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Research paper

Strengthening of Soil Slope by Berms

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Abstract

Slopes are part and parcel of every construction. The construction of residential building or roads or railways all needs embankments or cutting. The stability of these slopes is a major concern for all geotechnical engineers since they can be catastrophic if it fails. The slope stability is affected by various factors like slope angle, index properties of soil, drainage conditions etc.
The stability of slope can be increased by providing geotextile or any other suitable reinforcement or by appropriate ground improvement techniques. The stability can also be increased by providing a horizontal berm which effectively divide a single slope in to two slopes. The modification in factor of safety by the introduction of berm is studied in this paper.
The berm width is varied and the factor of safety is evaluated using Swedish method of slices. The effect of different berm width on three different slope angles are evaluated. The optimum location of berm is also evaluated for a selected berm width. The berm of sufficient width improves the stability of the slope. A berm width about 0.2 to 0.25 times the total height of slope located at mid height of slope is found to provide optimum factor of safety.

***Keywords**: Slope stability, Berm, Slope angle, Factor of safety, Method of slices.*

1. Introduction

Infrastructural activities involve construction of various structures in different locations. The location may be on a sloping ground or adjacent to the steep hillocks or in weak soils. The analysis of the stability of slopes is necessary in artificial slopes that are constructed in the development of infrastructure. The man made slopes can be earthen dams or embankments for roadways and railway tracks. In the construction of buildings adjacent slopes are made steep to get more area and proper retaining walls are designed based on the available factor of safety. The existing slope also requires the stability analysis as it is subjected changes both internally and externally due to weathering actions.
The provision of highways or railways are also requiring large number of embankments or cuttings in the soil. The sloping angle of embankment or cutting depends on the type of soil and other drainage conditions that exist at the site. Mild slope angle requires more area thereby increasing the cost of project. The stability of slope can be improved by soil nailing, reinforcement by geotextiles or by the application of ground improvement techniques that are suitable at the given site.
The slope of height H can be divided in to two slopes by providing a berm in between. The berm reduces the height of the slope and reduces the weight of the sliding wedge [1]. The berm also decreases the effect of rain water [2] by reducing the surface velocity of runoff and helps in reducing the scouring of soil. In addition, the method does not require any additional investment like soil nailing or ground improvements etc. The construction of a berm is easy and can be done with the existing construction equipment. The provision of berm is economical and environmentally feasible.

2. Stability Analysis

Evaluation of stability is essential prior to any construction of slope. Various methods are available to evaluate the factor of safety of a slope. In case of zoned earthen dams, the effective angle of shearing resistance is varying over the length of failure surface, method of slices is more appropriate in this situation. In this method, the potential failure surface is assumed to be a circular arc passing through toe of slope with centre O and radius R. The centre of rotation is obtained by applying Fellinious directional angles [4], [6] which is a function of slope angle. The soil mass above an assumed slip surface is divided by vertical planes into a series of slices of width b as shown in Fig. 1.

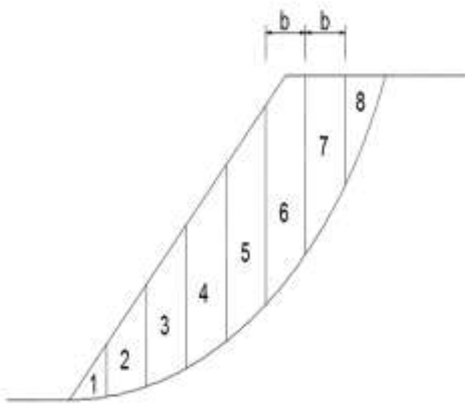

Fig. 1: Division of failure surface in to number of slices.

The factor of safety is evaluated by analysing the contributions to the actuating and resisting forces mobilized by each slice [5]. The forces and their components acting on a typical slice are shown in Fig. 2.

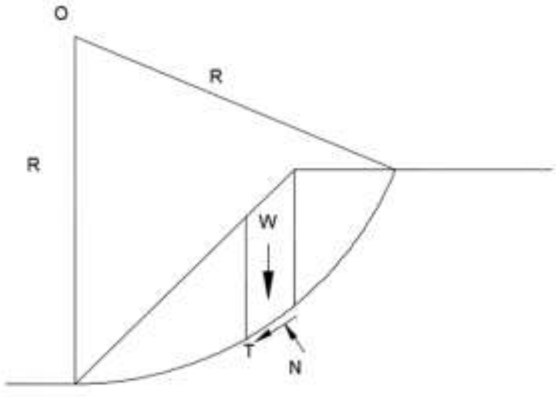

Fig. 2: (a) Forces acting on a slice.

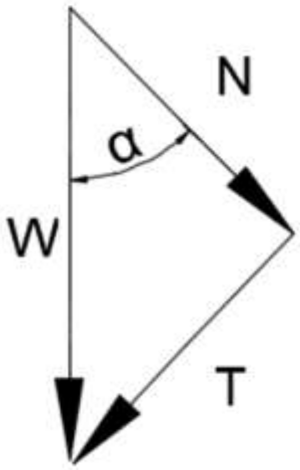

Fig. 2: (b) Normal and Tangential components of weight of slice.

The weight of the slice W is the product of mid height of slice (h), width of slice (b) and unit weight of soil (γ).

Total weight of slice W = γbh

The weight W is resolved in to normal component (N) in radial direction and tangential component (T) perpendicular to the radial direction which are acting on the lower boundary of the slice. The normal force N and tangential force T may also be determined by resolving the weight W of the slice in a direction normal to the arc, at the midpoint of the slice, as shown in Fig. 2 (b).

N = W Cos α

T = W Sin α

where α is the angle of inclination of the line joining the mid-point of slice at the assumed failure arc to the centre of rotation with vertical.

The factor of safety is the ratio of the maximum load or moment that a soil can sustain to the actual load or moment that is applied [3], [5]. In other words, the factor of safety (FS) is defined as the ratio of the shear strength available τ_f to the shear strength mobilized τ_m to maintain a condition of limiting equilibrium.

The Ordinary method of slices (OM) satisfies the equilibrium of actuating and driving moments for a circular slip surface, but neglects both the inter slice normal and shear forces. This method is simple in solving the FS, since the solution does not require an iteration process. In addition, this method gives the most conservative value of factor of safety [5]. Considering moments about centre of rotation O, the sum of the sliding moments of the shear forces T on the failure arc must be equal the moment of the weight of the soil mass. The factor of safety for c – Ø soil is given by the equation

FS = {cu (Rθ) + ΣN tan Ø} *R/ (ΣT * R)

= {cu (Rθ) + ΣN tan Ø}/ ΣT

The factor of safety for Ø = 0 soil is given by the equation

FS = {cu (Rθ)} *R/ (ΣT * R)

= {cu (Rθ)}/ ΣT

Where cu = Cohesion of soil in the slope.

R = Radius of sliding wedge

θ = Angle in radians subtended by sliding wedge at centre of rotation.

ΣN = Algebraic sum of Normal components of all slices.

ΣT = Algebraic sum of Tangential components of all slices.

Ø = Angle of internal friction of soil.

3. Cross Section of Slope

An existing roadway in between continuous slope had problems regarding its stability. This road was constructed on a natural slope of about 49 degrees with horizontal extending more than 25 m at some point. The soil at outer edge of the road which is provided beyond the original slope line was unstable. The total shear stress parameters cu and Øu are evaluated in the laboratory. The cross section of slope is shown in Fig. 3. The terms used in the slope are

HU = Height of upper slope.

HL = Height of lower slope.

H = Total height of slope = HU + HL

αU =Slope angle of upper part.

αL =Slope angle of lower part.

B = Width of berm.

αA, αB = Fellinious directional angles as given in Table I.

Table I: Fellinious Criteria for Locating centre of slip circle of a slope in a Ø = 0 soil. [5]

Slope Ratio	αAin degrees	αB in degrees
1:0.577	29	40
1:0.767	28.5	38.5
1:1	28	37
1:1.5	26	35

R = Radius of slip surface

In the analysis c - Ø soil and Ø = 0 soil are considered. In each soil type the effect of tension crack is also taken into the account. The depth of tension crack is calculated using the following equation.

$Z_0 = (2c)/(\Upsilon\sqrt{Ka})$

Where Ka is the active lateral earth pressure coefficient.

The tension crack is assumed to be dry.

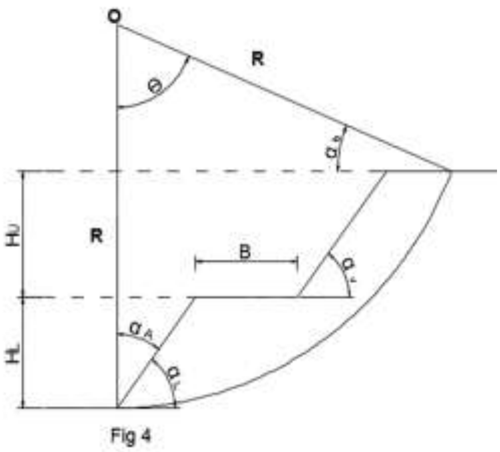

Fig. 3: Cross section of slope.

4. Results and Discussions

In the evaluation of factor of safety using method of slices, the values of HU and HL are taken as 10.0 m. The slope angle is taken as 45, 52.5 and 60 degrees. Width of berm is varied from 0 to 6 m with an interval of 1 m. The soil samples brought from the site gave total shear stress parameters as cu = 20 kN/m^2 and Øu = 30° which are used in the analysis.
The analysis is carried out in c – Ø soil and Ø = 0 soil. In both cases the effect of dry tension crack is also considered separately.

4.1. Effect of Berm Width in C – Ø Soil

The effect of berm width on factor of safety at 45, 52.5 and 60 degrees' slope angle is shown in Fig 4. The factor of safety at slope angle 45 degrees is increasing with the increase of berm width till 4 m and then remains constant. The factor of safety at slope angle 52.5 and 60 degrees is increasing with the increase of berm width till 5 m and then decreases marginally. The percentage increase is up to 27% when the berm width is increased to 4 m from 0 m when the slope angle is 45 degrees. The percentage increase is up to 55% when the berm width is increased to 4 m from 0 m when the slope angle is 52.5 degrees and the increase is about 28% when the slope angle is 60 degrees.

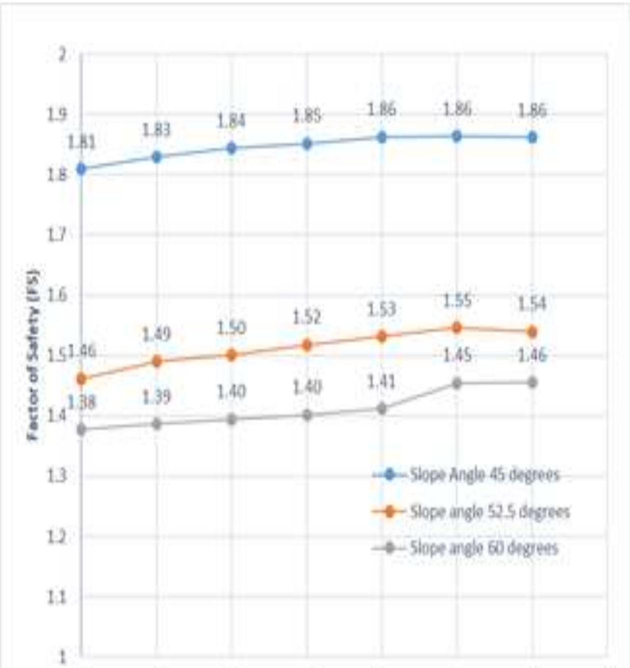

Fig. 4: Effect of berm width on factor of safety in c - Ø soil without tension crack.

The effect of berm width on factor of safety with tension crack at 45, 52.5 and 60 degrees' slope angle is shown in Fig 5. The dry tension crack reduces the factor of safety by 1 to 3% in the case of c – Ø soil. The factor of safety at slope angle 45 degrees is increasing till 3 m and then remains constant. The factor of safety at slope angle 52.5 and 60 degrees are increasing till 5 m and then remains constant. The percentage increase is up to 4% when the berm width is increased to 4 m from 0 m when the slope angle is 45 degrees. The percentage increase is up to 7% when the berm width is increased to 5 m from 0 m when the slope angles are 52.5 and 60 degrees.
Provision of berm of width 0.2 to 0.25 times the total height of slope is beneficial in improving the stability of slope.

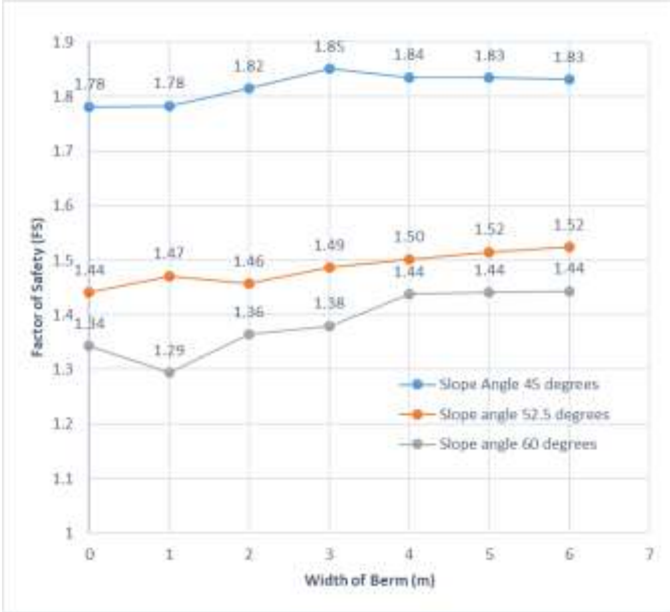

Fig. 5: Effect of berm width on factor of safety in c - Ø soil with tension crack.

4.2. Effect of Berm Width in Ø = 0 Soil

The effect of berm width on factor of safety at 45, 52.5 and 60 degrees' slope angle is shown in Fig 6. The factor of safety at slope angles 45 and 60 degrees is increasing with the increase of berm width till 4 m and then remains constant. The factor of safety at slope angle 52.5 degrees is increasing with the increase of berm width till 5 m and then remain same. The percentage increase is up to 11% in the case of slope angle 45 degrees and about 7% in the case of slope angle 60 degrees when the berm width is increased to 4 m from 0 m. The percentage increase is up to 6% when the berm width is increased to 4 m from 0 m when the slope angle is 52.5 degrees.
The effect of berm width on factor of safety with tension crack at 45, 52.5 and 60 degrees' slope angle is shown in Fig 7. The tension crack reduces the factor of safety by 6 to 12% in the case of Ø = 0 soil. The factor of safety at slope angle 45 and 60 degrees are increasing till 4 m and then remains constant. The factor of safety at slope angle 52.5 degrees is increasing till 5 m and then remains constant. The percentage increase is up to 6% and 12% when the berm width is increased to 4 m from 0 m when the slope angles are 45 and 60 degrees respectively. The percentage increase is up to 17% when the berm width is increased to 5 m from 0 m when the slope angle is 52.5 degrees.

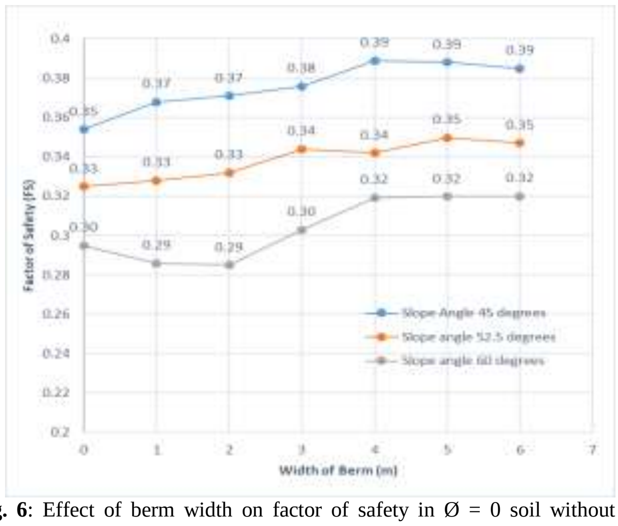

Fig. 6: Effect of berm width on factor of safety in Ø = 0 soil without tension crack.

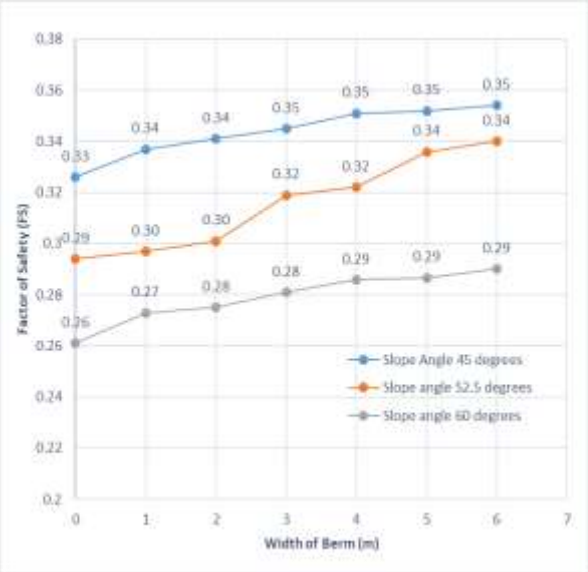

Fig. 7: Effect of berm width on factor of safety in Ø = 0 soil with tension crack.

Provision of berm of width 0.2 to 0.25 times the total height of slope is beneficial in improving the stability of slope.

4.3. Effect of Berm Location

The effect of berm location on factor of safety at two slope angles of 45 and 60 degrees are shown in Fig 8. In the analysis, the berm of 5.0 m width is considered. The factor of safety at slope angle 45 degrees is maximum when the berm of width 5 m is provided at a height of 10 m from the toe of slope and the increase is about 14%. Similarly, in the case of slope angle 60-degree factor of safety is maximum when the berm of width 5 m is provided at a height of 10 m from the toe of slope and the increase is about 15%. The berm location at 0.5 times the total height of slope (H) is optimum in terms of factor of safety.

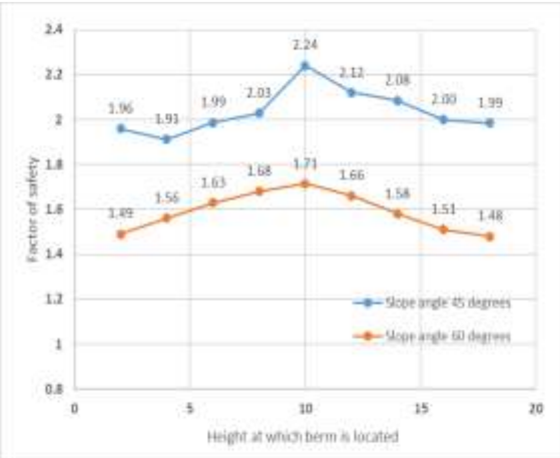

Fig. 8: Effect of berm location on factor of safety.

5. Conclusions

The stability of slope is an important factor in the development of infrastructural facilities. Provision of berm is one of the technique which can be effectively used in improving the performance of slope. The conclusions are summarised as follows.
The berm of width about 0.2 to 0.25 times the total height of slope is found to be effective in providing improved factor of safety both in c – Ø soil and Ø = 0 soil.
The optimum location of berm is found to be at mid height of slope.

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