AN ANALYTICAL STUDY ON SLOPE STABILITY OF A HIGHWAY EMBANKMENT

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Abstract - *The analysis of slope stability has received wide attention nowadays because of its practical importance. To provide steepest slopes which are stable and safe, various investigation are ongoing.*

The main objective of the project is to analyze slope of embankment by calculating factor of safety. So that an appropriate side slope can be chosen and used for the construction of highway. For this, limit equilibrium analysis has been done using GEO5 software. Swedish circle method (Graphically) has been used to performed manual analysis.

In this study, embankment of different heights (3 to 9m) under different 8 slopes (i.e. 1:2, 1:1.75, 1:1.5, 1:1.25, 1:1, 1:0.83, 1:0.7 & 1:0.58) , different values of cohesion and friction angle were considered. The analysis has been performed on two different cases and the result regarding that is obtained.

***Key Words*: Slope Stability, GEO5, Swedish Circle Method, Factor of safety**

1. INTRODUCTION

Slope stability is an important and delicate problem in civil engineering particularly for large projects such as dam, mining, highway, tunnel. Many technique exist for evaluation of slope stability. The main interest of slope stability analysis is typically to determine a factor of safety value against slope failure. Failure of slope may be caused by movement within the human created cut or fill in nature slope or a combination of both. In man-made slope, properties of subsoil & fills soils are greatly effected on stability.

Slope stability analysis involves determining the shear stress developed along the most likely rupture surface & compare it with the shear strength of soil. The most likely rupture surface is critical surface that has the minimum factor of safety.

Many alternative slope stability analysis methods have been proposed. In general slope stability analysis methods fall into two categories. The limit equilibrium method (LEM) & numerical method have been widely used. Limit equilibrium method further divided into Swedish circle method, Fellenius, Bishop Method.

1.1. Objectives of Study

- The objective of study is to understand the concept of factor of safety.
- To find out the relation between different parameters of soil and factor of safety.
- The objective of the present work is to get familiar with the different software used for slope stability.

1.2. Types of slope

1. Infinite slope:

If a slope represents boundary surface of a semi-infinite soil mass and the soil properties for all identical depths below the surface are constant, it is called as infinite slope.

2. Finite slope:

If the slope is of limited extent it is called as finite slope.

1.3. Type of slope failure

A. Toe failure:

In this case failure surface passes through the toe and occurs when the slope is steep and homogeneous.

B. Base failure:

In this case of failure surface passes below the toe. This is generally occurs when the soil below the toe is relatively weak and strong.

C. Face failure:

This type of a failure occurs when the slope angle is large and the soil at the toe portion is strong.

2. LITERATURE REVIEW

A wide range of slope stability analyses are performed using general purpose computer programs. There are many options and features to be considered such as soil strength and procedure analyses. Each of these options and features have sub combinations that lead to about thousands probable options and features for a comprehensive slope stability program.

2.1. Review of Past Works

Nezar Atalla Hammouri, Abdallah I. Husein Malkawi, Mohammad M.A Yami (2008):In their research paper "Slope Stability Analysis Using The Finite Element Method And Limit Equilibrium Approach" conclude that in the differences in the values of safety factor obtained by comparing the methods, it is recommended that engineer should analyze critical slopes using both FEM and LEM

Omar Ali M. Moudabel (2013): In his project named "Slope Stability Case Study By Limit Equilibrium And Numerical Method" give detailed information about stability analysis of slopes susceptible to different types of failure can be performed with different techniques. The selection of an appropriate technique is a very important process of slope stability evaluation. In this paper, he analyze the slope stability using different software. From this, it was found that both the method have their own advantages and disadvantages.

Zhaleh Habibnezhad (2014): Published the paper named "Stability Analysis Of Embankment Founded On Clay"(a comparison between LEM and 2D/3D FEM). He conclude that the work has involved analysis and comparison of the stability through estimate of the SF and the critical failure surface obtained through 2D and 3D programs. He take four case configuration studied for the stability analysis, in each case variation in plastic parameters of clay (ϕ-c) or load geometry was the scenario to make the comparison analysis.

3. ANALYTICAL STUDY

3.1. Introduction

The Failure of soil mass occurs along a plane or curved surface when large mass of soil slides with respect to the remaining mass, In general, there is a outward and downward movement of soil mass. A slope failure occurs when the forces causing failure are greater than shearing resistance (shear strength) developed along a critical surface of failure.

The cost of earth work would be minimum if the slopes are made steepest. However, very steep slopes may not be stable.

3.2 DETAIL PROCEDURE OF PRESENT STUDY

In our present study, we visited the site located near Shivni village, Ner-Yavatmal road. The construction of Samruddhi Mahamarg is being constructed at that site. It is 8 lane highway, 4 on each side connecting the 10 major districts of Maharashtra. It is having high embankment heights up to 9 meter. In visit we collected various data from the site including unit weight of soil(γ), angle of internal friction(ϕ), cross sectional details of embankment and side slope of embankment they adopted.

The main objective of the project is to analyze the slope of embankment by calculating the factor of safety (using various cases). For achieving this objective, the total experimental approach involved in this work has been divided into 2 different cases. The data taken in the study are cohesion ranges from 0kN/m^2 to 30kN/m^2 at a interval of 10kN/m^2, angle of internal friction 30^0, 32^0, 34^0 & 36^0 and unit weight of soil are 19kN/m^3, 20.2kN/m^3.

3.2.1. Case 1-Analysis of single layered soil embankment

This case is further divided into 2 parts by varrying the soil parameters (C and Ø) as follows:

(Part A): Analysis of Single layer embankment by considering and varying only angle of internal friction.

(Part B): Analysis of Single layer embankment by considering both Cohesion and angle of internal friction.

The problem has been solved by using Swedish circle method manually and by GEO5 software. The following steps involved in solving the problem.

1. Formation of problem statement including slope angle, angle of internal friction, height of slope, type of failure, cohesion, unit weight of soil, etc.
2. Calculation of radius of critical circle by using correct direction angles α and β by Fellenius method.
3. Analyze the factor of safety by using Swedish circle method (graphically).
4. By varying the value of internal friction (ϕ) in Part A and Varying both cohesion and angle of internal friction in Part B (keeping all the parameters same, again calculate the factor of safety).
5. Solve the same problem using GEO5 software and calculate the factor of safety.
6. After solving, comparing the results and discussion.

Firstly we have decided various height and slope for which a Factor of safety to be calculated. We have taken height of slopes from 3 meter to 9 meter and total 8 slopes were taken to calculate factor of safety. Following are the 8 slopes that has been taken

1. 1:2
2. 1:1.75
3. 1:1.5
4. 1:1.25
5. 1:1

6. 1: 0.83

7. 1:0.7

8. 1:0.58

In the first part of case1 we have only varied the value of internal friction. To check the change occur in the value of factor of safety with increment in angle of friction. In this case we have solved problem only for single layered soil embankment. One single height of slope were given 8 different side slopes, 4 different ϕ values, only gamma value was kept constant and factor of safety were calculated. For example: 1 height of slope * 8 slopes * 4 ϕ values = 32 problems for single height.

32 * 7 total heights = 224 problems were solved in Case 1 (part A)

From these problems, increments in the factor of safety with respect to ϕ were studied.

In the Second part of case 1 we have varied both the value of angle of internal friction and cohesion . To check the change occur in the value of factor of safety with increment in angle of internal friction and cohesion. In this case we have solved problem only for single layered soil embankment. One single height of slope were given 8 different side slopes, 4 different ϕ values (30,32,34,36) , 3 different cohesion values(10,20 and 30 kN/m^2), only unit weight value was kept constant and factor of safety were calculated. For example:

1 height of slope * 8 slopes * 4 ϕ values* 3 cohesion = 96 problems for single height

96 * 7 total heights = 672 problems were solved in Case 1 (part B)

From these problems, increment in the factor of safety with respect to ϕ and cohesion were studied.

3.2.2 Case-2: Analysis of two layered soil embankment

Analysis of embankment having 2 different layers of soil with varying cohesion value.

1. Formation of problem statement including angle of slope, height of slope, type of failure, unit weight, cohesion, angle of internal friction and soil layers.
2. Calculation of radius of slip circle by using correct direction angles α and β by Fellenius method.
3. Analyze the Factor of Safety manually by using Swedish circle method(Graphically).
4. By varying the cohesion in both layers and keeping all the parameter same, again calculate the Factor of Safety.
5. Solve the same problem by GEO5 software and calculate the factor of safety.
6. After solving comparing the manual and software results and discussion.

In this Case-2, We have divided the embankment into 2 different layers of soil. Each layer containing different properties of soil. The first layer is provided at 50% of height of embankment. In this case, We have only varied the cohesion in both soil layers.

Generally in the construction of highway embankment, we use single soil to fill the embankment. We have adopted case 2 to check the variation occur in factor of safety after using two soil with different parameters.

For example: Layer 1:C= $0kN/m^2$, γ = $19kN/m^3$, ϕ = 32°

Layer 2:C= $11kN/m^2$, γ = $20.2kN/m^3$, ϕ = 25°

4. RESULTS AND DISCUSSIONS

The following results were obtained by comparing manual and GEO5 software output.

4.1 Result of single layered soil embankment

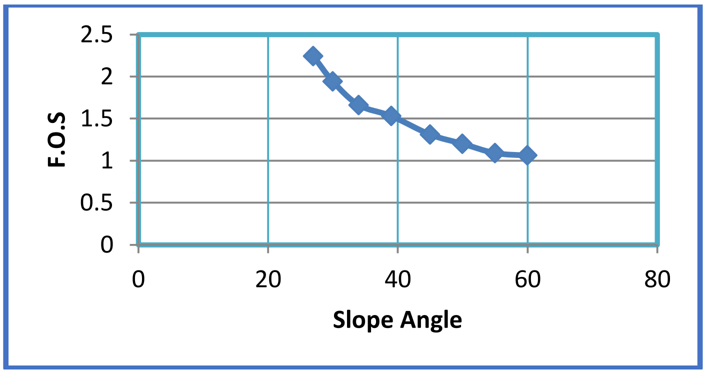
4.1.1Considering different slope

Considering cohesion=0 kN/m^2, angle of internal friction=30^0 . The results are shown below in the table.

Slope	Height	F.O.S(Manually)	F.O.S(GEO5)
1:2	5	2.24	2.15
1:1.75	5	1.94	2.03
1:1.5	5	1.66	1.70
1:1.25	5	1.53	1.55
1:1	5	1.31	1.36
1:0.83	5	1.20	1.22
1:0.7	5	1.09	1.12
1:0.58	5	1.06	1.04

Table-1: Calculation of FOS by taking height 5m.

Fig -1: Slope angle vs factor of safety for height 5m



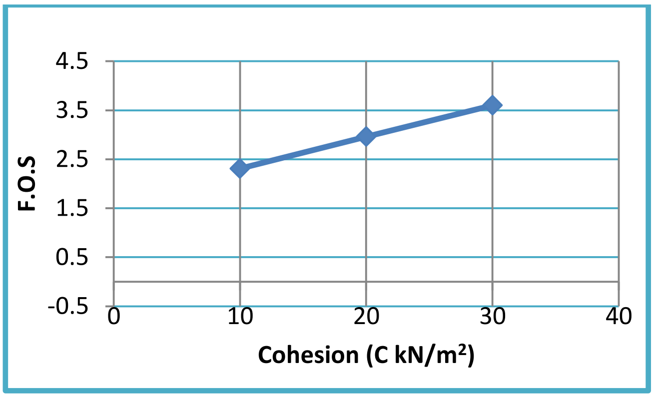
4.1.2. Analysis result by considering cohesion

The result are drawn considering cohesion=10 kN/m^2 and angle of internal friction=30^0.

Table -2: Calculation of FOS by taking 5m height.

Slope	Ht	Cohesion	F.O.S (Manually)	F.O.S (GEO5)
1:2	5	10	2.93	3.22
1:1.75	5	10	2.60	2.71
1:1.5	5	10	2.31	2.37
1:1.25	5	10	2.16	2.21
1:1	5	10	1.89	1.98
1:0.83	5	10	1.79	1.81
1:0.7	5	10	1.65	1.71
1:0.58	5	10	1.60	1.60

Fig-2: Cohesion vs factor of safety graph



4.2 Result of double layer of soil
4.2.1 By considering different slope geometry

In order to study the influence of slope geometry on Factor Of Safety, the value of slope surface varying from 1:2 to 1:0.58 were chosen while the unit weight (γ), cohesion (C), height (Ht), angle of internal friction (ϕ) taken as

1. For 1st layer: γ= 19 kN/m^3, C= 0 kN/m^2, Ht= 1.5 m, ϕ=32^0
2. For 2nd layer: γ=20.2 kN/m^3, C=11 kN/m^2, Ht= 1.5m, ϕ = 25^0

Table-3: Analysis of result by considering different slope geometry

Slope	Height	Manually	GEO5
1:2	3m	2.20	2.27
1:1.75	3m	2.10	2.29
1:1.5	3m	2.01	2.04
1:1.25	3m	1.86	1.86
1:1	3m	1.78	1.82
1:0.83	3m	1.58	1.61
1:0.7	3m	1.40	1.50
1:0.58	3m	1.30	1.38

We can see from above table factor of safety decreases as slope increases.

4.2.2. Analysis of result by increasing cohesion

In order to study the influence of cohesion on factor of safety, we compare the two condition and results are shown in the table below,

Condition 1

1.For 1st layer: γ= 19 kN/m^3, C= 0 kN/m^2, Ht= 1.5 m, ϕ =32^0

2.For 2nd layer: γ=20.2 kN/m^3, C=11 kN/m^2, Ht= 1.5m, ϕ = 25^0

Condition 2

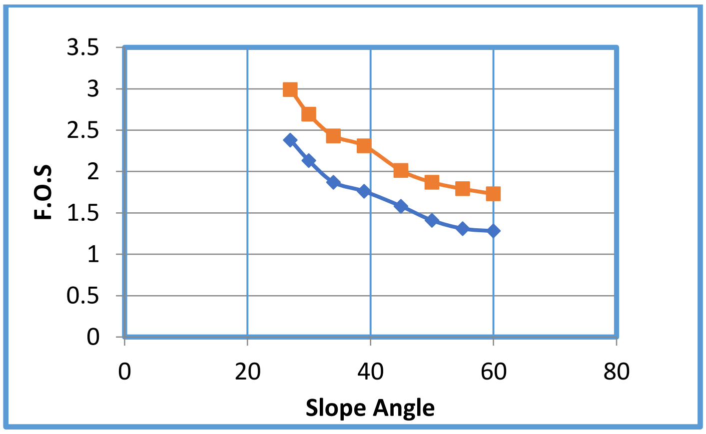
1.For 1st layer: γ= 19 kN/m^3, C= 10 kN/m^2, Ht= 1.5 m, ϕ=32^0

2.For 2nd layer: γ=20.2 kN/m^3, C=16 kN/m^2, Ht= 1.5m, ϕ= 25^0

Table-4:Analysis result by increasing cohesion for 5m .

Slope	Ht	Cond. 1 Manual	Cond. 1 GEO5	Cond.2 Manual	Cond.2 GEO5
1:2	5	2.38	2.46	2.99	3.08
1:1.75	5	2.13	2.25	2.69	2.86
1:1.5	5	1.87	2.04	2.43	2.59
1:1.25	5	1.76	1.80	2.31	2.34
1:1	5	1.58	1.59	2.01	2.11
1:0.83	5	1.41	1.47	1.87	1.97
1:0.7	5	1.31	1.36	1.79	1.83
1:0.58	5	1.28	1.28	1.73	1.79

Fig-3: Factor of safety vs slope angle for 5m ht. for both condition in double layer.



Here condition is indicated by blue line and condition is indicated by orange line.

From the above table we can conclude that by increasing the cohesion value the factor of safety is increases by 26%.

5. CONCLUSIONS

On the basis of investigations the following conclusions and recommendations have been drawn:

- This study has illustrated that for a particular height of embankment factor of safety against slope stability increases with increase in the flatness of slope.
- The embankment of 1:2 and 1:1.75 slope exhibits highest factor of safety, but also the dis-advantage of covering the largest area of ground.
- Possible trials made in value angle of internal friction, it has been concluded that as the value of angle of internal friction increases, the value of factors of safety also increases which means more the value of angle of internal friction more is the stability of slope.
- By the increment of cohesion in the soil from 10 kN/m^2 to 20 kN/m^2, there is an increment of 28% in the factor of safety is found.
- From the present study we can conclude that it is better to use C-ϕ soil rather than ϕ soil as it gives maximum factor of safety as compared to sandy soil.

6. Future Scope of Study

In view of this, in the present study, an attempt is made to find out the factor of safety of slope of embankment by considering different values of slopes and different parameters of soil. Future work concerns deeper analysis of slope stability of highway embankment. Following recommendation are provided as ideas for future expansion of this project.

- Finite elements method can be used to calculate FOS by using PLAXIS 2D.
- Earth retaining wall should be provided so that reduce land acquisition and also maintain stability.
- Use of stabilizer such as fly ash, cement, grouting, vetiver roots, etc. reduces area and better stability will be achieve.
- Side Slope should be analyze taking into account soil Stability (seepage & slope sliding). phreatic line analysis and slope stability check should be considered to select the design slope and overall embankment width.
- Gabion wall provided same as retaining wall which protects landslides and it is most economical and efficient solutions for stabilization of natural ground slope.

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