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Parametric Study of Slope Stability of Embankment

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Abstract—*The project focuses on the reckoning of the stability factor of embankment, with regard to the limit equilibrium method, using Slope/W Software by GeoSlope. Hence, the parametric study of slope stability of embankment has been critically analysed with the Slope/W Software.*

While using Limit Equilibrium Method, fundamental factors such as cohesion, angle of friction etc are required for the calculation of factor of safety for different slope values. Whereas, the Finite Element Method requires additional parametric details, corresponding to the slope's potential performance. The use of effective shear strength characterisation of the soil is compulsory to depict the plausible result while performing slope stability analysis. Drained & Undrained soil strength of the cohesive soil must be divided & separated. Drained condition is the condition where drainage is allowed, whereas undrained condition is where drainage is strictly restricted. The worst scenario occurs when the water level of the river increases rapidly & consequently rushes down, while the water table in the embankment is retained on a tremendously high level, possibly resulting in the failure, due to low effective stresses.

In Slope/W analysis, critical slip surface failure is considered. Factor of safety is calculated for different slope values obtained. In order to obtain substantial effect of a certain parameter on factor of safety, that very parameter is allowed to vary, while other parameters are kept strictly constant.

1. INTRODUCTION

An earthen slope is an unsupported inclined surface. One such earthen surface is known as an embankment. An Embankment is 'a wall or bank of earth or stone built to prevent a river flooding an area'. Embankments occasionally face many severe complications such as erosion. Factors such as faulty design, seepage, poor quality of materials used in the construction and low maintenances affect the embankments considerably.

Among all the challenges for a civil engineer, slope stability and the challenges related to it are of utmost importance. Analysis and study of earthen embankments has been of high significance, thus detailed engineering and research has been practiced on it in the past 75 years. The stability analysis of such embankments in one of the most important aspects in geotechnical engineering. Proper stability analysis is necessary to ensure the safety of man-made and natural embankments. Slope stability is surely a matter of concern as it can incur huge loss of life and property, in case of failure.

This study was done by using the SLOPE/W software by *GeoStudio*. SLOPE/W software uses limit equilibrium method to calculate the Factor of Safety (FOS).

A parametric study has been performed to compute the dependency of Factor of Safety (FOS) on varying slopes of the embankments, assuming the other parameters affecting the slope stability as constant, throughout.

2. OBJECTIVES OF THE STUDY

The objective of this study is to check the variance of factor of safety with respect to the change in slope of embankments for a hypothetical situation and assumed values. The detailed description is as follows:

1. The Factor of Safety of an embankment will be computed with respect to the variance in slope for a simple slope embankment.
2. The Factor of Safety of an embankment will be computed with respect to the variance in slope for a step slope embankment.
3. A comparison will be made between the Factor of Safety with respect to a simple slope and a step slope.

3. THEORY

3.1 Soil Type

Yamuna is a 2900 m long gigantic river in the Indian sub-continent with a total of 22 km stretch in the Delhi-NCR region itself, largely affecting the type and properties of soil

present in this region. Yamuna River has a tendency to frequently change its course thereby eroding and widening the banks in its course of flow. Both banks of the river have widened 70 metres per year averagely from the year 1970 to year 1990. Since the early, 1990s, the widening has decreased to 30-50 metres per year, averagely. [1]

To evaluate the stability of soil, it's of utmost importance to understand the type of soil evaluated in the study. The type of soil considered here for evaluation is the alluvial soil of the Delhi residing on the banks of Yamuna river. The alluvial soil is formed mainly due to the deposition of silt, hence it has a weak profile and the porosity of the soil is the result of its loamy nature. The proportion of Nitrogen is usually low, while that of potash, phosphoric acid & alkalis are sufficient. The quantity of iron oxide and lime in the alluvial soil has a wide variance.

3.2 Factor of Safety

The term *Factor of Safety* (FoS) refers to the load-bearing capacity of a structure (an embankment in this case). In mathematical terms, the factor of safety is the ratio of ultimate stress to the working stress.

As FoS is a ratio, it tends to be close to 1 at all times. The value of FoS as 1 means that the structure will fail as soon as it reaches its design load and cannot bear any sort of excessive load. The FoS value tending to less than 1 is simply not viable and such structures cannot exist. The FoS value of structure always tends to be higher than 1. Higher the value of Factor of Safety more is the strength of the relative structure.

3.3 Slope/W Software by GeoStudio

SLOPE/W software by GeoStudio has been one of the most useful limit equilibrium analysis programs for the past few decades. In order to achieve the objective of this study, GeoStudio software has been utilized. Slope/W is a very substantial software analysis program. The main goal to use Slope/W is to calculate the factor of safety for both simple and complex problems for variety of slip surfaces, pore water pressure conditions, loading orders, soil properties and analysis methods.

4. METHODOLOGY

For the purpose of this study, the soil sample was collected from the banks of river Yamuna in the location of Delhi-NCR. Precisely three locations were chosen to collect the soil samples. This was done to ensure maximum accuracy. The collected samples were thereby studied parametrically to determine the dependency of factor of safety on the slope of the embankments.

Eight unique slope values were considered for the studies which were 1:1.5, 1:2, 1:2.5, 1:3, 1:3.5, 1:4, 1:4.5 and 1:5. Factor of safety for these slopes was calculated for both simple slope and step slope.

The constant parameters of the embankment are as follows:

Height of the embankment = 20m

Slope Given on both side of embankment = 1:3.5

Cohesion = 31kPa

Angle of Friction = 16^0

Unit weight of the soil = 17.25 kN/m^3

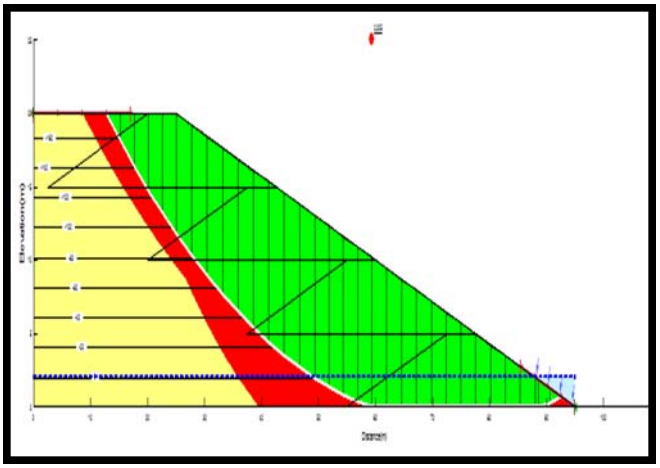

Figure 1 : Analysis of Simple Slope Embankment in SLOPE/W

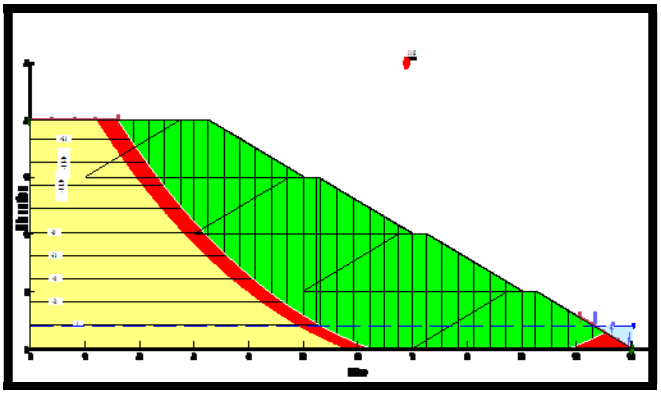

Figure 2 : Analysis of Step Slope Embankment in SLOPE/W

To perform the slope stability analysis, various methods such as ordinary method of slices, Bishop's method of slices, Spencer's method of slices, Morgenstern-Price Method of slices etc can be utilized.

Modified Bishop's Method has been used in this study. The purpose of using Modified Bishop's Method is that it tends to highly accurate relative to any other method by reducing any errors during calculations. In rather simple words, it can be said that the iterative methods have to be used to calculate the factor of safety. Modified Bishop's Method is suited to most stability analysis problems where a circular slip surface is likely to occur.

The basic assumptions made in Modified Bishop's Method are that the resultant inter-slice forces are horizontal and there are no inter-slice shear forces. Various other research papers were consulted to get the values of cohesion and angle of friction mentioned above.

The general equation formulated to compute factor of safety by Modified Bishop's Method is:

$$F = \frac{\sum \left\{ [c'\Delta X + (W - u\Delta X)\tan\phi'] \frac{1}{M_\alpha} \right\}}{\sum W \sin\alpha}$$

Where

$M_\alpha = \cos\alpha + (\sin\alpha \tan\phi' F)$,

c' is the effective cohesion, ϕ' is the angle of friction,

ΔX is the width of the slice, W is the height of each slice,

u is the water pressure at the base of each slice.

5. RESULTS AND DISCUSSIONS

The Factor of Safety computed by the software SLOPE/W by GeoStudio for an embankment with varying slope and constant parameters like cohesion, angle of friction, unit weight etc is shown is represented in the table below:

5.1 For Simple Slope Embankment

For a simple slope embankment with varying slope, the variance in Factor of Safety is as shown in Table 1:

Table 1 : Variation of factor of safety in simple slope

Slope of Embankment	Factor of Safety (FoS)
1:1.5	1.286
1:2	1.515
1:2.5	1.783
1:3	1.975
1:3.5	2.205
1:4	2.403
1:4.5	2.643
1:5	3.144

The variance of Factor of Safety with respect to slope value is shown in graph in Figure 3:

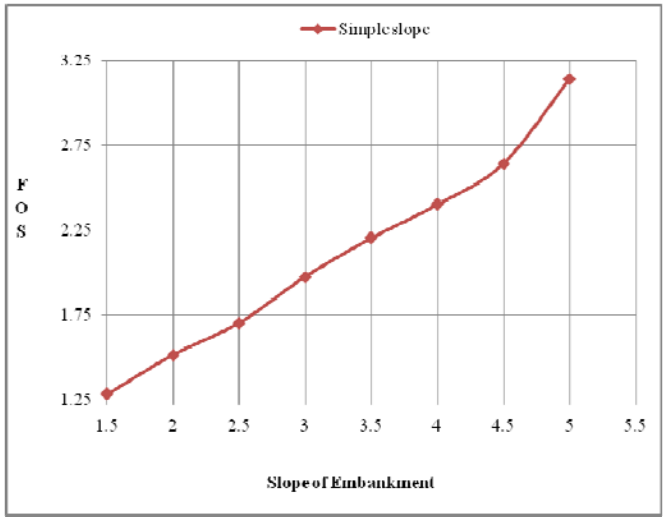

Figure 3 : Variation of FoS plotted on graph

5.2 For Step Slope Embankment

For a step slope embankment with varying slope, the variance in Factor of Safety is as shown in Table 2:

Table 2: of factor of safety in step slope

Slope of Embankment	Factor of Safety (FoS)
1:1.5	1.728
1:2	1.862
1:2.5	2.090
1:3	2.300
1:3.5	2.405
1:4	2.908
1:4.5	3.031
1:5	2.862

The variance of Factor of Safety with respect to slope value is shown in graph in Figure 4:

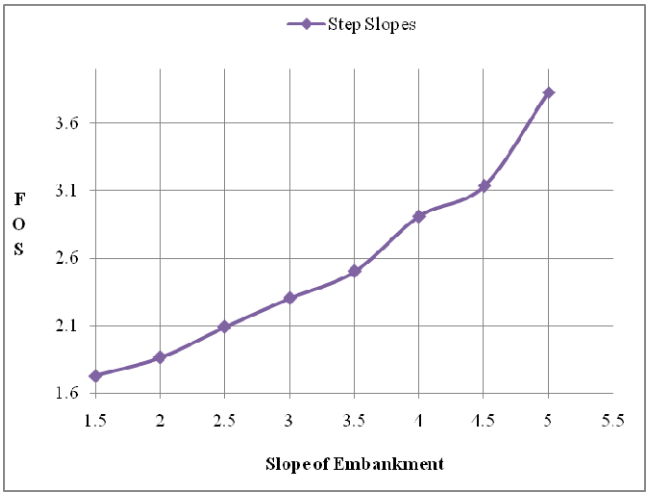

Figure 4: Variation of FoS plotted on graph

5.3 Comparison of Simple Slope with Step Slope

The plotting of graph makes it easier to comprehend the values and understand the trend of growth or dip. Hence, to compare the factor of safety with respect to the change in slope in simple slope embankment and step slope embankment, a graph has been plot which is as shown in figure 5:

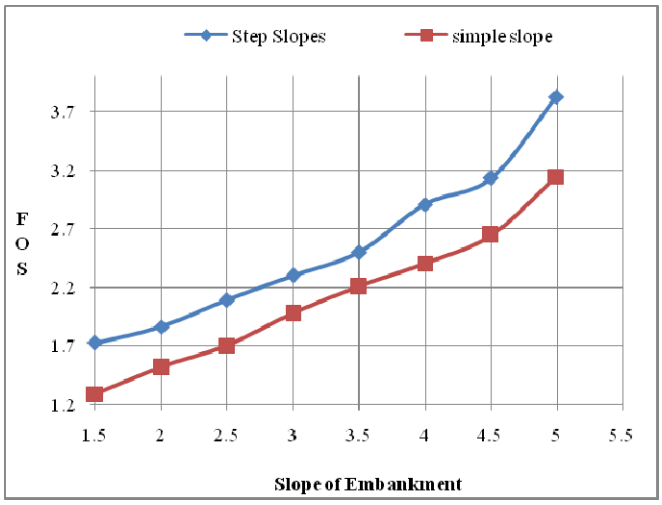

Figure 5: Comparison of simple slope with step slope

6. CONCLUSIONS

From this study and the results obtained, we have come down to the following conclusions:

1. For constant values of parameters like cohesion, angle of friction, pore water pressure conditions etc, the Factor of Safety increases with decrease in steepness of slope, i.e., milder the slop, more will be the factor of safety. In steeper slopes, the weight of the slope is more susceptible to fall than in gentle/milder slopes.
2. From the graph in figure 5, it is visible that the Factor of Safety is increased in step slopes as compared to simple slope, at every slope value. Hence, step slopes are more stable than simple slopes.

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