

Influence of Foundation Layer Strength on Slope Stability When Water Level Drops Slowly

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Abstract. Construction projects for construction, railway, highway, water conservancy, and urban infrastructure will involve the problem of slope stability without exception. Slide loss will not only affect the normal use of the building, but also cause significant losses to human life and property. Therefore, the analysis of the stability of the slope has very important theoretical significance and practical value. There are two main analysis methods of slope stability. The limit balance method and strength discount of the finite element method. However, most of the landslide stability analysis used in practice still uses the limit balance of the basis of the basics of decades of unchanged slices. Law. This article mainly uses the finite element method for numerical simulation. The finite element software Slope 64 is used to establish a data model and iterates to calculate the results, and the results are obtained, and further analysis is made to provide the theoretical foundation for future practical applications. Analyze the average slope and the stability change trend, the laws of stability coefficient, and the rules of damage when the water level decreases slowly. The finite element method can take into account the geometric shape of the slope that cannot be considered, the model and non-linear loading of the soil body, and the non-linear loading. The strong slope stability analysis method has high accuracy and high accuracy, and requires less assumptions, especially in terms of destroying the mechanism. In the end, with the slow decline in the water level, there is a certain trend of the security factor of the slope. Generally, the lowest point will occur first and then there will be a short period of time. The safety factor of completely drowned slope is not affected by the depth of water above the top. The stability of the sub-slope is higher than the stability of the slope. As the strength of the basic layer increases, the stabilization coefficient of the slope is unchanged when the water level slowly decreases, but the water level of the lowest stability coefficient continues to rise, and the base layer strength increases to the stable coefficient size of the slope when the slope is increased to a certain value. The stability coefficient of the average slope of changes and the slow decrease in the water level tends to be consistent.

Keywords: Finite element method, slope stability analysis, slow drop of water level, foundation layer strength, safety factor.

1. Introduction

1.1. The Purpose and Significance of Slope Stability Analysis

Landslides are widely distributed and destructive. It is not easy to find and is often accompanied by other geological disasters. In the world, a large number of casualties and economic losses are caused by disasters such as landslides[1]. Many landslides are in a state of unstable or stable state, which directly affects the safety of residential property and county roads before the slope. Therefore, it is urgent to perform engineering governance of the landslide, which can not only ensure the safety of the lives and property of the residents before the slope, but also have a good promotion effect on the stability and development of the national economy[2]. To effectively and effectively landslide governance, it is bound to analyze a comprehensive and detailed analysis of the stability of the landslide. At present, there are many stability analysis methods, but these stability methods have their own limitations. How to choose a reasonable stability analysis method is particularly important.

1.2. Development and Research Status of Slope Theory

1.2.1. Development of slope stability theory

The stable analysis method of the slope can be divided into two categories in general [3]. One is the method of determining the analysis method, the content mainly includes the limited balance method, the limit analysis method, and the finite element method, etc [4]. The other category is a non-definitive analysis method. Non-deterministic analysis methods are relatively complicated and the theoretical development is relatively late. At present, there are fewer people using this method in the project, and more applications are the limited balance method and the finite element method [5]. The advantage of the limit balance method is that the model is simple, easy to calculate, and can be quantitatively evaluated by the soil slope. Its disadvantage is that it needs to assume the position of the sliding surface in advance and introduce some simplified assumptions. Better development. The finite element method fills many of the shortcomings in the limited balance method, and does not need to assume the position of the sliding surface in advance. Popular content.

1.2.2. Finite element method for slope stability analysis

The finite element method is a new type of numerical analysis method developed in the 1960s and 1970s. It solves many complex problems. It has fast calculation speed and high efficiency. It is widely used in actual engineering. The basic idea of the finite element method is to first split a continuous entity into a unit with limited number. Generally, the shapes of these units are very regular. These units only keep in touch on limited nodes. Converted into the force that only acts on nodes, and the boundary constraints become node constraints. After that, the force and displacement on each node is calculated through mechanics methods, so as to calculate the power and size of each unit until the entire structure and the displacement. [6]. The finite element law will make some assumptions that can only get a approximate solution, but the accuracy of the final result can still meet the project request.

The procedures used in this article are based on Smith and Griffith (1998) "Program Slop 64". Graphic output ability. This program is a two-dimensional plane strain analysis for elastic-complete viscosity soil. With the Moore Cutun Guideline, during the process of gravity load, in the stage of the rigid matrix of the algorithm and the stress heavy distribution stage, 8 node quad-sideline units are adopted, and the eight-node quad-shaped unit, and and of. Reduce points (4 Gaussian dots in each unit). First of all, it is assumed that the soil is elastic soil, and the model generates a method for stress and shear stress on all Gaussian dots in the grid. These stress are then compared with the Moore Kulun criteria. If the stress of a specific Gaussian dot is located in the range of Moore Curon's failure, it is assumed that the location is kept elastic[7]. If the stress is located or beyond the failure package, then this position is assumed that it is yielded. Symbol stress re-distributed in the entire grid, using Perzyna 1966, Zienkingicz, and Cormeau, 1974). When there is enough Gaussian dot to make it develop into a mechanism, overall cutting and damage occur.

Linear issues such as predicting sedimentation and deepening variables, and stable penetration flow are particularly suitable for solving with finite elements[8]. Traditional methods are often sufficient for conventional problems, but if the traditional chart method cannot be solved Change, the finite element method is very practical. The finite element method can avoid the possibility of generating misleading results, to better explain the mechanism of decline, and simplify a large amount of calculation process.

1.2.3. The advantages of finite element method

Compared with the traditional limit equilibrium method, the advantages of the finite element method in slope stability analysis can be summarized as:

1. There is no need to assume the shape and position of the slope in advance. Failure "naturally" occurs in areas within the soil where the soil's shear strength is unable to resist the applied shear stress.
2. Since there is no slice concept in the finite element method, there is no need to assume edge forces, and the finite element method maintains global equilibrium before reaching "failure".

3. If real soil compressibility data are available, the finite equation solution will give information on deformation at the operating stress level.

4. The finite element method is a method used to monitor progressive failure up to and including global shear failure.

1.3. Research methods and content of the paper

1.3.1. Introduction to slope64

Slope64 is a software that uses finite element to analyze landslide stability written by Professor Griffith of Colorado School of Mines in September 2015. After the slope stability software runs normally, EX4.Res (indicate the estimated safety factor for the output file) and ex4.dis (the file of the deformation grid) will be obtained.

Soil model used in this study includes 6 parameters, as shown in Table 1.

Table 1. Six parameters of soil model

Parameters	symbol
friction angle	ϕ
Cohesion	c
expansion angle	Ψ
Young's modulus	E
Poisson's ratio	γ
Unit weight	γ

The soil model dimensions used in this study are shown in Figure 1:

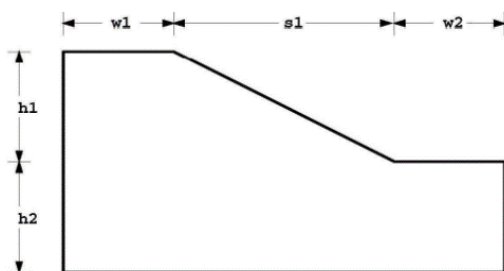


Fig. 1 Model size

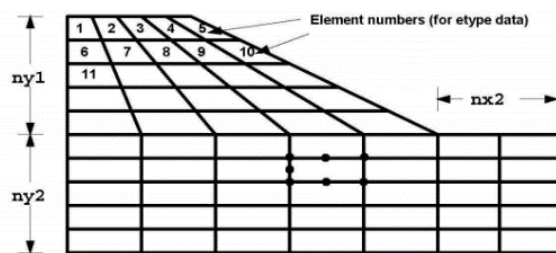


Fig. 2 Model meshing

The soil model mesh used in this study is shown in Figure 2:

Based on the strength reduction finite element theory and with the help of slope 64 software, this paper conducts an in-depth and thorough study of the influence of the foundation layer strength on slope stability, explores the instability criteria and instability rules, and finally applies the obtained results to specific applications. in the project.

1.3.2. Specific research content and conclusions of the paper

(1) Based on the strength reduction finite element theory, with the help of slope 64 software, for the same slope example, the convergence, displacement mutation and deformation grid diagram and deformation vector diagram were generated, and the total plastic strain energy mutation was calculated. The theory is used as a criterion for slope instability to calculate the safety factor, and the results under various circumstances are compared and analyzed to obtain the slope stability change trend, and the calculated safety factor is more accurate.

(2) Using the total plastic strain energy mutation theory as the criterion for slope instability, the influence of the strength of the base layer on the safety factor of the slope was studied, and the influence trend of the strength c_2 of the base layer on the safety factor was obtained.

(3) A numerical model was constructed to calculate the safety factor of the slope using the total plastic strain energy mutation theory as a criterion, thereby making an accurate judgment on the stability of the slope and laying a theoretical foundation for future research.

2. The effect of slow decline in water level on the stability of the average slope

As shown in Figure 3, there is a horizontal free surface at the depth L at the peak. Using the above method, the safety coefficient of the landslide has been calculated. This coefficient has several different values (L/H) that changes from -0.2, and its change is -0.2(the water level is completely immersed in the top of the top 0.2h) to 1.0(Water level at the bottom of the landslide). The problem can be interpreted as the problem of "slow". Among them, at the top of the slope (L), it gradually dropped to the bottom, and the water level in the slope maintained the same level. The total weight $20\text{KN}/\text{m}^3$ that has been distributed to the entire slope above and below.

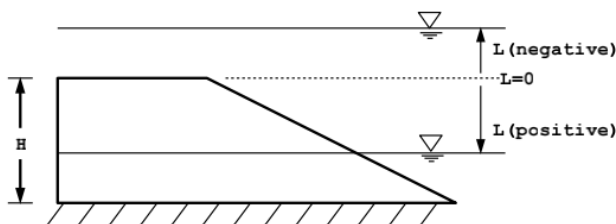


Fig. 3 Slowly lowering the water level, the average slope of the horizontal free surface.

Assuming the parameters are as follows:

$$w1 = 12; s1 = 20; w2 = 0; h1 = 10; h2 = 0; C = 10; \gamma = 9.8; E = 10^5; \nu = 0.3$$

2.1. Analysis of the stability of the average slope when the water level drops slowly when $\Phi \neq 0^\circ$

Suppose $\phi = 20^\circ$, The trend of stabilization coefficient FOS with the change of L/H is shown in Figure 4 below:

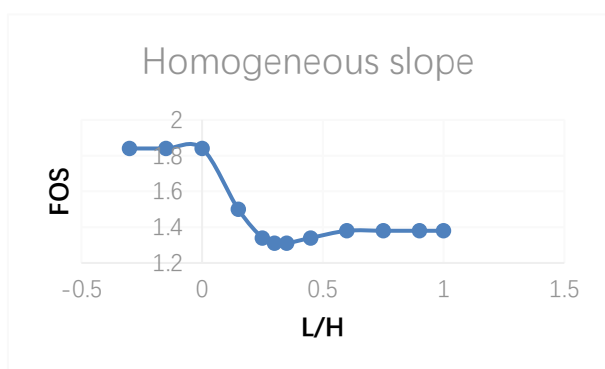


Fig. 4 The trend in the stability coefficient

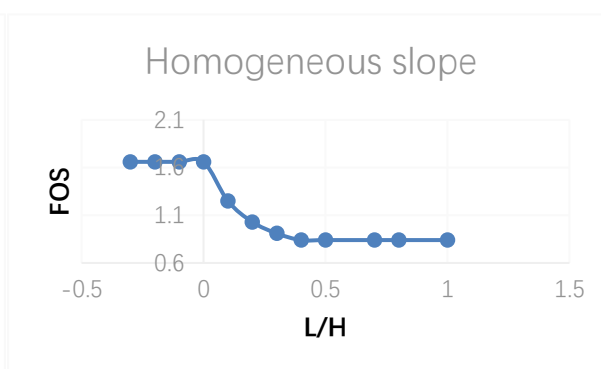


Fig. 5 The trend in the stability coefficient

The stability coefficient changes in Figure 4 slowly decreased.

During the decline of the water level, the stability coefficient will go through a process of stability-decline-rising. When the local water level is completely immersed in the slope, the stability coefficients are the largest and remain unchanged, and the slope remains stable; when the water level drops slowly, when $L/H = 0.3$, $FOS = 1.31$ reaches the minimum value; then gradually rebounds, and then gradually increases, and then gradually increases, and then gradually increases, and then gradually increases. Towards stability. However, the stability coefficient was reduced at the beginning, and the reduction rate gradually decreased; and the phenomenon of slow recovery when the slope stability coefficient reached a minimum value, but the increase in increased at this time was small, and then gradually tended to gradually tend to gradually tend to be. Yu smooth.

The deformation diagram of the stable coefficient of the stable coefficient is in Figure 6:

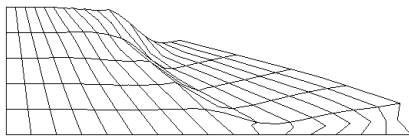


Fig. 6 Slope deformation grid

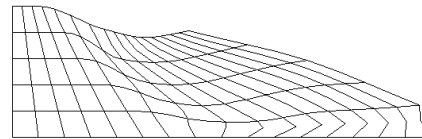


Fig. 7 Slope deformation grid

The safety factor of $L/H = 0$ and $L/H = 1$ shows that the sneak slope is shown in a higher safety factor than the dry slope.

It explains the minimum value generated by changes in the bonding strength of the slope (not affected by the bulge) and the balance between the weight of the soil weight and the soil shear strength. At the beginning of the decline ($L/H < 0.3$), the increased weight ratio of the increased weight and the safety factor of the increased stability effect. However, at a high level of gap ($L/H > 0.3$), the increase in friction intensity has a greater impact on the weight increase, and the safety factor also increases.

2.2. Analysis of the stability of the average slope when the water level drops slowly when $\Phi=0^\circ$

The trend of stabilization coefficient FOS with the change of L/H is shown in Figure 5. From the figure, at $L/H = 0.4$, $FOS = 0.84$ reaches the minimum value.

The deformation diagram of the stable coefficient of the stable coefficient is in Figure 7:

The safety factor of $L/H=0$ and $L/H=1$ shows that the submerged slope has a higher safety factor than the dry landslide.

The minimum value due to the cohesive strength of the slope (independent of uplift) and the tradeoff between soil weight and soil shear strength as the level of decline changes is explained. In the initial descent ($L/H < 0.4$), the increased weight has a greater destabilizing effect than the increased friction strength and safety factor. But at higher drop levels ($L/H > 0.4$), the increase in friction strength begins to have a greater impact than the added weight, and the safety factor increases. Lane and Griffith (2000) report other results in which such slopes are stable when "dry" or completely submerged ($FOS > 1$), but become unstable when they drop below a critical value of L/H . It should also be noted from the horizontal part of the figure (corresponding to) that the safety factor of a completely submerged slope is not affected by the water depth above the top.

Compared to the example in the previous chapter, there is no rebound in this example. In the process of water level falling, the stability coefficient will go through a process of stability-declining stability. When the ground water level is completely immersed in the slope, the stability coefficient is maximum and remains unchanged, and the slope remains stable. When the water level drops slowly, $FOS=0.84$ reaches the minimum value when $L/H=0.4$. Then it gradually leveled off. Unlike the previous example, when the stability coefficient is lowest, the stability coefficient is below 1, and it is highly likely that a failure has occurred.

3. Influence of foundation layer strength on slope stability when water level drops slowly

When the parameters are as follows:

$w1=12$; $s1=20$; $w2=12$; $h1=10$; $h2=10$; $C1=10$; $\gamma=9.8$; $E = 10^5$; $\nu=0.3$.

3.1. Slope Stability Analysis under Different Foundation Layer Strength When the Water Level Drops Slowly When $\Phi \neq 0^\circ$

Suppose $\phi=20^\circ$.

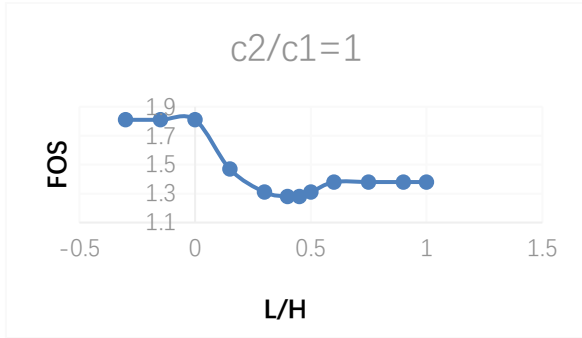


Fig. 8 When $C2/C1 = 1$, FOS changes with L/H

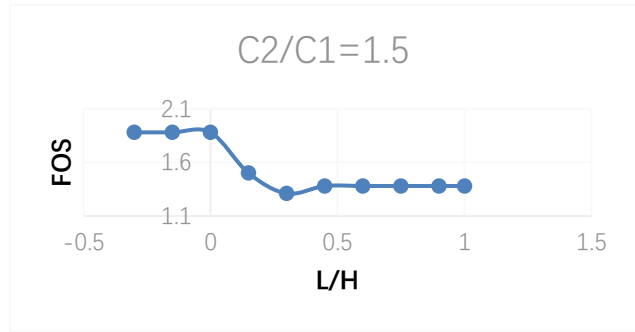


Fig. 9 When $C2/C1 = 1.5$, FOS changes with L/H

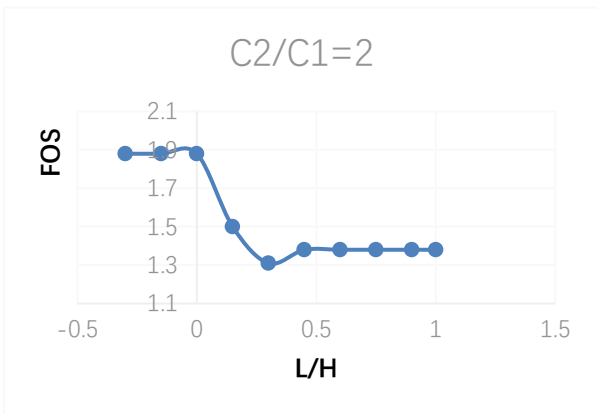


Fig. 10 When $C2/C1 = 2$, FOS changes with L/H

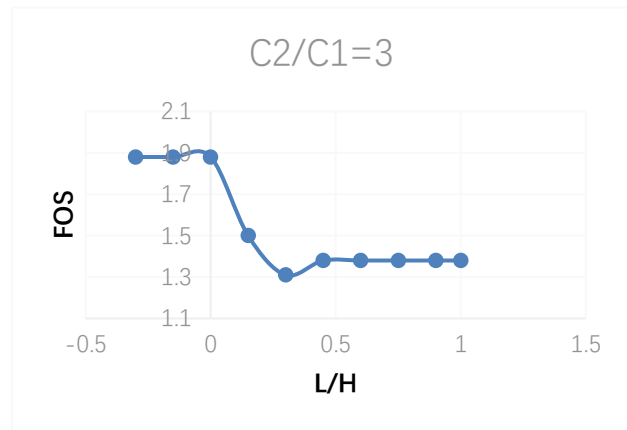


Fig. 11 When $C2/C1 = 3$, FOS changes with L/H

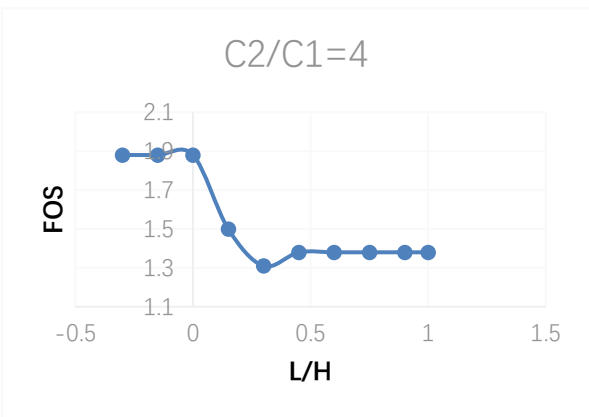


Fig. 12 When $C2/C1 = 4$, FOS changes with L/H

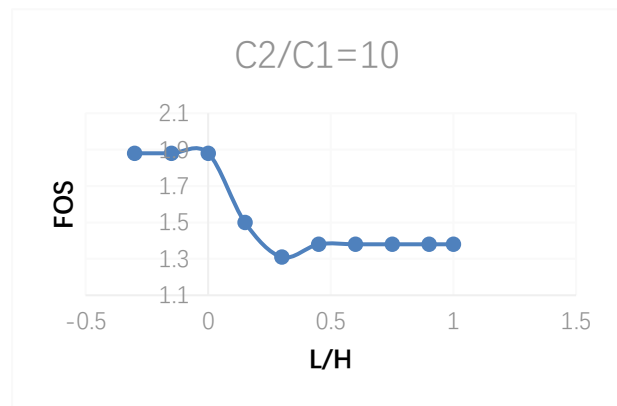


Fig. 13 When $C2/C1 = 10$, FOS changes with L/H

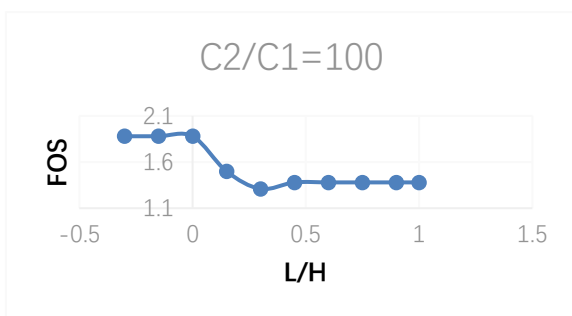


Fig. 14 When $C2/C1 = 100$, FOS changes with L/H

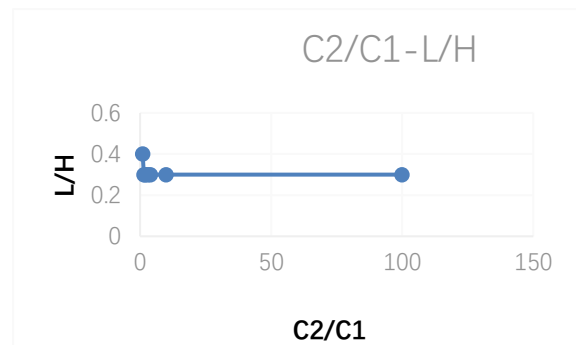


Fig. 15 L/H changes with the base layer

with L/H

From the figure, when the FOS reaches the minimum value, the relationship between C2/C1 and L/H is:

Table 2. FOS low, C2/C1 and L/H relationship

Numble	C2/C1	L/H	FOS
1	1	0.4	1.28
2	1.5	0.3	1.31
3	2	0.3	1.31
4	3	0.3	1.31
5	4	0.3	1.31
6	10	0.3	1.31
7	100	0.3	1.31
8	average slope	0.3	1.31

That is, as the base layer strength C2 increases, the L/H value of the lowest stability coefficient is getting closer and more than 0.3, the greater the base strength, and the deformation is lighter. The stable coefficient size is the same as the critical value of the average slope.

3.2. Slope Stability Analysis Under Different Foundation Layer Strength When The Water Level Drops Slowly When $\Phi=0^\circ$

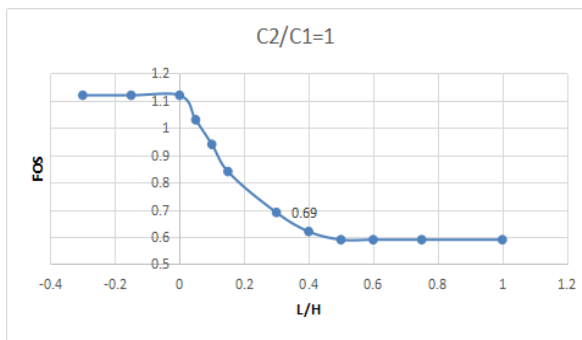


Fig. 16 When C2/C1 = 1, FOS changes with L/H

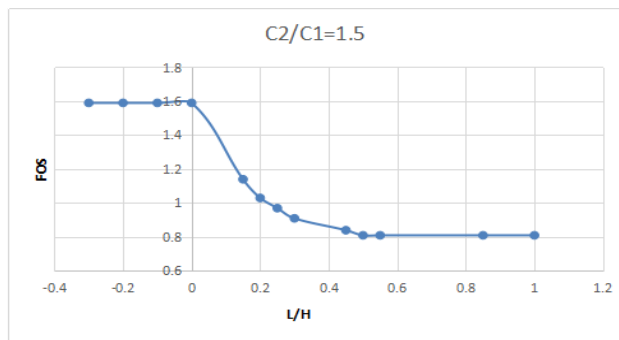


Fig. 17 When C2/C1 = 1.5, FOS changes with L/H

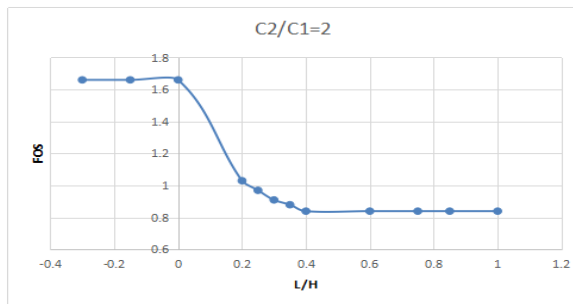


Fig. 18 When C2/C1 = 2, FOS changes with L/H

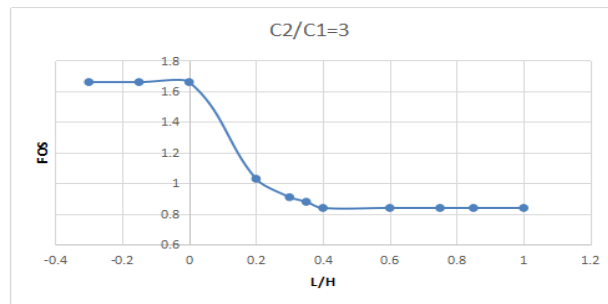


Fig. 19 When C2/C1 = 3, FOS changes with L/H

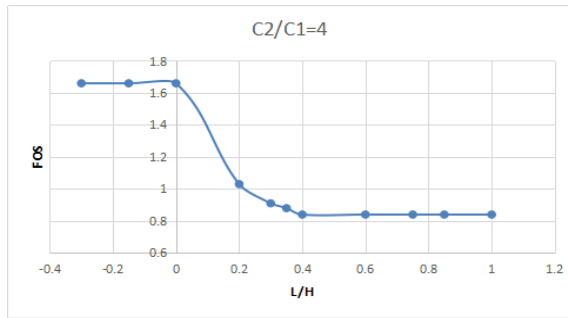


Fig. 20 When $C2/C1 = 4$, FOS changes with L/H

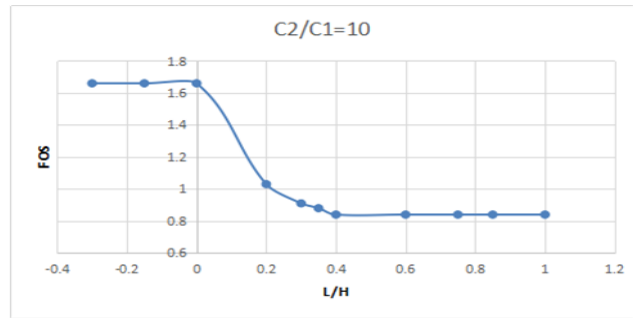


Fig. 21 When $C2/C1 = 10$, FOS changes with L/H

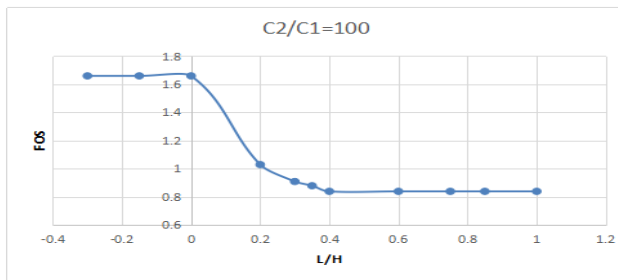


Fig. 22 When $C2/C1 = 100$, FOS changes with L/H

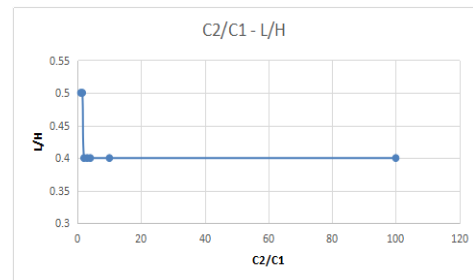


Fig. 23 L/H changes with the base layer

From the figure, when the FOS reaches the minimum value, the relationship between $C2/C1$ and L/H is:

Table 3. FOS low, $C2/C1$ and L/H relationship

Numble	$C2/C1$	L/H	FOS
1	1	0.5	0.59
2	1.5	0.5	0.81
3	2	0.4	0.84
4	3	0.4	0.84
5	4	0.4	0.84
6	10	0.4	0.84
7	100	0.4	0.84
8	average slope	0.4	0.84

Trend: stability-drop to minimum-stability. When the stability coefficient reaches the minimum point, the slope is unstable, and the stability coefficients have been damaged at the early hours. With the increase of the base layer strength $C2$, the value of the L/H when the stability coefficient becomes stable is getting closer and more than 0.4, and the deformation is getting lighter and lighter with the basic layer intensity, which is the same as the critical value of the average slope. They are all 0.4.

4. Summary

1. In real life, the Φ value is generally not 0. As the strength of the base layer increases, the stability coefficient will undergo a stabilization-decline-rise process as the water level decreases. When the groundwater level completely submerges the slope, the stability coefficient is the largest and remains unchanged, and the slope remains stable; when the water level slowly drops, in the above example when $L/H=0.3$, $FOS=1.31$ reaches the minimum value; then it gradually rises, Then it gradually stabilized. However, the stability coefficient decreases greatly at the beginning, and the rate of decrease gradually decreases; when the slope stability coefficient reaches the minimum value, it slowly rises again, but at this time the increase is smaller than the decrease, and then gradually

increases. Yu Ping. And as the strength of the foundation layer increases, it can be seen that the slope deformation mechanism when the stability coefficient is the smallest becomes shallower and shallower.

The safety factor of a fully submerged slope is not affected by the depth of water above the top.

This is a minimum due to the cohesive strength of the slope (which is not affected by uplift) and the trade-off between soil weight and soil shear strength as a function of drawdown level. In the early stages of descent ($L/H < 0.3$), the increased weight has a greater destabilizing effect than the increased friction strength and safety factor. But at higher drop levels ($L/H > 0.3$), the increase in friction strength starts to have a greater impact than the added weight, and the safety factor also increases.

2. When the Φ value is 0, as the strength of the base layer increases and the water level decreases, the stability coefficient will undergo a stabilization-decline-stability process. When the groundwater level completely submerges the slope, the stability coefficient is the largest and remains unchanged, and the slope remains stable; when the water level decreases slowly, in the above example, when $L/H=0.4$, $FOS=0.84$ reaches the minimum value; and then gradually tends to Yu Ping. The difference from the previous example is that when the stability coefficient is the lowest, the stability coefficient is lower than 1, and the slope has been damaged. And as the strength of the foundation layer increases, it can be seen that the slope deformation mechanism when the stability coefficient is the smallest becomes shallower and shallower.

Likewise, the safety factor of a fully submerged slope is not affected by the depth of water above the top.

This is again a minimum due to the cohesive strength of the slope (which is not affected by uplift) and the trade-off between soil weight and soil shear strength as a function of drawdown level. Because the friction strength is 0, in the early stage of descent ($L/H < 0.3$), the increased weight has a relatively large destabilizing effect on the safety factor. However, at a higher drop level ($L/H > 0.3$), the friction strength has no effect, and the increased weight has less impact on the stability coefficient, so the safety factor also increases.

3. In short, as the strength of the base layer increases, the stability coefficient of the slope remains unchanged when the water level slowly decreases. When the water level drops to a certain level, there will always be a minimum value of the slope stability coefficient, and as the strength of the base layer increases, the stability coefficient of the slope remains unchanged. At this time, the ratio of the distance between the water level and the upper surface of the slope to the height of the slope becomes smaller and tends to a stable value, that is, the water level becomes higher and higher. At the same time, it was also found that when the strength of the foundation layer increases to a certain value, the changes in the stability coefficient of the slope tend to be consistent with the stability coefficient of the homogeneous slope when the water level slowly decreases.

When the minimum stability coefficient is greater than 1, failure may not necessarily occur, but when the stability coefficient is less than 1, the slope will become unstable.

4. Regardless of changes in the base layer, submerged slopes have a higher stability coefficient than dry landslides.

5. The conclusion of this article plays an early warning role for actual events to a certain extent. When analyzing landslide stability, the influence of base layer strength on slope stability should be considered. At the same time, it also shows that the rise and fall of groundwater level is a very important factor affecting the induced slope instability.

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