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Analysis of Road Embankment Slope Stability

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Abstract

The stability of earthworks (cuttings, embankments, dikes) and natural slopes is a problem that is of concern to geotechnicians, both practitioners and researchers. The disorders generated by breaking the slopes are usually spectacular, often destructive and sometimes murderers. Many methods of calculating stability have been proposed. These are differentiated by the assumptions accepted by their authors (methods of calculation in equilibrium limit, methods of calculation at break, deformation calculation methods) and the ease of their implementation (calculations using charts, automatic calculations using software), but they all agree to define an overall factor of safety according to which the stability of the studied slope is considered to be insured or compromised, or by safety factor spartial effects on the one hand, applied stresses and, on the other hand, the mechanical properties soil. Various embankment strengthening techniques have been developed. They are differentiated by the process of their realization, their cost and their durability. The main objective of this study is to present the problems of both natural and artificial slope stability on construction projects. In this regard, special emphasis is given to the sensitivity of the calculation model input parameters (soil, load), which should contribute to raising awareness about this issue, as a prerequisite to make the right decisions and optimal technical solutions in this area.

Keywords

Slope Stability, Soil Parameters, Factor of Safety, Simplified Bishop Method

1. Introduction

Construction of road embankment with varied heights is constantly carried out in China. Construction of embankment is not infrequently done over a relatively incompressible soft soil consistency; so that needs to be improved to avoid the dangers of slope sliding both internal and overall stability. Landslide could have been caused by its own weight embankment, the slope embankment and the traffic loads over the road embankment. Experience and observations suggest that the instability of slopes in most cases shows as sliding mass of soil, the sliding body, in a straight or curved sliding surface. Because of the stresses in the top and negligible soil strength, especially in the case of fine-grained soil, an opening crack occurs, which due to the direction of motion, may be revealed as a scarp on the surface. The appearance of such crack is a clear sign of instability of the slope at an early stage of its occurrence. Crack suggests that it may continue into the new sliding surface. The area of the sliding body and the environment around it is called a landslide. Slip of the slope can occur rapidly with the advent of large displacements which is achieved in a short period of time, after which the sliding mass stays in the new equilibrium position. But, sliding can be a longtime and complex process, which sometimes influences changes in geometry of the landslide.

2. Stability Analysis

Two methods are used to solve subgrade stability analysis: Finite Element Method (FEM) and Limit Equilibrium Method (LEM). In development LEM method is more often used by Engineers because they are more familiar than the FEM method. To simplify the calculations, analyzes were performed using several auxiliary computer programs. Some of the previous limit equilibrium method is still using a simple method that is able to be calculated by hand without the use of assistive computer programs. An example is the analysis of landslide by Haefeli (1948) and $\phi u = 0$ for un-drained analysis by Fellenius (1918) [1]. With the development of the technology, the calculation of landslide analysis developed using computer program. The calculation of the program is still based on the method of slices. The first slice method was developed by Fellenius (1927) and then developed several analytical studies using slice method in 1950-1960s [2].

Bishop (1955) also developed a method of sliding analysis with slices method [3]. This was followed by other researchers: Janbu *et al.* (1956) [4], Lowe and Karafiath (1960), Morgenstern and price (1965) [5] and Spencer (1967) [6]. Other methods of 2D slices with Limit equilibrium method has been studied by Fellenius and Krahn (1984), Nash (1987); Morgenstern (1992), Duncan (1996). Zhu *et al.* (2003) have summarized some results of calculations by the method of slices [7].

All existing methods are used to calculate the value of 'factor of safety' (FS) for the sliding of embankment. FS values obtained in the analysis of failure of embankment are from the ratio between the ultimate shear strength (resistance force) with Mobilized shear stress (driving force) in a landslide. Several formulas can be used to obtain the value of FS. Assumption of the calculated Fs value is constant throughout the field of landslides and the result of force and moment equilibrium on a slip plane. Formulas used are:

2.1. Moment Equilibrium

Typically used in the analysis of the rotation of a slip plane in the embankment. FS values in this assumption are the ratio of resistance moment to a driving moment.

$$\frac{Mr}{Md} = FS \quad [8]$$

where Mr is the sum of the resisting moments and Md is the sum of the driving moment.

For a circular failure surface, the centre of the circle is usually taken as the moment point for the convenience. For a non-circular failure surface, an arbitrary point for the moment consideration may be taken in the analysis. It should be noted that for methods which do not satisfy horizontal force equilibrium (e.g. Bishop Method), the factor of safety will depend on the choice of the moment point as "true" moment equilibrium requires force equilibrium. Actually, the use of the moment equilibrium equation without enforcing the force equilibrium cannot guarantee "true" moment equilibrium.

2.2. Force Equilibrium

Usually used in translation or rotational sliding on the slip plane-shaped planar or polygonal. FS value is the ratio between the resisting forces and driving forces. The moment equilibrium method is referenced in this research.

$$\frac{Fr}{Fd} = FS \quad [9]$$

where Fr is the sum of the resisting forces and Fd is the sum of the driving forces.

Based on the method often used is Ordinary/Fellenius, Simplified Bishop, and Morgenstern-Price is a method based on the moment equilibrium; While the method developed by Janbu uses the Force equilibrium method as shown in **Table 1**.

Spencer uses both methods in his research. Fredlund and Krahn (1977) conducted a comparative analysis of the five methods mentioned above to calculate the values of Fs on the same embankment height but different subgrade. FS

Table 1. Comparison of factor of safety equation.

Method	Factor of safety based on	
	Moment equilibrium	Force equilibrium
Ordinary of Fellenius	x	
Simplified Bishop	x	
Spencer's	x	x
Janbu's simplified		x
Morgenstern-Price	x	x

values obtained from each method are almost equal with the difference value is around ± 0.1 as shown in Table 2.

3. Choice of Slope Stability Calculation Method

Another important choice, which depends on the means that can be used, is that between a method that models the entire soil mass and a method defined locally, along a fracture surface, for example. However, with the possibilities of analyzing a large number of potential failure curves, the two approaches come together. In the case of an all-mass calculation, this will directly provide the most probable failure zone, whereas a method based on a previously defined curve will be repeated a large number of times for a similar result. This choice must therefore be made by examining the available means, the overall behavior of the slope, but also by ensuring the possibility of obtaining the calculation parameters corresponding to the model. The overall behavior of the slope corresponds to four mechanisms that result in differently distributed soil displacements (Vaunat *et al.*, 1992).

- When a rigid mass can move along a well-defined surface of geometry, the behaviour is controlled by the Mohr-Coulomb law, which gives the tensile shear strength τ. In undrained conditions, this resistance is the undrained shear strength S_u. When interstitial pressures are known, shear strength can be expressed in effective stresses, according to the empirical relation, which represents the Mohr-Coulomb's law of breaking. The most commonly used variation is Terzaghi's theory of shear strength which states that:

$$C' + \sigma_n \tan\phi = \tau'_f \quad [10]$$

which is the case of fractured rock masses, for which the kinematics of movement is conditioned by discontinuities and their spatial orientation, and so is the

Table 2. Comparison of factors of safety for example problem (Fredlund and Krahn, 1997).

Case No.	Example problem	Ordinary method	Bishop Simplified method	Spencer's method	Janbu Simplified method
1	Simple 2:1 slope, 40ft (12 m) high, $\phi' = 20$; $c' = 600$ psf (29 kpa)	1.928	2.08	2.073	2.041
2	Same as 1 with a thin, weak layer with $\phi' = 10$; $c' = 0$	1.288	1.377	1.373	1.448
3	Same as 1 except with ru = 0.25 for both materials	1.607	1.766	1.761	1.735
4	Same as 2 except with ru = 0.25 for both materials	1.029	1.124	1.118	1.191
5	Same as 1 except with a piezometric line	1.693	1.834	1.830	1.827
6	Same as 2 except with piezometric line for both materials	1.171	1.248	1.245	1.333

case for soils when there is movement along a pre-existing sliding surface. In the case of reactivations, it is the angle of Residual friction that must be taken into account. For all these cases, the so-called limit equilibrium methods are very appropriate because one can easily write the equations that connect the variables.

Cohesion (c) is the result of bonds between the particles. It has great importance in the cohesive soils, especially clay, while is negligible in cohesionless soils (sand, gravel …). The angle of internal friction (φ) is the result of friction between the soil particles. It is higher in the sand than the clay. As already stated, the problem of slope stability is defined by determining the relationship between the available shear strength and mobilized shear strength, which is needed in order to maintain the sliding body in balance. The factor of safety is a number that is necessary to reduce the effective shear strength in order to achieve the state of limit equilibrium of the fracture surfaces.

$$\frac{\tau_f}{\tau_m} = \text{FS} \quad [11]$$

The engineering methods of limit equilibrium imply that the safety factor, FS, is a constant value along the sliding surface. Similar to the safety factor, the values of cohesion and angle of internal friction are defined. The stability analysis's task is to find the sliding surface, which gives the minimum value of safety factor.

- One of the famous analytical methods that takes into account interslice forces, was presented by Bishop in 1955. This method is named after him, Bishop's method. Bishop's method assumes circular surface rupture. It represents the slices method, and so it is possible to analyse the stability of homogeneous slopes containing materials of different shearing strengths. Bishop's method is graphically presented in Figure 1.

According to Bishop's method, the factor of safety can be calculated as:

$$\frac{1}{\Sigma W \sin\alpha} \Sigma \left\{ \left[c'b + \tan\phi \left(w - ub \right) \right] \frac{\sec\alpha}{1 + \dfrac{\tan\phi \tan\alpha}{\text{FS}}} \right\} = \text{FS} \quad [12]$$

4. Slope Stability Calculation Methodology

Slope stability analysis is usually done at break using the slices method. This

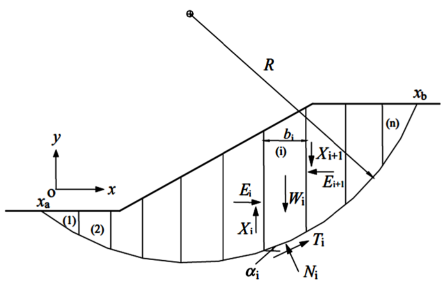

Figure 1. Bishop's method.

method gives, through the safety coefficient, an idea of the equilibrium state of the studied slope with respect to the limit equilibrium. The expression of the factor of safety is different according to whether it is a plane, circular or any other rupture. In all cases, the stability calculations are carried out in short-term total stresses and/or in long-term effective stresses. The degree of precision of the calculations will depend, however, on the quality of determination of the shear parameters, but also on the means of calculations used. Nowadays, there are various calculation methods that are supported by programming software (ABAQUS, GEO5, SLOPE/W, etc.).

The methods can be divided into those which assume irregular surface rupture (Janbu, Bjerrum) and those which assume circular surface rupture (Bishop, Fellenius). Most of the fractures in the soil occur accordingly to the model that describes fracture of continuum as shown in Figure 2. Most of the slipping in the rock mass is a result of unfavorable orientation of discontinuities, where the fracture surface, in this case, follows the discontinuities. The stability of slopes that are not in the state of limit equilibrium is expressed using the factor of safety FS. The factor of safety is then defined as the ratio of resisting forces and disruptive forces.

The most appropriate method of calculation for computer programming and solving the general problem of slope stability, as well as for defining the fracture mechanisms, is hypothetical division of the sliding body into slices. Figure 3 represents a slice from sliding body with forces acting on it.

- Shearing forces in basis of each slice: T
- Sizes of normal components of interslice forces: E
- Eccentricity of normal forces in basis of each slice: e
- The positions of normal components of interslice forces: r
- The sizes of shearing components of interslice forces: X
- Normal effective forces in basis of each slice: N’

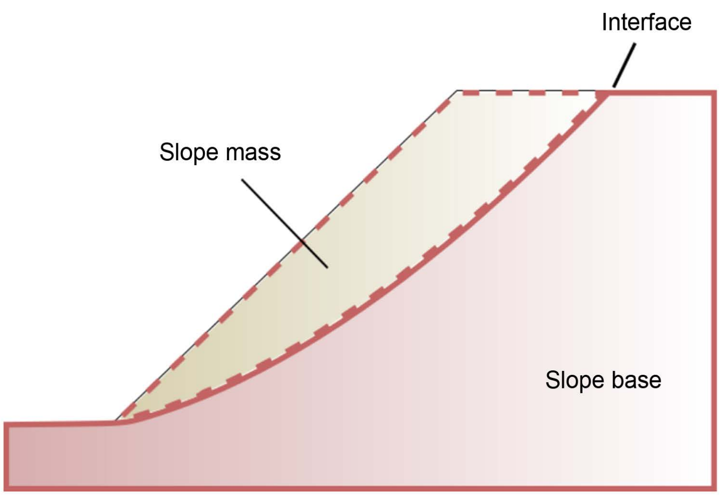

Figure 2. The instability of the soil mass that acts as an equivalent continuum.

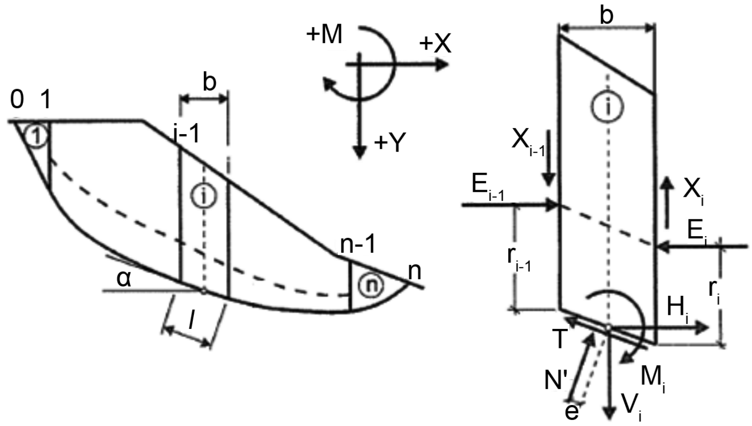

Figure 3. Stresses and Forces acting on a typical slice.

5. Conclusions

This paper presents a methodology to evaluate the stability of embankments with a height limited of the depth of subgrade and particular slope embankments. Empirical formulations have been presented in this study, but there is still need for further studies to determine the stability of embankment on soft soil with different thicknesses and different consistence.

In determining the stability of the embankment and determine the type of selected reinforcement; the value of FS is not used as a criterion. Delta moment resistance is more used as a standard in conducting the design. This can be seen from the value of FS, which is highly non-linear with increasing height of the embankment.

Preliminary results indicate that the magnitude of the increase in the bearing capacity of subgrade will be different when using different empirical formulas. This difference may be due to differences in soil conditions that are used for each test. Further studies need to be done to determine the cause of the differences that occur.

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