SLOPE STABILITY ANALYSIS OF AN EMBANKMENT

A project submitted in partial fulfillment of the requirements for the award ofdegree of

BACHELOR OF TECHNOLOGY

In

CIVIL ENGINEERING

Submitted by

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MVGR COLLEGE OF ENGINEERING (AUTONOMUS)

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Vizianagaram-535005

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DEPARTMENT OF CIVIL ENGINEERING

Vision of department:

To become a pre-eminent Department of Civil Engineering that brings out technically competent, ethically sound and globally employable professionals capable of addressing societal challenges by providing sustainable solutions.

Mission of Department:

Aspire to reach higher quality benchmarks in training students on all skills expected of a computer professional through a meticulously planned yet flexible learning process administered:

M1. Design and develop curriculum for UG and PG programs of Civil Engineering that adds value to student competencies abreast with changing industry needs.

M2. Impart students with knowledge of Civil Engineering and use of modern tools and provide the best learning resources.

M3. Provide an enabling environment to equip students to serve the society as leading professionals, academicians, innovators and entrepreneurs.

M4. Promote and undertake academic research to address societal challenges.

M5. Provide testing and design consulting services to the industry and create Industry-Academia synergy for improving employability of students.

Program Educational Objectives (PEOs):

PEO 1: DOMAIN KNOWLEDGE Graduates will have the fundamental knowledge of mathematics, science, economics and computing and in-depth knowledge in Civil Engineering concepts through theoretical, laboratory and project-based experiences so as to design, develop and solve engineering problems.

PEO 2: EMPLOYMENT Graduates will get employed in national and international; government and private organizations, and will succeed in their chosen engineering careers through their skills, knowledge, personality and aptitude for innovation.

PEO 3: HIGHER STUDIES & LIFELONG EDUCATION Graduates will pursue advanced degrees in engineering and other fields; and will have skills of continued, independent and life-long learning to become experts in their profession by self-instilled passion and systematic approach.

PEO 4: PROFESSIONAL CITIZENSHIP Graduates will organize and present information, write and speak well, work effectively with strong organizational skills in multidisciplinary teams on team-based engineering projects and practice ethics and have a sense of social responsibility.

PEO 5: MODERN TOOLS: Graduates will plan, design, execute, maintain and rehabilitate civil engineering structures / systems and solve civil engineering problems using analytical methods or modern tools and techniques.

Mapping of Mission statements with PEO's:

MISSION STATEMENTS OF THE DEPARTMENT	PEO 1	PEO 2	PEO 3	PEO 4	PEO 5
M1	3	3	3	2	1
M2	3	-	2	1	3
M3	2	3	-	3	-
M4	1	2	3	2	1
M5	1	3	2	3	2

(3-Highly Relevant, 2-Medium, 1-Low)

POs and PSOs

POs

1. **Engineering Knowledge:** Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.

2. **Problem Analysis:** Identify, formulate, research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

3. **Design/development of Solutions:** Design solutions for complex engineering problems and design system components or processes that meet t h e specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

4. **Conduct Investigations of Complex Problems:** Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

5. **Modern Tool usage:** Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modelling to complex engineering activities with an understanding of the limitations.

6. **The Engineer and Society:** Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

7. **Environment and Sustainability:** Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

8. **Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

9. **Individual and Team Work:** Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

10. **Communication:** Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

11. **Project Management and Finance:** Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

12. **Life-long Learning:** Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

PSOs

1 - Able to synergize domain knowledge, problem solving skills and emerging tools to develop sustainable solutions in their chosen civil engineering verticals.

2 - Able to communicate and apply civil engineering knowledge for addressing societal challenges.

Project Outcomes:

Students will be able to

1) Identify & formulate the problem statement for the project based on literature survey.
2) Describe a methodology to be adopted for solving the problem.
3) Apply modern tools and techniques for developing solutions to identified problems.
4) Plan, analyze, design and develop solution for Civil Engineering Problems.
5) Develop communication and report writing skills effectively.
6) Practice to work in teams effectively.
7) Appreciate the need for following ethical principles and practices in carrying out the project.

PO Attainment for project work

	CO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7	PO-8	PO-9	PO-10	PO-11	PO-12	POS-1	POS-2
Project outcomes	**CO-1**	2	3											2	3
	CO-2	2	3	2										2	3
	CO-3	2	3	2		3							2	2	3
	CO-4	2	3	2										2	3
	CO-5										3				
	CO-6									3					
	CO-7								3				2		

CERTIFICATE

This is to certify that the main project entitled "SLOPE STABILITY ANALYSIS OF AN EMBANKMENT" is the bonafide work carried out during the academic year 2021-2022 by **"B.CHAKRADHAR, Ch.SEKHAR, A.ANANTH PRITHVI and B.GOVARDHAN KUMAR"** under the guidance of **MR.B.RAMU** Assistant Professor submitted to the Department of Civil Engineering, MVGR College of Engineering(Autonomous), Vizianagaram in partial fulfillment of the requirements for the award of degree of '**Bachelor of Technology'** in '**Civil Engineering'.**

HOD-Civil Engineering	Project Guide
Dr. P. Markandeya Raju	**Mr.B.Ramu**
Professor	**Assistant professor**

DECLARATION

We hereby declare that the project title "SLOPE STABILITY ANALYSIS OF AN EMBANKMENT" is the work done during the academic year 2021-2022 under the guidance of Mr. B. Ramu Assistant professor is submitted to the Department of Civil Engineering, Vizianagaram in the partial fulfillment of the requirement for the award of degree of '**Bachelor of Technology' 'Civil Engineering.'**

We ensure that the project is not submitted by any other student in our college.

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ACKNOWLEDGEMENT

We would like to take this opportunity to express our sincere thanks to our guide **Mr.B. Ramu** (Assistant professor), Department of Civil Engineering for his valuable guidance and assistance, without him the accomplishment of this task would have never been possible. We also thank him for giving the opportunity of doing such a wonderful project which is major requirement of present society.

We express our sincere thanks to **Dr. P. Markandeya Raju**, HOD,for his support in completing the project, We also thank to all faculty and Lab-In charges for providing an opportunity to work on this project and helping us in completion of project.

We also place a record, our sense of gratitude to one and all who indirectly have lenttheir hands in this project.

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ABSTRACT

Choosing a problem of embankment solution at Tagarapuvalasa located on NH 16 road. Collect the soil samples for testing to determinations of soil classification by grain size analysis. And remining soil properties are adopted from previous project study which was conducted by seniors. And determination of shear strength parameters are cohesion and angle of internal friction by direct shear test. Above soil parameters needs to solve the embankment problem analytically by Jumiki's (1962) after extension of Fellinius method for locating most critical slip circle for C-φ soil and also method of slices used for stability analysis of embankment. Results are solved by analytically withhelp of AutoCAD. Solving problem only for embankment without considering any pavement load and vehicle load. Calculations of soil is done for two various slope values. Solving problem without reinforcement gives in instability, so it is necessary that provide the reinforcement (Geo-grid) at toe, so it's satisfied the stability of embankment.

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CHAPTER – 1

INTRODUCTION

1.1 WHAT IS SLOPE STABILITY?

Slope stability is the process of calculating and assessing how much stress a particular slope can manage before failing. Examples of common slopes include roads for commercial use, dams, excavated slopes, and soft rock trails in reservoirs, forests, and parks. Considering the importance of slope stability to their work, it’s beneficial for civil engineers to understand how toproperly evaluate slope stability and leverage various techniques to achieve slope stabilization.

1.2 DIFFERENTSLOPES:

On the basis of method of construction

1. Natural slopes
2. Artificial Slopes
3. Finite Slopes
4. Infinite Slopes

1.2.1 Natural slopes:

The slopes formed due to natural process and exist naturally are called natural slopes. Natural slopes are those that exist in nature and are formed by natural causes. Such slopes exist in hilly areas. The sides of cuttings, the slopes of embankments constructed for roads, railway lines, canals etc. and the slopes of earth dams constructed for storing water are examples of manmade slopes.

1.2.2 Artificial slopes:

The slopes formed by unnatural process. Artificial slopes are formed by humans as per requirement

On the basis of type of soil:

i. **Cohesive soil slope:** Having purely cohesive soil as its content

ii. **Frictional soil slope:** Slopes having frictional soil as its contents

iii. **Cohesive frictional soil:** Slopes made up of soil which has both frictional as well as cohesive properties.

1.2.3 Infinite Slopes:

The type of slope extending infinitely, or up to an extent whose boundaries are not well defined. For this type of slope the soil properties for all identical depths below the surface are same. In the making of natural slopes, there is no contribution from our side.

1.2.4 Finite Slopes:

The slope that is of limited extent. We the engineers deal with this type of slopes. The term infinite slope is used to designate a constant slope of infinite extent. The long slope of theface of a mountain is an example of this type, whereas finite slopes are limited in extent. The slopes of embankments and earth dams are examples of finite slopes. The slope length dependson the height of the dam or embankment.

1.3 CAUSES OF SLOPE FAILURE:

1.3.1 Steepness of the Slope:

It goes without saying that the steeper a slope is, the more unstable it will be. It's true for making sand castles and it's true for making hillside homes. The natural tendency of steep slopes is to move some of its materials downwards until the natural angle of repose is found. Any form of slope modification, whether it be through natural means such as a stream undercutting the banks of a river or by workers removing a section of the slope's base to build roads, will impact the stability of a slope.

1.3.2 Water and Drainage:

Water is several times heavier than air. During heavy rains when the soil becomes saturated and water takes the place of air between the grains of soil, the earth in slopes becomes a lot heavier.

This becomes a problem when the earth is being held back by a retaining wall at its base. Specifically, if the weight of the earth behind the retaining wall exceeds the retaining wall's structural capacity, the retaining wall will buckle and collapse releasing the earth behind it in a catastrophic deluge.

Water also reduces grain-to-grain contact which, in turn, reduces cohesiveness and the soil's angle of repose. Along with changes in the groundwater fluid pressure in slope rocks during the rainy season, water saturation by itself already increases the probability of downslope mass movement.

1.3.3 Soil Composition:

The composition of the slope's soil is a very important consideration when it comes to mitigatingslope failure. Different types of soils will have very different characteristics when it comes to frictional resistance to erosion and cohesion among the grains. Loose soil or sand, for example, has very low cohesion and will easily erode when saturated with water. Soils that have a large amount of clay, on the other hand, tend to expand when exposed to water; this makes them heavier and more prone to movement.

1.3.4 Vegetation:

The amount and type of vegetation found in a slope is also proportional to the strength of that slope. Vegetation, specifically its roots, holds the soil in place and makes it more resistant to erosion. The bigger the size of vegetation, the more widespread its roots are and the more it is able to hold the soil in place. The more vegetation there is, moreover, the more stable the slope islikely to be. This is the reason why slopes that have had their vegetation removed or razed by bush fires are prime candidates for slope failures during the rainy season.

1.4 Slope stability analysis

Slope stability analysis is a static or dynamic, analytical or empirical method to evaluate the stability of earth and rock-fill dams, embankments, excavated slopes, and natural slopes in soil and rock. Slope stability refers to the condition of inclined soil or rock slopes to withstand or undergo movement. The stability condition of slopes is a subject of study and research in soil mechanics, geotechnical engineering and engineering geology. Analyses are generally aimed at understanding the causes of an occurred slope failure, or the factors that can potentially trigger a slope movement, resulting in a landslide, as well as at preventing the initiation of such movement, slowing it down or arresting it through mitigation countermeasures.

The stability of a slope is essentially controlled by the ratio between the available shear strength and the acting shear stress, which can be expressed in terms of a safety factor.

Factor of safety is defined as the ratio of resisting moment to driving moment. Where the normal stress components are causing resisting moment and the tangential component may act in an opposite direction, causing a restoring moment. T is taken as positive when causing a driving moment and negative when causing a resisting moment. The algebraic sum of T will always be positive and contribute to the driving moment.

If the obtained factor of safety is greater than 1.5 the slope is under safe condition. If the factor of safety is less than 1.5 the slope is under failure condition and calculations should be done by providing reinforcement to resist the slope under failure. There is no effect on driving moment due to reinforcement.

To increase the value of factor of safety we should increase the numerator value i.e resisting moment by providing reinforcement. We use geogrids as primary reinforcement in this study.

Geogrids is geosynthetic materials used as reinforcement in construction works. Types of geogrids, its functions and applications in construction works are discussed. Geogrids can be categorized as geosynthetic materials that are used in the construction industry in the form of a reinforcing material. It can be used in the soil reinforcement or used in the reinforcement of retaining walls and even many applications of the material are on its way to being flourished.

The high demand and application of Geogrids in construction are due to the fact that it is good in tension and has a higher ability to distribute load across a large area.

The geosynthetic material, geogrids, are polymeric products which are formed by means of intersecting grids. The polymeric materials like polyester, high-density polyethylene and polypropylene are the main composition of geogrids.

These grids are formed by material ribs that are intersected by their manufacture in two directions: one in the machine direction (md), which is conducted in the direction of the manufacturing process. The other direction will be perpendicular to the machine direction ribs, which are called as the cross-machine direction.

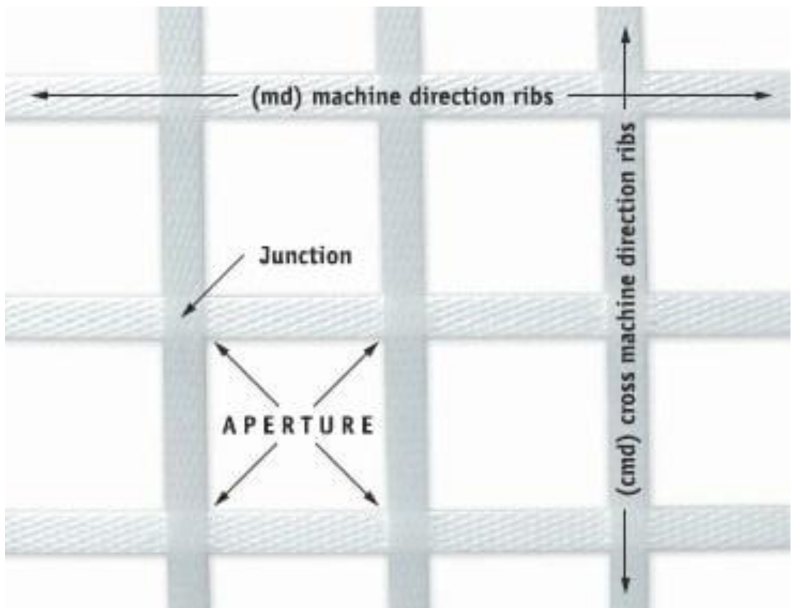


Fig-1.1 geo grids-ribs-formations

Among different types of geotextiles, geogrids are considered stiffer. In the case of geogrids, the strength at the junction is considered more important because the loads are transmitted from adjacent ribs through these junctions.

Many manufacturing choices are available for ribs. Here we are going to discuss three most used method of manufacturing of geogrids.

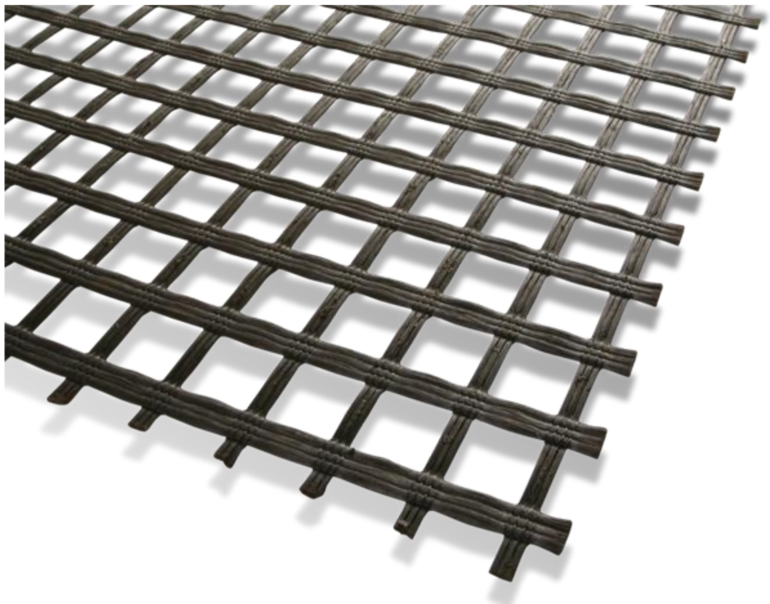


Fig-1.2 geogrids

Fig-1.3 geogrid mesh

1.5 SCOPE OF PRESENT STUDY:

The present study deals with the slope stability analysis of an embankment located on NH-16 at Tagarapuvalasa. The field and lab tests are carried out and parameters required for the slope stability analysis are noted. Ordinary method of slices is selected for the stability analysis and the manual calculations are carried out. We selected the Fellenius (1936) and Jumikis (1962) to obtain the slip surface. From the obtained slip surfaces by using method of slices factor of safety is calculated. Minimum factor of safety value gives the most critical circle. From the minimum factor of safety we conclude whether the slope is under safe condition or not.

1.6 OBJECTIVES OF THE PRESENT STUDY:

- To study the principles of limit equilibrium method
- To study the stability of soil and slope condition of the embankment.
- To analyze the Factor of Safety by using **Ordinary Method of Slices.**
- To compare the factor of safety obtained from the soil sample collected at the field withsoil sample assumed.
- To provide the reinforcement, if the slope is not in a safe condition.
- To check the settlement criteria of the soil under the embankment.

1.7 ORGANISATION OF THE THESIS:

The entire project work is planned in five chapters.

Chapter -1 deals with the introduction and, objectives, scope, importance and necessity of the present study,

Chapter -2 deals with the reviews and literature related to the present study.

Chapter -3 deals with the methodology and location of most critical circle.

Chapter -4 deals with the results obtained and their discussions are presented.

Chapter -5 deals with the conclusions.

At last, the references are included.

CHAPTER-2

LITERATURE REVIEW

2.1 Christopher D.Kiser and Prabir K.Kolay (2013):

This paper includes computer modeling foranalysis. The software used is GALENA, is the powerful slope stability analysis program designed for engineers to solve geotechnical problems. The program results which include cross sections showing failure surface along the resulting factor of safety. In actual project, soil sampling from the project site should have been conducted to obtain more defensible input data for the GALENA model. Hence it is only acceptable and necessary to satisfy academic exercise.

2.2 S. K SARMA(1987):

This paper is simple but accurate method for stability analysis for embankments, slopes based on principle of limit equilibrium and method of slices. It includes computing the critical horizontal acceleration that is required to bring the mass of soil bounded by the slip surface and the free surface to a state of equilibrium. The physical acceptability of thesolution must be checked before the result is accepted.

2.3 Robert w. Day and Gregory w. Axten (1989)

This paper deals with surficial failures of clay slopes, which is quite common in Southern California due to prolong seasonal rainfall because of seasonal variations the clay becomes shrunken and desiccated. The water percolates through fissures causing the slope to swell and saturate which indeed reduces the shear strength of the clayey slope. The factor of safety equation is derived by assuming seepage parallel to the slope. Some of the assumptions are, minimum acceptable vertical depth is 1.2m. And minimum factor of safety is 1.5. The drained shear strength envelopes for different compacted clays are nonlinear especially at lower normal stresses. Here the FOS would be overestimated for compacted clays because the effective stress is much greater than the actual cohesion at lower effective stress this results in overestimation ofFOS.

2.4 Burman, S. P. Acharya etc. all (2015):

"Comparative study of slope stability analysis using traditional limit equilibrium method and finite element method" In that they concluded that present work, limit equilibrium technique (ordinary slice method, Bishop's method, Spencer's method, Morgenstern-Price method) and finite element method have been used to the study different slope stability problems. Also, it is observed that ordinary slice method provides most conservative estimation of factor of safety values amongst all the limit equilibrium techniques considered in this paper. Therefore, any design of slopes carried out with ordinary slice method is likely to be always on the safer side. Other limit equilibrium methods like Ordinary Bishop's Method, Spencer's Method and Morgenstern and Price's method attempt to establish a more realistic estimation of interstice forces which may develop in reality. But they lead to somewhat higher estimation of factor of safety. The FOS values obtained using finite element method compare very well with that obtained from limit equilibrium methods. In finite element method, the FOS for critical slip surface is automatically obtained. In case of limit equilibrium methods, several slip surfaces should be analyzed to find the critical slip surface. These type of trial and error calculations are not required with FEM to find out the critical slip surface because the failure occurs through the zone of weakest material properties and automatically the critical slip surface is determined. Furthermore, finite element method satisfies the equations of equilibrium and compatibility equations from theory of elasticity. Therefore, it serves as a more mathematically robust platform. Also, displacements, stress and strains at various nodes in the slope domain are also obtainable from finite element method. These are few of the additional benefits of using finite element method.

CHAPTER-3

METHODOLOGY

3.1 INTRODUCTION:

In this chapter, the overall methodology followed and methods used are described.

Overall methodology:

The study involves following steps:

1) First we studied various literature reviews based selected topic for the project.

2) Sample collection: The sample is collected from Tagarapuvalasa, Vishakhapatnam.

3) Soil properties are taken from previous project reports.

4) Location of most critical slip circle by Jumiki's (1962) after extension of Fellinius method.

5) Solution of embankment by analytically with method slices with the help of AutoCAD.

6) Check stability of embankment with another slope value i.e. 1:1.

7) Check stability of embankment without and with reinforcement and comparison with assumed soil data.

8) Check settlement criteria.

3.2 C-Φ ANALYSIS - METHOD OF SLICE:

Fig. 3.1 shows the section of a slope with AB as the trail slip surface. For a soil having c-Φ strength parameters, the shear strength at different points on the slip surface varies according to the value of the effective normal stress at those points. The analysis of stability in such a situation is carried out by the method of slices which was first introduced by Fellinius (1926) and is also known as the Swedish circle method. In this method, the soil mass above the assumed slip circle is divided into a number of vertical slices of equal width, as shown in Fig. 3.1. The number of slices may vary from 6 to 12, when hand computations are to be used.

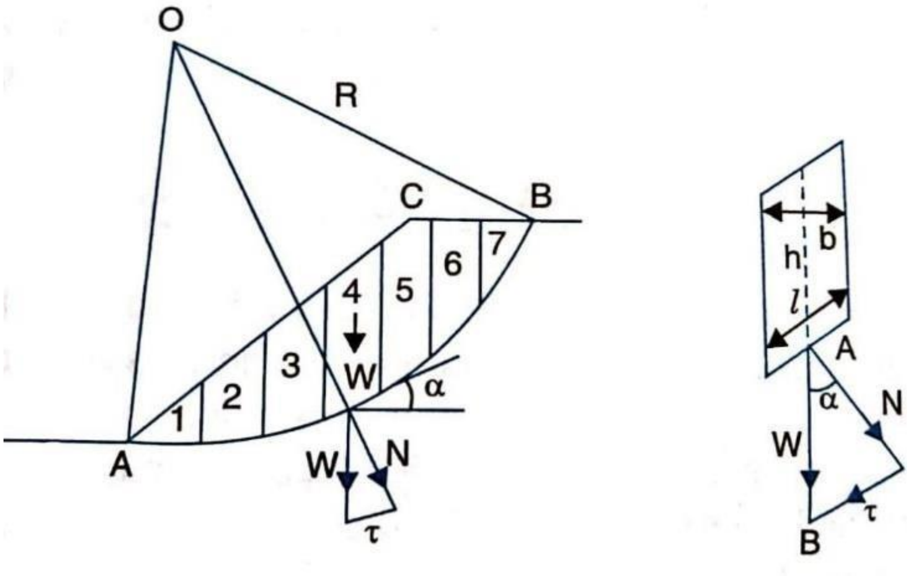


Fig. 3.1 C-φ analysis – method of slices

In the conventional method, the forces between the slices are neglected and each slice is considered to be an independent column of soil of unique thickness. If slice no. 4 is taken as a typical slice, the weight of the slice W is calculated as equal to γhb where γ is the bulk unit weight of the soil, h the average height of the slice and b its width. The weight W is plotted as a vector PQ and then resolved into its normal and tangential components N and T, respectively, at p. since the normal component N passes through P and the center of rotation O, it doesn't have a driving moment, but mobilizes frictional resistance along the slip surface. The 32 tangential component T causes the rotating moment. In the end slice, such as slice no.1 in fig 3.1, the tangential component may act in an opposite direction, causing a restoring moment. T is taken as positive when causing a driving moment and negative when causing a resisting moment. The algebraic sum of T will always be positive and contribute to the driving moment.

As we consider the slope at a national highway, the factor of safety is affected with additional forces such as pavement load and load due to vehicles. Here the load due to pavement (dead load) causes resisting force. Load due to vehicles (live load) causes driving force.

3.3 FACTOR OF SAFETY WITHOUT ANY REINFORCEMENT:

- Radius of slip circle (R)(m)
- Included angle of slip circle (δ) ^{O}
- Length of arc in slip circle (L) = $2\pi R\delta/360$
- Resisting moment (MR) (kN-m) = $(CL+\Sigma N \tan\varphi+\Sigma N1 \tan\varphi) R$
- Driving moment (MD) (kN-m) = $(\Sigma T+\Sigma T1)*R$
- Factor of safety (F) = MR/MD

If the obtained factor of safety is greater than 1.5 the slope is under safe condition. If the factor of safety is less than 1.5 the slope is under failure condition and calculations should be done by providing reinforcement to resist the slope under failure. There is no effect on driving moment due to reinforcement.

3.4 FACTOR OF SAFETY WITH REINFORCEMENT:

- If the obtained factor of safety is greater than 1.5 the slope is under safe condition. If the factor of safety is less than 1.5 the slope is under failure condition and calculations should be done by providing reinforcement to resist the slope under failure.
- Perpendicular distance between bottom reinforcement at Ground level to Origin O point (m)
- Spacing between reinforcement (S) (m)
- Allowable Tensile strength of reinforcement (T) (KN/m)
- Perpendicular distance of first reinforcement to origin point O (Y1) (m)
- Perpendicular distance of second reinforcement to origin point O (Y2) (m)

3.5 LOCATION OF THE MOST CRITICAL CIRCLE:

Since the determination of the minimum factor of safety for a slope is very crucial for design, it is important to locate the most critical slip circle with as few trails as possible. In a random trial and error approach, the 3 geometric parameters, namely, the center of rotation, the radius of slip circle and the distance of intercept in front of the toe are varied and the minimum factor of safety obtained. This requires a very large number of trails, but computers have made the method feasible. However, it is known that there is a certain pattern in slip circle behavior and knowledge of this pattern can be used to advantage and the number of trails reduced. For instance, it is known that the most critical circle passes through the toe of the slope when (a) the angle of shearing resistance Φ is greater than 3° and (b) the slope angle β exceeds 53°, irrespective of the value of Φ. The most critical circle intersects the slope in front of the toe if Φ is less than 3° and β<53°.

Fellinius (1936) proposed an empirical procedure to find the center of the most critical circle in a φu = 0 soil. The center O for the toe failure case can be located at the intersection of the 2 lines drawn from the ends A and B of the slope at angles α and ψ (fig. 4.10). The angles α and ψ vary with the slope.

Slope angle	Slope ratio	Angle α*	Angle ψ*
60°	1 : 0.58	29°	40°
45°	1 : 1	28°	37°
	1 : 1.5	26°	35°
	1 : 2	25°	35°
	1 : 3	25°	35°
	1 : 5	25°	37°

Table-3.1 Fellinius’s criteria for locating the center circle of a slope in a φu = 0 soil

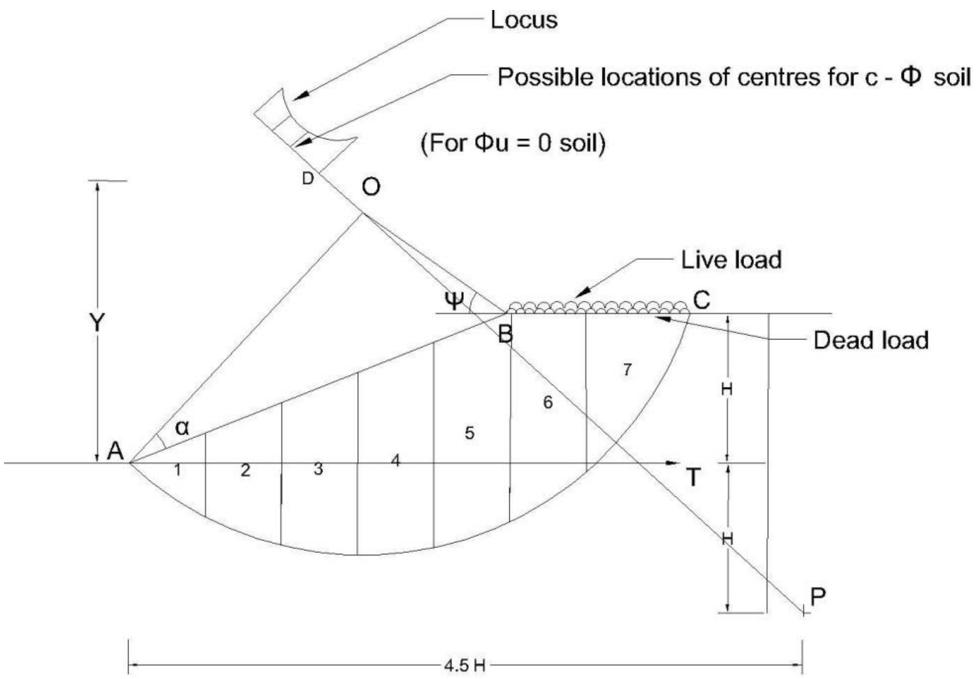


Fig 3.2 location of critical circle

Jumikis (1962) further extended this method to the case of a homogeneous, c-Φ soil. After obtaining the center O for a φu = 0 soil, point P is located at a distance 4.5H horizontally fromthe toe of the slope and H below the toe of the slope. The center of the critical is then assumed to lie on the extension of line PO1 and the factors of safety obtained are plotted to obtain a locus from which the minimum factor of safety obtained are plotted to obtain a locus from which the minimum factor of safety can be read.

CHAPTER-4

RESULTS AND DISCUSSIONS

4.1 EMBANKMENT OF SLOPE 1:2:

The factor of safety is obtained from the critical circles in which centers are assumed to lie on the extension of line PO with an interval of 0.5m. With the obtained values the minimum factor of safety is read and considered as the most critical circle.

4.1.1 Critical circle with the center at a distance of 0.5m from point O:

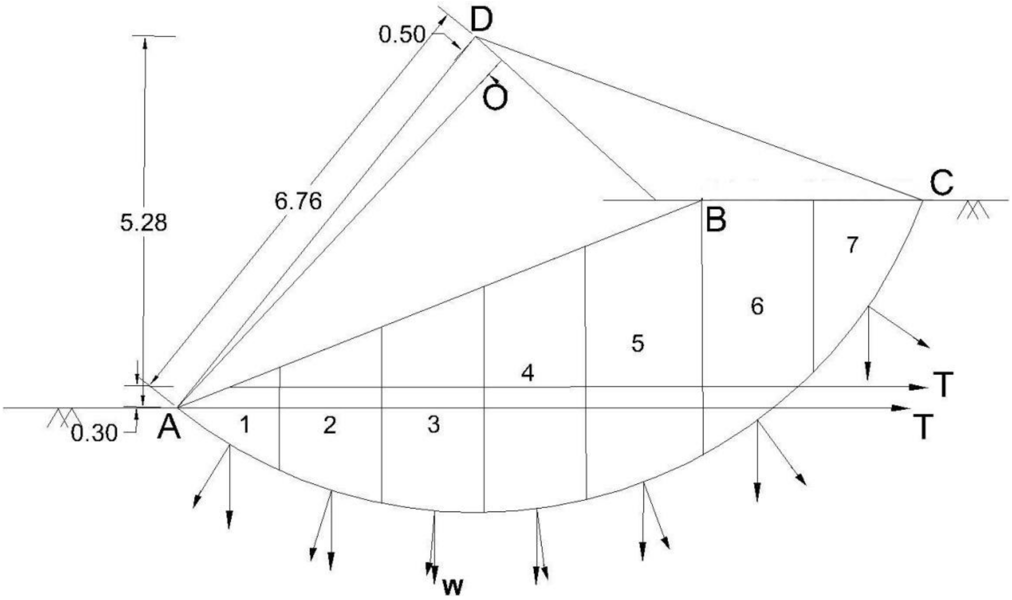


fig-4.1 critical circle with center 0.5m interval

Slice Number	Area of slice (m^2)	Weight of slice (W) (KN)	α (degrees)	N (kN/m) = W cosα	T (kN/m)= W sinα
1	1.11	22.2	-31	19.03	-11.43
2	2.91	58.2	-18	55.35	-17.98
3	4.16	83.2	-5	82.88	-7.25
4	4.95	99	7	98.26	12.06
5	6.02	120.4	21	112.4	43.15
6	4.86	97.2	36	78.64	57.13
7	2.12	42.4	56	23.71	35.15
				470.27	110.83

Table-4.1 details of slices under 1st slip surface

4.1.1.1Calculation for the soil sample collected at the field:

Embankment and foundation soil properties	Unit weight of soil in (γ) (kN/m^3)	**20**
	Cohesion (C) (kPa)	**3**
	Angle of internal friction $(\varphi)^{O}$	**20**

Length of arc in slip circle (L) = 2πRδ/360

Without reinforcement	Resisting movement (M_R) (kN-m) = (CL+ΣN tanφ)R	182.291*R	
	Driving movement (M_D) (kN-m) = ΣT)*R	103.34*R	
	Factor of safety (F) = M_R/M_D	1.764	>1.5 safe

4.1.1.2 Calculation for the assumed soil sample for comparison:

Embankment and foundation soil properties	Unit weight of soil in (γ) (kN/m^3)	20
	Cohesion (C) (kPa)	11
	Angle of internal friction (φ)^{O}	30

Factor of safety (F) = Resisting movement (M_R) /Driving movement (M_D)

= 3.575 >1.5 safe, So reinforcement is not required

4.1.2 Critical circle with the center at a distance of 1.0m from point O:

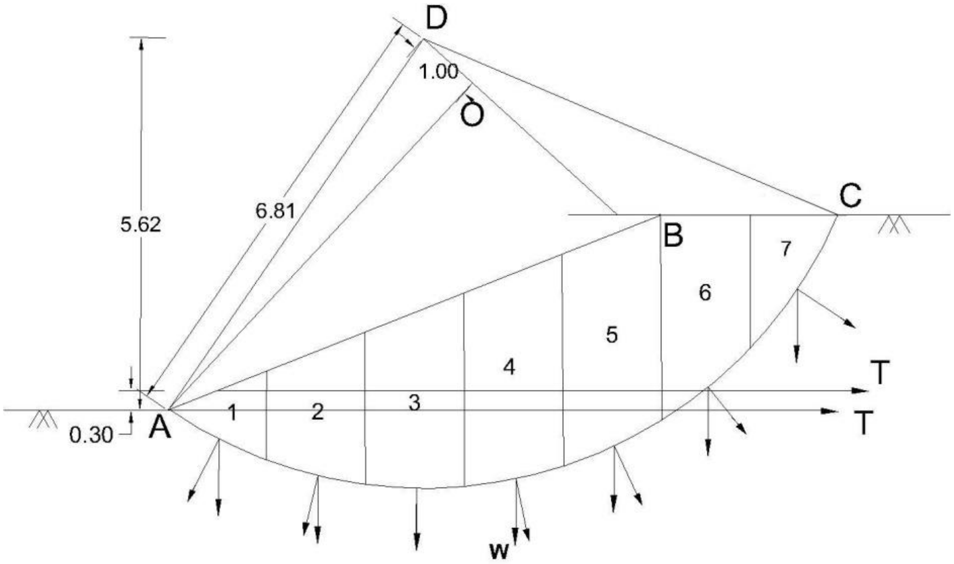


fig-4.2 critical circle with center 1.0m interval

Slice Number	Area of slice (m^2)	Weight of slice (W) (KN)	α (degrees)	N (kN/m) = W cosα	T (kN/m)= Wsinα
1	1.02	20.4	-27	18.17	-9.26
2	2.74	54.8	-14	53.17	-13.25
3	3.91	78.2	-1	78.18	-1.36
4	4.58	91.6	12	89.59	19.04
5	4.74	94.8	25	85.91	40.06
6	3.48	69.6	39	54.08	43.81
7	1.45	29	57	15.79	24.32
				394.93	103.34

Table-4.2 details of slices under 2nd slip surface

4.1.2.1 Calculation for the soil sample collected at the field:

Embankment and foundation soil properties	Unit weight of soil in (γ) (kN/m^3)	**20**
	Cohesion (C) (kPa)	**3**
	Angle of internal friction (φ)^O	**20**

Length of arc in slip circle (L) = $2\pi R\delta/360$

Without reinforcement	Resisting movement (M_R) (kN-m) = ($CL+\Sigma N \tan\varphi$)R	182029*R	
	Driving movement (M_D) (kN-m) = (ΣT)*R	103.34*R	
	Factor of safety (F) = M_R/M_D	1.764	>1.5 safe

4.1.2.2 Calculation for the assumed soil sample for comparison:

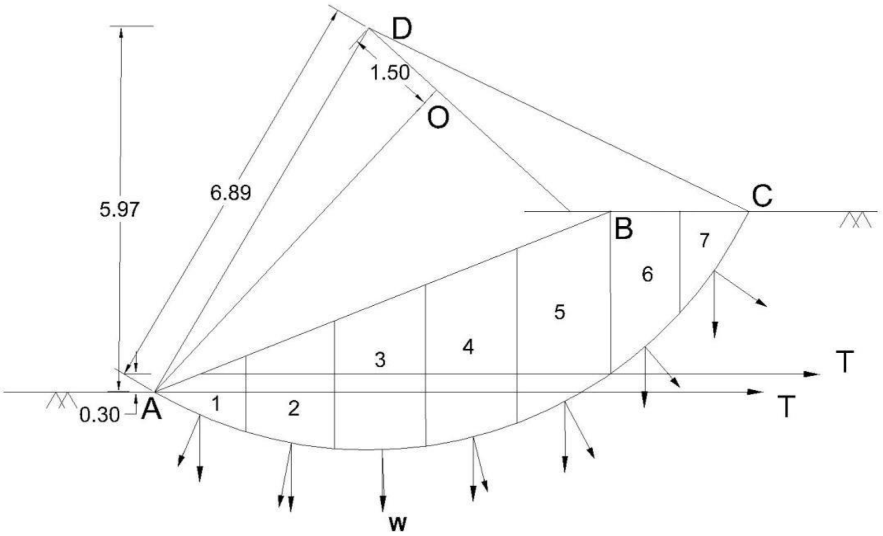
Embankment and foundationsoil properties	Unit weight of soil in (γ) (kN/m^3)	20
	Cohesion (C) (kPa)	11
	Angle of internal friction (φ)^O	30

Factor of safety (F) = Resisting movement (M_R) /Driving movement (M_D)

= 3.536 >1.5 safe, So reinforcement is not required

4.1.3 Critical circle with the center at a distance of 1.5m from point O:

fig-4.3 critical circle with center 1.5m interval



Slice Number	Area of slice (m^2)	Weightof slice(W) (KN)	α (degrees)	N (kN/m) = Wcosα	T(kN/m = Wsinα
1	0.96	19.2	-23	17.67	-7.50
2	2.44	48.8	-10	48.05	-8.47
3	3.55	71	2	70.95	2.47
4	4.12	82.4	15	79.59	21.32
5	4.26	85.2	27	75.91	38.68
6	2.49	49.8	41	37.58	32.67
7	1.01	20.2	55	11.58	16.54
				341.36	95.72

Table-4.3 details of slices under 3rd slip surface

4.1.3.1 Calculation for the soil sample collected at the field:

Embankment and foundation soil properties	Unit weight of soil in (γ) (kN/m^3)	**20**
	Cohesion (C) (kPa)	**3**
	Angle of internal friction (φ)^O	**20**

Length of arc in slip circle (L) = 2πRδ/360

Without reinforcement	Resisting movement (M_R) (kN-m) = (CL+ΣN tanφ)R	164.638*R	
	Driving movement (M_D) (kN-m) = (ΣT)*R	95.72*R	
	Factor of safety (F) = M_R/M_D	1.72	>1.5 safe

4.1.3.2 Calculation for the assumed soil sample for comparison:

Embankment and foundationsoil properties	Unit weight of soil in (γ) (kN/m^3)	20
	Cohesion (C) (kPa)	11
	Angle of internal friction (φ)^O	30

Factor of safety (F) = Resisting movement (M_R) /Driving movement (M_D)

= 3.575 >1.5 safe, So reinforcement is not required

4.1.4 Critical circle with the center at a distance of 2.0m from point O

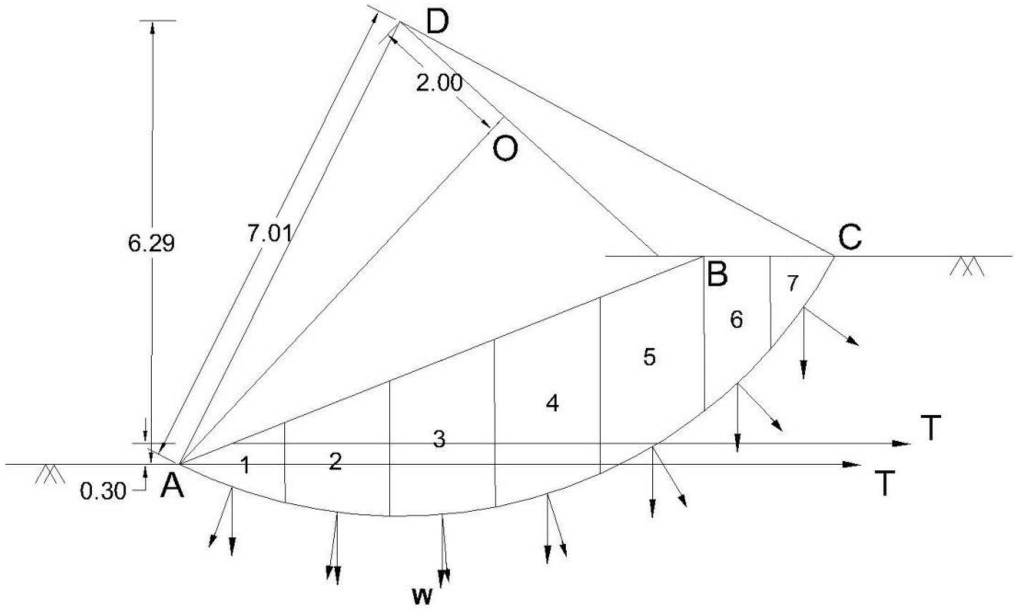


fig-4.4 critical circle with center 2.0m interval

Slice Number	Area of slice (m^2)	Weight of slice (W) (KN)	α (degrees)	N (kN/m) = W cosα	T(kN/m)= Wsinα
1	0.88	17.6	-20	16.53	-6.02
2	2.3	46	-7	45.65	-5.61
3	3.22	64.4	5	64.15	5.61
4	3.66	73.2	17	70.01	21.40
5	3.51	70.2	31	60.17	36.15
6	1.67	33.4	43	24.43	22.78
7	0.64	12.8	55	7.34	10.48
				288.29	84.81

Table-4.4 details of slices under 4th slip surface

4.1.4.1 Calculation for the soil sample collected at the field:

Embankment and foundation soil properties	Unit weight of soil in (γ) (kN/m^3)	**20**
	Cohesion (C) (kPa)	**3**
	Angle of internal friction (φ)^O	**20**

Length of arc in slip circle (L) = $2\pi R\delta/360$

Without reinforcement	Resisting movement (M_R) (kN-m) = (CL+ΣN tanφ)R	143.32*R	
	Driving movement (M_D) (kN-m) = (ΣT)*R	84.81*R	
	Factor of safety (F) = M_R/M_D	1.69	>1.5 safe

4.1.4.2 Calculation for the assumed soil sample for comparison:

Embankment and foundationsoil properties	Unit weight of soil in (γ) (kN/m^3)	20
	Cohesion (C) (kPa)	11
	Angle of internal friction (φ)^O	30

Factor of safety (F) = Resisting movement (M_R) /Driving movement (M_D)

= 3.63 >1.5 safe, So reinforcement is not required

4.2 EMBANKMENT OF SLOPE 1:1:

The factor of safety is obtained from the critical circles in which centers are assumed to lie on the extension of line PO with an interval of 0.5m. With the obtained values the minimum factor of safety is read and considered as the most critical circle.

4.2.1 Critical circle with the center at point O:

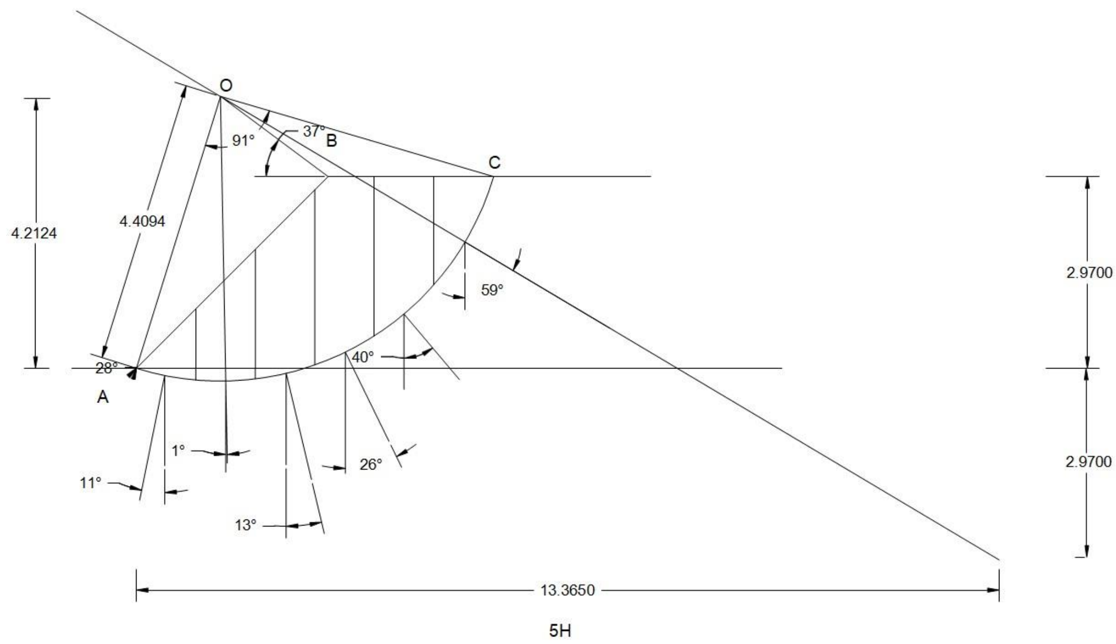


fig-4.5 critical circle with center at point O

Slice Number	Area of slice (m^2)	Weight of slice (W) (KN)	α (degrees)	N (kN/m) =W cosα	T(kN/m)= Wsinα
1	0.519	10.380	-11	-10.189	-1.980
2	1.444	28.880	1	28.875	0.504
3	2.186	43.720	13	42.599	9.834
4	2.476	49.520	26	44.508	21.708
5	1.936	38.700	40	29.645	24.875
6	0.869	17.380	59	8.951	14.897
				144.389	69.838

Table-4.5 details of slices under 1st slip surface

4.2.1.1 Calculation for the soil sample collected at the field:

Embankment and foundation soil properties	Unit weight of soil in (γ) (kN/m^3)	**20**
	Cohesion (C) (kPa)	**3**
	Angle of internal friction (φ)^O	**20**

Length of arc in slip circle (L) = 2πRδ/360

Without reinforcement	Resisting movement (M_R) (kN-m) = (CL+ΣN tanφ)R	73.539*R	
	Driving movement (M_D) (kN-m) = (ΣT)*R	69.838*R	
	Factor of safety (F) = M_R/M_D	1.053	<1.5 not safe

Factor of safety (F) <1.5 so reinforcement is required

4.2.1.2 Calculation for the soil sample by providing reinforcement of tensile strength 40 Kn/M:

With reinforcement	Perpendicular distance between bottom reinforcement at Ground level to Origin O point(m)	4.212	
	Spacing between reinforcement (S) (m)	0.3	
	Allowable Tensile strength of reinforcement (T) (kN/m)	40	
	perpendicular distance of first reinforcement to origin point O (Y1) (m)	3.912	
	Resisting force due to reinforcement (kNm) $=T_1 Y_1$	156.48	
	Resisting movement (M_R) (kN-m) = $(CL+\Sigma N \tan\varphi)R + T_1 Y_1$	480.845	
	Driving movement (M_D) (kN-m) = $(\Sigma T)*R$	307.943	
	Factor of safety (F) = M_R/M_D	1.561	>1.5 safe

4.2.1.3 Calculation for the assumed soil sample for comparison:

Embankment and foundationsoil properties	Unit weight of soil in (γ) (kN/m^3)	20
	Cohesion (C) (kPa)	11
	Angle of internal friction $(\varphi)^O$	30

Factor of safety (F) = Resisting movement (M_R) /Driving movement (M_D)

= 2.296<1.5 safe, So reinforcement is not required

4.2.2 Critical circle with the center at a distance of 0.5m from point O

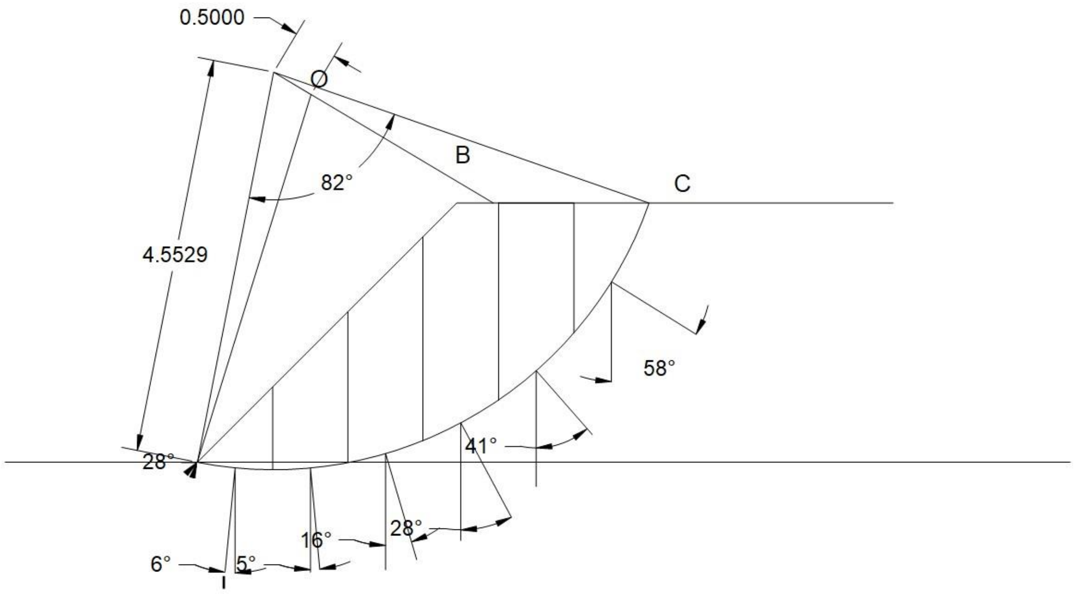


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fig-4.6 critical circle with center 0.5m interval

Slice Number	Area of slice (m^2)	Weight of slice (W) (KN)	α (degrees)	N (kN/m) = Wcosα	T(kN/m)= Wsinα
1	0.417	8.340	-6	-8.294	-0.871
2	1.182	23.640	5	23.550	2.060
3	1.762	35.240	16	33.874	9.713
4	2.085	41.700	28	36.818	19.576
5	1.635	32.700	41	24.679	21.453
6	0.710	14.200	58	7.524	12.042
				118.151	63.973

Table-4.6 details of slices under 2nd slip surface

4.2.2.1 Calculation for the soil sample collected at the field:

Embankment and foundation soil properties	Unit weight of soil in (γ) (kN/m^3)	**20**
	Cohesion (C) (kPa)	**3**
	Angle of internal friction (φ)^O	**20**

Length of arc in slip circle (L) = $2\pi R\delta/360$

Without reinforcement	Resisting movement (M_R) (kN-m) = ($CL+\Sigma N \tan\varphi$)R	62.501*R	
	Driving movement (M_D) (kN-m) = (ΣT)*R	63.973*R	
	Factor of safety (F) = M_R/M_D	0.977	<1.5 not safe

Factor of safety (F) <1.5 so reinforcement is required

4.2.2.2 Calculation for the soil sample by providing reinforcement of tensile strength 40 Kn/M:

With reinforcement	Perpendicular distance between bottom reinforcement at Ground level to Origin O point(m)	4.468	
	Spacing between reinforcement (S) (m)	0.3	
	Allowable Tensile strength of reinforcement (T) (kN/m)	40	
	perpendicular distance of first reinforcement to origin point O (Y1) (m)	4.168	
	Resisting force due to reinforcement (kN-m) =T_1 Y_1	166.72	
	Resisting movement (M_R) (kN-m) = ($CL+\Sigma N \tan\varphi$)R + T_1 Y_1	451.51	
	Driving movement (M_D) (kN-m) = (ΣT)*R	291.267	
	Factor of safety (F) = M_R/M_D	1.55	>1.5 safe

4.2.2.3 Calculation for the assumed soil sample for comparison:

Embankment and foundationsoil properties	Unit weight of soil in (γ) (kN/m^3)	20
	Cohesion (C) (kPa)	11
	Angle of internal friction (φ)^{O}	30

Factor of safety (F) = Resisting movement (M_R) /Driving movement (M_D)

= 2.186>1.5 safe, So reinforcement is not required

4.2.3 Critical circle with the center at a distance of 1.0m from point O

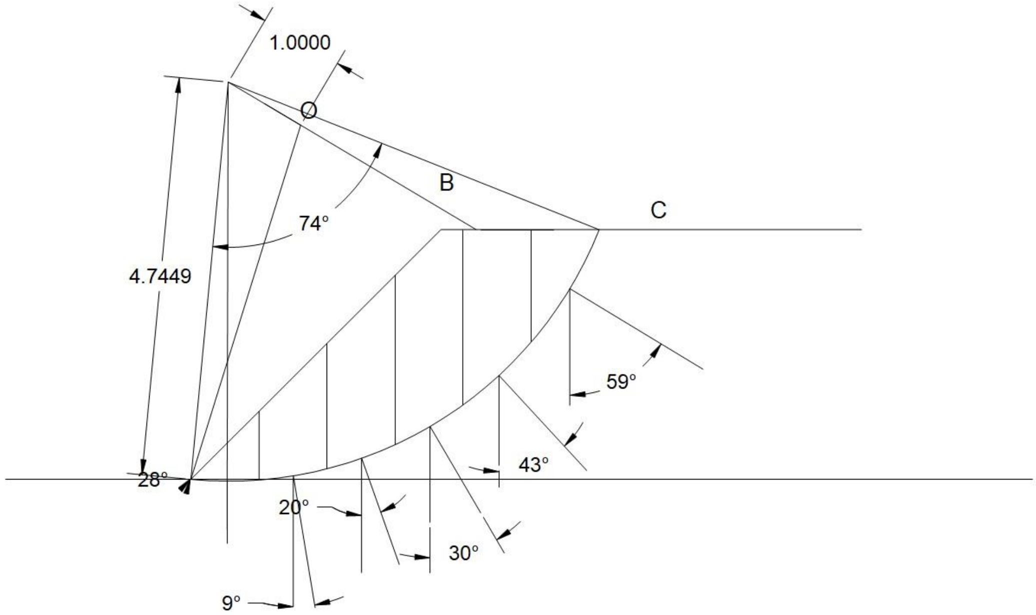

fig-4.7 critical circle with center 1.0m interval

Slice Number	Area of slice (m^2)	Weight of slice (W) (KN)	α (degrees)	N (kN/m) = Wcosα	T(kN/m)= Wsinα
1	0.335	6.700	0	6.7	0
2	0.939	18.780	9	18.548	2.937
3	1.425	28.500	20	26.781	9.747
4	1.740	34.800	30	30.137	17.4
5	1.401	28.020	43	20.492	19.109
6	0.710	14.200	59	7.313	12.171
				109.971	61.364

Table-4.7 details of slices under 3rd slip surface

4.2.3.1 Calculation for the soil sample collected at the field:

Embankment and foundation soil properties	Unit weight of soil in (γ) (kN/m^3)	**20**
	Cohesion (C) (kPa)	**3**
	Angle of internal friction (φ)^O	**20**

Length of arc in slip circle (L) = $2\pi R\delta/360$

Without reinforcement	Resisting movement (M_R) (kN-m) = ($CL+\Sigma N \tan\varphi$)R	58.357*R	
	Driving movement (M_D) (kN-m) = (ΣT)*R	61.364*R	
	Factor of safety (F) = M_R/M_D	0.951	<1.5 not safe

Factor of safety (F) <1.5 so reinforcement is required

4.2.3.2 Calculation for the soil sample by providing reinforcement of tensile strength 40 Kn/M:

With reinforcement	Perpendicular distance between bottom reinforcement at Ground level to Origin O point(m)	4.724	
	Spacing between reinforcement (S) (m)	0.3	
	Allowable Tensile strength of reinforcement (T) (kN/m)	40	
	perpendicular distance of first reinforcement to origin point O (Y1) (m)	4.424	
	Resisting force due to reinforcement (kNm) =T_1 Y_1	176.96	
	Resisting movement (M_R) (kN-m) = ($CL+\Sigma N \tan\varphi$)R + T_1 Y_1	454.11	
	Driving movement (M_D) (kN-m) = (ΣT)*R	291.472	
	Factor of safety (F) = M_R/M_D	1.558	>1.5 safe

4.2.3.3 Calculation for the assumed soil sample for comparison:

Embankment and foundationsoil properties	Unit weight of soil in (γ) (kN/m^3)	20
	Cohesion (C) (kPa)	11
	Angle of internal friction (φ)^{O}	30

Factor of safety (F) = Resisting movement (MR) /Driving movement (MD)

= 2.133>1.5 safe, So reinforcement is not required

4.2.4 Critical circle with the center at a distance of 1.5m from point O

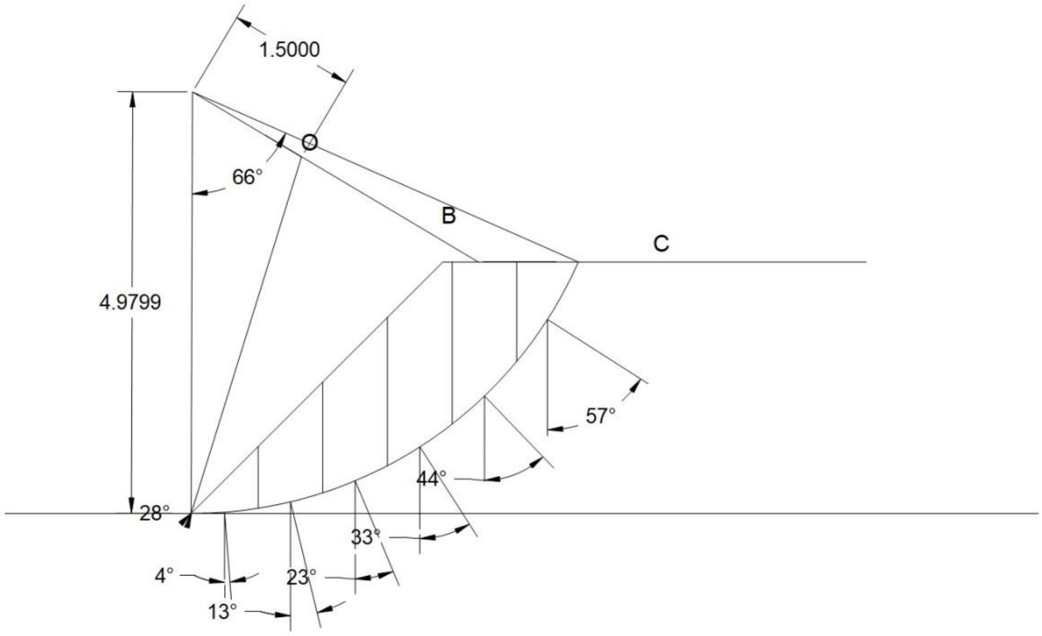

fig-4.8 critical circle with center 1.5m interval

Slice Number	Area of slice (m^2)	Weight ofslice (W) (KN)	α (degrees)	N (kN/m) = Wcosα	T(kN/m)= Wsinα
1	0.296	5.920	4	5.905	0.412
2	0785	15.700	13	150297	3.531
3	1.177	23.540	23	21.668	9.197
4	1.445	28.900	33	24.237	15.740
5	1.193	23.860	44	17.163	16.574
6	0.458	9.160	57	4.988	7.682
				89.258	53.136

Table-4.8 details of slices under 4th slip surface

4.2.4.1Calculation for the soil sample collected at the field:

Embankment and foundation soil properties	Unit weight of soil in (γ) (kN/m^3)	**20**
	Cohesion (C) (kPa)	**3**
	Angle of internal friction (φ)^O	**20**

Length of arc in slip circle (L) = 2πRδ/360

Without reinforcement	Resisting movement (M_R) (kN-m) = (CL+ΣN tanφ)R	49.682*R	
	Driving movement (M_D) (kN-m) = (ΣT)*R	53.136*R	
	Factor of safety (F) = M_R/M_D	0.935	<1.5 not safe

Factor of safety (F) <1.5 so reinforcement is required

4.2.4.2 Calculation for the soil sample by providing reinforcement of tensile strength 40 Kn/M:

With reinforcement	Perpendicular distance between bottom reinforcement at Ground level to Origin O point(m)	4.982	
	Spacing between reinforcement (S) (m)	0.3	
	Allowable Tensile strength of reinforcement (T) (kN/m)	40	
	perpendicular distance of first reinforcement to origin point O (Y1) (m)	4.682	
	Resisting force due to reinforcement (kNm) = T_1 Y_1	187.28	
	Resisting movement (M_R) (kN-m) = (CL+ΣN tanφ)R + T_1 Y_1	434.712	
	Driving movement (M_D) (kN-m) = (ΣT)*R	264.564	
	Factor of safety (F) = M_R/M_D	1.645	>1.5 safe

4.2.4.3 Calculation for the assumed soil sample for comparison:

Embankment and foundationsoil properties	Unit weight of soil in (γ) (kN/m^3)	20
	Cohesion (C) (kPa)	11
	Angle of internal friction (φ)^O	30

Factor of safety (F) = Resisting movement (M_R) /Driving movement (M_D)

= 2.157>1.5 safe, So reinforcement is not required

4.2.5 Critical circle with the center at a distance of 2.0m from point O

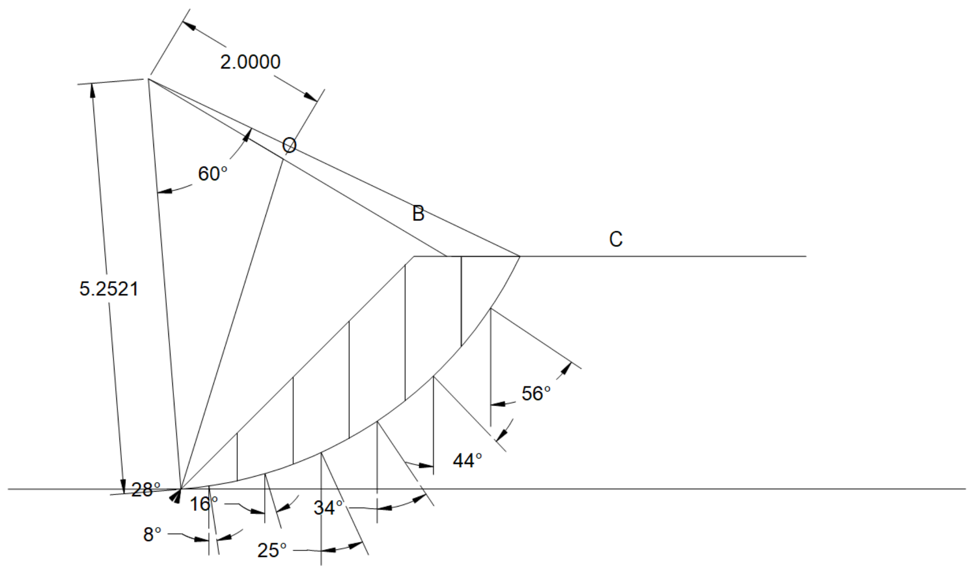

fig-4.9 critical circle with center 2.0m interval

Slice Number	Area of slice (m^2)	Weight ofslice (W) (KN)	α (degrees)	N (kN/m) = Wcosα	T(kN/m)= Wsinα
1	0.222	4.440	8	4.396	0.167
2	0.620	12.400	16	11.919	3.417
3	0.938	18.760	25	17.002	7.928
4	1.161	23.220	34	19.250	12.984
5	1.070	21.400	44	15.393	14.865
6	0.450	9.000	56	5.032	7.461
				72.992	47.272

Table-4.9 details of slices under 5th slip surface

4.2.5.1 Calculation for the soil sample collected at the field:

Embankment and foundation soil properties	Unit weight of soil in (γ) (kN/m^3)	**20**
	Cohesion (C) (kPa)	**3**
	Angle of internal friction (φ)^O	**20**

Length of arc in slip circle (L) = 2πRδ/360

Without reinforcement	Resisting movement (M_R) (kN-m) = (CL+ΣN tanφ)R	43.017*R	
	Driving movement (M_D) (kN-m) = (ΣT)*R	47.272*R	
	Factor of safety (F) = M_R/M_D	0.910	<1.5 not safe

Factor of safety (F) <1.5 so reinforcement is required

4.2.5.2 Calculation for the soil sample by providing reinforcement of tensile strength 40 Kn/M:

With reinforcement	Perpendicular distance between bottom reinforcement at Ground level to Origin O point(m)	5.235	
	Spacing between reinforcement (S) (m)	0.3	
	Allowable Tensile strength of reinforcement (T) (kN/m)	40	
	perpendicular distance of first reinforcement to origin point O (Y1) (m)	4.935	
	Resisting force due to reinforcement (kNm)=T_1 Y_1	197.4	
	Resisting movement (M_R) (kN-m) = (CL+ΣN tanφ)R + T_1 Y_1	423.575	
	Driving movement (M_D) (kN-m) = (ΣT)*R	248.119	
	Factor of safety (F) = M_R/M_D	1.707	>1.5 safe

4.2.5.3 Calculation for the assumed soil sample for comparison:

Embankment and foundationsoil properties	Unit weight of soil in (γ) (kN/m^3)	20
	Cohesion (C) (kPa)	11
	Angle of internal friction (φ)^{O}	30

Factor of safety (F) = Resisting movement (M_R) /Driving movement (M_D)

= 3.63 >1.5 safe, So reinforcement is not required

CHAPTER-5

CONCLUSION

1. Choosing a problem of embankment at Tagarapuvalasa, Visakhapatnam.
2. Soil sample collection at location.
3. Location of most critical slip circle by Jumiki's (1962) after extension of Fellinius method.
4. Solution of embankment by analytically with method slices with the help of AutoCAD:Modeling of embankment, finding dimensions, areas and angles.
5. Solution of the same embankment by changing its original slope to 1:1 by analytical with method of slices with the help of AutoCAD: Modeling of embankment, finding dimensions, areas and angles.
6. Doing calculations for assumed soil soil sample for comparison.

7. Overall results

a. Embankment with slope 1:2

Soil type	**Factor of safety**				
Soil C=3kPa and φ = 20^O	Without reinforcement	**1.89**	**1.564**	**1.72**	**1.69**
Soil C=11kPa and φ = 20^O	Without reinforcement	**3.72**	**3.575**	**3.536**	**3.63**

b. Embankment with slope 1:1

Soil type	**Factor of safety**					
C=3kPa & φ =20^O	Without reinforcement	**1.053**	**0.977**	**0.951**	**0.935**	**0.910**
	with reinforcement	**1.561**	**1.55**	**1.558**	**1.645**	**1.707**
C=11kPa&φ =30^O	Without reinforcement	**2.296**	**2.186**	**2.133**	**2.157**	**3.63**

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