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Analysis of Influence Factors of Slope Stability

Cheng CHEN
Highway and Railway Engineering, Chongqing Jiaotong University, Chongqing, CHINA

Abstract: Slip4ex is a special technique for slope stability analysis, and this technique is also used to evaluate the influence of vegetation on slope stability. In the application of this program, you can enter the parameters of the specific slope segment into the program, and then use different analysis methods to compare the safety factors. One of the biggest advantages of Slip4ex is its simplicity, after the input parameters, users can more easily understand the results of the analysis characteristics, but also to further explore the hypothesis that and to compare different analysis method between the advantages. The program also has an advantage is that it can change the water pressure according to the user's wishes, to change the vegetation as well as external force, so as to analyze and compare their impact on the road section of the slope.

Keywords: SLIP4EX; Reinforcement; Slopes; Stability analysis; Vegetation

1. Introduction

SLIP4EX is based on the earlier SLIP3 is program. The slope section is drawn up and dimensions and parameters are fed in to SLIP4EX program for stability calculations and comparisons of Factors of Safety using different methods of limit equilibrium analysis by the method of slices. The simplicity of the program makes it ideal for preliminary problem analysis. It enables the user to understand the nature of the analysis, explore the parameter assumptions made and compare the different methods of analysis. Geosynthetic reinforcement may be included and vegetation effects such as enhanced cohesion, changed water pressures.

2. Example Application of SLIP4EX to Determine the Factor of Safety of a Vegetated Slope

2.1. Initial calculation without vegetaion

As shown in Figure 1, Slice dimensions and the angles between the base of each slice and the horizontal, are scaled from the diagram and appropriate soil and water parameters assigned for each slice as indicated in Table 1. The notation used and details of the dimensions are given in the Appendix. The prepared slice data is then input manually into the SLIP4EX spreadsheet program which calculates the forces acting on each slice of the analysis and the total forces acting on the slip surface. It calculates the Factor of Safety of the slip surface by the different methods commonly used by geotechnical engineers in the Table 2.

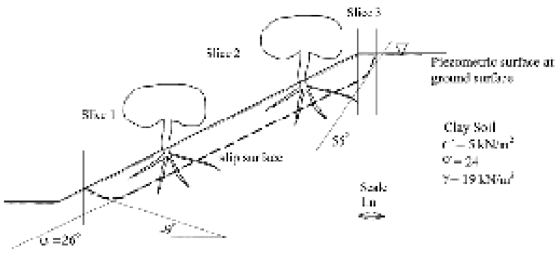

Figure 1. Scale drawing of slope and potential slip surface. Slices selected and parameters assigned

Table 1. Slice data prepared from scale drawing ready for input to SLIP4EX spreadsheet

Slice	Avge height of slice	Unit weight of soil	If other soil layers present in slice			
	Height 1 (m)	Unit wt.	Height	Unit wt.	Height	Unit wt.
1	0.6	19	1.9	−9	0.6	0.5
2	1.2	19	9.2	26	1.2	0.5
3	0.6	19	0.75	55	0.6	0.5

The Factor of Safety is calculated both in terms of moment equilibrium and horizontal force equilibrium where appropriate. The iteration for the Bishop and Janbu solutions is done manually in this version by re-inputting the output Factor of Safety until the output value = input value. Automatic iteration can be done on the spreadsheet by addition of more columns. There is an option in the Greenwood General and Simple methods to assess the additional effects of horizontal earth pressures.

2.2. Including the effects of vegetation

Appropriate additional parameters are assigned to each slice and input to the spreadsheet. In this example an additional tensile root reinforcing force is assumed to act on the base of each slice. The effects are added to the General, Simple and Swedish equations but not the Bishop and Janbu methods where the iterative process and imposition of the Factor of Safety on to each slice in the stability equations does not permit easy inclusion of the additional forces. In this example the vegetation has increased the calculated Factor of Safety from 1.08 to 1.21.

3. Note on Calculation of Available Root Force

SLIP4EX was developed with the intention of including vegetation effects. It may be helpful to describe the way in which a typical available root force is assigned in the above example following the procedure recommended by Norris and Greenwood Typically from observation and tests, assuming 4 roots of 12.5 mm diameter, each having an ultimate pull out resistance of 8 MN/m2, cross each square metre of soil at 1.2 m depth. The ultimate root force per square metre across the slip plane.

Tru = 4 π × 0.01252 × 8 × 1000/4=approx 4 kN per square metre of soil

Applying a partial Factor of Safety of 8 to allow for uncertainty in root distribution and incompatibility of failure strain between the root and the soil, the design root force persquare metre, Trd, is given by: Trd = Tru/8 = 4/8 = 0.5kN/m2.

Root forces, T, for each slice may therefore be calculatedas follows:

Slic	Trd kN/m2	(approx) m	T = Trd ×kN
1	0.5	1.9	0.95
2	0.5	10	5
3	0.5	1.2	0.6

The effective angle between the operational roots and the slip surface, θ, is assumed to be 45◦. Parametric studies on both geosynthetic and root reinforcement have indicated that the calculated resistance due to the reinforcement is not particularly sensitive to 0 because as the enhanced normal component acting across the slip surface decreases, the tangential component, will increase. As more investigation, testing and monitoring of vegetation is carried out, it should be possible to better define the vegetation related parameters and the partial Factor of Safety applicable to root forces for particular sites.

4. General application of SLIP4EX

SLIP4EXhelp gain an initial understanding of a slope problem and the main influences on stability. The less experienced practitioner can develop a feel for the aspects of the stability analysis and explore different mechanisms of failure before progressing to more sophisticated search programs to find critical slip surfaces. It is valuable as a student learning aid because the engineering process of drawing the slope, deciding on slip surfaces and assigning appropriate parameters is all kept under the user's control. Another application is where a particular slip surface generated by a commercial search program. SLIP4EX spreadsheet provides opportunity to use the Excel plotting facilities to demonstrate aspects of the calculated output.

5. Future developments

SLIP4EX is recognized that the next stage is to set up the full slope mode land to run a search program to find the most critical slip surface. An 'automated' version of SLIP4EXin which the problem is set up on the computer, slice dimensions and properties automatically assigned and the critical slip surface identified, is currently under development in collaboration. Copies of the development version of SLIP4EX together with guidance notes are available by email request to john.greenwood@ntu.ac.uk. As a non commercial package this is provided with no guarantees, backup or support.

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7. Appendix

7.1. Notation and equations used in SLIP4EX spreadsheet

The notation used and details of the dimensions are given inTablesA1and A2, and Figures A1-A3.The equations used in the SLIP4EX spreadsheet are derived from the basic limit equilibrium stability Equation:

Assumption 1 :Areasonable assumption is that the resultant of the effective intersliceforces is parallel to the base of the slice, i.e. in the direction of movement - a logical assumption as failure progresses.

Assumption 2: An alternative assumption is to ignore vertical interslice forces or atleast assume they are equal and opposite (i.e. assume $(X2-X1)=0$) reasonable assumption when the slip mass is acting as a single unit – and assume that the effective horizontal interslice forces, E1 and E2, relate to the horizontal earthpressure, i.e. $\sigma h = K\sigma v$ where K is the coefficient of lateral earthpressure. Assuming K is constant with depth and constant water table conditions.

$$E_2 - E_1 = -K\tan\alpha\left(rh - rhb\right) = -k\ \tan\alpha\left(w - ub\right)$$

Assuming K is constant with depth and constant water table conditions but for level ground surface h2 − h1 = −b $\tan\alpha$ and $(h2+h1)/2 = h$ (average height)and for sloping ground surface, parallel to a slip surface, h2 − h1 = 0and the term reduces to zero. This equation may be related to the General but in general the assumptions do not correspond with the real distribution of the inter slice pore water forces. The Bishop solution is prone to errors and the equation can become mathematically unstable for high values of α . It may consequently overestimate the Factor of Safety for deep slip surfaces. The Janbu stability equation is identical to Bishop except that the equation is expressed in terms of horizontal force equilibrium, and a compensatory multiplying factor is introduced relating to the geometry of the slip surface .

The Limit equilibrium slope stability analysis by 'Method of Slices' - Dimensions and parameters assigned for each slice is shown as Figure 2.

7.2. Horizontal Force Equilibrium

It is sometimes convenient to express the Factor of Safety in terms significant near horizontal movement or to relate to retaining wall design. The equivalent horizontal forces are determined for each slice of the analysis simply by dividing the numerator and denominator of the stability equation by $\cos\alpha$. General with K included, Greenwood with K included, Simple, and Swedish, may all be converted to horizontal force equilibrium in the same way as the Bishop equation converts to the Janbu equation. of horizontal force equilibrium. The forces associated with each slice is shown as Figure 3.

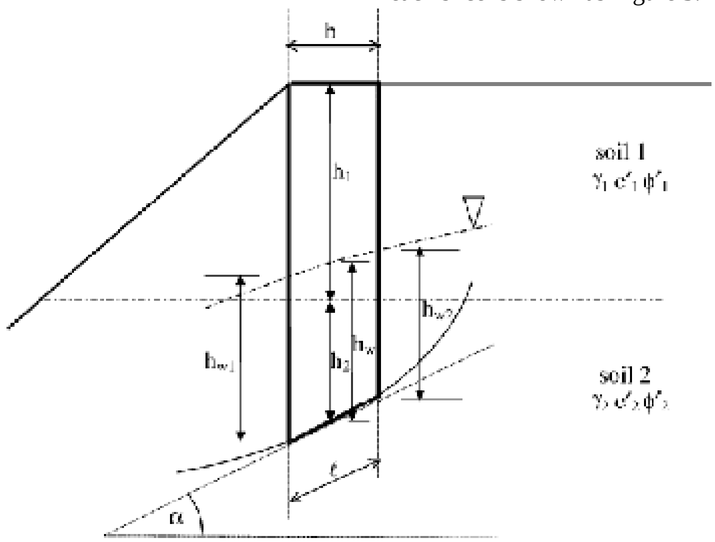

Figure 2. Limit equilibrium slope stability analysis by 'Method of Slices' – Dimensions and parameters assigned for each slice

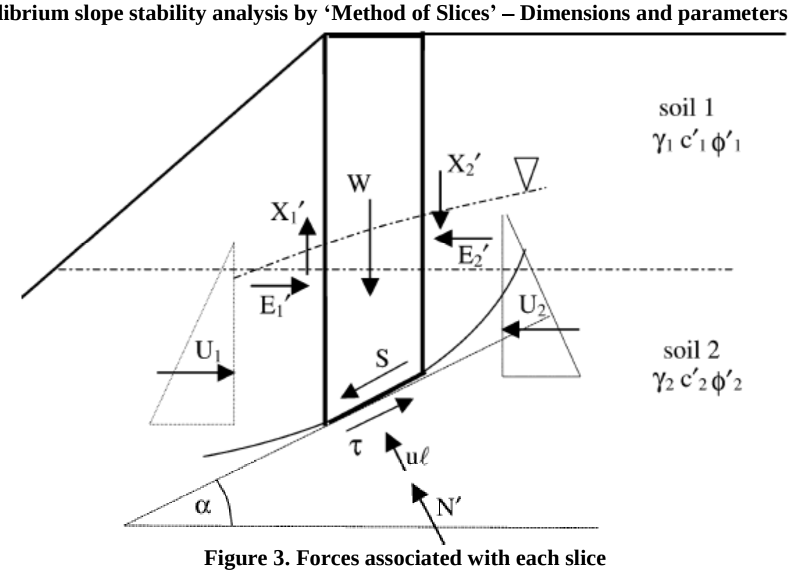

Figure 3. Forces associated with each slice

7.3. Effects of reinforcement, vegetation and hydraulicchanges

Greenwood stability equations with the Factor of Safety simply expressed by a summation of restoring and disturbing moments or forces makes the inclusion of additional forces due to ground reinforcement, anchors or vegetation effects relatively straightforward. It is not straightforward to add these additional forces in the Bishop, Janbu and other 'sophisticated' published solutions where the global factor of safety is applied to the shear strength parameters for each slice of the analysis resulting in some unrealistic force scenarios for the slices where anchor and reinforcement loads.

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