km.108+570.000 - Km.108+635.000	LT	0.491
30	12	Wang Thong – Kek Noi	Km.108+890.000 - Km.108+940.000	LT	0.108

5.2 Slope stability map

From the result, this research will be presents the slope stability assessment in "Factor of Safety Map in Northern Thailand". The results of a factor of safety have been interpolated to evaluate the stability of the area. Levels of a factor of safety are classified into 15 levels. The map is shown in Figure 10.

6. Discussion

Slope stability analysis in this research is the N-Value from the Standard Penetration Test in the slope failure area (or nearby at a distance of not more than 30 kilometers). The N-Value can compare to correlate the shear strength of soil (effective friction angle and cohesion), but N-Value should change to N_{60} (Bowles, 1997 and Aggour, 2001) before being calculated.

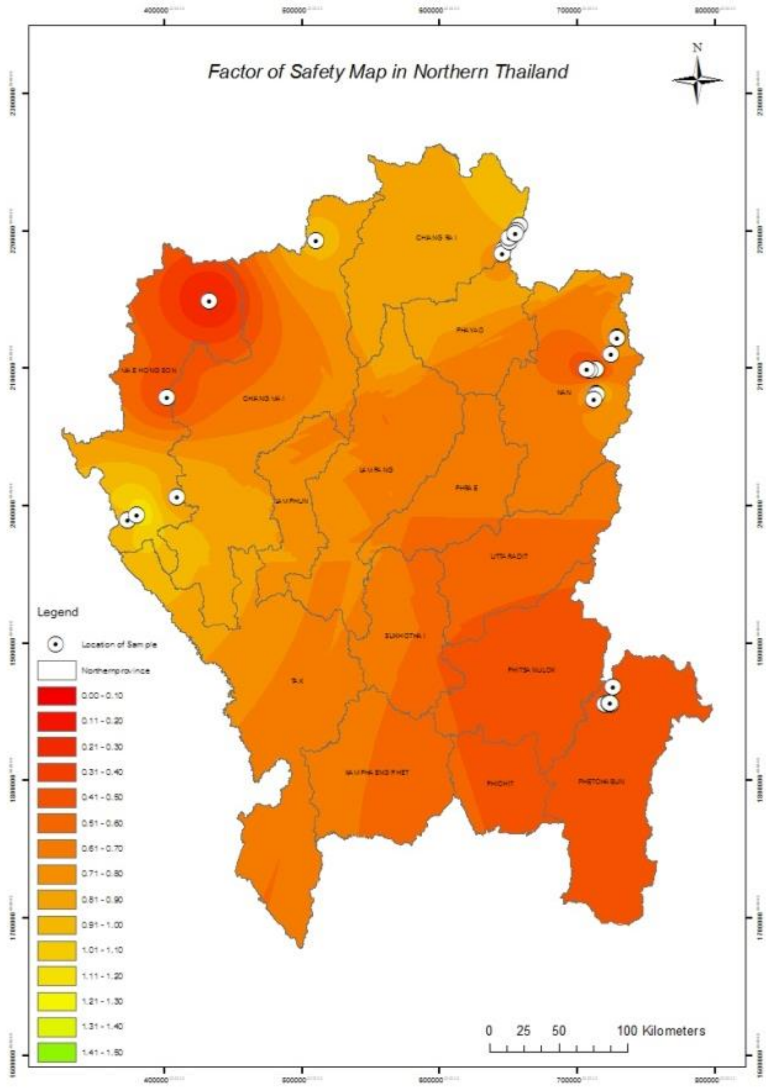

Figure 10. Factor of Safety Map in Northern Thailand

This research analyzes the effective friction angle and cohesion of soil from the Standard Penetration Test and calculates a factor of safety. According to research by Dechpatungwesa and Chairatanangamdaj (2019) studied and analyzed the cause of slope failure of Highway embankment No.1194 Mae Sariang - Mae Samlaep route sta.21+150 with is located theclosest to Study area no.18 (Highway No.1194 km.26+775-km.26+900 LT). Dechpatungwesa and Chairatanangamdaj analyzed the engineering properties of soil from the Direct Shear Test at normal humidity and high humidity. This research compared with the test at high humidity conditions. The factor of safety in high humidity is 1.10 (in normal conditions is 1.547), which similar to the calculation in this research is 1.287. However, the factor of safety is still different. In addition, there are different methods of obtaining the factor of safety. This may because this research focuses only on engineering properties in high moisture conditions (m=1), but Dechpatungwesa and Chairatanangamdaj were studied other properties as well because Mae Hong Sorn Province has an active fault. So, in areas with active fault, the earthquake force should be considered, and analysis of the factor of safety in each area should consider other natural factors as well.

7. Conclusions

This research focuses on the factor of safety from the Standard Penetration Test. Because a factor of safety is one of the indicators for evaluating slope stability by back-calculation analysis to calculate the factor of safety in slope failure area. N-value from the Standard Penetration Test can be compared to shear strength parameters: cohesion and friction angle. The result of calculating the factor of safety is approximately 0.108-1.471.

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