“SLOPE STABILITY ANALYSIS OF KOTROPI LANDSLIDE AND ITS REMEDIATION”

A PROJECT

Submitted in partial fulfilment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision of

Mr. Niraj Singh Parihar

(Assistant Professor)

By

Sourav Thakur [171626]

Nikhil Thakur [171633]

Aman Thakur [171067]

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

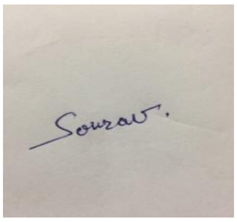
WAKNAGHAT, SOLAN – 173234

HIMACHAL PRADESH, INDIA

MAY-2021

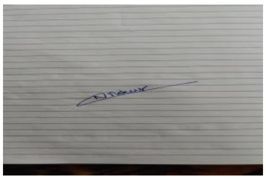
STUDENT DECLARATION

We hereby declare that the work presented in the Project report entitled **"Slope Stability Analysis of Kotropi Landslide and Its Remediation"** submitted for partial fulfilment of the requirements for the degree of Bachelor of Technology in Civil Engineering at **Jaypee University of Information Technology, Wakhnaghat** is an authentic record of my work carried out under the supervision of Mr. Niraj Singh Parihar. This work has not been submitted elsewhere for the reward of any other degree/diploma. I am fully responsible for the contents of my project report.



Sourav Thakur

(171626)



Nikhil Thakur

(171633)

Aman Thakur

(171067)

CERTIFICATE

This is to certify that the work which is being presented in the project report titled **"SLOPE STABILITY ANALYSIS OF KOTROPI LANDSLIDE AND ITS REMEDIATION"** in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering and submitted to the Department of Civil Engineering, Jaypee University of Information Technology, Wakhnaghat is an authentic record of work carried out by **Sourav Thakur[171626]** , **Nikhil Thakur[171633]** and **Aman Thakur[171067]** during a period from August 2020 to May 2020 under the supervision of **Mr. Niraj Singh Parihar,** Assistant Professor Department of Civil Engineering, **Jaypee University of Information Technology, Wakhnaghat.**

The above statement made is correct to the best of our knowledge.

Date…17-05-2021…

HOD
CE DEPT

Dr. Ashok Kumar Gupta
Professor& Head of Department
Civil Engineering department
Jaypee University of Information Technology

Mr. Niraj Singh Parihar
Assistant Professor
Civil Engineering department
Jaypee University of Information Technology

External Examiner

ACKNOWLEDGEMENT

It is our proud privilege and duty to acknowledge the kind of help and guidance received from several people in preparation of this report. It would not have been possible to prepare this report in this form without their valuable help, cooperation and guidance.

The topic **“SLOPE STABILITY ANALYSIS OF KOTROPI LANDSLIDE AND ITS REMEDIATION”** was very helpful to us in giving the necessary background information and inspiration in choosing this topic for the project. Our sincere thanks to **Mr. Niraj Singh Parihar,** Project Guide and Project Coordinator for having supported the work related to this project. Their contributions and technical support in preparing this report are great acknowledged. We wish to thank **Prof. Ashok Kumar Gupta**, Head of the Department, Civil Engineering Department for all his support by the way of providing wonderful working environment and facilities for the study in general and this work in particular. We are forever grateful to our families for their unconditional support.

ABSTRACT

The Prior existence of small landslides and heavy rainfall on August 13, 2017, near the village of Kotropi (Mandi District, Himachal Pradesh), India is believed to have resulted in a debris flow type of landslide. Two transport buses were swept away causing 47 fatalities in this disastrous landslide. Due to a massive 1153 m of slope run-out Extending over 190 m of slope width, a stretch of 300-m on National Highway-154 was completely buried under sludge. The present work aims to modify the Kotropi slope failure. The present work also aims to provide remedial measures such as anti-slide piles and to check the slope stability. Anti-slides piles are used for stabilizing the failed slope along with the favourable soil conditions. By calculating the factor of safety in GEO 5 software using slope stability program, the stability of anti-slide pile slope is obtained. In comparison with 1.56 in optimization, a factor of safety of 1.60 is achieved through standard type analysis.

Keywords: landslides, slope failure, anti-slide piles, slope stability.

CONTENT

Table of Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ABRREVATION	FULL FORM
GEO	GEOTECHNICAL SOFTWARE
NH	NATIONAL HIGHWAY
HRTC	HIMACHAL ROADWAYS TRANSPORT CARPORATION
FOS	FACTOR OF SAFETY
V/S	VERSUS
K_H	HORIZONTAL SEISMIC COEFFICIENT
K_V	VERTICAL SEISMIC COEFFICIENT
LOP	LENGTH OF PILE

CHAPTER 1: INTRODUCTION

1.1PREFACE TO LOCATION

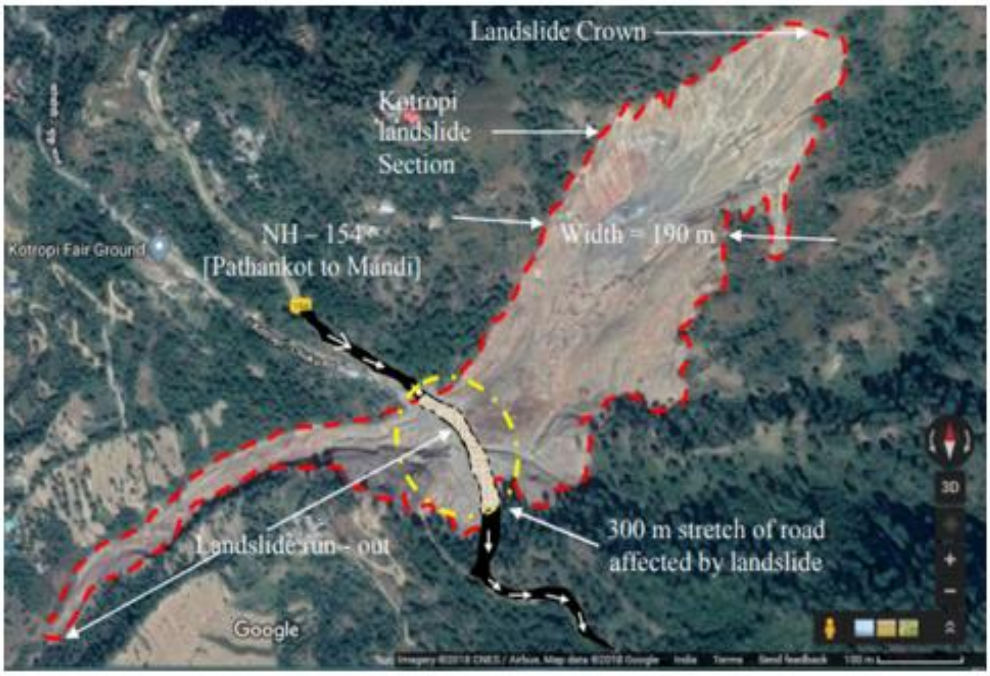


Fig 1 site view

The engineers and the society, often face the challenge of landslide in Hilly regions. The cause of landslides can be both natural as well as Man-made. Implying to huge loss to humans and property, each year Landslides affect the habitats of living creatures terribly. Significant changes in climatic and topographical structures are the Results of the urbanization of the region. Consequently, a various number of Landslide danger zones are created due to excessive rainfall in the Areas, living all life forms vulnerable to the aftermaths of climate change. In one such zone near the village of Kotropi in Mandi District Of Himachal Pradesh, India occurred a massive landslide. The location of the calamitous landslide was on National Highway (NH)-154, running Between Mandi and Pathankot. A large section of the slope collapsed completely resulting in bury two buses of Himachal Road Transport Corporation (HRTC) along with few other vehicles to be buried under the debris. Owing to this slope Failure the vehicles were swept 800 m down the slope. Thereby disrupting the communication of the region with adjacent areas, almost 300 m of the highway was entirely buried under sludge. 46 casualties were reported by the media as a result of catastrophic debris flow. The report showed that slope failure was triggered due to Excessive infiltration resulting from continuous rainfall in Kotropi Region. The objective of present study is to provide remedial measure for the slope stabilization of Kotropi region with the technique of Anti-slide pile. The techniques such as retaining wall, conventional soil nailing, and rock bolting can be used for remediation of landslide.

1.2 STUDY AREA

Landslide befell near the village of Kotropi Mandi H.P., which is the wettest place in Himachal Pradesh. The region is extended between 31.9121-degree N latitude and 76.8879-degrees E longitude. Containing mainly dolomites, brick red shale, purple clay, and mudstones. It proved to be a highly prone area to landslides since rocks are weak in strength

1.3 OBJECTIVES

1.3.1 IDENTIFICATION OF ENDANGERED AREA

Identification of the endangered areas are most important because it helps us to know about the conditions of that area and how we can save that area so that there should not be any loss to habitat and so as to save the areas from natural disasters.

1.3.2 POSSIBLE REMEDIAL MEASURES

Possible remedial measure to be provided so as to achieve the desired goal of saving the slope. There are various measures given by various people. The remedial measure used is anti-slide pile helps to control the erosion and reinforce the desired slip surface.

1.4 MERITS OF LANDSLIDE STABILIZATION

- Landslide stabilization helps to control the erosion of soil through which lots of trees and habitat can be saved.
- Future disasters can be controlled with the help of landslide stabilization as awareness spreads.
- Landslide stabilization leads to no loss of human and land.
- There is no loss as the risk of landslide is reduced.
- One of the main merits of landslide stabilization is as there is no issues to connectivity. Connectivity from one place to another is not affected and the things can be provided time to time without any loss to capital.

1.5 SCOPE OF PROJECT

The objective and aim of the study are to control the landslide so that there are no barriers in the NH-154. People can move easily from one place to another, there should not be any scarcity or shortage of material. By knowing the geotechnical engineering properties of soil and working on the slope using geo5. The slope is assessed by modeling the slope in geo5 software and remedial measure is proposed to be found out by using piles.

1.6 SIGNIFICANCE

This project is significant in various ways as the prevention of landslides leads to less hazard to human life and livelihood in almost every parts of the world, especially in the regions which have gone through rapid population and economic growth.
Soil degradation and flow of the land can be reduced which will help as the loss of the land is reduced. It will lead to less damage to the surroundings and the future damage can be controlled.

CHAPTER 2: LITERATURE REVIEW

1. **Pankaj Sharma, Saurabh Rawat, Ashok Kumar Gupta (December 2018); Study and remedy of Kotropi land slide area**

According to this research paper the investigation of geotechnical properties of Kotropi landslide has been done. In addition to the evaluation of factors of safety from LEM, the FEM analysis of stabilized Kotropi landslide slope is also carried out using helical soil nails. The factor of safety, deformation, and nail forces of unreinforced and reinforced Kotropi slope have been presented and compared. The various properties of the soil and the slope has been taken from the research paper and it is considered as the mother research paper.

2**. Shantanu Sarkar and Manojit Samanta (June 2017); Stability Analysis and Remedial Measures of a Landslip at Keifang, Mizoram – A Case Study**

A study on a landslide at oil drilling site was done to provide precaution measure. Study showed that the slope was at the verge of failure and can fail by any natural action in the near future. RCC retaining wall was provided to deal with the future disaster of slope failure. The slope is stabled so that there should not be any casualties and the habitat can be saved. The remedial measure used to stabilize is to use gabion wall or the rcc wall. The wall was built at site to decrease the cost and it was effective as the factor of safety significantly increases.

3**.Rajneesh Yadav, Sandeep Sushil Shrivastava, Amit Singh, Sriram (2014); Landslides and its Remedial measures: An Overview**

We are on the way to preparing for landslides remedial measures. Not fully capable but doing fair in this area. We are still learning to be properly prepared for future events. Correct data was available about the landslide movements which was a great help in analysing the situation. We are preparing well for the future by using remote sensing techniques, reduction techniques, and onsite measures. These measures can reduce future damage but cannot fully extinguish it. Making good development in the field of landslides forecast, remediation, and reduction. But the journey is not limited to it, there is a lot of work to be done, technology, and ideas to be implanted.

4. **R. Chitra and Manish Gupta (2016); Geotechnical Investigations and Slope Stability Analysis of a Landslide**

After analysing the slope stability, we found that many existing sections are unsafe. Seepage force can be the driving factor of the landslide in the coming monsoon. We have to prepare for the coming monsoon. Remedial measures were suggested that slopes of the Pomendi cutting should be properly compacted with proper turfing to confine surficial erosion. To avoid the landslide and mitigate it proper measures must be taken as proper drainages should be installed at slopes like cross drains etc. Geomembranes and geosynthetics in the cross drains can provide a leak-proof system.

5. **Zhang Xuanwen (2015); Analysis of Soil and Rock Slope Stability Influence by Anti-slide Piles Position**

This research telling us about reinforcement in soil slope and rock slope to maintain the stability of the slope. An anti-slide pile is been introduced to stabilize the slope. Studies on both soil slope and rock slope is been done and the results show that a low pile gives the highest stability factor in soil slope and a medium pile gives the highest stability factor in rock slope. Anti-slide piles can resist shear force and bending moments efficiently. For rock, slopes sink buried pile construction technology is introduced. Pile is buried in rock or soil up to a certain depth ensuring good stability, reduce pile length, and saving reinforcement cost.

6. **Jinqiu Pan, Zhiyong Wang, Tianxiong Dong and Bo Liang (2017); Analysis on the best position and the pile distance of anti-slide pile of reinforced soil slope.**

ABAQUS software is been used in the research. It was found that the stability of the slope depends upon the position of the anti-slide pile. It was found that the stability varies with distance variation of the anti-slide pile from the toe of the slope. As we increase the distance of the anti-slide pile from the toe of the slope, the stability factor first increased and then decreased.

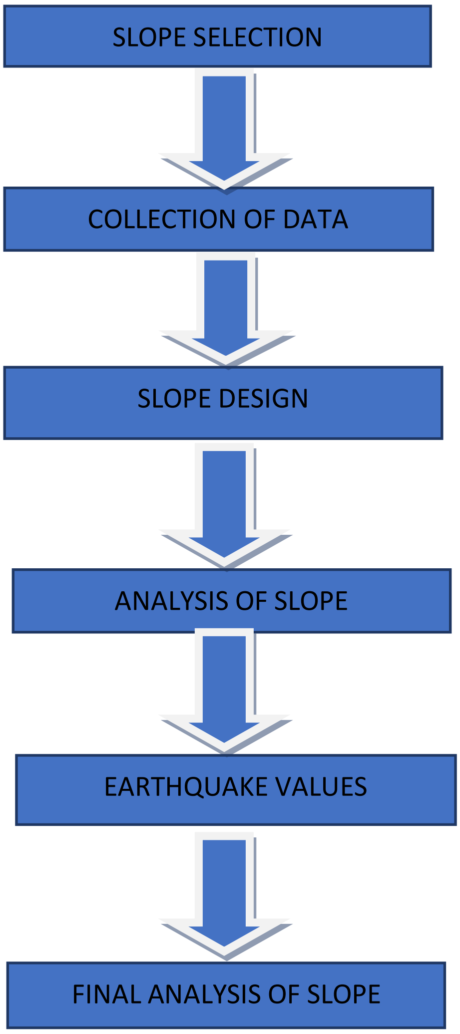
With different pile spacing, observed there was different stability factor

2.1 SUMMARY OF LITERATURE REVIEW

Landslides in terrain and hilly areas are hazardous if the properties of the soil and the seismic coefficients of that region are not accounted for excavation. Heavy rainfall pattern is also responsible for landslides. Hence, proper methods for the stability of the slope must be taken when the planning of the project is going on so as to reduce the risk. Among the factors that govern the stability of hill slopes, the structural condition of rocks and soils, the gradient of the slope, and the amount of water that finds access under-ground play very crucial roles in initiating and controlling landslides, Seismic shocks trigger and accelerate mass-movement on a larger scale but the principal-agent is always water. It not only acts as a lubricant, especially if mixed with clays or other slimy or rocks. The incidence of landslides is therefore very frequent and their magnitude greater during rainy spells.

CHAPTER 3: METHODOLOGY

3.1 METHODOLOGY



3.2SLOPE MODEL

Reinforced slope- The compacted embankment using the geosynthetic reinforcements to improve the stability of soil structure is termed as a reinforced slope.

Unreinforced slope- The slope with no reinforcement is an unreinforced slope. The slope is very much steep or the soil structure is well inside the factor of safety. If required the reinforcement can be provided in such slopes.

3.3 SLOPE SELECTION AND DATA COLLECTION –

Inputting geometry and other parameters according to the data. The coordinates of the slope are added in the dimension interface and similarly, three different interfaces for three different soils are added according to their coordinates.

The data taken from the research of Saurabh Rawat, Pankaj Sharma, and Ashok Kumar Gupta on the Study and remedy of Kotropi landslide area is taken into account. The parameters like the unit weight of soil, angle of internal friction, and cohesion of soil is added for three different soils and the further procedure is followed.

3.4 ANALYSIS OF SLOPE-

Analysis of slope is carried out by two different methods,

1. Optimization
2. Standard Analysis

1. Optimization – This consists of finding the critical slip surface that is, the slip surface having the lowest stability. In circular slip surfaces, optimization analyses the total slope and is very dependable. In this way, results for critical slip surfaces even with different initial slip surfaces can be found. Mainly Bishop method is been used.

2. Standard Analysis- Using this analysis, the slip surface evaluated for all methods corresponds to the critical slip surface. Method type can be set on All methods, but to get better results one by one method should be used.

These both type of analysis is carried out on basis of two different conditions,

1. Static condition
2. Dynamic condition

1. Static Method- The analysis carried out under static conditions that are, following the conditions of equilibrium. Under static analysis, the methods used are the Swedish circle method, Friction circle method, Bishop stability method, Friction stability method, and Janbu`s method.
   The Factor of safety by Swedish circle method –

$$F.S. = \frac{(CL + \tan\phi \sum N)}{\sum T}$$

The factor of safety by Bishop stability method (trial and error method)-

$$F.S.\ (F_s) = \frac{\sum_{i=1}^{n} (\,Cli + Wi \tan\phi i\,)\,[\frac{1}{\beta i(\theta)}]}{\sum_{i=1}^{n} Wi \sin\theta i}$$

2. Dynamic method- The analysis in which the earthquake forces are also considered. The inertial forces due to earthquakes are represented by a constant horizontal force equal to the weight of the potential sliding mass multiplied by a coefficient. To find out the factor of safety we use seismic coefficients. Two different methods can be used in the study
   1. Design spectrum method (IS 1893-2002)
   2. Newmark`s method.

CHAPTER 4: METHOD AND ANALYSIS

4.1GEO5 SOFTWRAE

Geo5 is a simple but significant geotechnical software used to solve the problems of the geotechnical world based on various traditional analytical methods. The geo5 software suite consists of simple and easy functioning tools and programs to solve and analyse our problems. This integrated suite helps to analyse different geotechnical tasks and get an output report.

Geo5 software has the solution to a large diversity of geotechnical problems. Not only the common geotechnical problems, but geo5 also helps to solve highly sophisticated matters like analysis of tunnels, rock slope stability analysis, building damage due to tunnelling, etc. Geo5 contains the variety of functions based on various traditional analytical methods, some of the analysis which can be performed in the software are,

1. Slope stability analysis
2. Retaining wall design
3. Cantilever walls design
4. Terrain settlements
5. Foundation and excavation designs
6. Soil settlement analysis
7. Spread footings analysis

4.2 KEY FEATURES OF GEO5

1. Integrated software suite- It can be called an integrated software suite, as all of its applications and programs are closely connected and works together and simultaneously to give us better results. As mentioned above, it helps not only for common geotechnical problems but also for highly sophisticated applications like tunnel analysis, stability analysis of rock slopes, and damage on building due to tunneling.

2. User-friendly environment- It is a very simple and easy-to-use tool and a lot of training of the software is not required for the user to operate this software. All the functions and programs are explained and defined and hence the software is very user-friendly.

3. Comprehensive graphical output- The outputs obtained from the software are good and appreciable. The output generation is one of the significant features of the software. Can generate graphical and text output reports and also can be edited according to our needs like adding a picture or logo, printed or saved in Word and PDF format.

4. Standards- Geo5 software is used all over the world and most of the countries adopt their geotechnical approaches in the software like their own standards and conventions. These different standards of Geo5 help to simplify the work and analysis.

4.3 STABILITY OF SLOPES

Slope stability is the calculation and analysis that how much stress a slope can bear before failing. The failure of slopes takes place mainly due to, the action of gravitational forces and seepage forces within the soil. For example, excavation at the foot of the slope, the disintegration of soil particles. The soil mass in a sloping surface is always subjected to shearing forces which are mainly due to gravitational forces which pull upper soil mass particles downwards. Slope stability analysis consists of two parts,

1. Determination of most stressed internal surface and magnitude of shear stress to which it is subjected.
2. Determination of shear strength of soil along the surface.

4.4 SLOPE STABILITY- SLOPE STABILITY ANALYSIS

Slope stability analysis is done to analyze the human-made or natural slopes to stabilize to these slopes if required. For e.g., embankments, excavations at the foot of slope, landfills etc and the equilibrium conditions. Slope stability is the resistance of steep surface to failure by sliding or collapsing. Choosing correct analysis technique depends on site conditions and the mode of failure and careful thoughts being provided on varying strengths, weaknesses and limitations of each methodology. A good design of the slope needs geological information and site characteristics, e.g., properties of soil/rock mass, slope geometry, groundwater conditions, alternation of materials by faulting, earthquake activity etc.

Two types of approaches are used in program for slope stabilization, one is the Classical analysis according to factor of safety and the other is, Analysis based on the theory of limit states.

4.4.1ANALYSIS ACOORDING TO THEORY OF LIMIT STATES

The process is based on the theory of Limit states. The theory of limit state provides the safety by comparing the resisting variable by the variable causing failure.

where: X_{pas}- A variable resisting the failure

$$X_{pas} > X_{act}$$

X_{act}- A variable causing the failure (sliding force, stress)

X_{act} is in general determined from the design parameters of soil and loading

- soil parameters are reduced by corresponding coefficients

- load (its action) is increased by corresponding coefficients

X_{pas} is determined based on the following assumptions:

- soil parameters are reduced by corresponding coefficients
- the calculated structure resistance is reduced by a corresponding coefficient

value of Vu is evaluated and then differentiated with the value of 100%. The value of Vu is given by:

$$V_u = \frac{M_a}{M_p} 100 < 100\%$$

where M_a -sliding moment

M_p- resisting moment

4.4.2 ANALYSIS ACOORDING TO SAFETY FACTOR

The process is based on the "Safety factor". It is the oldest and most used method for structure safety analysis. Its main advantage is that it is simple and significant approach.

The safety is demonstrated using the safety factor:

$$FS = \frac{X_{pas}}{X_{act}} > FS_{req}$$

where: FS-Computed safety factor

X_{pas}- A variable resisting the failure (resisting force, strength, capacity)

X_{act}- A variable the causing failure (sliding force, stress)

FS_{req}- Required factor of safety

Verification according to the factor of safety:

$$\frac{M_p}{M_a} > SF_s$$

where: M_a- sliding moment

M_p- resisting moment

SF_s- factor of safety

4.5 CRITICAL SLOPE SURFACES

The surface where failure is most likely to happen can be called a critical slope surface. When the external forces exceed the shear strength of soils, such surfaces are formed. The cause can be natural like weathering, erosion, etc, or human activities. In instability calculations, the curve representing the real surface of sliding is usually represented by an arc of the circle. There are two basic types of failures of the slope, one is the slope failure and the other is a base failure. Slope failure further divides into Face failure and toe failure.

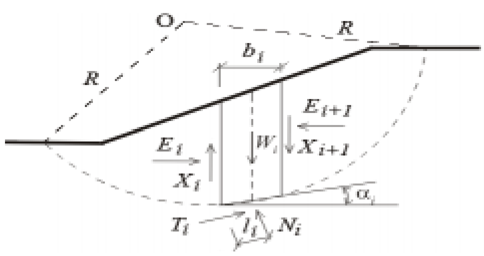
Types of failure surfaces or slip surfaces -

1. Planar failure surface
2. Circular failure surface
3. The non-circular failure surface

4.5.1 CIRCULAR SLIP SURFACES

The slip surfaces have arcs that are flat at the ends and sharper at the center. A circular rupture surface was firstly given by Petterson in 1916. Afterward field investigations by Swedish Geotechnical Commission computed circular arcs as a close estimation of the actual slip surface inhomogeneous and isotropic soil conditions. The assumption of circular failure surface was found out to be accurate for solving simple problems.

Every method of limiting equilibrium supposes that the soil above the slip surface is divided in blocks.



Xi and Ei = shear and normal force acting between individual blocks
Ti and Ni = shear and normal forces on individual segments of the slip surface
Wi = weight of the individual blocks
Methods of slices differ in assumptions for satisfying the equation of equilibrium of force and moment about center O.
Various analytical methods adopted here are –

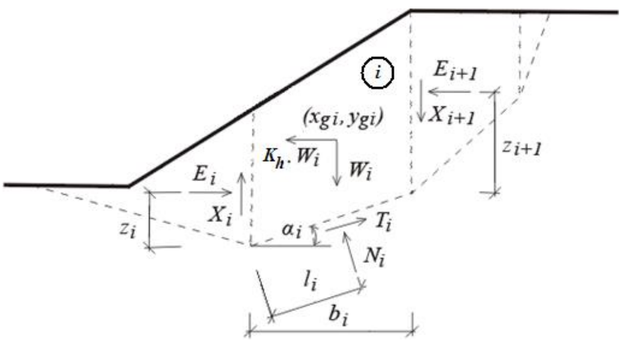
1. Petterson method
2. Bishop method
3. Spencer
4. Janbu method
5. Morgenstern Price method

OPTIMIZATION OF CIRCULAR SLIP SURFACES

The procedure aims to locate the slip surface with the lowest factor of slope stability. The circular slip surface is an arc consisting of 3 points, two points on the surface of the ground and the third one at the centre of the arc, i.e., inside the soil mass. The point inside the soil mass has two degrees of freedom and the other two points on the ground surface have single degrees of freedom. There are different parameters in the optimization process that helps giving reliable outputs.
The slip surface which gives the lowest slope stability factor is the critical slip surface thus, this approach succeeds the most in finding the critical slip surface.
The procedure can be confined by numerous limitations. This can be helpful to pass the slip surface through a particular region

4.5.2 POLYGONAL SLIP SURFACE

Polygonal slip surface or also known as polygonal sliding surface works on the method of the limit state of forces acting on the soil above the slip surface. So as to introduce the forces the surface is further divided in blocks by different planes.



The figure shows forces acting on individual blocks of soil. If the region above the slip surface is divided into blocks, then for the evaluation of unknowns we have: n normal forces Ni acting on individual segments and corresponding n shear forces Ti; n-1 normal forces between blocks Ei and corresponding n-1 shear forces Xi; n-1 values of zi representing the points of application of forces Ei, n values of li representing the points of application of forces Ni and one value of the factor of safety SF. Forces Xi can be in some methods replaced by the values of inclination of forces Ei. Most often points of application of individual forces acting between blocks or their inclinations are selected. Solving the problem of equilibrium proceeds in an iterative manner, where the selected values must allow for satisfying both the equilibrium and kinematical admissibility of the obtained solution.

Various methods that can be adopted are:

1. Sarma
2. Spencer
3. Janbu
4. Morgenstern-Price
5. Shahunyants
6. ITF Method

OPTIMIZATION OF POLYGONAL SLIP SURFACE

In optimization of polygonal slip surface or polygonal sliding surface software itself calculates and takes the weakest points, points in which the value of the safety factor is very less. Software it self interprets the data and the required slip surface is made on the screen with every run the step size is reduced. We can pass the polygonal slip surface from the certain or particular region which is very advantageous as we compare it to the standard sometimes not able to find out the exact location of the slip surface or the weakest points of the slip surface that is why the optimization is done so that there should not be any chances of skipping the weakest parts.
In case of several soil layers and profiles or complex slope's certain locations of slip surface can provide the more accurate values.

4.6 FACTOR OF SAFETY

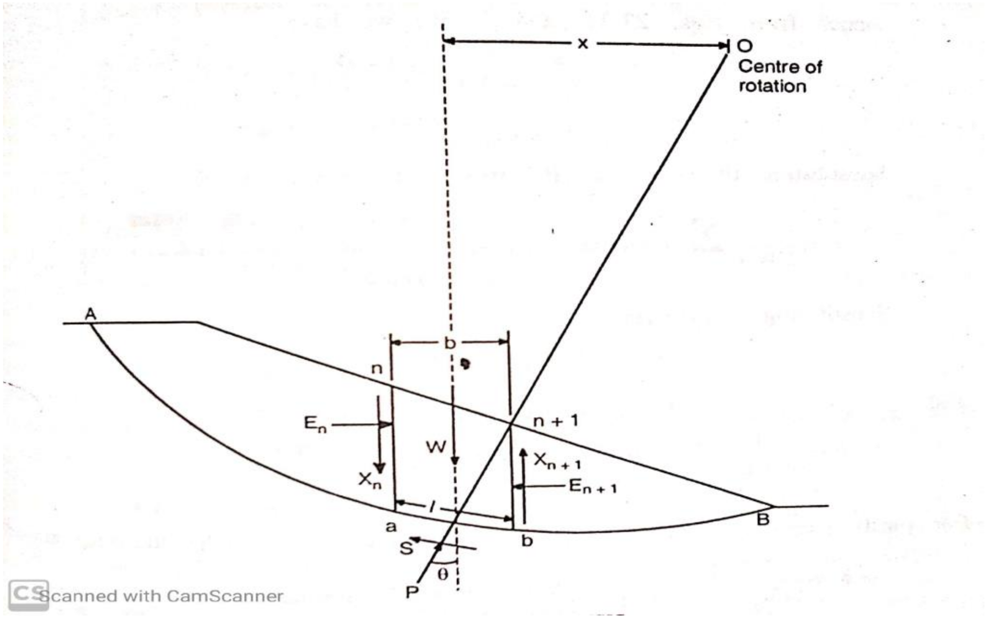
The factor of Safety is the ratio of maximum permissible stress to the applied stress. Here in our case factor of safety is the ratio of ultimate shear strength of soil to mobilized shear stress. The factor of safety is assumed to be constant along the slip surface and is defined as WRT the force or moment equilibrium.
1. Concerning moment equilibrium –
FOS = sum of resisting moments/sum of driving moments
The center of the circle is taken as a moment point.
2. Concerning force –
FOS = sum of resisting forces/sum of driving forces
An allowable factor if safety is required of the efficiency of slope in present and future. Present conditions and future possibilities should be kept in mind like deforestation, infiltration, excessive loading, huge storms, etc. Monitoring of pore water pressure, using inclinometers, use of strain gauges and optical fibres in nails, GPS, and many other ways can help monitor the efficient functioning of slopes.

4.7 SLOPE STABILITY ANALYSIS METHOD (ANALYTICAL)

1. **Bishop Method-**

Allan W Bishop in 1955 proposed a simplified method for calculating the stability of slopes. Bishop took into account the forces acting on the sides of slices which were neglected in the Swedish Slip Circle Method. The slip surface is supposed to be an arc of a circle. The factor of safety is given as actual shear strength divided mobilized shear strength.

This method also took into account the pore water pressure acting on the slice.
The factor of safety = Actual shear strength/Mobilised shear



En and En+1 = resultant horizontal forces on section n and n+1 resp.
Xn and Xn+1 = resultant vertical shear forces
W= Weight of a slice
P= total normal force acting on the base of the slice
S= shear force acting along the base of the slice
z = shear force acting along the base of the slice
l = length of the arc ab of the slice
b= horizontal width of the slice
x = horizontal distance of the slice from the center of the rotation
and theta is the angle of the base ab of the slice with horizontal
The Normal stress on the slice = P/l
And effective stress is mainly taken into account as the pore water pressure is present.

2.Fellenius/Petterson Method

The method was developed by Wolmar Fellenius as a result of the failure of slopes in sensitive clays (Sweden). This reduces the resolution of forces of the slope to statically determinate structure. This uses the simplest method of slices and assumes only the overall moment equation of equilibrium written WRT the slip surface center, that is the shearing and compression forces are not significant. The normal and shear forces between blocks are neglected. The expression of Factor of Safety according to the method is as follows,

$$FS = \frac{1}{\sum_i W_i . sin \alpha_i} . \sum_i [c_i . l_i + (N_i - u_i . l_i) . tan\varphi_i]$$

u(i)=pore water pressure within block

W(i)= block weight

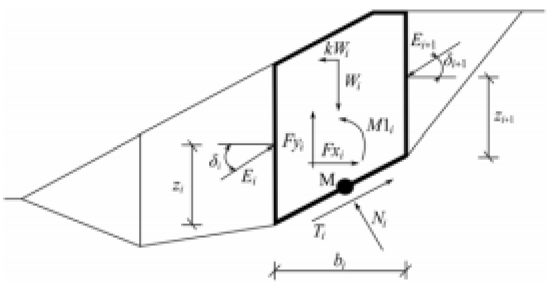
N(i) = Normal force on segment of slip surface

Alpha(i)= inclination of segment of slip surface

l(i) = length of segment of the slip surface

3. Spencer Method –

The Spencer Method is another method of slices developed based upon the limiting equilibrium. It needs equilibrium of forces and moments acting upon the individual blocks. These particular blocks are made by dividing the soil by dividing planes above slip surface. Forces acting on all individual blocks is shown in the figure below.



The forces contribution from each block is as follows-

W(i) = block weight including the material surcharge including effect of vertical earthquake coefficient Kv

Kh*Wi = horizontal inertial force with the earthquake effect (horizontal acceleration due to earthquake)

Ni = Normal force on slip surface

Ti= shear force on slip surface

Ei and E(i+1) = forces exerted by adjacent blocks inclined from horizontal plane by angle delta.

F(xi) and F(yi) = Other horizontal and vertical forces.

M(li) = moment of vertical and horizontal forces about the point M which is the centre of i(th) segment of slip surface.

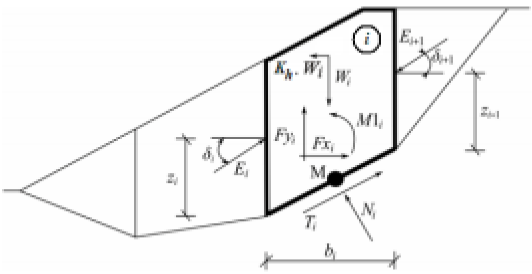
U(i)= pore water pressure resultant on the i(th) segment of slip surface

Assumptions made in the Spencer Method-

1. Dividing planes are always vertical between the blocks.
2. The line of action of weight of the block passes through centre of i(th) segment (M) of slip surface.

4. Janbu Method –

It is another general method of slices developed on the basis of limiting equilibrium. Equilibrium of forces and moments is been acted upon individual blocks (only the moment equilibrium at last block is not satisfied). Again the blocks are made by dividing the soil above slip surface by dividing planes. Display of forces is shown in the figure below.



The forces contribution from each block is as follows-

W(i) = block weight including the material surcharge including effect of vertical earthquake coefficient Kv

Kh*Wi = horizontal inertial force with the earthquake effect (horizontal acceleration due to earthquake)

Ni = Normal force on slip surface

Ti= shear force on slip surface

Ei and E(i+1) = forces exerted by adjacent blocks inclined from horizontal plane by angle delta.

F(xi) and F(yi) = Other horizontal and vertical forces.

M(li) = moment of vertical and horizontal forces about the point M which is the centre of i(th) segment of slip surface.

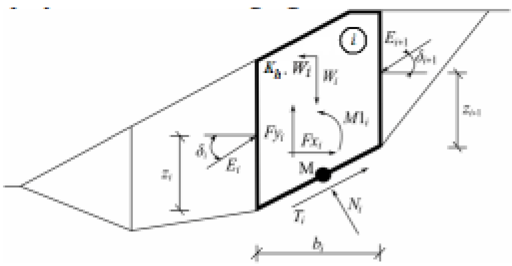
U(i)= pore water pressure resultant on the i(th) segment of slip surface.

Assumptions made in Janbu method-

1. Dividing planes are always vertical between the blocks.
2. The line of action of weight of the block passes through centre of i(th) segment (M) of slip surface.

3. **Morgenstern Price Method** –

   The Morgenstern Price Method is another method of slices developed based upon the limiting equilibrium. It needs equilibrium of forces and moments acting upon the individual blocks. These particular blocks are made by dividing the soil by dividing planes above slip surface. Every block contributes due to same forces like Spencer Method.



Some assumptions made in Morgenstern Method-

1. Dividing planes are always vertical between the blocks.
2. The line of action of weight of the block passes through centre of i(th) segment (M) of slip surface.
3. The normal force is acting at the centre of i(th) segment of slip surface that is M.
4. Inclination of forces acting between the blocks is constant for all blocks and = delta and at end points of the slip surface, delta = 0.

4.8 ANTI-SLIDE PILES

The anti-slide piles are used to stabilize the steep slope. Anti-slide pile is same as the pile walls. The anti-slide pile cut through the slip surface and stabilizes the slope. These are circular or square having variable length and diameter. This can be cast in-situ as well as ex-situ or pre-casted piles can be used. There are some assumptions made by the software itself. Anti-slide piles can reduce the risk of landslide as it strengths the stretch by providing suitable properties such as length, diameter and the pile spacing.

4.8.1 Assumption and default properties of software

- It is assumed that the anti-slide pile is a circular bored pile in-situ.
- The pile is always perpendicular to the surface.
- Presumed bearing capacity (Vu)-KN.
- Passive force direction: perpendicular to pile by default.

4.8.2Active and Passive force on Anti-slide pile

There are two types of forces which act on anti-slide pile, Active and Passive force. The active force always takes action on the pile from upper part of the slope. The active force helps in the failure of the slope. The passive force always takes action towards preventing landslide and contributes in the slope stability. If the passive is equal to zero, this implies that the pile is not stable. The difference between the active and passive force is the force, required to be transferred by the pile to reach a stable factor of safety. In a simple way, this is the bearing capacity a pile must carry out.

CHAPTER 5: SLOPE DESIGN AND ANALYSIS

5.1 INTERFACE

The interface framework tells every individual soil interface into the soil body. In this program, interfaces can be import or export in the DXF format. They can also be put in gINT format. The entire interface is copied within the 2D GEO5 program using "Geoclipboard". The entire slope is divided into three interfaces. The modeling of the interface is done

accordingly, to the given coordinates.

The model of slope has been shown with the stratification in fig 5.1

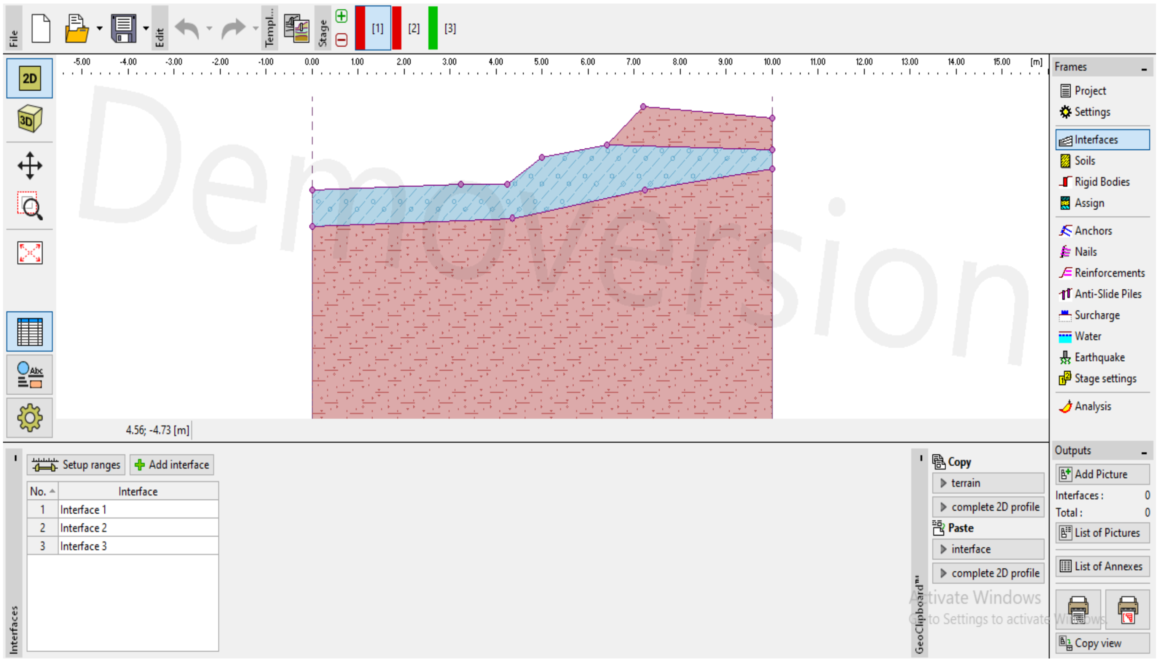


Fig 5.1 SLOPE DESIGN

Fig 5.1 shows the model of the slope with the stratification

5.1.1 INTERFACE 1

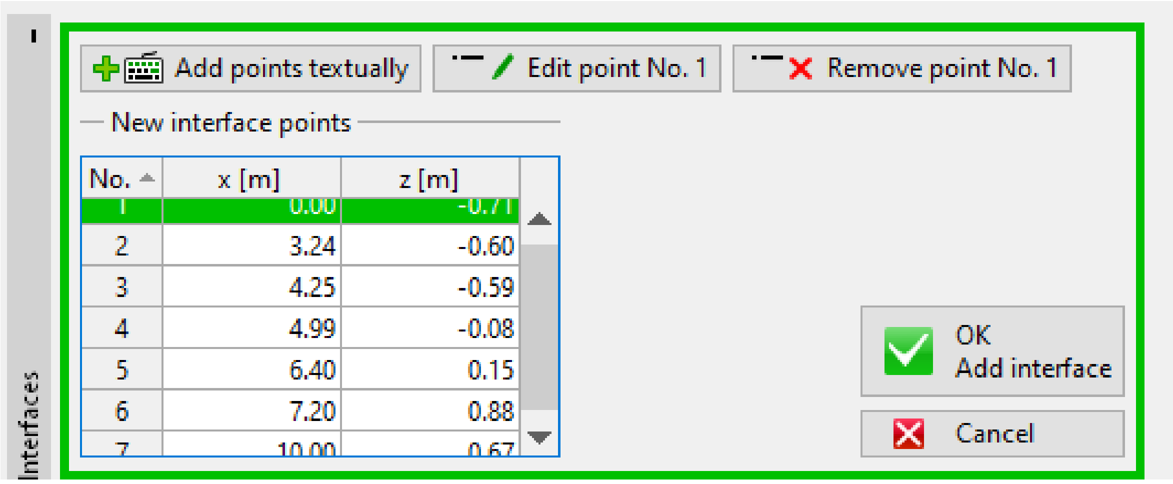


Fig 5.2 INTERFACE 1

Fig 5.2 shows the dialogue box in which the points x,z are inserted manually so as to achieve the desired interface.

5.1.2 INTERFACE 2

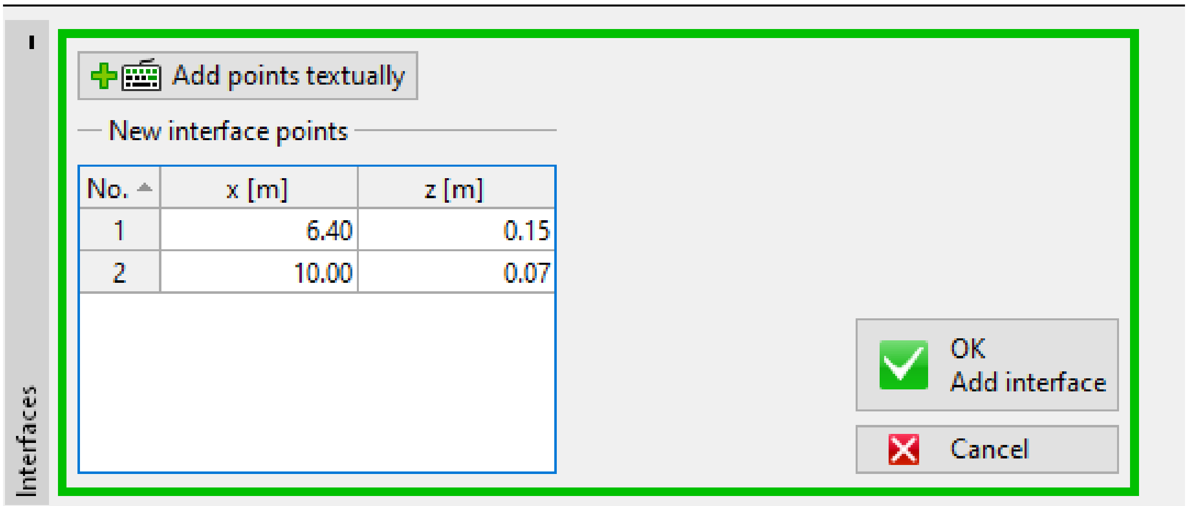


Fig 5.3 INTERFACE 2

Fig 5.3 shows the values of x,z which are inserted manually.

5.1.3 INTERFACE 3

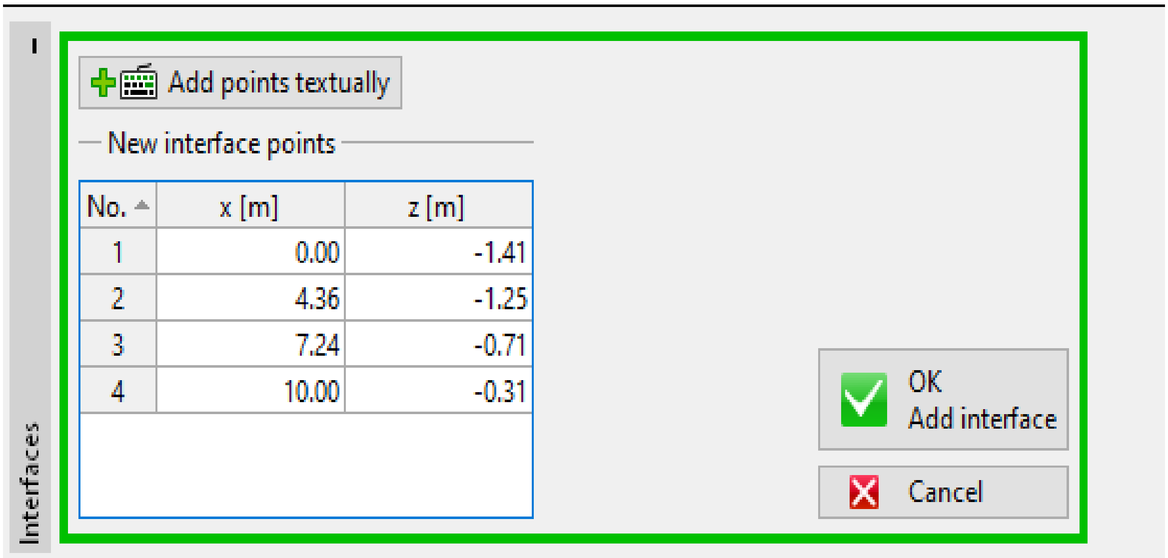


Fig 5.4 INTERFACE 3

Fig 5.4 shows the interface and the points given manually, we can add interface according to the need

5.2 SOIL PROPERTIES

In kotropi, the soil is clayey sand and gravely silts. The geotechnical investigation of the kotropi landslide showed the presence of poorly graded soil. The value of cohesion and the angle of friction is taken.

5.2.1 Soil 1

The property of the soil is shown in the model as per the report. The soil is used in soil 1 is gravelly silt. The default properties of the soil have been taken. The unit weight of the soil is 16KN/m^3. The value of cohesion is 26KpA. The angle of internal friction is 32.5 degrees.

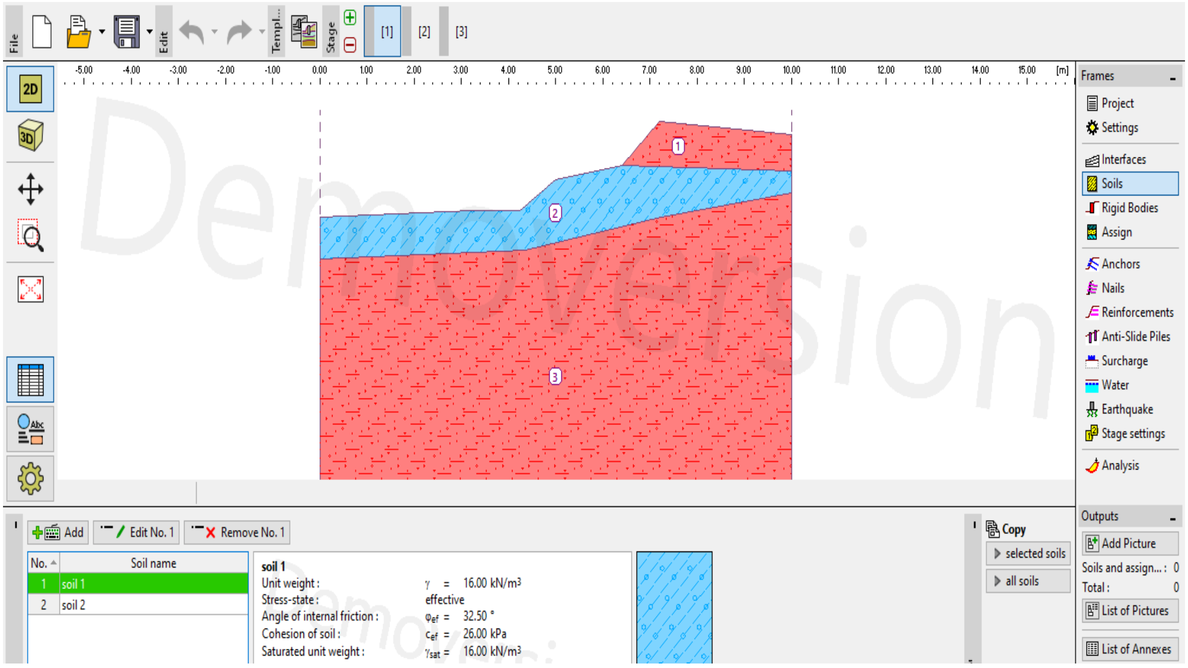


Fig 5.5 SOIL 1

Fig 5.5 shows the values given to soil 1 and the colour assigned to it

Type of soil	Gravelly silt
Unit weight	16KN/m^3
Cohesion of soil	26 / kPa
Angle of internal friction	32.5

Table no. 5.1

The above table shows the properties of the soil which are taken from the mother research paper

5.2.2 SOIL 2

In this, the soil is clayey sand. The unit weight of the soil is 16N/m^3. The value of cohesion is 28Kpa. The angle of internal friction is 32.5 degrees.

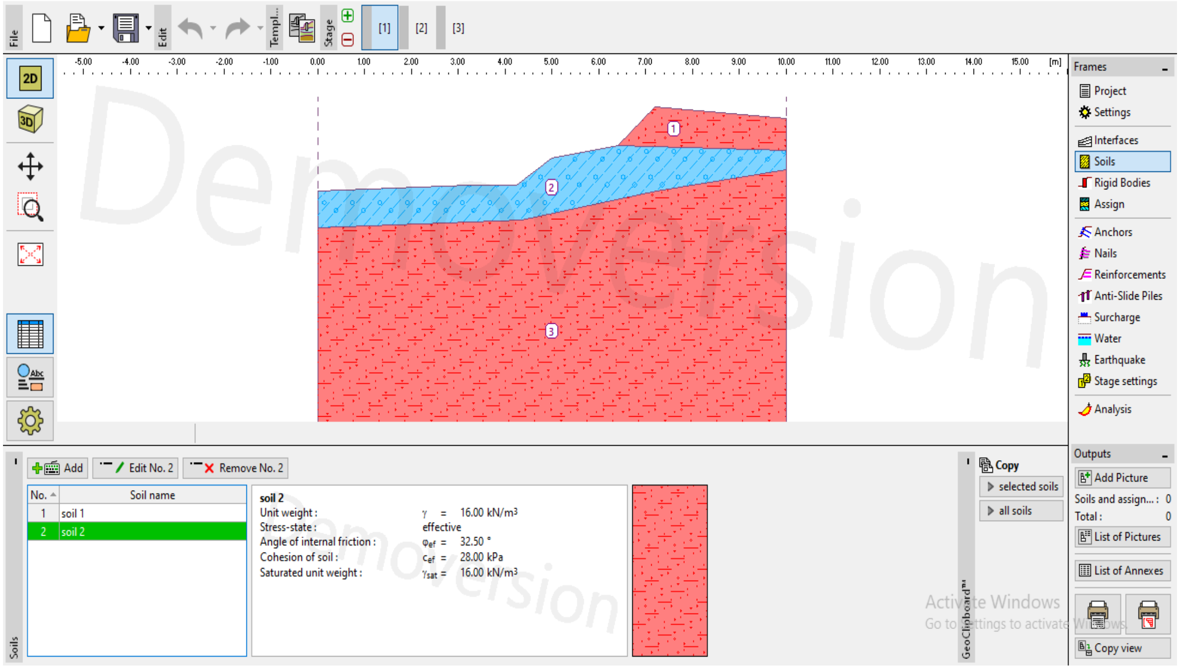


Fig 5.6 SOIL 2

Fig 5.6 shows the values given to soil 2 and the colour assigned to it

Type of soil 2	Clayey sand
Unit weight	16KN/m^3
Cohesion of soil	28kPa
Angle of internal friction	32.5

Table no. 5.2

The above table shows the properties of soil 2 which are taken from the mother research paper

5.3 STATIC SLOPE STABILITY ANALYSIS

For our case study, one static method is considered, the Bishop stability method. Bishop stability method is the trial-and-error method. The convergence of trial is very rapid and also gives more accurate results. In static slope analysis, the analysis type is normal as shown in fig [5.7]. In this, the analysis is done on a circular slip surface. The factor of safety is failing in all methods as shown in fig [5.7].

$$F.S.\ (F_s) = \frac{\sum_{i=1}^{n} (\,Cli + Wi \tan \phi i\,)\,[\frac{1}{\beta i\,(\theta)}]}{\sum_{i=1}^{n} Wi \sin \theta i}$$

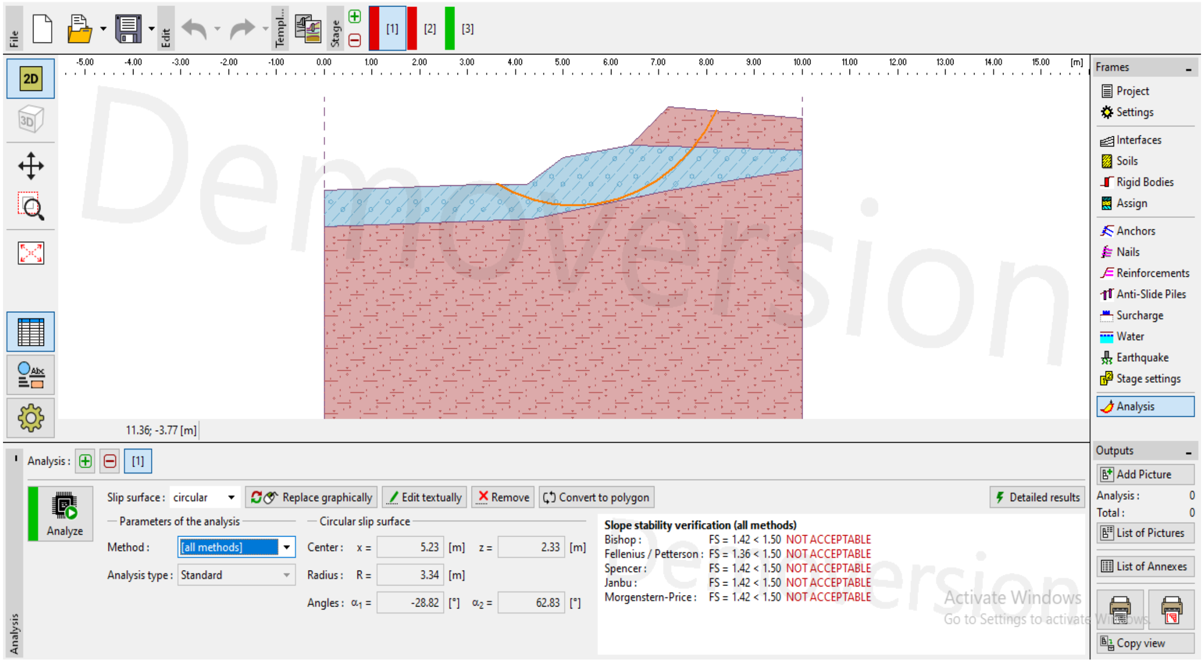


Fig 5.7 ANALYSIS

Fig 5.7 shows the analysis done when the slip surface is inserted manually as analysis type is standard

Type of methods	Safety factor
Bishop	1.42
Fellenius / Petterson	1.36
Spencer	1.42
Janbu	1.42
Morgenstren-Price	1.42

Table no. 5.3

The above table shows the value of safety factor achieved by the various methods when the analysis type is set to standard and static analysis is done.

5.4 DYNAMIC SLOPE STABILITY ANALYSIS

In dynamic slope stability analysis using limit equilibrium methods. In which the inertia force due to earthquake shaking is represented by constant horizontal force. In this to find out the factor of safety, use seismic coefficient.

5.4.1 VALUES OF EARTHQUAKE ZONE

The values of the earthquake zone are taken as per site. This site is in zone 4, so the horizontal seismic coefficient and vertical seismic coefficient values are taken. The values of zone 4 vary from 0.05-0.25. [IS 1984: CRITERIA OF EARTHQUAKE RESISTANT DESIGN]

Horizontal seismic coefficient: Kh	0.22
Vertical seismic coefficient: Kv	0.08

Table no. 5.4

The above table shows the values of earth quake coefficients taken from that region as it is seismic zone 5.

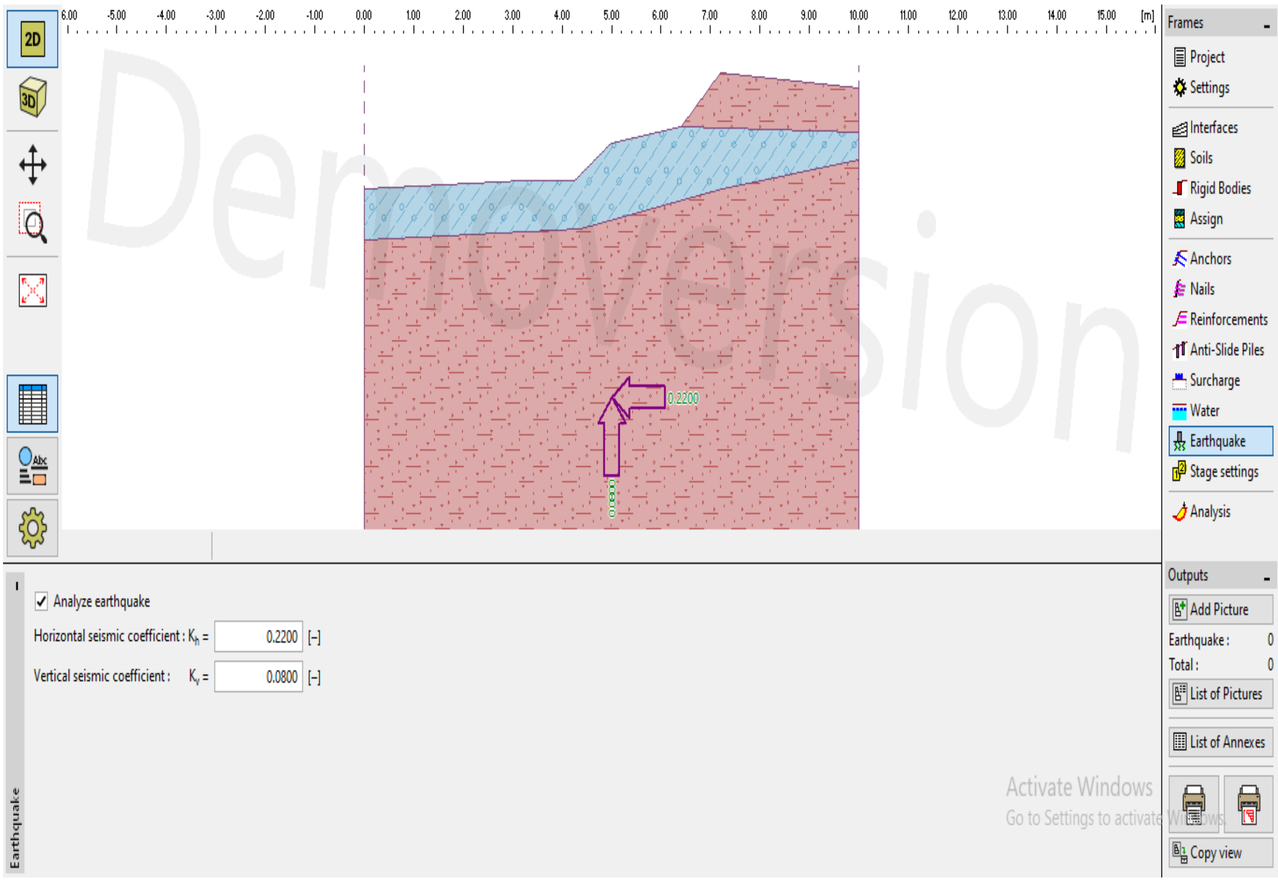


FIG 5.8 SLOPE WITH EARTHQUAKE ZONE

Fig 5.8 shows the values of the earth quake i.e., values of coefficients k_h,k_v according to the region or seismic zone

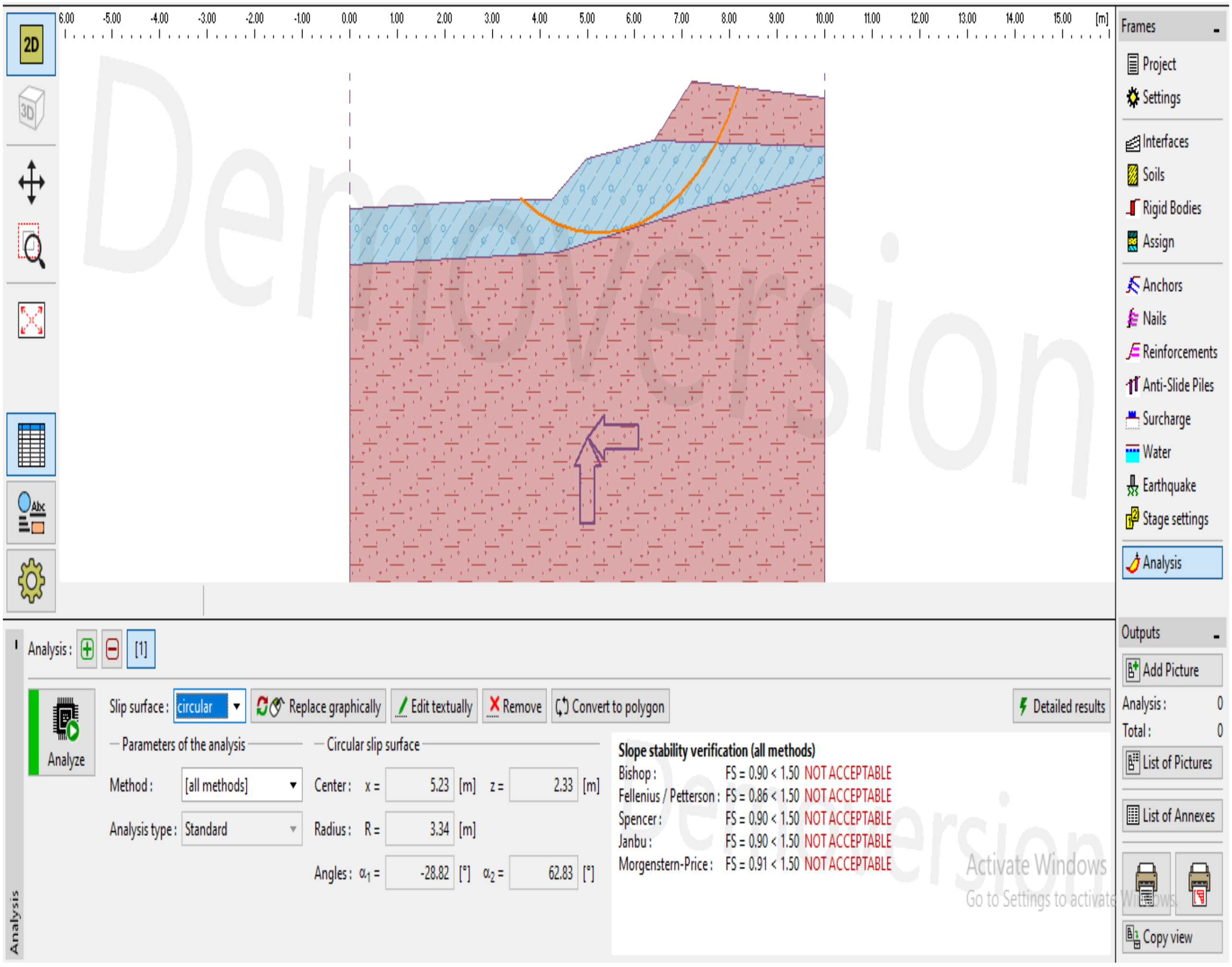


Fig 5.9 DYNAMIC SLOPE STABILITY

Fig 5.9 shows the factor of safety received when analysis type is standard and the earth quake values are inserted

Types of methods	Safety factor
Bishop	0.90
Fellenius / Petterson	0.86
Spencer	0.90
Janbu	0.90
Morgenstern-Price	0.91

Table no. 5.5

The above table shows the values of safety factor received when the analysis type is set to standard and done for the dynamic stability.

5.5 ANALYSIS TYPE: OPTIMIZATION

Now the analysis type has been changed from standard to optimization. In the optimization software itself takes the weakest parts of the slip surface as the properties given to the software.

5.5.1 STATIC ANALYSIS TYPE: OPTIMIZATION

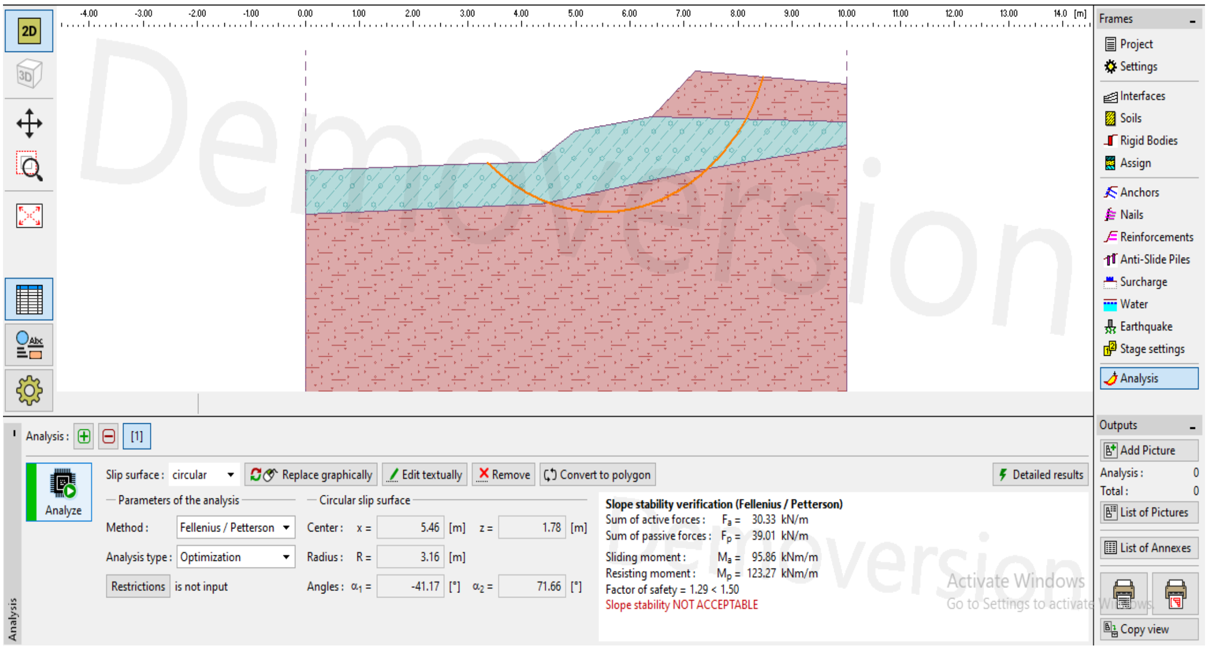


Fig 5.10 STATIC ANALYSIS WITH OPTIMIZATION

Fig 5.10 shows static analysis in which slip surface is drawn in optimization mode

Method	Factor of safety (Analysis type standard)	Factor of safety (analysis type optimization)
Bishop	1.42	1.37
Fellenius/Petterson	1.36	1.29
Spencer	1.42	1.37
Janbu	1.42	1.37
Morgenstren-price	1.42	1.37

Table No.5.6

The table 5.6 shows the values of the safety factor achieved when analysis type is set to optimization for static slope analysis

5.5.2 DYNAMIC ANALYSIS TYPE: OPTIMIZATION

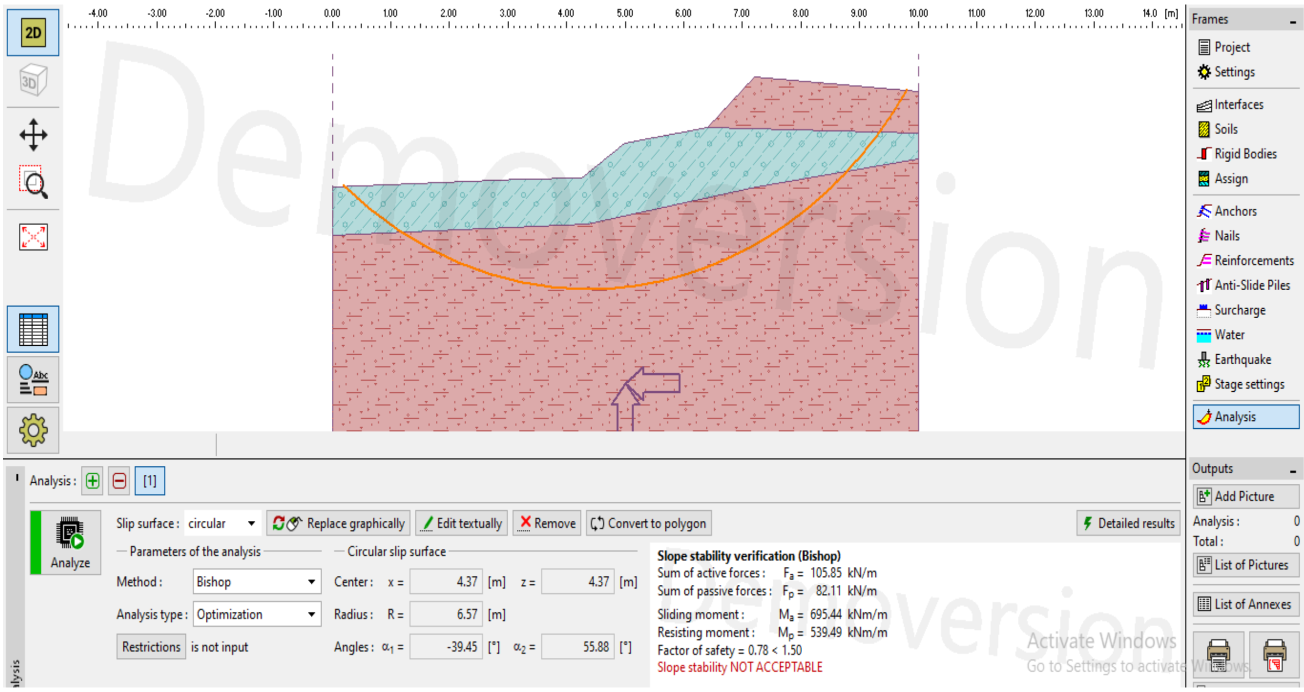


Fig 5.11 DYNAMIC ANALYSIS WITH OPTIMIZATION

Fig 5.11 shows the analysis in which the slip surface is drawn in optimization mode

Method	Factor of safety (Analysis type standard)	Factor of safety (analysis type optimization)
Bishop	0.90	0.78
Fellenius/Petterson	0.86	0.76
Janbu	0.90	0.78
Spencer	0.90	0.78
Morgenstern-price	0.91	0.78

Table No.5.7

Table 5.7 shows the safety factor achieved when the analysis type is set to optimization for dynamic slope stability

5.6 INPUT DATA ON ANTI SLIDE PILE

1. The framework consists of input pile framed in a tabular form. This is done in two different ways

1.1 Add-in dialog button

1.2 Add graphically button

2. The location of the pile is input by modifying the pile properties window.

3. The `locate to the terrain` button locates the starting point of the pile on the ground surface.

4. Input the pile cross-sections, the diameter of the pile (d) in meters, length (l) in meter, pile spacing (b) in meter.

5. Now the pile parameters are, the length of the pile, maximum bearing capacity (Vu) in kN, the direction of passive force, and gradient K.

6. These parameters can be altered while constructing.

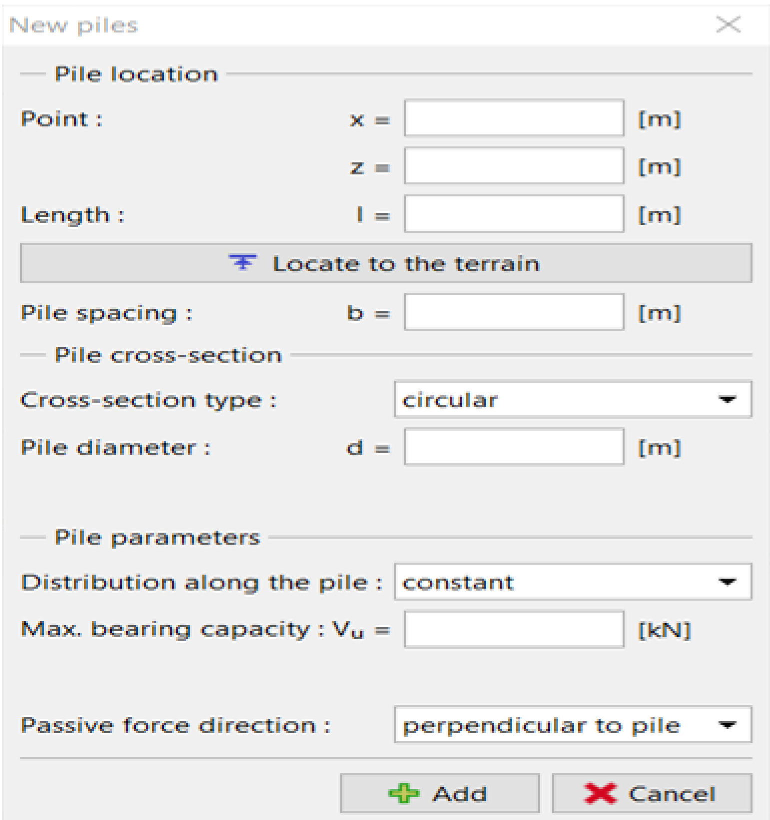


Fig 5.12 INPUT DATA TABLE

Figure 5.12 shows the dialogue box appears when the anti-slide piles are introduced

5.6.1 INPUT TABLE:

Anti- slide Number	Length l(m)	Pile spacing b(m)	Cross section d(m)	Pile bearing capacity Vu(KN)
1.	5	1.20	0.60	60
2.	5	1.20	0.60	60

Table no.5.8

Table 5.8 shows the inputs given to the program

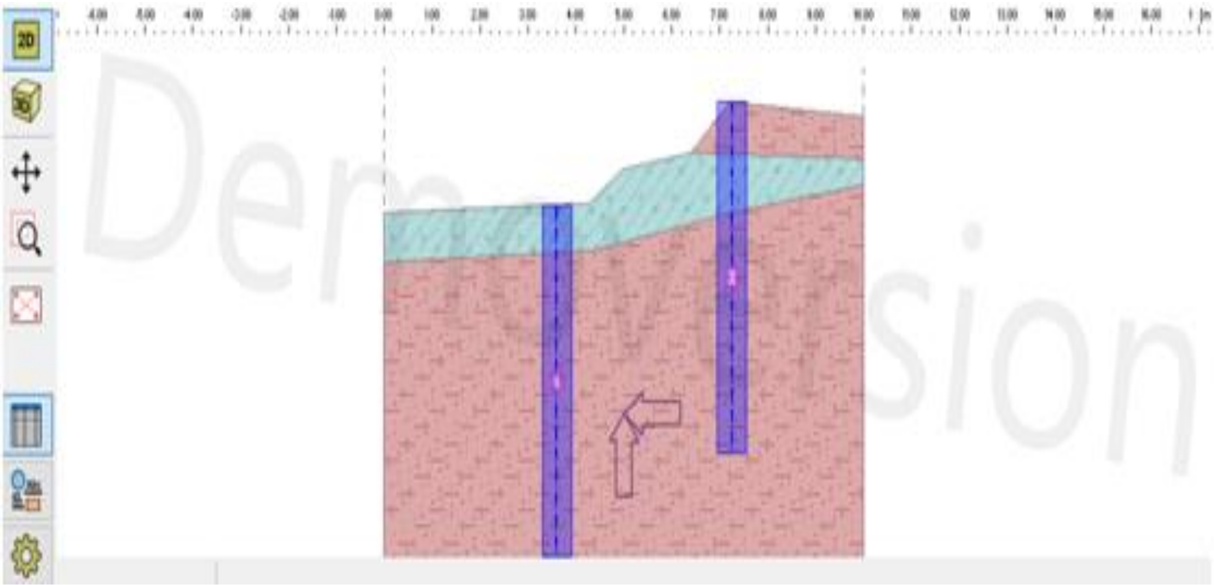


FIG 5.13 ANTI-SLIDE PILE

Fig 5.13 shows after inserting the values of the anti-slide pile the next outcome on the screen

5.7 SAFETY FACTOR TYPE: STANDARD

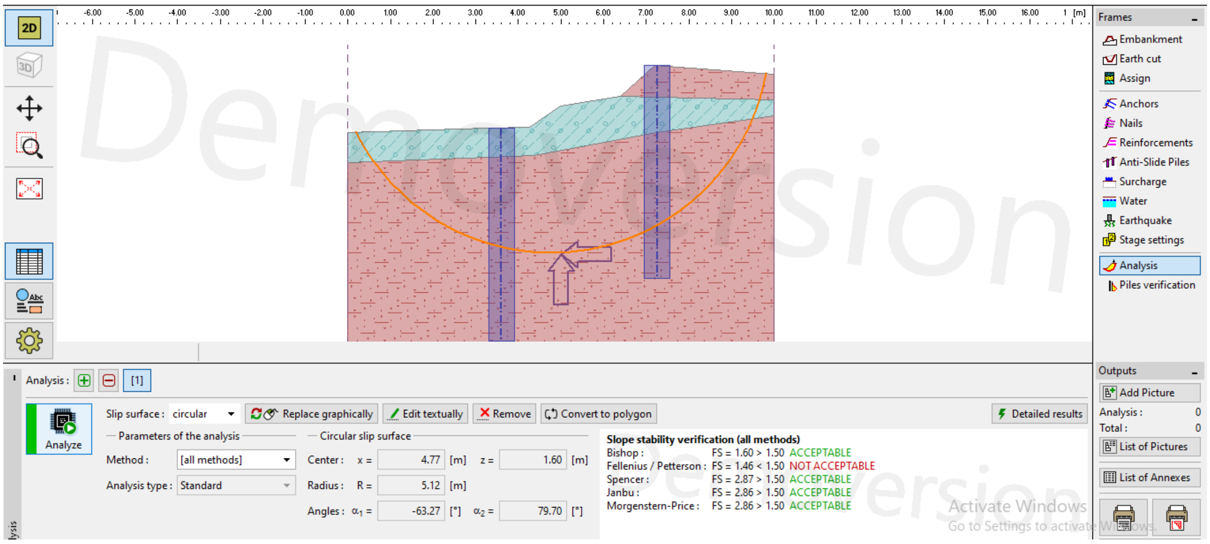


Fig 5.14 SAFETY FACTOR: STANDARD

Fig 5.14 shows after inserting the reinforcement and the analysis type is standard

5.7.1 SAFETY FACTOR TYPE: OPTIMIZATION

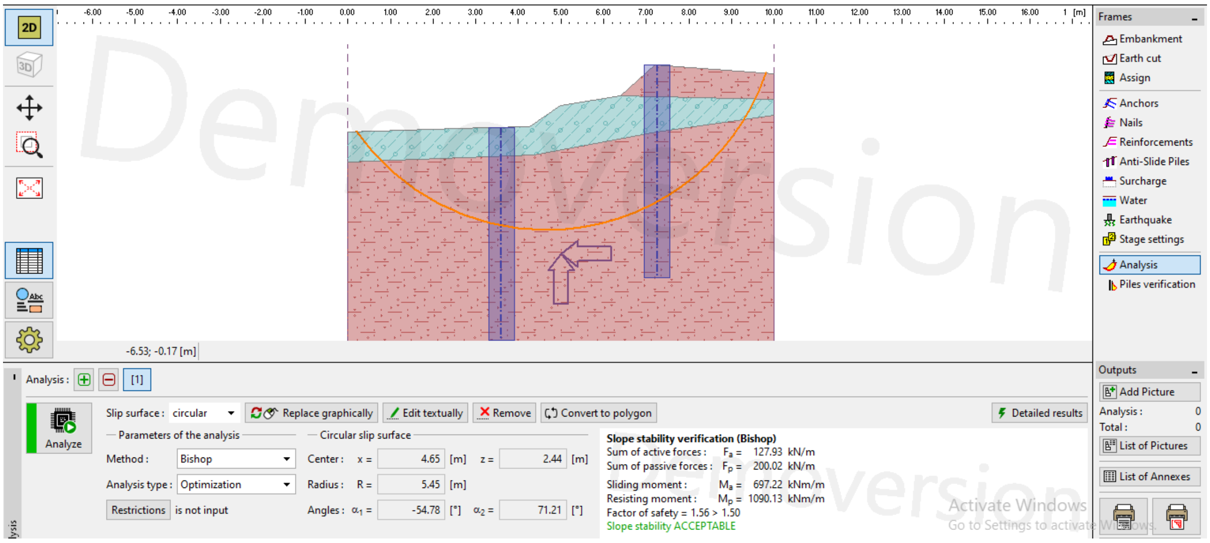


Fig 5.15 SAFETY FACTOR: OPTIMIZATION

Fig 5.15 shows after inserting the reinforcement and the analysis type is optimization for bishop method

5.8 SLOPE SATABILITY ANALYSIS

Method	Factor of safety (analysis type standard)	Factor of safety (analysis type optimization)
Bishop	1.60	1.56
Fellenius /Petterson	1.46	Solution not found
Janbu	2.87	2.87
Spencer	2.86	2.86
Morgenstern-Price	2.86	2.86

Table no.5.9

The above table shows the difference between the safety factor when reinforcement is provided.

GRAPHICAL REPRESENTATION

The graphical representation helps to find out the data easily as it is more convenient and helpful to analyse the data properly. The change in trends can be seen easily according to the data provided to the given axis.

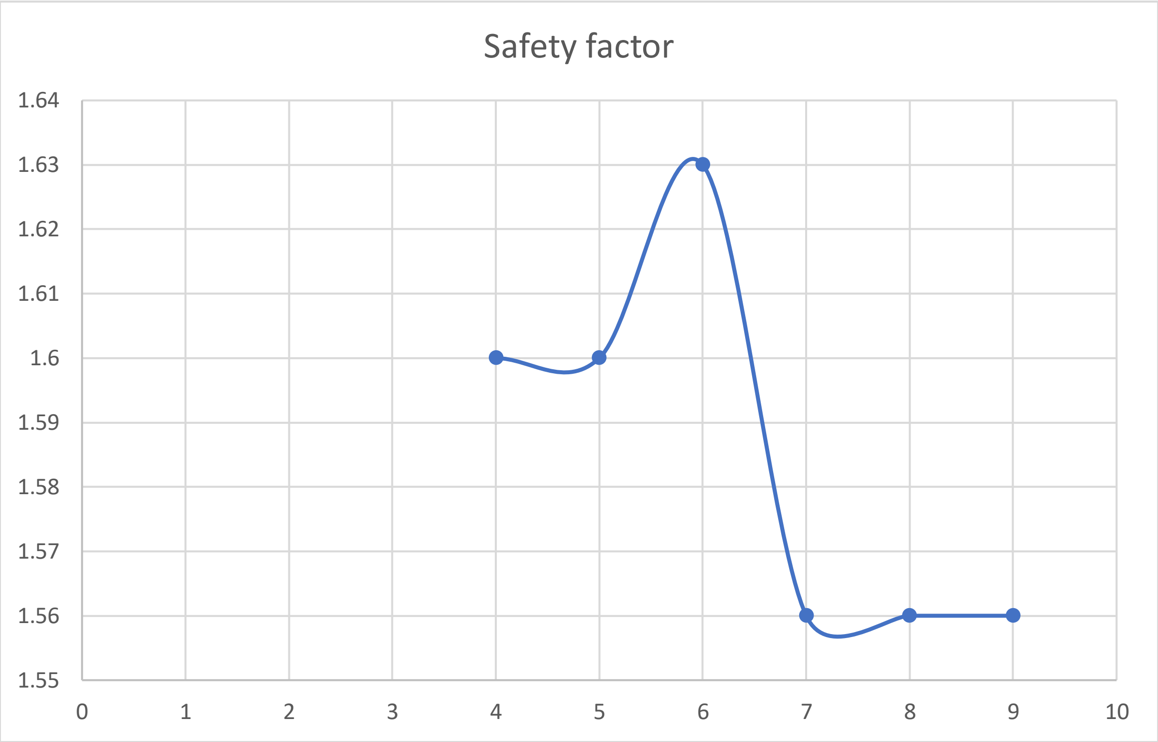


Fig 5.16 SAFETY FACTOR GRAPH FOR FOS V/S LOP

The above graph shows Fos which is on y – axis v/s length of pile which is on x- axis. where the analysis type is Standard

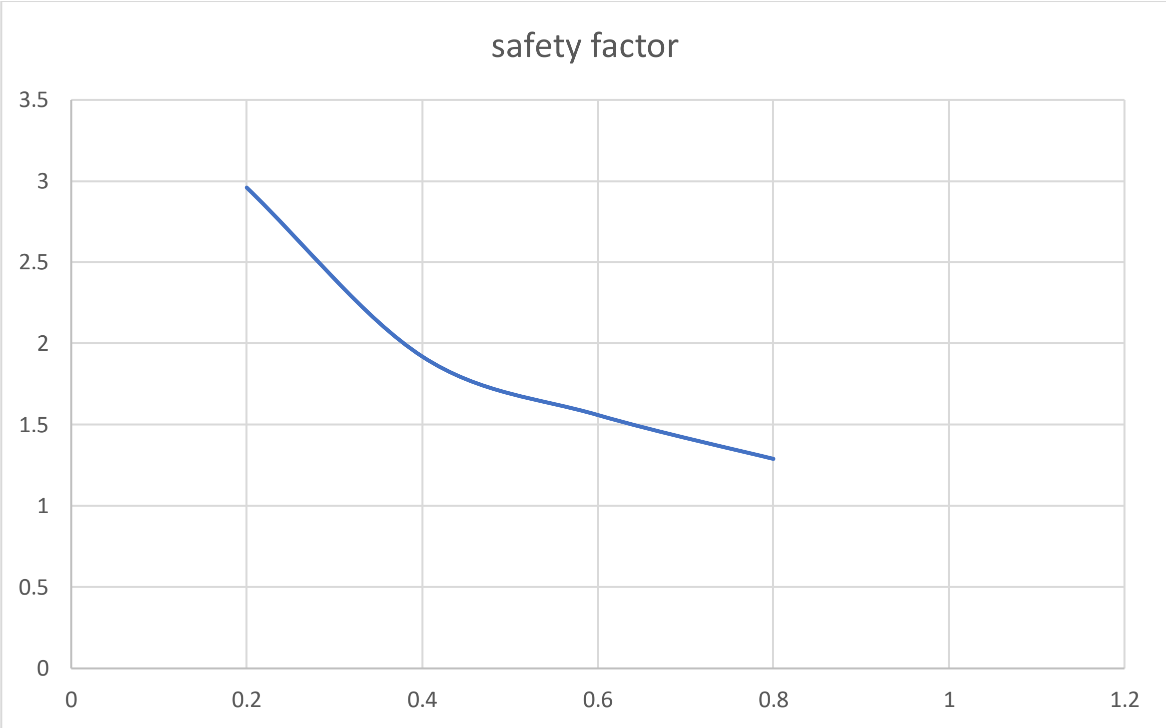


Fig 5.17 FOS V/S CROSS SECTION d OPTIMIZATION

The above graph shows Fos which is on y-axis v/s cross section d of pile which is on -axis when the analysis type is set to optimization

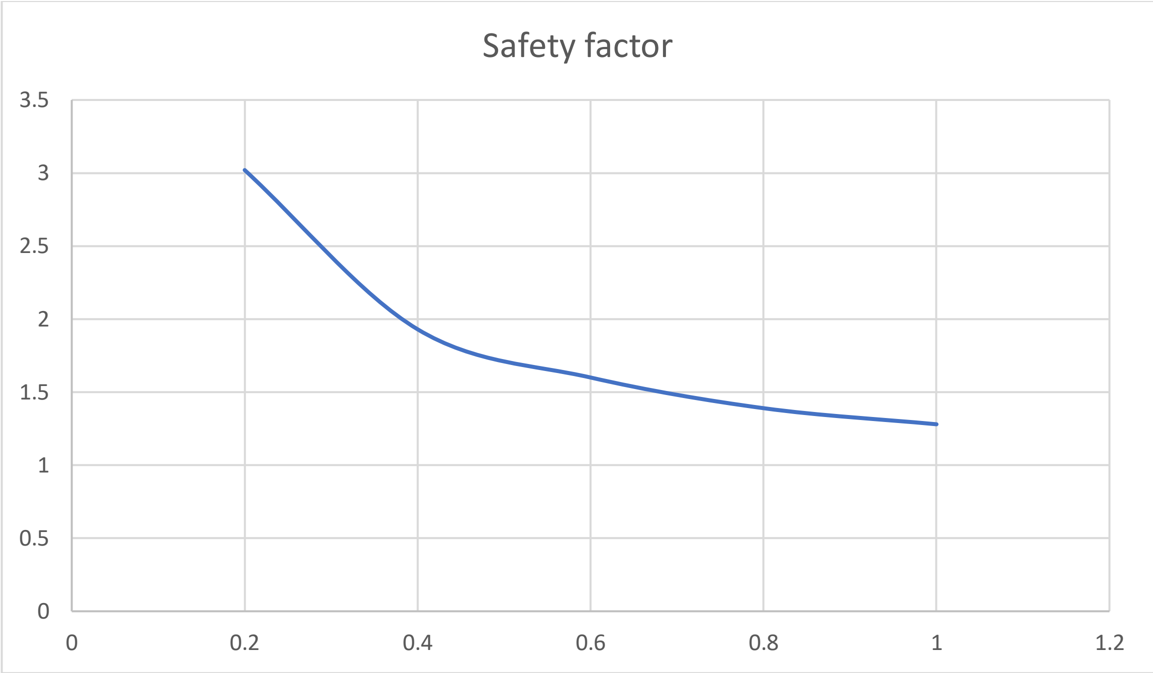


Fig 5.18 FOS V/S CROSS SECTION d STANDARD

The above graph shows Fos which is on y-axis v/s cross section d of pile which is on x-axis when the analysis type is set to standard

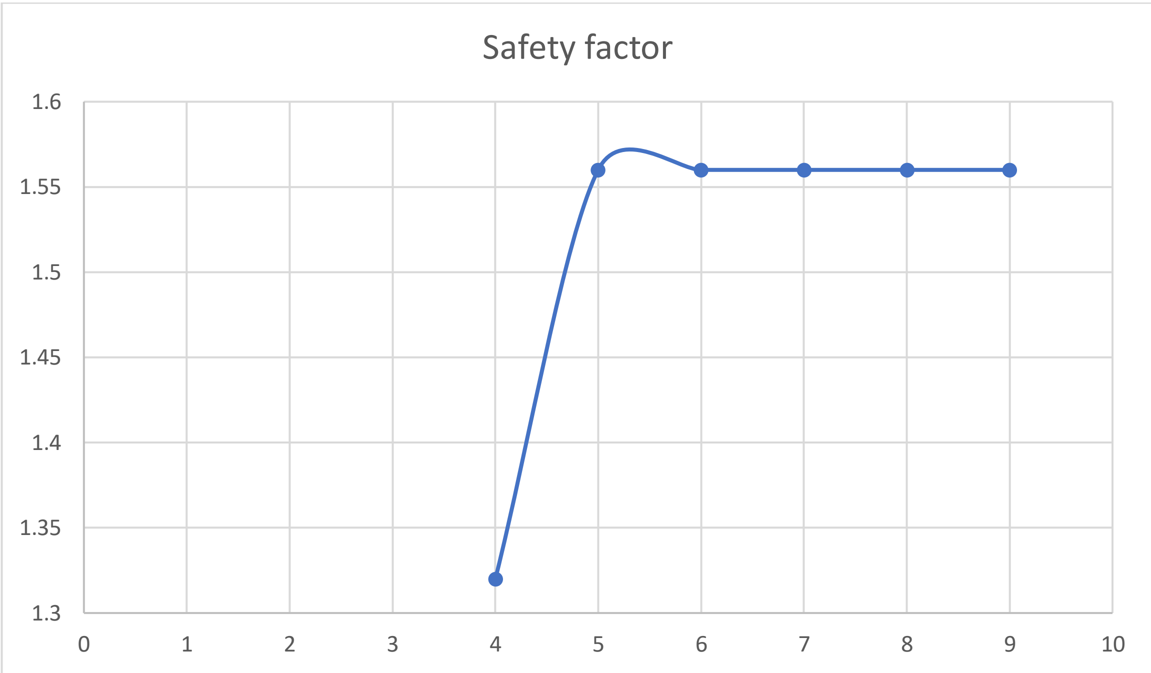


Fig 5.19 FOS V/S LENGTH OF PILE

The above graph shows Fos which is on y-axis v/s length of pile which is on x-axis when the analysis type is set to optimization.

CHAPTER 6: CONCLUSION

Work on Geo5 slope stability software through which conclusion is given in following points.

Some key points are following:

- Co-ordinates are given in three interfaces, so as to achieve the appropriate slope.
- Two types of soil present in our research field, by adding the appropriate values in the software we received the failure of the safety factor as shown above in the figure 5.7.
- Since the area is in earthquake prone region giving the values of the vertical and horizontal seismic values, again the factor of stability is not achieved as desired.
- The remedial for the slope stability which is anti-slide piles is used so as to reinforce the desired slope as shown in figure 5.13.
- Various graphical representations are shown between safety factor and the pile spacing, length.
- This project is useful in various ways as it will control the soil erosion, future damage to the surroundings.

REFERENCE

1. Sharma P, Rawat S, Gupta AK. Study and remedy of kotropi landslide in Himachal Pradesh, India. Indian Geotechnical Journal. 2019 Dec;49(6):603-19

2. Sarkar S, Samanta M. Stability analysis and remedial measures of a landslip at Keifang, Mizoram–a case study. Journal of the Geological Society of India. 2017 Jun;89(6):697-704.
3. Yadav R, Shrivastava S, Singh A, Dr. Sriram (2014); Landslides and its Remedial measures: An Overview.
4. Chitra R, Gupta M. Geotechnical Investigations and Slope Stability Analysis of a Landslide. International Journal of Engineering Research & Technology (IJERT). 2016;5(02):390-8.
5. Xuanwen Z. Analysis of soil and rock slope stability influence by anti-slide piles position. Electronic Journal of Geotechnical Engineering. 2015;20(11):4527-34.
6. Pan J, Wang Z, Dong T, Liang B. Analysis on the best position and the pile distance of anti-slide pile of reinforced soil slope. InIOP Conference Series: Earth and Environmental Science 2017 Apr 1 (Vol. 61, No. 1, p. 012107). IOP Publishing.
7. Geo5 slope stability www.geoengineer.org/software/geo5-slope-stability .
8. Standard I. Criteria for earthquake resistant design of structures. Bureau of Indian Standards, Part. 1893;1

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY, WAKNAGHAT

PLAGIARISM VERIFICATION REPORT

Date: 16/05/2021

Type of Document (Tick): PhD Thesis | M.Tech Dissertation/ Report | **B.Tech Project Report** | Paper

Name: Sourav Thakur, Nikhil, Aman **Department:** Civil Engineering **Enrolment No** 171626,633,067

Contact No. 9736627915 **E-mail.** Souravonweb9@gmail.com

Name of the Supervisor: Mr. Nirai Singh Parihar

Title of the Thesis/Dissertation/Project Report/Paper (In Capital letters): SLOPE STABILITY ANALYSIS OF KOTROPI LANDSLIDE AND ITS REMEDIATION

UNDERTAKING

I undertake that I am aware of the plagiarism related norms/ regulations, if I found guilty of any plagiarism and copyright violations in the above thesis/report even after award of degree, the University reserves the rights to withdraw/revoke my degree/report. Kindly allow me to avail Plagiarism verification report for the document mentioned above.

Complete Thesis/Report Pages Detail:

– Total No. of Pages =51
– Total No. of Preliminary pages =10
– Total No. of pages accommodate bibliography/references =1

(Signature of Student)

FOR DEPARTMENT USE

We have checked the thesis/report as per norms and found **Similarity Index** at ....24..... (%). Therefore, we are forwarding the complete thesis/report for final plagiarism check. The plagiarism verification report may be handed over to the candidate.

(Signature of Guide/Supervisor)

HOD
CE DEPT

Signature of HOD

FOR LRC USE

The above document was scanned for plagiarism check. The outcome of the same is reported below:

Copy Received on	**Excluded**	**Similarity Index (%)**	**Generated Plagiarism Report Details** (Title, Abstract & Chapters)	
	• All Preliminary Pages • Bibliography/Images/Quotes • 14 Words String		Word Counts	
Report Generated on			Character Counts	
		Submission ID	Total Pages Scanned	
			File Size	

Checked by
Name & Signature **Librarian**

....

Please send your complete thesis/report in (PDF) with Title Page, Abstract and Chapters in (Word File) through the supervisor at plagcheck.juit@gmail.com