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An Analysis of the Slope Stability of Young Rock Cliffs in Sibang, Bali Using GEO5

Analisis Stabilitas Lereng Tebing Batuan Muda Di Sibang, Bali menggunakan GEO5

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Abstract

This study presents a comprehensive analysis of slope stability for young rock cliffs in the Sibang region of Bali, employing advanced geotechnical software GEO5. The investigation is crucial due to the dynamic geological conditions and rapid changes in land use in the area, posing potential risks to infrastructure and environmental stability. The research focuses on young rock cliffs, characterized by recent geological formations, which are inherently susceptible to slope instability. This slope stability analysis is carried out using the GEO5 auxiliary program which will produce a Safety Factor value which is used as the basis for building a construction which interprets whether the slope is safe or not. The safety factor value used as the minimum value is 1.5, so the slope must have a SF value $\geq$ SF min = 1.5. This analysis was carried out on 4 cross sections with 2 method which name is Morgenstern-Price and Bishop Method because the analysis carried out was complex in terms of force and moment. The Safety Factor of cross section on BH-03 to BH-01 is not safe because the value is 1,16 and 1,15 which is < 1,5 (the minimum safety factor). Therefore, the slope must modelled with terraced slopes and also retaining wall reinforcement for each modelled terrace height.

Keywords: GEO5; Young Rock Cliffs; Slope Stability

Abstrak

Studi ini menyajikan analisis komprehensif stabilitas lereng tebing batuan muda di wilayah Sibang, Bali, menggunakan perangkat lunak geoteknik canggih GEO5. Investigasi ini penting karena kondisi geologi yang dinamis dan perubahan penggunaan lahan yang cepat di wilayah tersebut, sehingga menimbulkan potensi risiko. terhadap infrastruktur dan stabilitas lingkungan. Penelitian ini berfokus pada tebing batuan muda, yang dicirikan oleh formasi geologi terkini, yang rentan terhadap ketidakstabilan lereng. Analisis kestabilan lereng ini dilakukan dengan menggunakan program bantu GEO5 yang akan menghasilkan nilai Faktor Keamanan yang dijadikan dasar dalam membangun suatu konstruksi yang menginterpretasikan aman atau tidaknya suatu lereng. Nilai faktor keamanan yang dijadikan nilai minimum adalah 1,5, sehingga lereng harus mempunyai nilai SF $\geq$ SF min = 1,5. Analisis ini dilakukan pada 4 penampang dengan 2 metode yaitu Metode Morgenstern-Price dan Metode Bishop karena analisis yang dilakukan rumit dari segi gaya dan momen. Faktor Keamanan penampang melintang pada BH-03 sampai BH-01 tidak aman karena nilainya 1,16 dan 1,15 yang < 1,5 (faktor keamanan minimum). Oleh karena itu lereng harus dimodelkan dengan lereng bertingkat dan juga perkuatan dinding penahan untuk setiap tinggi teras yang dimodelkan.

Kata Kunci: *GEO5, Stabilitas Lereng, Tebing Batu Muda*

INTRODUCTION

The foundation is an important part of the structural system of a building, where the function of the foundation is to transfer the loads from the upper structure to the layer of soil underneath (Nur, 2021). Foundation design cannot be separated from the knowledge of the soil condition, while the soil

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condition is related to the soil type. The condition of a clay soil is different from that of a sandy soil in its ability to support the load of a structure. Therefore, when designing the foundation of a building structure, soil investigation is required. The physical and technical properties of the soil can indicate the results of soil investigation. These two properties are needed to determine soil condition in accepting load of a structure Bokade, 2021; Nazara et al., 2018). Therefore, this land investigation work took form of an SPT at 6 points at the Sibang, Bali. This soil investigation work is divided into two stages, namely field work and laboratory work stage. The field work starts early, while the next stage is laboratory work Soil investigation result report as medium for presenting result of the soil investigation that contains information regarding type of soil and analysis of foundation along with result of settlement. SPT test at 6.

The Standard Penetration Test, or SPT continues to be the most widely used in-situ test in the field of used in geotechnical engineering. Its earliest application was to determine pile capacity. However, the use of numerical analysis is becoming increasingly widespread in geotechnical problems. In particular, finite element calculations are now commonly used in foundation design (Hasibuan and Ismaili, 2019).

The points were drilled at depths of 15 m, 20 m and 30 m. Standard Penetration Test (SPT), where the SPT value per 2 metres is a multiple of the. Sampling can be seen in the table below. Sampling depth is measured from land surface. The location of soil investigation work with SPT at Sibang, Bali will be shown in Figure 1.

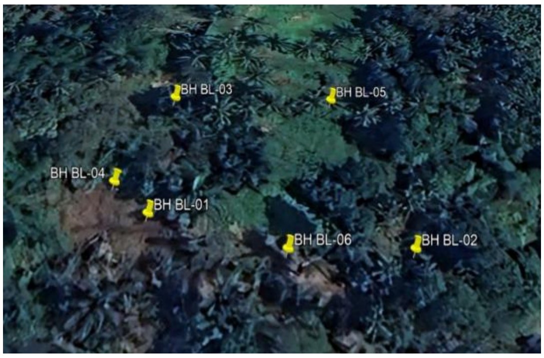

Figure 1. Work Location

The Slope Stability software, a stand-alone program included in the GEO5 software suite, was used to analyse the slope. Various regional and national standards, including the Eurocode, are used in this programme. The program uses standard methods to obtain circular and polygonal slip areas as described by (Görög and Török, 2007). The stability of the slope was determined using the 1 and 3 methods. Information on soil types, their physical parameters and soil stratification are included in the geotechnical study.

RESEARCH METHOD

Slope Stability Analysis

The limit equilibrium method (LEM) is a valuable numerical tool that can be used to solve a variety of engineering and mathematical physics problems. With the rapid advancement of computer technology, LEM has gained increasing popularity in geotechnical engineering, particularly in comparison to traditional methods. In this research, we explore the potential of the limit equilibrium method to numerically obtain the factor of safety for the slope of homogeneous soil.

Limit Equilibrium Method (LEM)

For the analysis of slope stability, a number of limit equilibrium methods (LEM) have been developed. Fellenius is believed to have introduced the first method, known as the normal or Swedish method, for a circular slip surface. Bishop further developed the original method by establishing a new relationship for the base normal force. As a result, the equation for FOS becomes non-linear. At the same time, Janbu developed a streamlined approach for non-circular failure surfaces by segmenting a potential mass into several vertical slices. The generalised procedure is a further development of the simplified method proposed by Janbu. Subsequently, significant contributions were made by Morgenstern-Price, Spencer, Sarma and many other researchers, who formulated alternative assumptions regarding the forces between the slices. Chuge developed a general limit balance procedure as an extension of the Spencer and Morgenstern-Price methods, which satisfies both the moment and forcebalance constraints SLOPE/W.

The following section examines these interdependencies with the aim of identifying the main differences between the various approaches to FOS determination. A common set of assumptions about the normal and shear forces acting between the plates is shared by the various limit equilibrium methods (LEMs). However, the way in which these forces are determined and assumed varies considerably from one method to another. Furthermore, the shape of the assumed slip surface and the equilibration conditions under which the FOS is calculated is another important consideration (Borbeli, 2019).

Morgenstern-Price Method

The Morgenstern-Price method (M-PM), based on the assumption of the interslice force function, also fulfils the requirements of both force and moment equilibrium. The slope of the interslice force can be expressed as an arbitrary function (f(x)) according to the M-PM:

$$T = f(x).\ \lambda.\ E \qquad (1)$$

The function f(x) represents the function of the interslice force, which varies in a continuous manner along the slip surface. The scale factor λ is used to assume the function. Any type of force can be assumed, e.g. sinusoidal, trapezoidal or custom.

The relationships between the base normal force (N) and the interslice forces (E, T) remain consistent with those presented in JGM. In order to compute the interslice forces for a given force function, an iterative procedure is employed until the following condition is satisfied: Ff is equal to Fm.

$$F_f = \frac{\sum[\{cl+(N-ul)tan\varphi\}sec\alpha]}{\sum\{W-(T_2-T_1)\}\tan\alpha+\sum(E_2-E_1)} \qquad (2)$$

$$F_m = \frac{\sum[\{cl+(N-ul)tan\varphi\}}{\sum W\sin\alpha} \qquad (3)$$

The forces under consideration in the context of BSM are illustrated in the accompanying sketch. In addition to considering interslice normal forces (E), the Bishop's Rigorous Method (BRM) also takes into account interslice shear forces (T). Moreover, the method postulates a singular distribution of the resulting forces and ensures that each slice attains moment equilibrium. The determination of the interslice T and E forces, and consequently the FOS, is achieved through an iterative procedure (Shah et al., 2021).

Determination of Safety of Factor

When performing a stability analysis, the factor of safety is a very important consideration. The most commonly used definition of the factor of safety for a slope is the ratio of the shear strength of the soil to the required shear stress. It can be determined from a limit equilibrium analysis using factorised strength parameters. Conventional limit-equilibrium methods can be used for the determination of a unique factor of safety for a slope analysis. Shear strength is often the most uncertain parameter when analysing slope stability. When F=1.0, a slope is considered to be on the boundary between stability and instability. A value of 1.01 would be acceptable (Pratap Singh et al., 2023) if all factors are calculated accurately. However, due to the uncertainty in the variables, the calculation of FOS values is not precise. Therefore, to be on the safe side, the factor of safety should be higher. Another approach to the factor of safety for a slope is the relationship between the resistance and the overturning moment on a circular slip surface (Shooshpasha et al., 2013).

$$F = \frac{available\ resisting\ moment}{actual\ driving\ moment} \qquad (4)$$

Available resisting moment,

$$M_r = \frac{clr}{F} \qquad (5)$$

Here, c is the cohesion, l is the length of the circular area and r is the radius. Actual motion (moment of overturning),

$$Md = Wx \qquad (6)$$

GEO5 Software

The GEO5 software suite is a suite of geotechnical software tools for the solution of a wide range of geotechnical problems. The easy-to-use suite is made up of individual programs with one consistent and user-friendly interface. All modules are designed for different geotechnical tasks, but they communicate with one another and form a complete suite. Analytical and finite element

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geotechnical software consists of programs designed to solve many common problems (Hallale et al., 2023; Singh and Kumar, 2023). It includes integrated modules like Hill Stability, Reinforced Hill Stability, Pinned Hill Stability, Rock Stability, Spreading Footings, Slab, Beam, Pile, Cantilever, Abutment, Gravity Wall, Gabion, Earth Pressure, Lining Design, Lining Control, Settlement, etc. It can be used to model a wide range of geotechnical problems that can be used to study the real behavior of materials in structures, such as beams on elastic foundations and excavations (Moniuddin, 2019).

There are many software packages on the market. Some use the Swedish method of disks and others use more sophisticated methods. The program analyses the stability of generic stratified ground embankments. It is mainly used for checking the stability of dams, cut-and-covers and anchored sheet piles. The sliding surface is regarded as a circle (Bishop, Fellenius and Peterson, Yanbu, Morgenstern and Price or Spencer method) or as a polygon (Santosh et al., 2016; Nur, 20-21).

The Slope Stability program can be used to analytically solve the stability of a generically specified slope consisting of soil or weathered rock. Slope Stability can incorporate stabilization elements such as anchors, nails, reinforcements and/or piles while determining the worst circular or polygonal slip surface and solving specific groundwater scenarios. (Nur, 2021; Dewi and Jaya, 2021)

RESULTS AND DISCUSSION

General condition

SPT conditions based on the SPT test results, as referenced in Hallale et al. (2023) and presented in Table 1.

Table 1 Recapitulation of Laboratory Test Results

Sands		Silts & Clay	
N_{60}	Relative Density	N_{60}	Consistency
0 - 4	Very loose	Below 2	Very Soft
5 - 10	Loose	2 - 4	Soft
11 - 30	Medium Dense	5 - 8	Medium
31 - 50	Dense	9 - 15	Stiff
Over 50	Very Dense	16 - 30	Very Stiff
		Over 30	Hard

Based on the results of the SPT and laboratory tests, the following conclusions can be drawn from this analysis:

1. BL BH-01 with a depth of 1-4 m is classified as Low Medium Plasticity Clay, 5-8 m is considered Very Dense, a depth of 9-12 m is considered Very Dense, and a depth of 13-20 is considered Very Dense.
2. BL BH-02 with a depth of 1-4 m is classified as Very Dense to Loose, 5-10 m is classified as Soft to Stiff Clay, and a depth of 11-15 m is classified as Very Dense to Hard.
3. BL BH-03 with a depth of 1-4 m is classified as Stiff to Very Stiff Clay, a depth of 5-10 m is considered Dense, a depth of 11-15 is considered Very Dense, and a depth of 16-30 is considered Very Dense.
4. BL BH-04 with a depth of 1-4 m is classified as Medium Dense, and a depth of 5- 15 m is considered Very Dense.
5. BL BH-05 with a depth of 1-6 m is classified as Loose, a depth of 7-15 m is classified as Dense, a depth of 16-23 m is considered Very Dense, and a depth of 24-30 is considered Very Dense.
6. BL BH-06 with a depth of 1-4 m is considered Very Dense, a depth of 5-10 m is Very Dense, and a depth of 11-15 m is Very Dense.

The conditions, as determined by laboratory test results conducted at the Soil Mechanics Laboratory, are presented in Table 2.

The shear strength test was carried out using the Direct Shear (DS) test, resulting in a shear angle value of 9,290 – 28,280 and a cohesion value of 0.09 kg/cm^2 – 0.940 kg/cm^2. A small shear angle is obtained so that it is classified as clay and sand type soil. In general, the soil layer at this location is categorized as Slightly – Moderately compressible. According to the LL value, it is land with a high to very high category (high to very high).

Slope Stability Analysis

This slope stability analysis is performed using the GEO5 tool, which produces a safety factor value used as the basis for constructing a construction interpreting whether the slope is safe or not (Manurung et al., 2021).

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Tabel 2. Recapitulation of Laboratory Test Results

No	Drill Point	Depth (m)	% Passing Sieve No. 200	Cu	Cc	LL	PI	Soil Classifi-cation	Dominant
1.	BH BL-01	3,5-4 m	53,16	22,75	0,54	-	-	CL	SW
		7,5-8 m	42,06	25,00	1.36	-	-	SW	
		11,5-12 m	8,71	8,57	0,88	-	-	SP	
		17,5-18 m	40,05	23,40	1,86	-	-	SW	
2.	BL BH-02	3,5-4 m	26,79	29,51	7.38	-	-	SP	SP
		9,5-10 m	56,56	22,50	0,34	-	-	CL	
		14,5-15 m	19,41	10,00	7,46	-	-	SP	
3.	BL BH-03	3,5-4 m	53,90	23,00	0,46	-	-	CL	SP
		9.5-10 m	49,16	26,83	0,64	57,54	19,98	SP	
		14,5-15 m	37,37	27,08	2,56	-	-	SW	
		19,5-20 m	45,54	29,27	0,90	-	-	SP	
		24,5-25 m	32,96	33,33	4,15	-	-	SP	
		29.5-30 m	47,06	31,71	0,61	-	-	SP	
4.	BL BH-04	3,5-4 m	38,60	27,08	1,96	59,61	21,45	SW	SP
		9,5-10 m	28,12	30,00	6,08	-	-	SP	
		14,5-15 m	33,90	30,77	3,91	-	-	SP	
		19,5-20 m	27,05	30,16	6,77	39,10	9,67	SP	
5.	BL BH-05	3,5-4 m	33,10	25,00	5,33	-	-	SP	SW/SP
		9,5-10 m	41,11	24,44	1,82	-	-	SW	
		14,5-15 m	33,55	27,45	4,71	-	-	SP	
		19.5-20 m	41,37	28,89	1,34	-	-	SW	
		24,5-25 m	37,84	2,45	0,26	-	-	SP	
		29.5-30 m	43.18	24,44	1,26	-	-	SW	
6.	BL BH-06	3,5-4 m	43,50	25,58	1,32	-	-	SW	SP
		9,5-10 m	29,01	28,33	6,43	-	-	SP	
		14,5-15 m	28,88	46,67	4,30	-	-	SP	

The safety factor value used as the minimum value is 1.5, so the slope must have a SF value ≥ SFmin = 1.5. This analysis was carried out on 4 cross sections with 2 method which name is Morgenstern-Price and Bishop Method because the analysis carried out was complex in terms of force and moment.

The cross section BH BL-03 to BH BL-01, BH BL-03 to BH BL-04, BH BL-05 to BH BL-02 and BH BL-05 to BH BL-06 as follows (Figure 2):

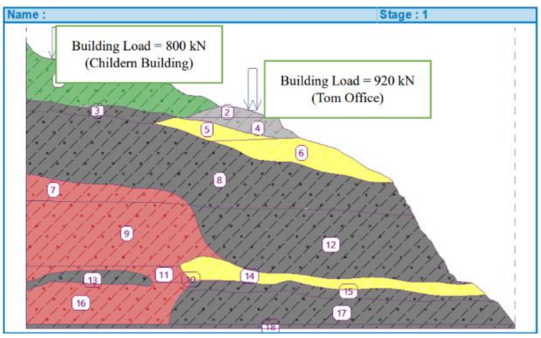

Figure 2 Slope stability analysis

After analyzing the slope stability, the following results were obtained, which is depicted in Figure 3.

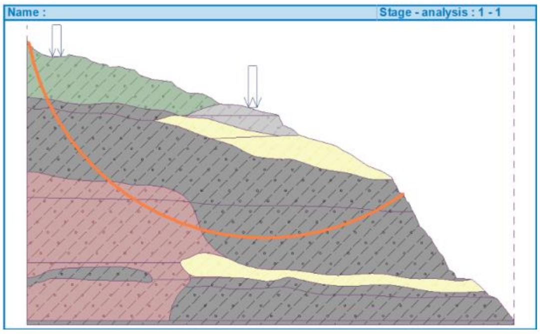

Figure 3 Line slide analysis

Based on Figure 3, the slip surface results are obtained which cut the part in the orange diagram which has the most critical safety factor values as follows. Slope stability verification (all methods):

Bishop :	FS = 1,16 < 1,50	NOT ACCEPTABLE
Fellenius / Petterson :	FS = 1,00 < 1,50	NOT ACCEPTABLE
Spencer :	FS = 1,16 < 1,50	NOT ACCEPTABLE
Janbu :	FS = 1,15 < 1,50	NOT ACCEPTABLE
Morgenstern -Price :	FS = 1,15 < 1,50	NOT ACCEPTABLE

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In light of the aforementioned results, two methods were employed: the Morgenstern-Price and Bishop methods. It was determined that the SF value was not secure, as the SF value was less than the permitted SF value of 1.5. This is due to the fact that the slope in question exhibits a considerable degree of steepness, coupled with the vulnerability of the soil on young rocks at the edge of the slope, which displays a relatively low soil bearing capacity. Consequently, it is imperative to reinforce the slope, a process that can be effectively achieved through the implementation of a counterweight model, which represents the optimal solution for repair, and is also a cost-effective option.

Apart from that, modeling terrace slopes as be seen in Figure 4, can be assisted by strengthening the retaining walls on each terrace. Terracing and retaining wall planning will be shown in Figure 5.

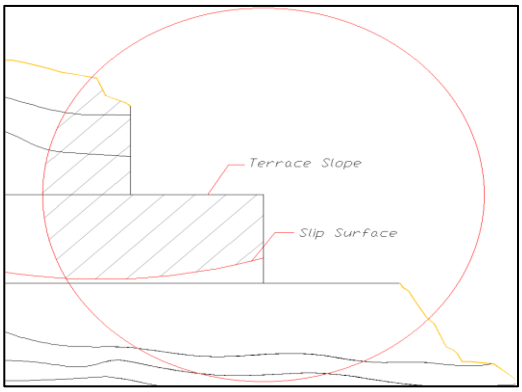

Figure 4 Modeling terrace slope

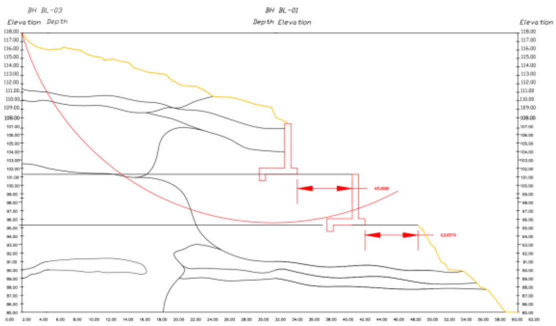
Figure 5 Retaining wall modeling

The retaining wall modeling above can be used with dimensions of a cantilever wall height of 5 m with embedded sections 1 m deep using concrete as the material. Retaining walls are modeled to cut slip areas that occur due to loads on the ground surface. Retaining walls can be modeled according to needs to increase the safety factor value before strengthening. The analysis can be shown in Figure 6.

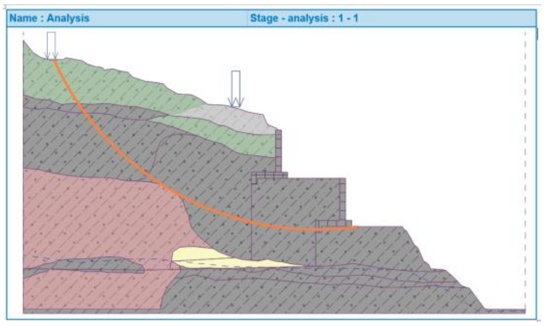

Figure 6 Strengthening the retaining wall

Slope stability verification after strengthening the retaining walls on each terrace (all methods).

Bishop :	FS = 1,98 > 1,50	**ACCEPTABLE**
Fellenius / Petterson :	FS = 1,81 > 1,50	**ACCEPTABLE**
Spencer :	FS = 2,07 > 1,50	**ACCEPTABLE**
Janbu :	FS = 2,01 > 1,50	**ACCEPTABLE**
Morgenstern -Price:	FS = 2,01 > 1,50	**ACCEPTABLE**

CONCLUSION

Based on SPT Test, Laboratory Test, and GEO5 result it can be concluded as follows:

1. The soil type is dominated by rocky sand which has a very dense consistency.
2. The Safety Factor of cross section on BH-03 to BH-01 is not safe because the value is 1,16 and 1,15 which is < 1,5 (the minimum safety factor). So therefore the slope must modelled with terraced slopes and also retaining wall reinforcement for each modelled terrace height.
3. The Safety Factor of cross section is safe because the value is more than 1,5 (the minimum safety factor). So the planned building can be built in that area. Even though these results are declared safe, it is necessary to strengthen the retaining wall to cut off the sliding area that occurs.
4. The recommended height of the retaining wall for the BH-03 to BH-01 section.

Geological analysis can serve as a valuable tool for field validation. By comparing it with SPt results, it is possible to identify discrepancies and correct any calculation errors that may have occurred while using GEO5. This additional step in the validation process can help to ensure the accuracy and reliability of the results obtained, which is critical for any project that relies on this data.

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