REMEDIATION AND STABILIZATION OF SLOPE IN RELDRI, BHUTAN

A

PROJECT REPORT

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

of

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision

of

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HIMACHAL PRADESH, INDIA

MAY - 2022

DECLARATION

I hereby declare that the work presented in the Project report entitled **"REMEDIATION AND STABILIZATION OF SLOPE IN RELDRI, BHUTAN"** submitted for partial fulfilment of the requirements for the degree of Bachelor of Technology in Civil Engineering at **Jaypee University of Information Technology, Waknaghat** 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.

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CERTIFICATE

This is to certify that the work which is being presented in the project report titled **"REMEDIATION AND STABILIZATION OF SLOPE IN RELDRI, BHUTAN"** in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering submitted to the Department of Civil Engineering, **Jaypee University of Information Technology, Waknaghat** is an authentic record of work carried out by **Sonam Tshewang Dema (181653) and Namgay Wangmo (181655)** during a period from August, 2021 to May, 2022 under the supervision of **Mr. Niraj Singh Parihar** (Assistant professor), Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

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ABSTRACT

Slopes are man-made and natural. Different techniques can be performed on slopes to calculate the slope stability analysis. Selection of an appropriate technique is important in determining the failure of the slope. To predict the failure of slope the main guide is factor of safety. Many structures are built by sloping the lateral faces since slopes are not expensive. Slopes become unstable because of the natural forces such as wind and water, which causes a shift in the topography of the soil. This study concerns with the stabilization of a natural slope in Reldri located near Reldri Higher Secondary School in Phuentsholing Thromde and techniques to prevent slope instability. This paper also provides the geological parameters of the slope.

With time, the growth in software and technology of our world has become exponential, which has helped reduce the on-site workload of many professions especially the civil engineering department. Geo5 software helps us to solve many engineering problems and, in this project, we are using this software to design the slope structure and to stabilize the slope.

The analysis of slope for its stability is important to understand the ways in which a slope can fail, to determine the stability of the slope and to discover the measures to mitigate the problem and reduce susceptibility to failure. The rising need for slopes on construction projects has increased the needs for proper understanding of slope and the factors influencing its stability, analytical understanding of the slop structure and finding the proper methods to stabilize the slope which both economical and functional.

This paper will help guide future researchers, students and geologists to understand the stability of slope in the area.

Key words: *Slope stability, Geo5, slope failure, Bhutan, Remedies, Landslides*

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LIST OF ACRONYMS & ABBREVIATIONS

NAPA	National Adaptation program and action
FOS	Factor of Safety
SW	Well Graded Sand
SM	Silty Sand
ISSCS	Indian Standard Soil Classifications
γ	Density
Ka	Coefficient of Active earth pressure
Kp	Coefficient of Passive earth pressure
Cu	Coefficient of uniformity
Ct	Coefficient of curvature

CHAPTER 1

INTRODUCTION

1.1 General background

Slope is a surface of the soil mass that is inclined at an angle. Slope stability analysis is a process where the maximum stress that a slope can hold before failure is calculated and assessed. Failure of slopes depends on the factors such as the gravity, seepage, earthquake, erosion, geological features, construction activities, the type of soil, stratification of soil and also the geometry of the slope.

1.1.1 Types of slope failures

The four types of slope failures:

1. Translational Failure: It occurs in infinite slopes, which means the soil that is under the open surface has same properties along the slope length and there are no definite boundaries, and. The surface of failure is parallel to the surface of slope.
2. Rotational Failure: It occurs in finite slopes and it may occur in three different ways: Face failure or slope failure takes place when the soil above the toe has frail soil and the failure plane crosses the slope above the toe, Toe failure where the failure plane passes the toe and Base failure where the failure plane passes through the base of the slope.
    i. Base failure
    ii. Toe failure
    iii. Slope failure

3. Wedge Failure: It is present in finite as well as infinite slopes. It is also known as plane failure.
4. Compound Failure: It is a blend of the first two types of failures i.e., translational failure and rotational failure.

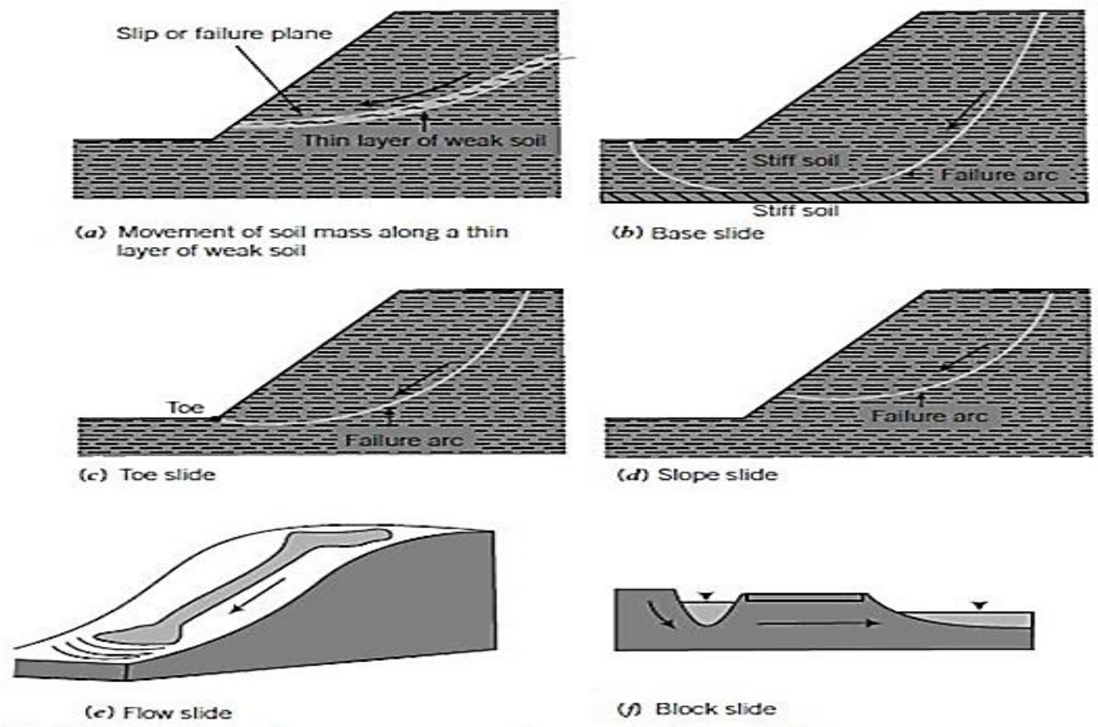


Figure 1 Some common types of slope failure

Types of slopes:

1. Natural slopes: These slopes originate in nature.

2. Manmade slopes: Humans make these slopes.

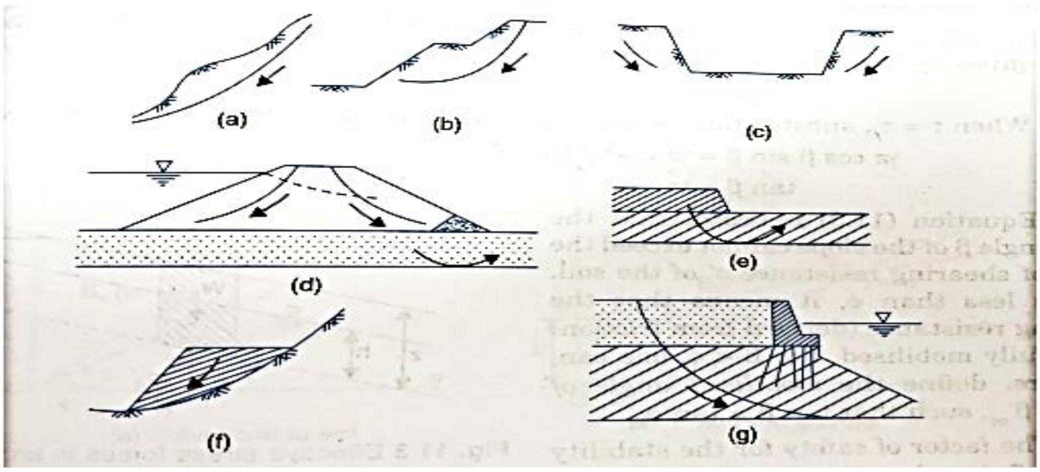


Figure 2 Different types of slopes (Source: Ranjan, G., and Rao,) (a) natural slope (b) cut slope (c) open excavation (d) earth dam (e) embankment over a poor soil (f) side hill fill (g) water front structure

1.1.2 Causes of slope failure:

- Gravity
- Seepage
- Earthquake
- Erosion
- Geological features
- Construction activities

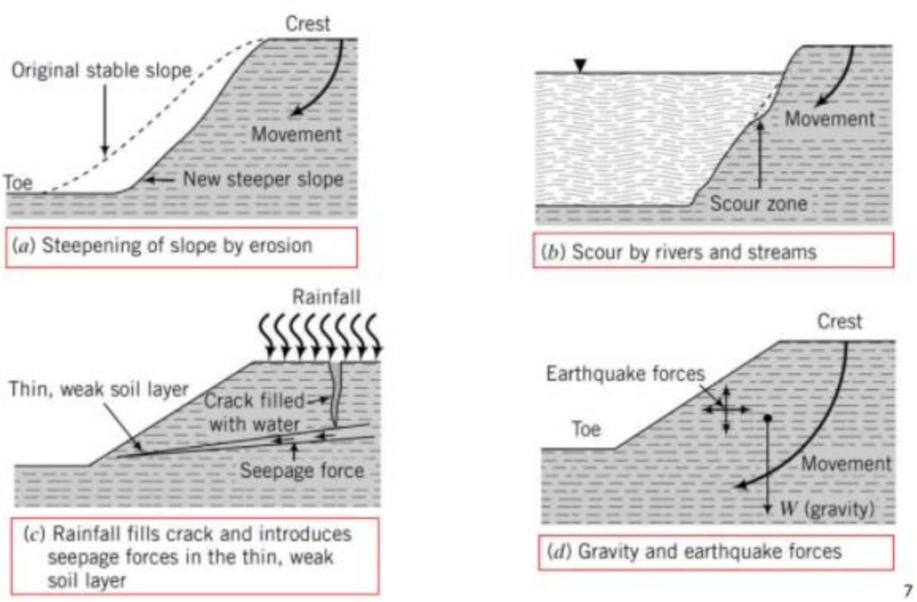


Figure 3 Some Causes of slope failures

1.2 SITE DESCRIPTION

The slope is located west to Reldri School under Phuentsholing Dungkhag. It is located within the geographical coordinates: N: 26˚50'52.4", E: 89˚24'16", Elevation: 408m.

It is one of the worst affected areas and a deteriorating one along the Phuentsholing Pasakha highway becoming an immediate threat to the school and residents near it. The slope has been investigated by Bhutan’s NAPA-II project, which has enabled us to obtain the required data about the soil and the slope.

The area has an approximate dimension of Length: 60m, Breadth: 80m.

The area experiences a humid tropical climate. The slip plane appears to be shallow but the mass movement is active in the process. Three types of soil in the study area were colluvial, fluvial and residual soil. Seepage of the water is most common in this landslide area and there is no growth of vegetation particularly in the active landslide area**.** Location of landslide as shown in figure 4 and 5.

Figure 4 Location of landslide area

Figure 5 Reldri landslide site

1.3 PROBLEM STATEMENT

The slope is not more than 20 years but there has been a rapid expansion of the landslide. It poses great risks to the school and college situated near the slope and also to the residents living near the area. It had been found that the people near the area are stressed and fear about the situation of the slope especially during the monsoon season when there is heavy rainfall, windstorms and unpredicted seismic activities which causes the topography of the soil to change, hampering the activities and lives of the people.

Also, a large amount of land in Kharbandi region was lost due to the sliding of slope over time. More areas can be washed-out in coming times if correct precautions are not taken. One such case was the loss of road, which had access to Reldri School. Thus, the area and the slope must be studied to come up with appropriate remediation measure.

1.4 OBJECTIVES

The objectives under this study comprise the following parts.

- To identify various possible causes of slope failure.
- To perform slope stability of slope in Reldri using Geo5 software.
- To suggest suitable and potential mitigation measures based on the outcome of the field study and the stability analysis.
- To perform slope stability analysis manually with different methods of analysis.

1.5 SCOPE

This project was started with the task of fulfilling the aforementioned aims and objectives within the given time period. However, this project limits the aforesaid objectives in the following areas:

- The data collection from the site could not be done due to lockdown being imposed in the site area.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Literary review has been done throughout the project, as this project requires a great deal of information from the past and to gain sufficient knowledge about how to stabilize the slope, which is the biggest challenge facing the site. There are research papers that tried using different method to stabilize the slopes and also papers that helped showing the importance of proper mitigation to prevent further damage to the soil and the structures. The results from these researches assisted in contributing more information regarding our project. Here are the lists of literatures that we reviewed.

2.2 Literature reviews

1. **Dikshit Abhirup,** Sarkar R, Pradhan B, Acharya S, Alamri AM **et al., 2020, Spatial Landslide Risk Assessment at Phuentsholing, Bhutan, Geosciences**

According to this research paper it was concluded that landslides were caused due to the seismic activities of the earth and also due to rainfall; seepage of water. Himalayan regions experience many landslides due to the monsoonal weather changes and it poses high risk to the regions. It focused on one study area, Phuentsholing but the study results can be used to estimate the stability of soils near the area. The method that this study used was to determine some factors of risk, which could cause landslide. The hazard map was created by displaying a link between yearly exceedance likelihood and annual exceedance probability (annual exceedance probability multiplied by landslide occurrence probability) (the probability of threshold that will exceed in a given year). The results obtained concluded that 11.7% of the area was under high to very high-risk category and 15.85% was under moderate risk.

2. **Tempa Karma, et al., 2020, Geotechnical parameter assessment of sediment deposit, Geomatics, Natural Hazards and Risk 12:1, pages 2904-2930.**

Per annum, flash floods in the downstream zone have been found, which connects the center town to the industrialized land, creating massive silt deposits this in turn posed a threat to the community and to the infrastructures near the vicinity. Seasonally, the site is eroded and then deposited by sediments from upstream. Building design is frequently influenced by soil qualities such as plasticity of the soil, compressibility of the soil, and the hardness of soil.

Pit investigations (open) of two pits were carried out to decide the stratification of soil to differentiate the soil properties. For the first pit, the depth was up to 1 m and it contained majority of gravel with few to little sand. It was found that 1 - 1.8 m the soil had more of gravel and less of sand and from 1.8 - 3 m it consisted of more sand and less gravel. For the second pit, it was found that till 1.6 m the soil had a good mixture of sand and gravel and between 1.6 – 3 m has more sand and less gravel.

3. Kumar T. K, et al., 2019, A Critical Review on Stability of Earth Retaining Structures, International Journal of Scientific Development and Research (IJSDR)

This paper discusses on site investigation of the soil type using methods such as boring, insitu soil exploration and others. Black soils, red soils, alluvial soils, and other soil types were largely considered. Exploration review of slope stability issues were also done to better understand the failure characteristics soils that is plastic as well as granular. To know the failure characteristics the soil was exposed to different weather conditions such as cold, defrosting, breeze, etc.
Right earth holding structure had to be selected, which was different for different slopes.
To further provide better soil retaining structure, plants, trees and anchors were also used.

4. Dini Benedetta, et al., 2019, Investigation of slope instabilities in NW Bhutan as derived from systematic DInSAR analyses, Engineering Geology,Volume 259

A concrete gravity dam in Bhutan, which was constructed in 2009, Punatsangchhu-1 hydropower plant recorded many failures of slope due to the toe being cut. The results from this research paper concluded that the slope was unstable since 2007 and its size was vigorously swelling from 2007 to 2018. Even though some remedies has been provided to protect the slope from failure but it protects only the smaller part of the slope and the continuing huge unstable slope is not protected.

The results obtained from DInSAR can be used to to analyze the outcome of various decisions throughout the project. The geomorphological characteristics was analyzed which shows that displacements caused rocks to slide, slopes both mountainous and rock, to be deformed (77.5%), soil creep (4%), soil to slide (1.9%) and rock glaciers (12.3%); 4.3% of the detected displacements remain of unknown origin.

5. **Salunkhe Digvijay P. et al., 2017, An overview on methods for slope stability analysis IJERT**

They studied the different limit equilibrium methods and finite element methods to stabilized the slope by computing the factor of safety and studying the types of soil and their conditions. Finite element Method is very popular because of how real the slopes can be designed on the software but there are a huge number of variables that has to be considered. Analysis can be done numerically, this delivered a rough answer to problems that would have been difficult to be solved by using predictable methods such as the geometry of soils, etc. This analysis allowed the soil to be deformed and to fail and was most helpful in cases where soil data were poor and not available. To analyze slopes with huge rocks continuum modeling could be used. For rocky slopes with discontinuous behavior discontinue modeling is approached. To get the full benefits the procedures could be mixed and used.

6. **Tenzin et al., May 2021, Landslide mitigation using soil nailing.**

From their studies it was concluded that the slope is unstable and the potential slip surface is very high without any remedies. The different nail angles (10°, 15° and 20°) with respect to horizontal are analyzed and it shows that 10° gives the best factor of safety compare to 15° and 20°.

7. Sazzad Mahmud, et al., 2016, Stability analysis of reinforcement slope using FEM, International Journal of Advanced Structures and Geotechnical Engineering, Vol. 05, No. 03

They studied the different limit equilibrium methods and finite element methods and also several methods to stabilize the slope by computing the factor of safety and studying the types of soil and their conditions. Arithmetical models with slope angles of 45, 49, 55 and 63.5 degrees were used. SI units were used as the dimensioning units. Mesh was also produced to give accurate results and to economize the analysis. Two meshes were produce one with six node triangular element and other one is a mixed mesh with a combination of 6 and 8 node quadrilateral element.

The relationships between slope stability of different slope angles along with different angle of inclination of reinforcing bars were studied. It was discovered that the factor of safety of the slope had a linear relationship with the angle of inclination but it decreased after some angle. It was observed that on using 14 bars, which had a length of 8.64 m, gave high factor of safety value. Also, the bars should be spaced equally to get highest factor of safety value.

8. Mizalazzmi N, et al., 2011, Geotechnical Approaches for Slope Stabilization in Residential Area The 2nd International Building Control Conference proceedings

Various kinds of soils had varying kinds of soil properties, which in turn led to having different geotechnical parameters. Data about the soil were collected so that proper slope stabilization remedies could be designed. These were important to understand the causes of slope instability in the area and to prevent the failure of slope. A soil with high plasticity was shown to have higher risks of slope instability.

9. N.A Muhammad, Aug 2013, Determination of the Critical Slip Surface in Slope Stability Analysis, Institute of Graduate Studies and Research

SLOPE/W, GEO5, and FLAC/Slope software programs were operated to determine the cause of slope failure and the acute failure surface. The study found a variable relationship between the soil's factor of safety and cohesion (c), internal friction angle (ϕ), and the unit weight (ɣ) of the soil. It was found that the factor of safety of soil increased with respect to cohesion of soil and the internal angle of friction since they were the force that resisted the failure of slope. Factor of safety decreased with the unit weight of soil since it is the dynamic force for slope instability.

Failure arc length increased with the increase in cohesion of soil and the unit weight of soil but it was contradictory in the case of internal friction angle. Beta angle had a direct impact on the factor of safety of soil but the value of alpha produced no visible changes in the factor of safety of the soil, this was because increase in the value of alpha angle was directly proportional to the failure arc length. It was also observed that GEO5 software gave results in a conventional manner in comparison to SLOPE/W as the factor of safety value is almost 5 percent lesser and FLAC/SLOPE gave the higher values for factor of safety than the other two methods.

10. Kuenza Karma, et al., Nov 12, 2009, Landslides in Bhutan, Department of Geology & Mines, Thimphu, Bhutan.

This paper delivers a synopsis of landslide issues, mitigation methods, and the need to advance the risk management plan. The most common geo-environmental hazard in Bhutan is rain-induced slope failure.

11. Ansary, Mehedi & Aasha, Sirazhum. (2018). Slope Stability Analysis of Embankments of Gaibandha Area, Bangladesh.

This study presents various case studies of embankment failure in Bangladesh and slope stability analysis of Gaibandha soil by GEO5 slope stability software. Hefty rainfall from Meghalaya hills has led to floods in various parts of Bangladesh. A slope of 1:1.5 is recommended for a balanced embankment slope. Due to the scarcity of good construction, no right upkeep following an environmental disaster, changes in the climate conditions made the embankments less efficient to endure strong wind and water drive. The embankment is filled with fine grains of silty clay that had low penetrability to protect it from flood and monsoon season.

2.3 Material description of the site

This section explains the earth materials faced at the study area. There are two types of material encountered at the site: Phyllite and colluvium,

A. Phyllite:

Phyllite comes from the Greek word ‘phyllon’ which means, “leaf”, the name refers to its usual green color and its ability to be flaked into thin sheets. This is a foliated metamorphic rock, that was formed from slate, (primarily composed of quartz, sericite, mica and chlorite). It is linked to regional metamorphism as a result of mountain formation. Phyllite has a hardness rating of 1-2 and grain sizes ranging from medium to fine coarse.

B. Colluvium: Colluvium refers to the unconsolidated sediments that has been dumped at the base of a slope by rain wash or by slow creep movement.

2.4 HISTORICAL INFORMATION OF THE SITE

The slope at Reldri region, started with the development of small-scale erosion from the small stream below the landslide area. Bhutan's NAPA-II project report revealed that the active erosion has been developing in the area since 2000. According to the Proprietor in-charge of Reldri Higher Secondary School, the landslide had started to occur in 2000 but the land degradation became clearly visible only since 2004 as given below in figure 6.
Google image is one of the important sources for tracing the historical information. However, the information is available only since 2004 and it was noticed that landslide has been in the stages of expansion over the times. A series of historical satellite images from Google earth since 2004 had to be examined to see the changes of areal expansion in Reldri shown below in the figure 7, 8 and 9.

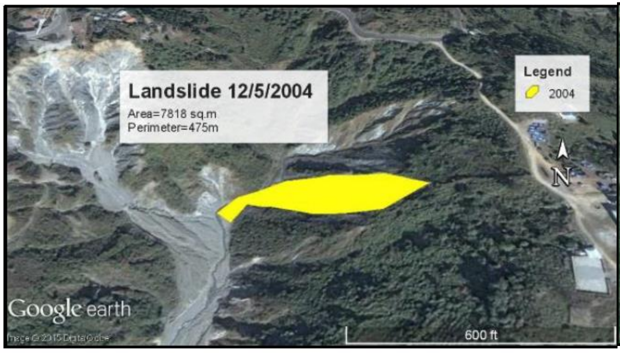


Figure 6 Satellite image of 2004

Figure 7 Satellite image 2010

Figure 8 Satellite image of 2014

Figure 9 Satellite image of 2020

2.5 GEOMORPHOLOGICAL INFORMATION

Numerous desk studies were carried out to understand the geomorphological condition of the site. After thorough desk studies and the visual inspection of the site, it was found out that the earth material present at the site was cracked, foliated and faulted phyllite. It extends from the base to the top of the landslide.

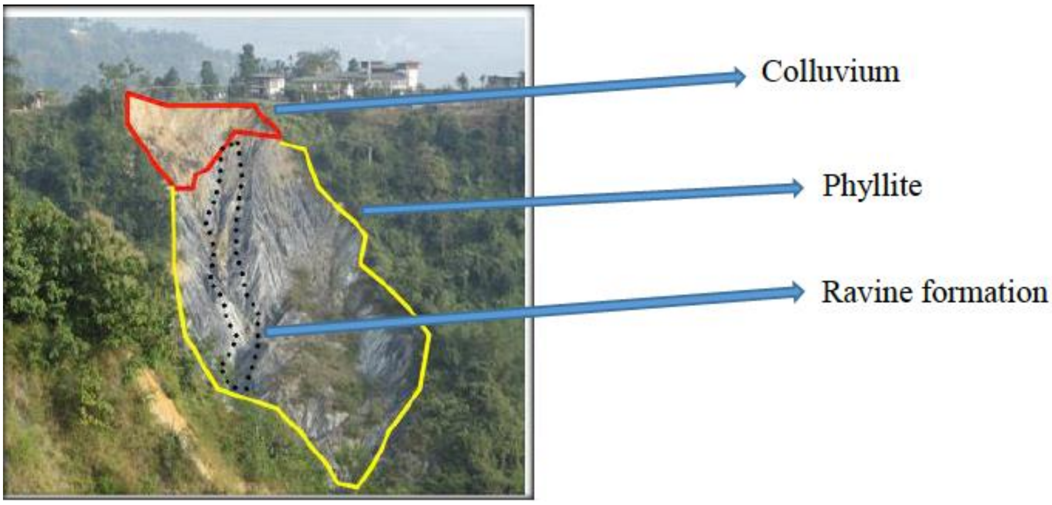
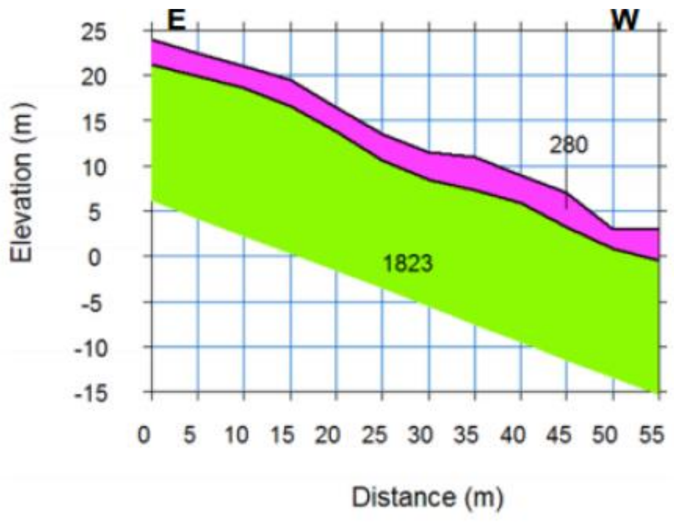


Figure 10 Surface geology

The studies conducted by Bhutan's NAPA-II project also confirmed that the rock encountered at the site is tendered phyllite. In some research papers it was also observed that the top of the landslide comprised of reddish-brown soil. The soil was found to overlie phyllite material only up to 0.5 m depth. It was then decided that soil had been deposited due rain-wash and soil creep. The soil was colluvium by the virtue of its resemblance in the characteristics with the colluvium materials.

Bhutan's NAPA-II project conducted the seismic refraction survey at Reldri landslide. The survey location and profiles are shown in the figure below



Very soft soil (280 m/s) on 2m, then rock (1800 m/s).

Figure 11 Underground profile of left bank of ravine (source: (Plotto, 2015))

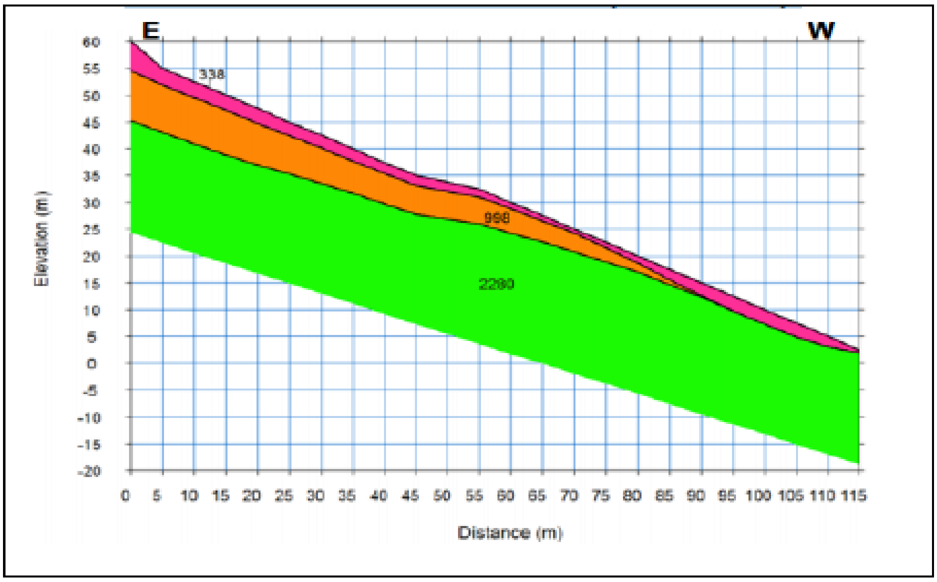


Figure 12 Underground profile of right bank of ravine (source: (Plotto, 2015))

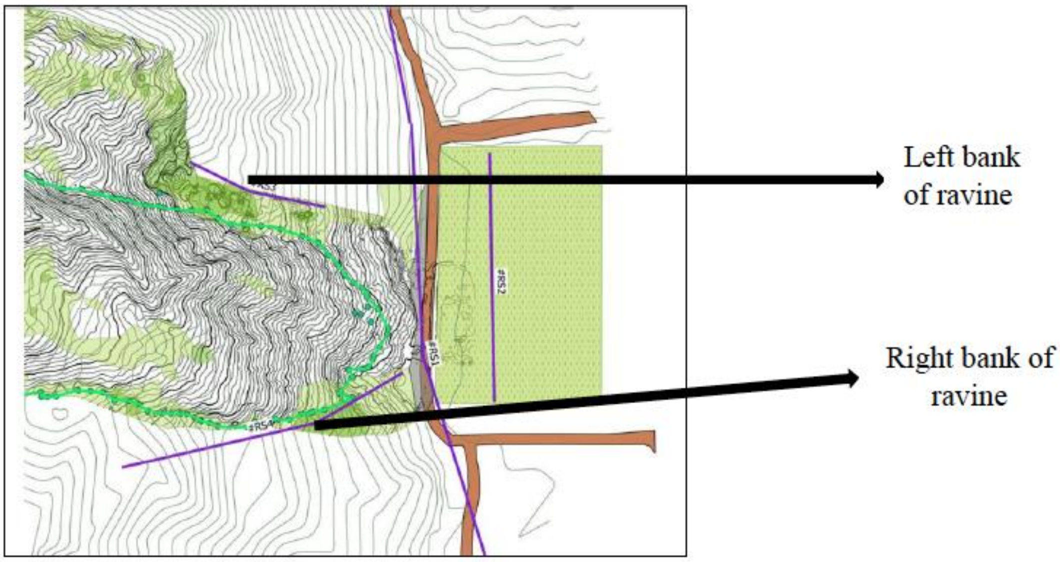


Figure 13 Seismic Survey location ravine (source: (Plotto, 2015))

Soft soil (300 m/s) on a thickness of 1 to 5m, then medium quality soil (1000 ms) on 10m thicknesses on the east side of the profile. This second layer disappears on the west side. Then the rock is uncounted (2200 m/s).

The left bank of the ravine is quite stable. From the profile it can be seen that the bedrock is faced at only 2 m from the surface. For this study, the profile of the right bank is used to know about the depth of the bedrock and the overlying layers. The bedrock is encountered at 15 m from the surface and it has some variation along the length of the slope and hence the chances of failure along the right bank are relatively high. The failure was physically observed during the rainy season at the right side. Therefore, the profile of the right bank was used in the stability analysis.

CHAPTER 3

METHODOLOGY

3. General

The following flowchart will show the methodologies adopted for this study. Due to the current pandemic situation the collection of data from the field and doing surveys was not possible and the data from other research paper had to be used.

3.1 Methodology

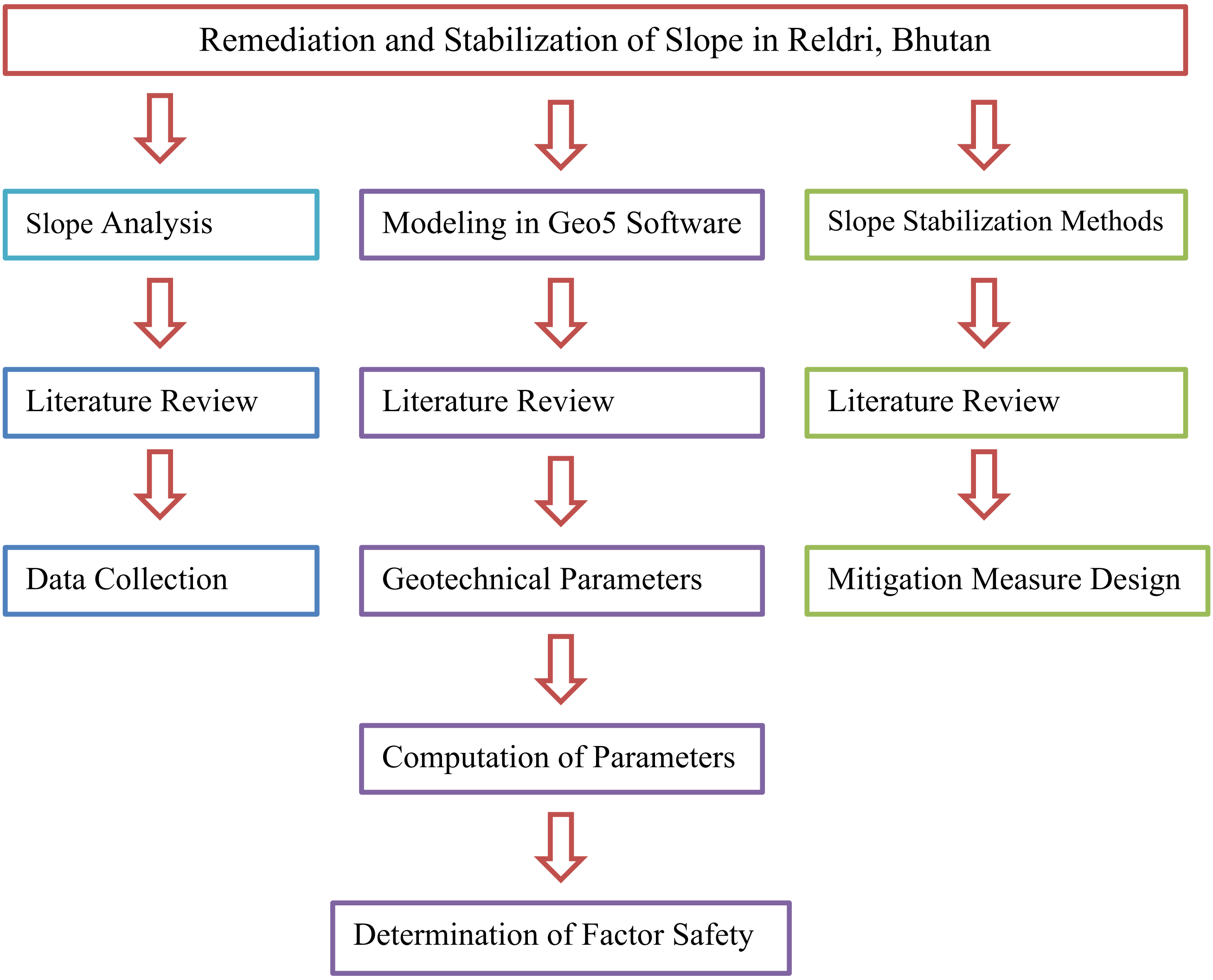


Figure 14 Methodology of project

3.2 Slope stability analysis

3.2.1 Introduction

(Kanjanakul et al., 2013) Slope stability is the ability of soil mass to resist mass movement of slope material. Stability of slope depends upon the shearing strength of soil to resist the stress developed within. There are generally two methods of finding the stability of slope as given in figure below

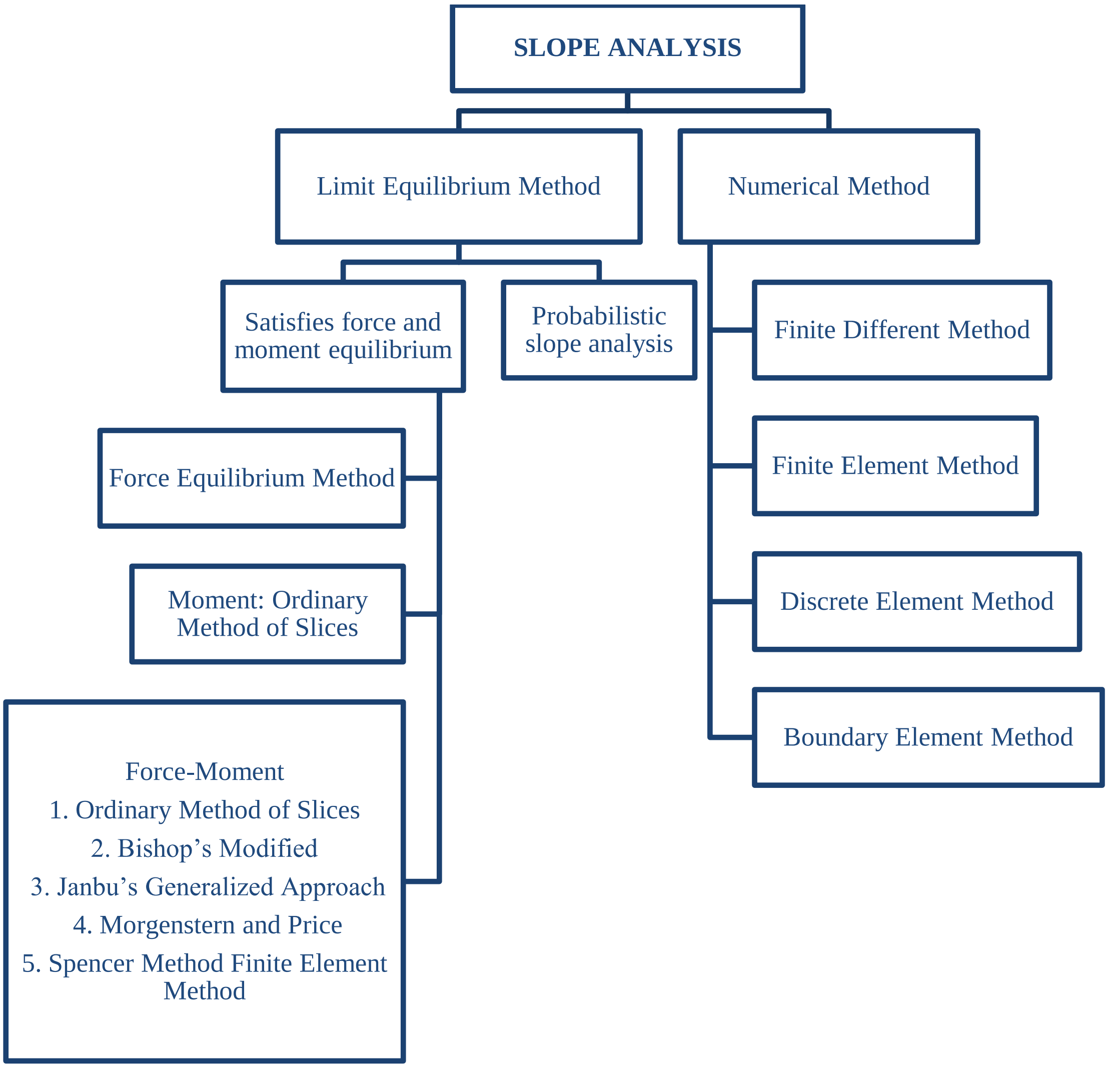


Figure 15 Methods of slope analysis

3.3 GEO 5 analysis

Geotechnical software GEO5 is a powerful tool, which is easy to use for solving geotechnical problems using both Finite Elements Method (FEM) and traditional analytical methods.

GEO5 is a powerful set of programs based on analytical methods and the Finite Element Method.

- Analysis of slope stability
- Design of retaining wall
- Design of foundation
- Analysis of soil settlement

3.3.1 Limit equilibrium method

The limit equilibrium method is the most common and widely used method of stability. This method generates the critical failure surface and mechanism based on the specific geotechnical situation. To achieve equilibrium against shear stresses, the shear strength of the soil is reduced by a significant factor of safety. This calculation is known as the limit equilibrium procedure (Duncan and Wright, 2005).

To calculate the factor of safety for slopes this method is the most prevalent. It is well known that the problem is indeterminate, and suppositions on inter-slice shear forces are to be made the problem determinate. LEM is divided further based on the number of equilibrium equations satisfied. There are force equilibrium satisfying methods and methods which satisfies both moment and force equilibrium equations.

The famous methods include those by Fellenius (1936), Bishop (1955), Janbu (1973), Lowe and Karafiath (1960), Spencer (1967), and Morgenstern and Price (1965).

The majority of Limit Equilibrium Methods are based on slice techniques, which can be vertical, horizontal, or inclined. The common features of the methods of slices have been summarized by Zhu et al., (2003):

1. The body sliding over the surface of failure is distributed into a predetermined number of slices. These slices are cut in three directions; vertically; horizontally and inclined. The cutting pattern does not have much difference however people use the vertical cut mostly.

2. A single safety factor that is applied to the entire failure mass. The slip surface's strength is organized to the same degree, bringing the sliding body to a limit state.

3. To make the problem determinate forces acting on the slices are assumed

4. Factor of safety is calculated from force or moment equilibrium equations.

The basic assumption underlying the limit equilibrium approach is that Coulomb's failure criterion is satisfied along the assumed failure surface, which could be a straight line, circular arc, logarithmic spiral, or other irregular surface. The shear resistance for equilibrium of a free body is calculated from the slope with known or assumed values of forces acting on the free body. The calculated shear resistance is compared to the material's estimated or available shear strength to provide an indication of the factor of safety. (Fang, 1997).

There are two methods for achieving static equilibrium. The first method considers the equilibrium for the entire mass of soil and solves it for a single free body. The other approach is to divide the soil into slices, each of which must satisfy all forces to equilibrium (Duncan and Wright, 2005).

i. Moment equilibrium: It is generally used for the analysis of rotational landslide. Factor of safety is given by: $F=\frac{Mr}{Md}$

Where M_r is the sum of the resisting moments and Md is the sum of the driving moment.

ii. Force equilibrium: It is generally applied to translational or rotational failure composed of planar or polygonal slip surfaces.

actor of safety is given by: $F=\frac{Fr}{Fd}$

Where Fr is the sum of resisting forces and F_d is the sum of the driving forces.

3.3.2 Ordinary method of slices

Fellenius (1936) developed the Ordinary Methods of slices. This is the most basic method of slicing. It is the only method that yields a linear factor of safety equation. The slip surface is thought-out to be circular and the mass of soil is distributed into a number of slices; vertical. In this method the inter-slice forces are ignored, because they run parallel to the bottom of each slice.

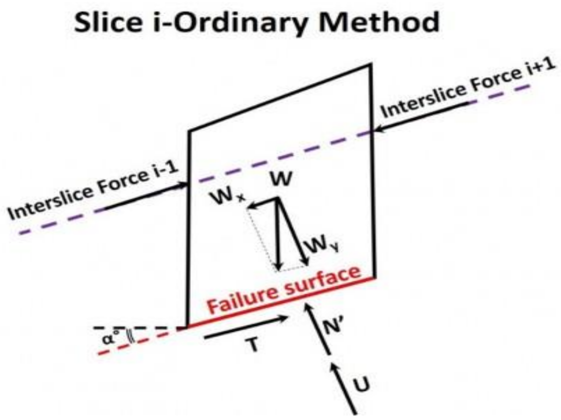


Figure 16 Based on the Ordinary Method of Slices, the forces acting on a typical slice. The interslice forces are assumed to be collinear and are therefore ignored.

Factor of safety by Ordinary Method of Slices is given by:

Fs=$\frac{c'L+tan\varphi\prime\sum(N-U)}{\sum T}$, N-Wcos∝;   T=Wsin∝

Where

c' = Effective cohesion

φ' = Effective angle of friction

U = Pore-water pressure

N = Slice base normal force

W = Slice weight

α = Inclination of slice base

3.3.3 Bishop's modified method

Inter-slice shear forces are ignored in these, and it is assumed that the perpendicular or horizontal force properly describes inter-slice forces. (Bishop 1955). The slip surface is assumed as a circular shape. The ratio of the available shearing strength of the soil to that required maintaining limiting equilibrium is characterized as the factor of safety against slope failure.

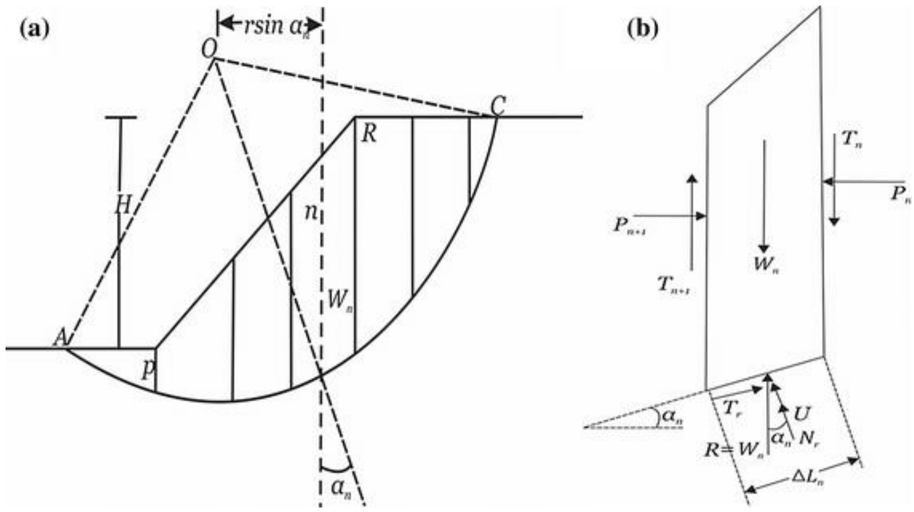


Figure 17 a) Soil slices above failure plane, b) Effect of the forces on the side of a particular slide.

Factor of safety by Bishop's method of slices is given by:

$$Fs=\frac{\sum\frac{1}{m}\{c\eta+[(W-Ucos\alpha)+\Delta T]tan\varphi'\}}{\sum Wsin\alpha}$$

Where, m = cos α + $\frac{tan\varphi sin\alpha}{Fs}$

3.3.4 Janbu's simplified method

Janbu's method is comparable to that of Bishop's Simplified method but this method satisfies only total horizontal force equilibrium and not total moment equilibrium. The closure of slice polygon is much improved than Bishop's Simplified method but the factor of safety is actually too low. This method is usable for both round and non-spherical surface of failure. Non-circular faces are more common in nature than the circular faces.

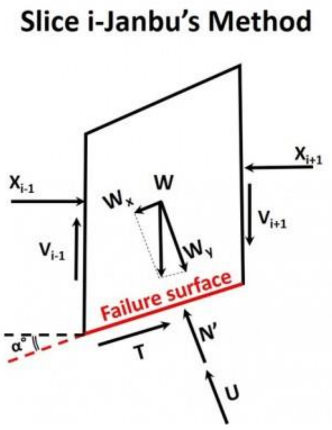


Figure 18 Forces acting on a single slice

Factor of Safety is given by:

$$Fs = \frac{\sum\left(c'\beta+(N-U\beta)tan\varphi\right)sec\alpha}{\sum Wtan\alpha+\sum \Delta E}$$

3.3.5 Morgenstern-price method

Morgenstern-Price invented a similar method to that of Spencer's with limit equilibrium as its' basis. It satisfies forces and moment equilibrium, which acts on specific slabs. Dividing the soil above the slip surface by dividing planes creates the blocks.

The factor of safety equation w.r.t force equilibrium is:

$$Ff = \frac{\sum [\{c'\beta + (N-u\beta)\ \tan\varphi'\}\ \sec\alpha]}{\sum\{W-(\Delta T)\}\tan\alpha + \sum \Delta E}$$

$\Delta T = T2 - T1$

$\Delta E = E2 - E1$

The factor of safety equation w.r.t moment equilibrium is:

$$Fm = \frac{\sum\{c'\beta+(N-u\beta)tan\varphi'\}}{\sum Wsin\alpha}$$

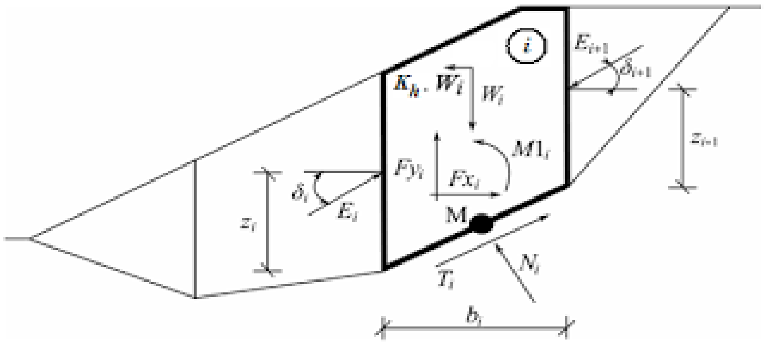


Figure 19 Forces acting on a single slice on a polygonal slip surface

3.3.6 Spencer's method

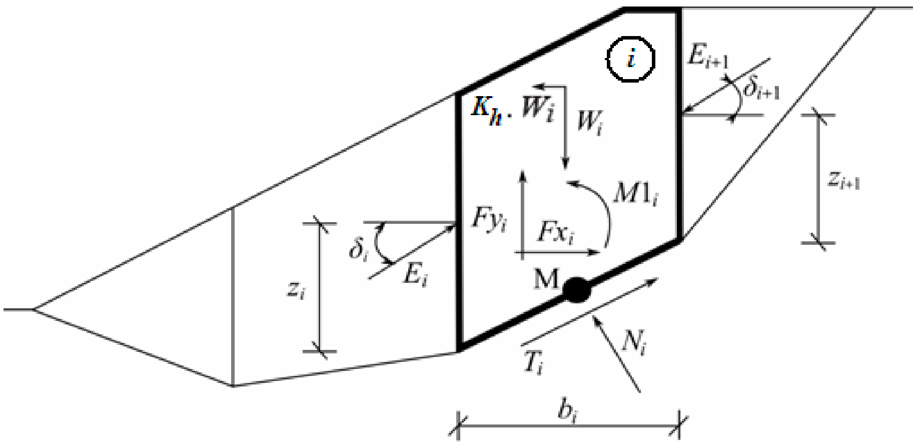


Figure 20 Forces acting on individual slip surface

CHAPTER 4

DATA COLLECTION

The data needed for the slope stability analysis were collected from various sources which ahs been listed in the literature reviews. The data were collected, compared and the average values of the sample are given below. The list of the data collected include the following:

4.1 Coefficient of uniformity and coefficient of curvature.

4.1.1 Sieve Analysis

The gradation test allowed the determination of the particle size distribution of a granular material. The distribution of different grain sizes affects the engineering properties of the soil. The grain size analysis provides the size distribution, which is required in the soil classification. Under the sieve analysis, the relation = $D30^2$/ (D60*D10) and Cu = D60/D10
Where,
Cc = coefficient of curvature
D60 = 60% finer of the particle size;
D30 = 30% finer of the particle size;
D10 = 10% finer of the particle size;
Cu = coefficient of uniformity;

From the laboratory test on sieve analysis conducted in the research paper we could conclude that
Average value of Cc = 2.03
Average value of Cu= 17.09

Interpretation: It can be concluded that the soil is well-graded sand (SW). This means the soil i.e., Phyllite contains sizes of the sand particles from 4.75 mm to 0.075mm sieve. It can also be classified as the silty sand (SM) as the soil contains a little amount of silt with the maximum of sand particles.
The above interpretation is based on Indian Standard Soil Classifications (ISSCS). Although the soil is well-graded sand, it is non cohesive but it was observed that the collected soil samples

could not be molded properly when moist and crumbled easily when dry. This can be one factor contributing to the occurrence of Reldri landslide.

4.2 Liquid limit, plastic limit and plasticity index

The strength exhibited by the soil in the form of resistance to deformation and rupture and the force, which holds the soil particles together, is known as the consistency test of soil. For the project, liquid limit and plastic limit were performed.

Liquid limit is defined as the minimum water content at which a part of soil cut by a groove of standard dimensions will flow to close a groove when jarred in a specific manner. At this limit the soil possesses a small value of shear strength, and offers practically no resistance to flow.

Plastic limit is defined as the water content at which the soil will just begin to crumble when rolled into threads of specific size. Thus, this is the minimum water content at which the change in shape of the soil is accompanied by visible cracks when worked upon the soil crumble.

1. Colluvium

Liquid limit (wl) = 26%

Plastic Limit(wp) = 21.5%

Plasticity Index (Ip) = 4.5 %

2. Phyllite

Liquid limit = 18 %

Plastic Limit = 15.7 %

Plasticity Index (Ip) = 2.3 %

Based on the limits and indices obtained from the research papers, the various conclusions can be drawn for the soil encountered in our study area.

i. Liquid limit, Plastic limit and plasticity Index (Ip)

The liquid limit and the plastic limit indicate the plasticity and liquidity both are dependent on the amount and type of clay in a soil.

As both colluvium and phyllite have the liquid limit less than 35%, they can be classified under the soil of low plasticity.
Their plasticity index (Ip) is less than 7. Hence, they can be described as the soil of low plasticity according to ISSCS. Low plasticity also indicates the low or negligible contents of clay, further showing less cohesion of the soil.
Colluvium encountered at top of the landslide up to the depth of around 0.5 m is slightly more plastic and cohesive as compared to phyllite.

ii. Relative consistency (Ic)

It is defined as the ratio of the difference between the liquid limit and the natural water content of a soil to its plasticity index. Mathematically,

I_c= $wl−wIp$,
where w= natural water content at 1 m depth of point 1.
The parent soil present at the site is phyllite and colluvium is present at top of the slide as a deposited material. Hence, the discussion will be done only for phyllite, a soil actually affecting the landslide.

I_c=1.74
As I_c is greater than 1, the soil at its natural water content is in a semi-liquid state and very hard. It was also found that the soil remained hard during dry season but behaves like a liquid.

iii. Liquidity index, Il

It is a ratio of difference between the natural water content of a soil and plastic limit to its plasticity index. Mathematically,
Il = $wN−wPIp$
Il= -0.74

As Il is less than 1, the soil is in semi liquid state and hard at it natural water content. This shows that soil will remain stable at its natural condition unless disturbed by the external factors such as earthquake and rising ground water table.

iv. Flow index, IF

It is the slope of the flow curve obtained between the number of blows and water content in the Casagrande test for the determination of liquid limit. The flow index indicates the rate of loss in shearing strength upon increase in water content. A soil with a higher value of flow index possesses lower shearing strength when compared to a soil with a lower value of flow index.

IF= $w1 - w2\log\left(\frac{N2}{N1}\right)$ = 8.05

As If for the given soil, phyllite is quite high, it can be concluded that the soil possesses lower shearing strength and rate of loss of shearing strength is quite high with increase in water content.

v. Toughness index, IT

It is a ratio of the plasticity index to flow index. Toughness index gives an idea about the shear strength of a soil at plastic limit.

IT = $IPIF$ = 0.29

As it is less than 1, the soil is friable (easily crushed) at the plastic limit.

4.3 Internal angle of friction and cohesion of the soil

Tri-axial test had been performed to obtain the strength parameters, which are used in the determination of shear strength of the soil.

For the soil at the study area,

Internal Angle of Friction (Φ) =37.4^0; Cohesion of the Soil= 0

The above values indicate that soil i.e., phyllite present at the site is sandy with no cohesion. Hence it can be concluded that the lack of cohesion is one factor that triggers the landslide. As the soil is cohesion less, the sample preparation and the test operation were slightly challenging.

4.4 Specific gravity

The specific gravity of a soil is defined as the ratio of its mass in air to the mass of an equal volume of water at reference temperature, 4 degrees Celsius. Specific gravity is an important factor, which is useful in computing soil properties, for example, the void ratio of a soil, its unit weight, in calculating the degree of saturation of a soil.

From the research papers, the density bottle was used to determine the specific gravity of the soil at the site, which was found out to be 2.25.

4.5 Slope angle

It was found out from the literature that the length of landslide between the toe and the top had been measured physically at the site using measurement tab. The elevation of the toe and the top of the slide were obtained using Global positioning system (GPS). The difference in the elevation gave the height of the landslide. The height and the length were used to determine the slope angle. The slope angle was also determined using Clinometer. The average value of slope angle obtained is 39.8 degree.

4.6 Dimension of the slope

For study area (Reldri),

L = 80 m

H= 8 m

The data acquired from the research papers helps to conclude that the slope situated at Reldri is a combination of both rotational and translational slopes. The top portion of the slide has an irregular concavity upward indicating the rotational behavior, the right bank of the ravine has vivid translational slides, and left bank of the ravine has irregular translational slides with single axle ravine.

4.6.1 Extent of the slope

Any slope of great extent with soil conditions essentially same for all identical depth below the surface are known as infinite slopes. According to the historical information obtained from

Google map, the Reldri landslide has been continuously expanding since 2004. Hence, the slope of Reldri landslide can also be classified as infinite slope.

4.6.2 Particle sizes

Reldri slope can be classified as mudflow. It had been found that the soil samples of the Reldri slope consisted of more than 50 percent by weight of particles of both sand and silt. Hence it could be concluded that the particles in the slope can be classified as mudflow.

Figure 21 Mudflow

4.7 Unit weight and unit saturated weight

For Phyllite: γ_w = 9.8 KN /m^2, γ_{sat} = 19.59 KN /m^2

For Colluvium: 17 KN /m^2

For bed Rock: γ = 25 KN /m^2

Water content

Point 1 for 1m depth: average moisture content = 14

Point 2 for 1m depth: average moisture content = 8.9

Point 2 for 0.5 m depth: average moisture content = 8.83

The parameters of soil are shown in Table 1

Table 1 Data of soil parameter

Bulk Density (ρ)	2.10 g/cm^3
Void Ratio (e)	0.372
Porosity (η)	39.26 %
Degree Of Saturation (S)	25.1%
Maximum Dry density	1.693 gm/cc
Optimum Moisture Content	14%

4.8 Typical causes of landslides

After thorough desk studies and stability analysis, the following factors were identified as the possible causes of the Reldri landslide.

1. **Toe disturbances**: The landslide below the check post started quite a few years before the landslide at Reldri.
   The mitigation measures were provided at the toe of that landslide leaving the opposite flank unmitigated. This diverted the lateral stream erosion towards the toe of the slope.
2. **Sub-surface water**: Heavy precipitation during monsoon season causes increased infiltration which results in increased pore water pressure due to increase in water

level. This decreases the shear strength of the soil. It is vividly known from the stability analysis that the FOS gets subsequently reduced due to increase in pore water pressure.

3. **Slope Angle (β):** The slope remains stable as long as β is equal to or less than the angle of internal friction (ϕ). The slope becomes unstable if β greater than ϕ (the constructor.org). For Reldri landslide, β is greater than ϕ. The slope is quite steep causing decreased shear strength.
4. **Seismic activities**: Bhutan lies in the highest earthquake zone i.e., zone 5, the slope movement and ground water alteration due to earthquake can be considered as one of the major causes of landslide.
5. **Soil properties**: Based on the sieve analysis and consistency tests from the papers, it was concluded that the soils encountered at the site is non-cohesive and less plastic, indicating that the shear strength of the soil is low.

CHAPTER 5

SLOPE STABILITY ANALYSIS

In this project, the slope stability analysis was carried out in GEO5 software using the parameters obtained from the research papers. To design the slope, the software required input data such as slope height, slope length, unit weight of soil, values of cohesion and internal angle of friction and the type of soil.

Initially, the interface of the slope was drawn in the software after defining the boundary. Then, using the tools in the software, soils and rigid body were assigned to the layers. After defining all the parameters, the software analyzed the slip surface that was chosen by using any of the Limit Equilibrium Methods and gave a value for Factor of Safety.

Required input for the stability calculations include the following:

Slope geometry

Slope angle in degrees (β)

Length (L) and Height (H) of the slope

Soil properties

Natural unit weight (γ) or dry unit weight (γ_d).

Moisture content (w) if needed to calculate γ_{sat}

The water content test allows the determination of the moisture content of the soil which is the ratio expressed as the percentage of the mass of pore water in given mass of the soil. For the soil, moisture content plays an important index used for establishing the relationship of air, water and solids. From the water content test, it was found out that the average water content of the soil at Reldri landslide in its natural state is 10.6%.

At this value the of water content, the slope failure will not occur but the failure may be induced with the further increase in the soil moisture due to the advent of the rainfall.

For the study area,

h = 9.2 m

The depth of the soil up to the bed rock based on geophysical survey conducted by NAPA

z = 15 m

Thus, slope angle, β = 39.8˚

Note: The depth of water nearest to the ground level is considered to effectively take into account the impact of ground water table on slope stability.

γ_w = 9.8 KN /m2, γ_{sat} = 19.59 KN /m2,

$$\text{FoS} = \left(1 - \frac{9.8*9.2}{19.59*15}\right)\frac{\tan 37.4}{\tan 39.8}$$

$$= 0.69 * 0.92$$

$$= 0.63 < 1 \text{ (unstable)}$$

As FOS is less than 1, it can be concluded that the slope has further failed due to the impact of water seepage into the soil.

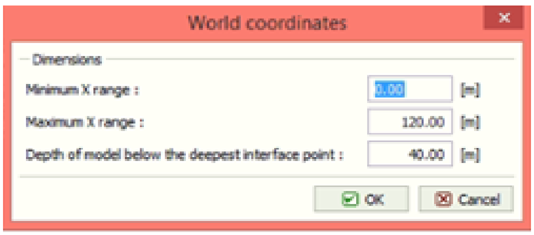
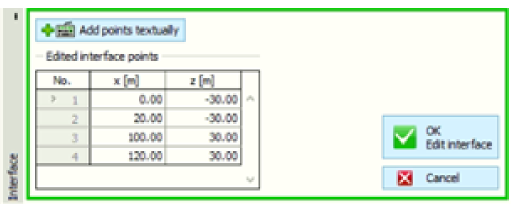


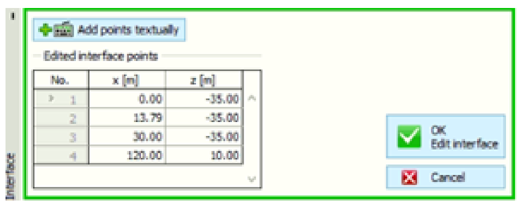
Figure 22 Coordinate of the slope in Geo5

The first step in the analysis of slope stability was to determine the interface and to do that we needed points to be plotted. The points were calculated with the knowledge of slope angle. We made three interfaces to show the two types of soil present in the study area, first one being Phyllite that is above the bedrock and the second one is colluvium soil that is 0.5 m above the phyllite soil. Then we assigned the soil to their respective interfaces, the green colored soil between interface 2 and 3 is phyllite. From the data it could be decided that phyllite was Silty Sand so the silty sand option was chosen and the data values for the soil were also filled in. The brown colored soil between interface one and 2 is the Colluvial soil, which is clayey soil with fines and the parameters for the soil were already in built in the software so we considered those values. We provided rigid body for the bedrock which is below the interface 3 and is gray in color. We then analyzed the slope for stability using different methods.

Interface 1



Interface 2



Interface 3

Figure 23 Interface points

The factor of safety generated using different methods of stability analysis is shown in figure 24, 25, 26 ,27 and 28.

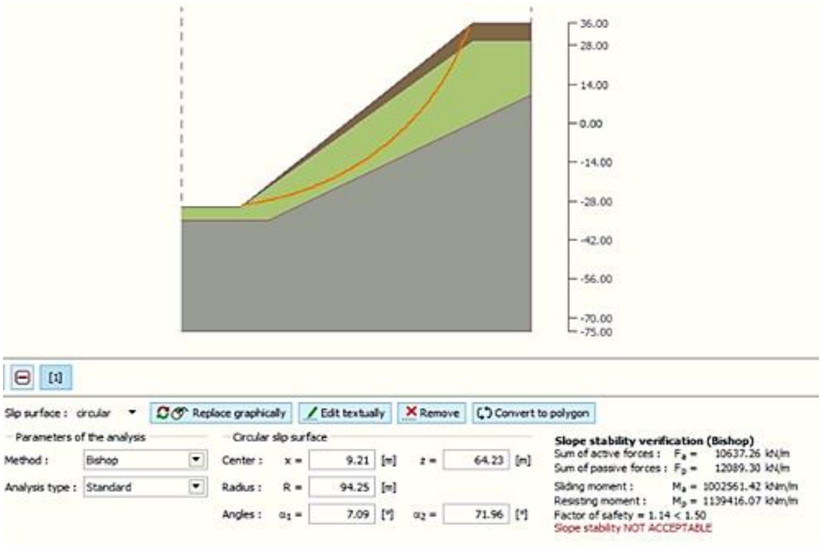


Figure 24 Factor of safety computed in Geo5 by Bishop's Modified Method

Bishop method:

The factor of safety comes out to be 1.14

1.14<1.50

Since the factor of safety is less than the maximum acceptable factor of safety the slope will fail and slope stability not acceptable.

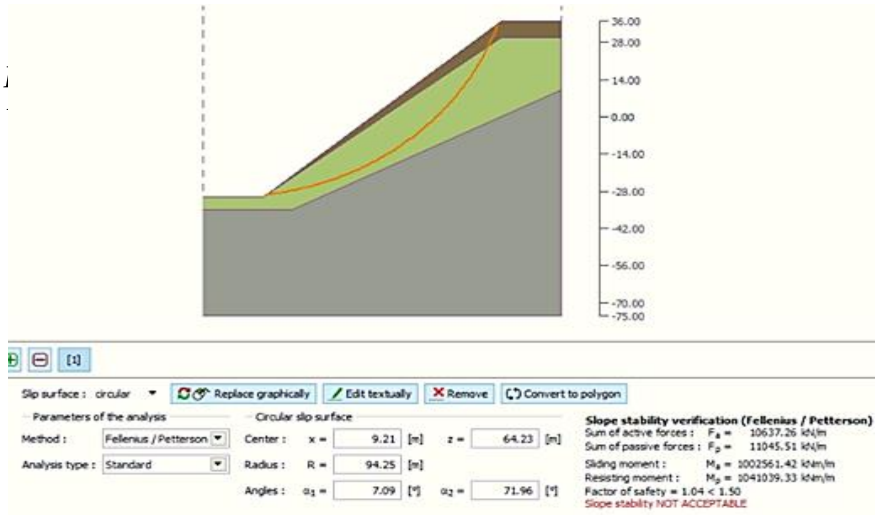


Figure 25 Factor of safety computed in Geo5 by Fellenius Method

Fellenius method:

The Factor of safety came out to be 1.04 and it is less than maximum acceptable factor of safety as shown in figure 25.

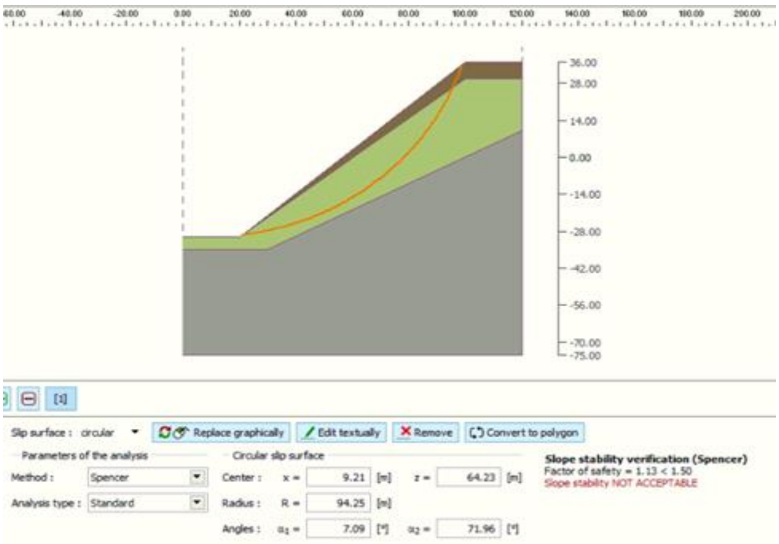


Figure 26 Factor of safety computed in Geo5 by Spencer Method

Spencer method:

The Factor of safety came out to be 1.13, which less than 1.50 as seen in the figure 26.

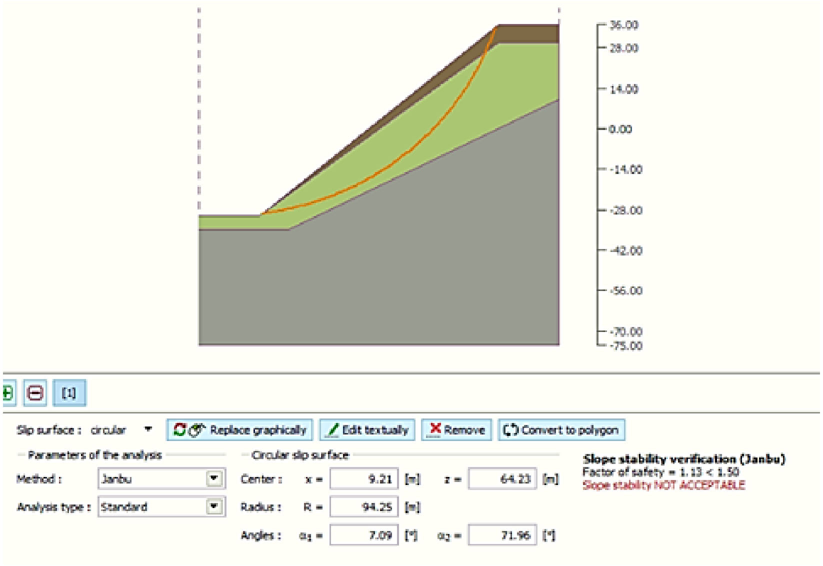


Figure 27 Factor of safety computed in Geo5 by Janbu Method

Janbu method:

The factor of safety came out to be 1.13. i.e., less than 1.50 and the slope stability is not acceptable as shown in figure 27.

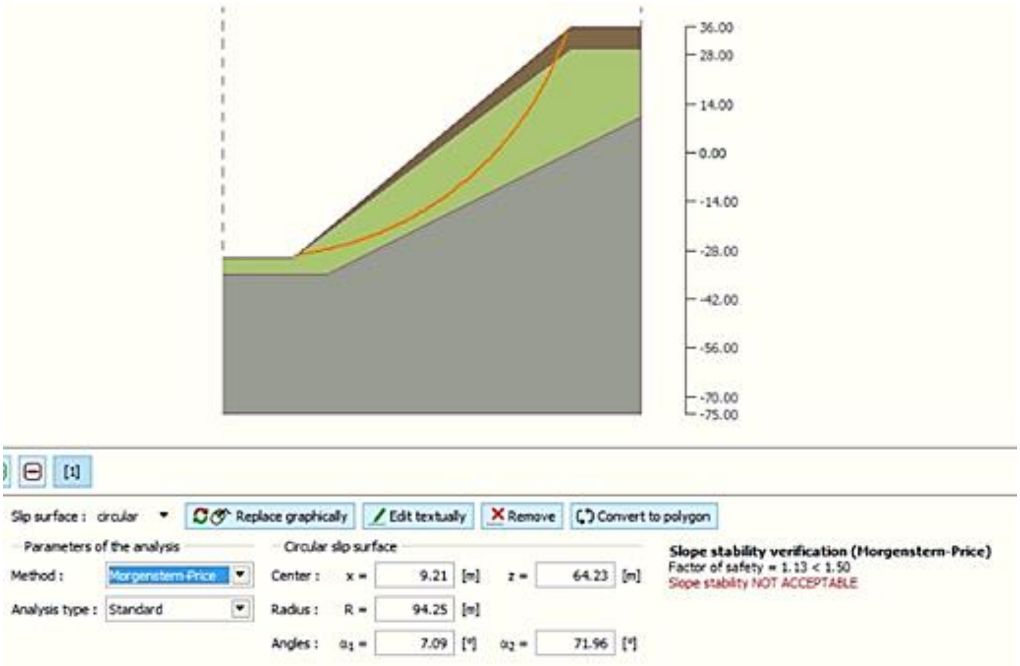


Figure 28 Factor of safety computed in Geo5 by Morgenstern-Price Method

Morgenstern-Price method:

The factor of safety came out to be 1.13 which less than the maximum acceptable factor of safety.

This graph shows the different values of factor of safety got from the GEO5 software by 5 types of methods.

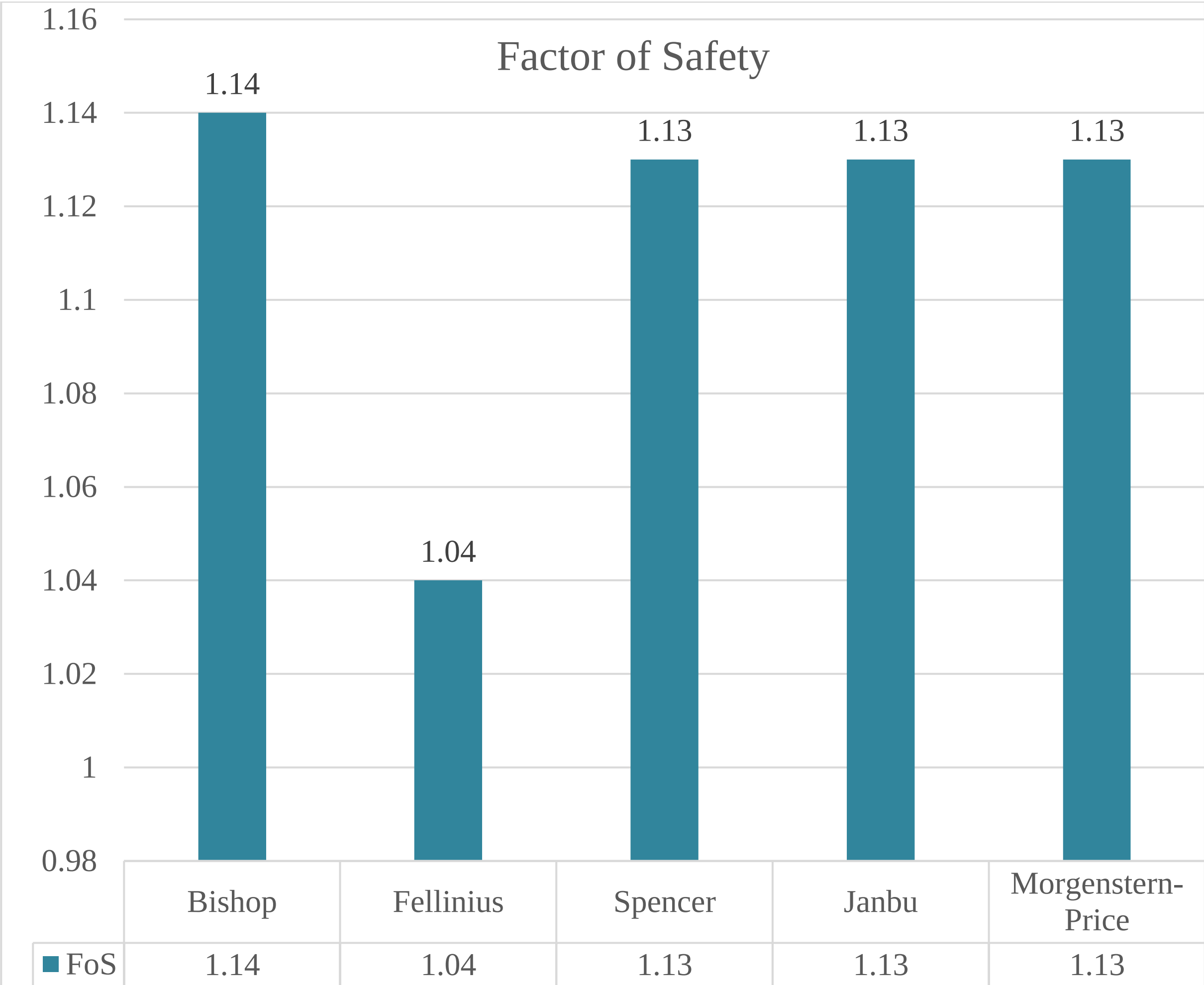


Figure 29 Graph plotted between factor of safety and various limit equilibrium methods

CHAPTER 6
RESULT AND DISSCUSSION

6.1 Introduction

Slope stabilization is the technique that aims to stabilize an unstable slope to prevent failure. It is broadly divided into structural mitigation and non-structural mitigation. Structural mitigation includes the construction of physical structures to diminish the failure of the slope at the site by constructing retaining structures, pier reinforcement, soil nailing, gabion wall etc. on the other hand, non-structural mitigation includes the use of vegetation and practice of bio-engineering stabilize the slope. There is also a third type of slope stabilization method, which is known as geo-technical method. In this method both bioengineering and technical structures are combined together as a unit to help stabilize the slope.

In this project, retaining wall was used as the mitigation measure to stabilize the slope in Reldri.

6.2 Retaining wall

Retaining walls are vertical or near-vertical structures designed to retain material on one side, preventing it from collapsing or slipping or preventing erosion.

6.3 Concrete cantilever retaining wall

A cantilever retaining wall is one that is attached to the foundation by a wall. A cantilever wall must be adequately engineered since it holds back a substantial volume of soil. The retaining wall acts like a beam, transferring horizontal stresses behind the wall to vertical pressures on the ground below.

6.4 Design of cantilever retaining wall manually

6.4.1. Manual Calculation

Depth of Foundation: From Rankine's equation

Total height of retaining wall [H]

$H = h' + D_f$

Depth of Foundation: From Rankine's equation

$$D_f = \frac{SBC}{\gamma}\left[\frac{1 - sin\emptyset}{1 + sin\emptyset}\right]^2$$

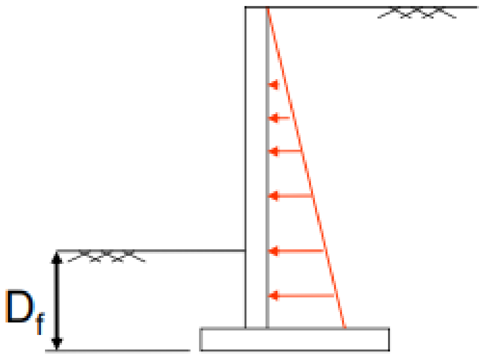


Figure 30 Depth of foundation

Df = 1 m

Therefore, H = 1+7 = 8 m

6.4.2. Proportioning Of Wall

1. Thickness of base slab = 0.08H to 0.125H)

= 0.64 m to 1 m

Thickness of base slab is assumed to be 0.8 m

2. Length of heel slab = 2.5 m

$X = \sqrt{(k_a/3)} \times h'$

3. Width of footing (B) = 0.5H to 0.7H

= 4 m to 5.6 m

The width of footing is assumed to be 5 m

4. Width of Heel = 0.5 B

Taking it as 2.5 m

5. Thickness of stem at base = H/12

Taking it as 0.67 m

6. Thickness of stem at top = $t_{base}/2$

Taking it as 0.335 m

7. Height of stem = H - t_{base}

Taking it as 7.330 m

8. Length of toe slab = 0.3B to 0.4B

Assuming it as 1.5 m

6.4.3 Preliminary dimensions of the retaining wall

Table 2 shows the dimensioning of the retaining wall that has been manually calculated

Table 2 Preliminary dimensions of the retaining wall

Descriptions	Values
Depth of foundation (D_f)	1 m
Total height of retaining wall (H)	8 m
Thickness of slab (0.08H to 0.125H)	0.250 m
Length of toe slab	1.5 m
Width of footing (B)	5 m
Width of heel slab	2.5 m
Thickness of Base slab	0.80 m
Thickness of stem at base	0.67 m
Thickness of stem at top	0.335 m
Height of stem	7.330 m

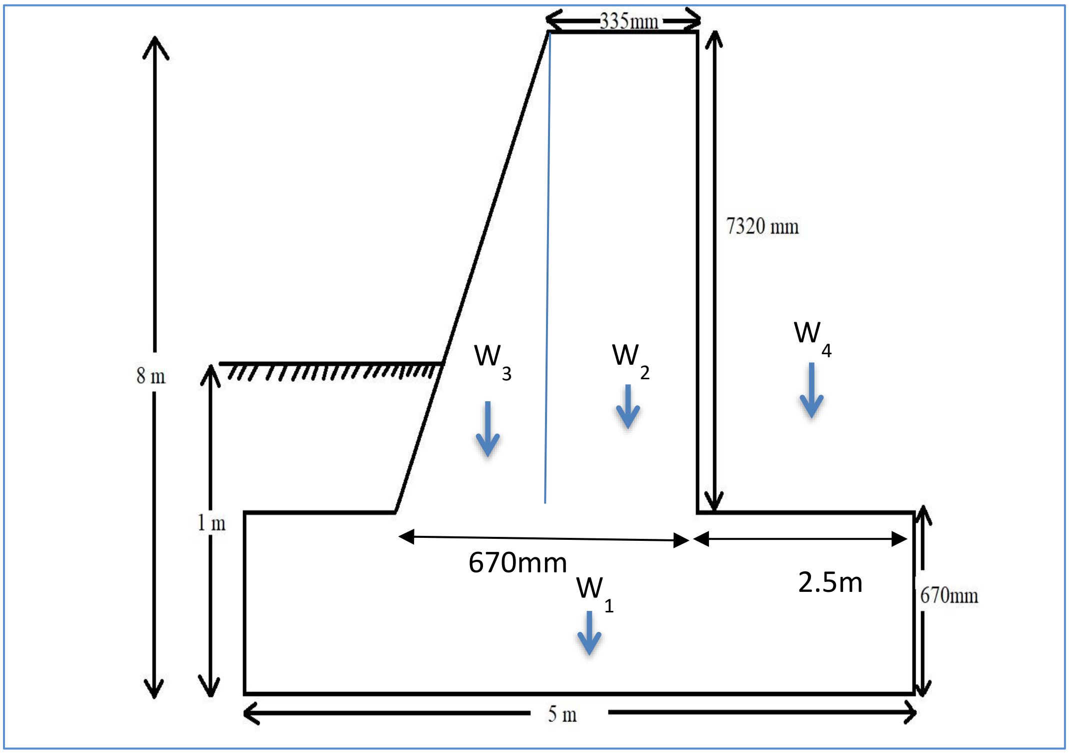


Figure 31 Diagrammatic representation of retaining wall

6.4.4 Calculation of forces and moments

For safety purposes of the cantilever retaining wall the forces and moments acting on the wall and the soil in the heel has to be calculated and is shown in table 3.

Table 3 Calculation of forces and moments

S/no	Notation	Item	Force (kN)	Distance from heel (m)	Moment (kNm)
1	W_1	Footing	33.5	2.5	83.75
2	W_2	Rectangular portion of wall	61.4	5.17	317.44
3	W_3	Triangular portion wall	30.7	2.65	81.65
4	W_4	Soil on heel	350	1.25	437.5

Summation forces (ΣW) = 475.6 kN

Stabilizing Moment (M_r) = 1460.09 kNm

Overturning Moment (M_0) = 397.68 kNm

6.4.5 Calculation of the Earth Pressure

Earth Pressure coefficients (K_a)

$K_a = 0.244$

Force due to active earth pressure

From Rankine's theory,

$$P_a = \{K_a \gamma_s (H')\}$$

$P_a = 149.13$ KN

- Horizontal component = $P_a \cos \theta = 149.13$ kN
- Vertical component = $P_a \sin \theta = 0$ kN

6.4.6 Check for stability

a. **Check for overturning**

$$\boxed{FS = 0.9 \times \frac{\text{stabilizing moment}}{\text{overturning moment}} > 2\text{-}3}$$

FS = 3.34 > 2-3

Hence safe against overturning

b. **Check for sliding**

$$\boxed{FSS = 0.9 \times \frac{\text{resisting force}}{\text{sliding force}}}$$

FS = 2 > 1.5

Hence, safe against sliding

c. **Condition for tension generation**

$$\text{Eccentricity} = \frac{\Sigma M + \Sigma M_0}{\Sigma W} - \frac{B}{2} < \frac{B}{6}$$

e = 0.30 m < 0.5 m

Thus, safe against tension.

d. **Pressure below the base slab**

$$q_{max} = \frac{\Sigma W}{B} \left(1 + \frac{6e}{B}\right)$$

$q_{max} = 125.9\ kN/m^2 < 180\ kN/m^2$

$$q_{min} = \frac{\Sigma W}{B} \left(1 - \frac{6e}{B}\right)$$

$q_{min} = 64.3\ kN/m^2 > 0$

6.5 DESIGNING CANTILEVER RETAINING WALL IN GEO5

Data is inserted into these individual frames:

1. Geometry: Dimensions of the cantilever retaining wall entered in the software.

   In the software dimensions for the retaining wall according to table 4 has been inputted. Figure 32 shows the dimensioning of the retaining wall in the GEO5 software

Table 4 Dimensions of retaining wall

Dimensions	value
k	0.33 m
h	7.33 m
xx	0.67 m
v_1	1.50 m
v_2	2.50 m
s_1	11:1

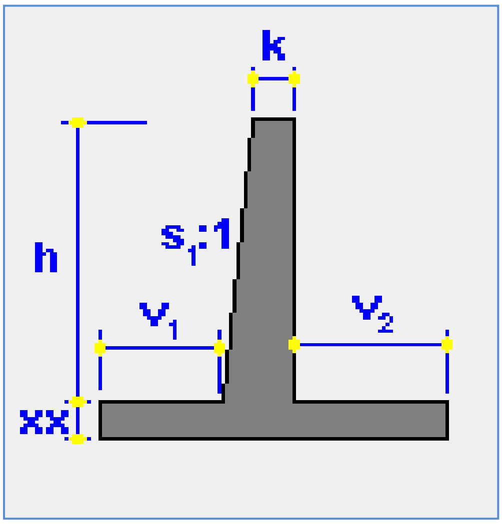


Figure 32 Cantilever retaining wall geometry

After dimensioning the retaining wall, material for the wall is chosen. Fe 415 steel and m20 grade of concrete is selected for the designing purpose.

Profiles as shown in figure 34 of depth 0.5 m and 7 were specified. After those respective soils were assigned to these depths as shown in figure 33.

2. Material: Concrete = M20
   Steel = Fe 415

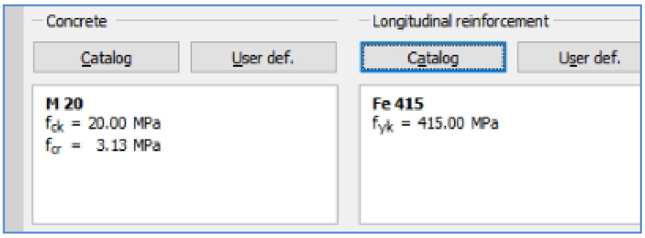


Figure 33 Catalog of concrete and steel

3. Profile:

   Profile 1 = 0.5 m

   Profile 2 = 7.5 m

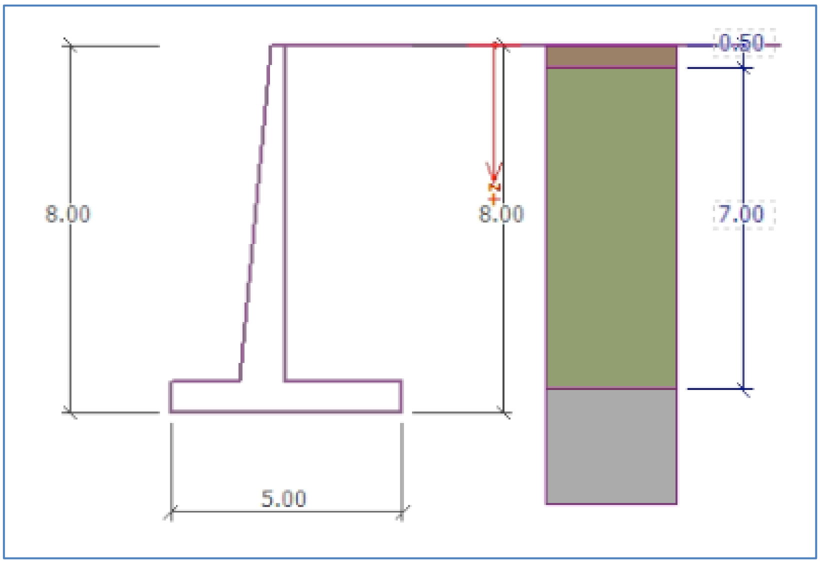


Figure 34 Profile of the soil

4. Soil:

Phyllite = Silty Sand

Colluvium = Clayey Sand

Bed rock = Poorly Graded Gravel

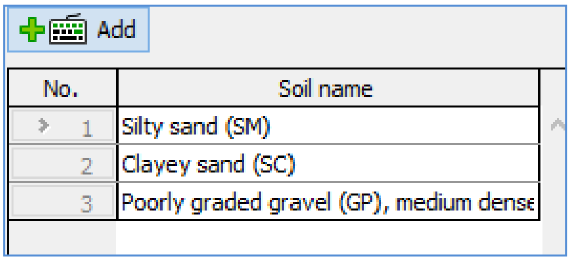


Figure 35 Labeling of individual soil profile

Figure 36 shows us the values of forces that has been computed by the software.

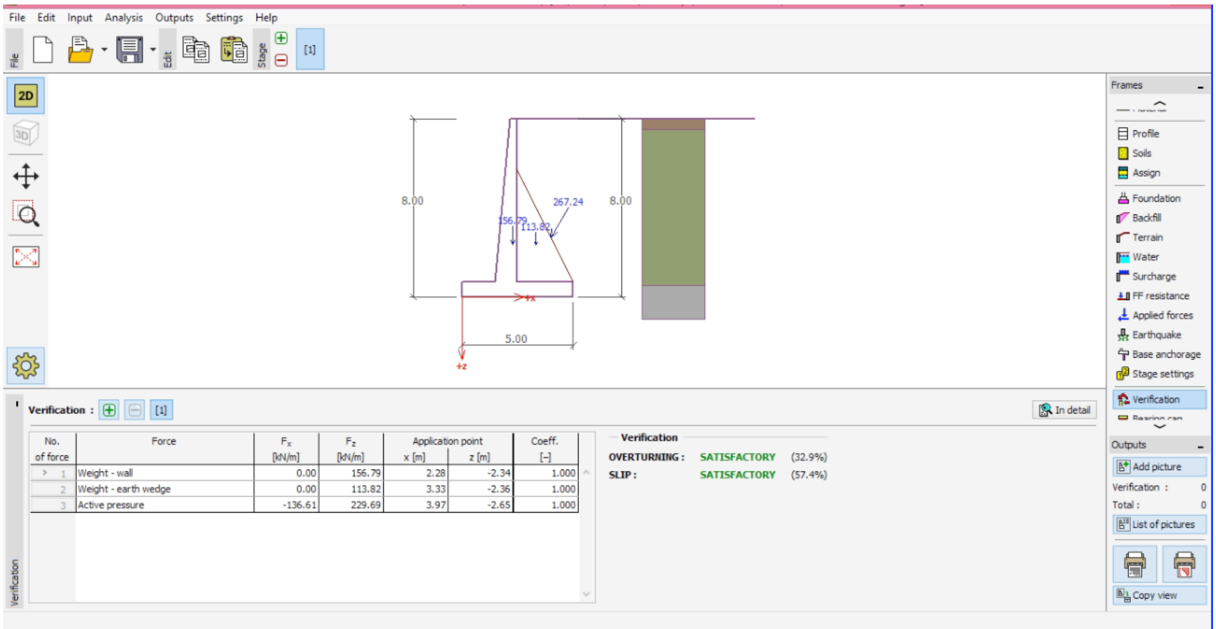


Figure 36 Forces calculated from Geo5 software

6.6 Verification of complete wall

Figure 37 shows the detail verification of the complete retaining wall analyzed by the software.

6.6.1 Check for overturning stability:

Resisting Moments (M_R): 1649.08 kNm

Overturning Moment (M_0): 361.60 kNm

Factor of safety = 4.56 > 1.5

Thus, stable against overturning.

6.6.2 Check for slip

Resisting horizontal force (H_{res}) = 356.86 kN/m

Active horizontal force (H_{act}) = 136.61 kN/m

Factor of safety = 2.61 > 1.5

Thus, stable against slip

6.6.3 Verification of bearing capacity of soil

Figure 38 shows the detailed verification of the bearing capacity of the soil

Bearing capacity of foundation soil = 180 kPa

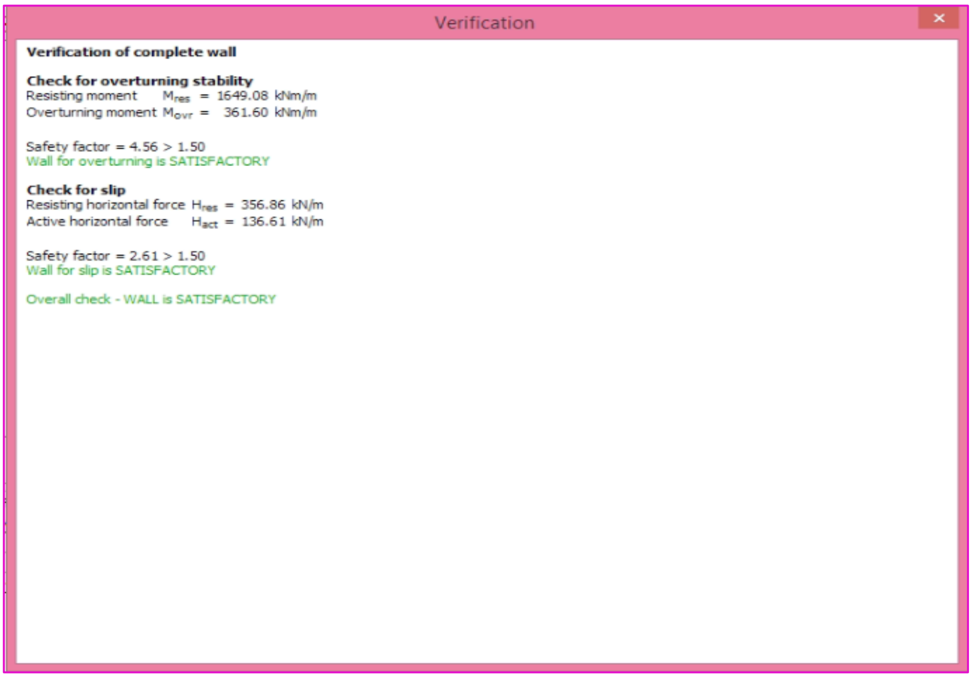
Maximum stress at the footing bottom = 100.13kPa

Factor of safety = 1.8 > 1.5

Bearing capacity of foundation soil is satisfactory.

6.6.4 Verification of eccentricity

e = 0.33 < 0.5



Verification

Verification of complete wall

Check for overturning stability
Resisting moment M_{res} = 1649.08 kNm/m
Overturning moment M_{ovr} = 361.60 kNm/m

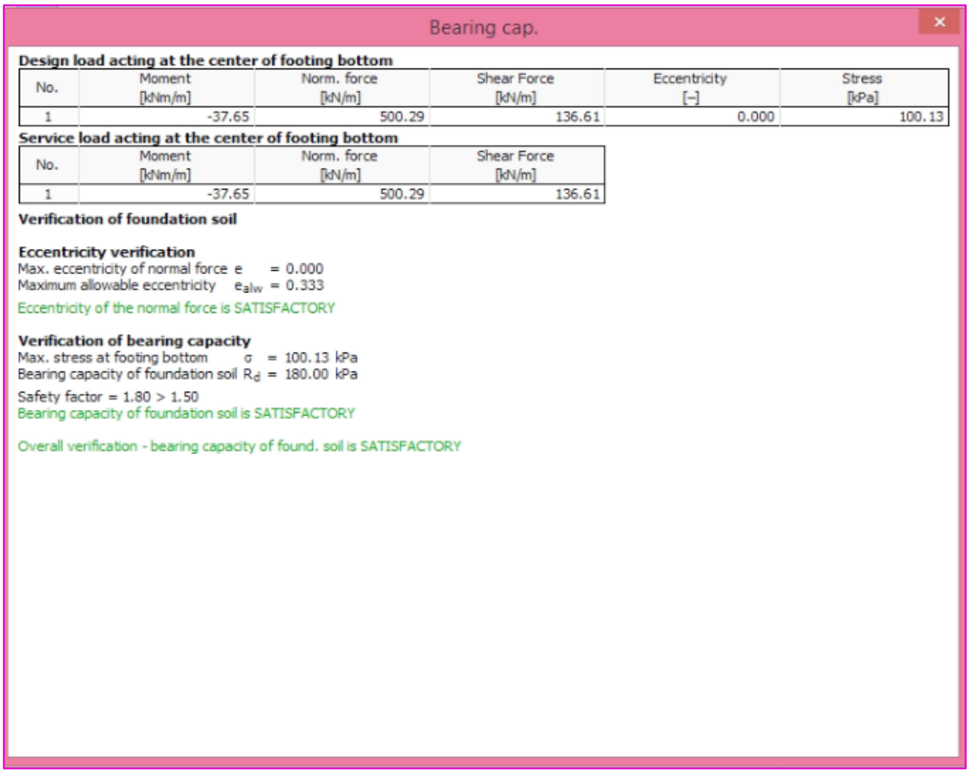
Safety factor = 4.56 > 1.50
Wall for overturning is SATISFACTORY

Check for slip
Resisting horizontal force H_{res} = 356.86 kN/m
Active horizontal force H_{act} = 136.61 kN/m

Safety factor = 2.61 > 1.50
Wall for slip is SATISFACTORY

Overall check - WALL is SATISFACTORY

Figure 37 Verification of complete wall



Bearing cap.

Design load acting at the center of footing bottom

No.	Moment [kNm/m]	Norm. force [kN/m]	Shear Force [kN/m]	Eccentricity [–]	Stress [kPa]
1	-37.65	500.29	136.61	0.000	100.13

Service load acting at the center of footing bottom

No.	Moment [kNm/m]	Norm. force [kN/m]	Shear Force [kN/m]
1	-37.65	500.29	136.61

Verification of foundation soil

Eccentricity verification
Max. eccentricity of normal force e = 0.000
Maximum allowable eccentricity e_{alw} = 0.333
Eccentricity of the normal force is SATISFACTORY

Verification of bearing capacity
Max. stress at footing bottom σ = 100.13 kPa
Bearing capacity of foundation soil R_d = 180.00 kPa
Safety factor = 1.80 > 1.50
Bearing capacity of foundation soil is SATISFACTORY

Overall verification - bearing capacity of found. soil is SATISFACTORY

Figure 38 Verification of bearing capacity of soil and eccentricity

6.7 Factor of safety from GEO5 software

After the dimensions of the retaining wall were inputted into the software, we ran the analysis to analyze the stability of the slope with retaining wall as the mitigation measure. The results were obtained from all the limit equilibrium methods.

6.7.1 Fellenius / Petterson Method

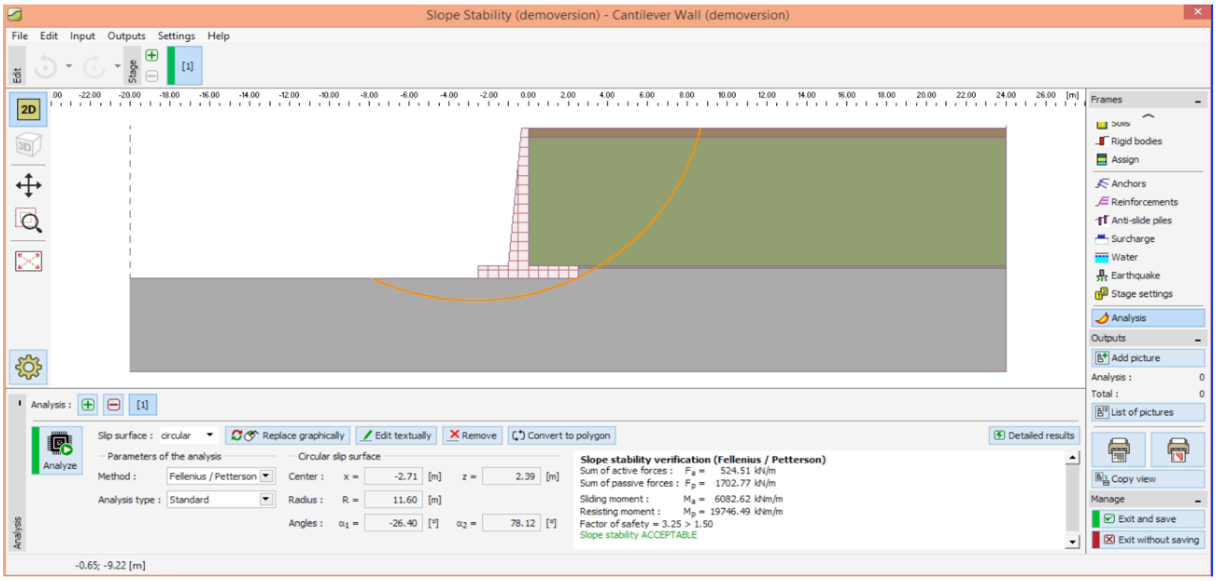


Figure 39 Factor of safety by Fellenius / Petterson method

6.7.2 Bishop Method

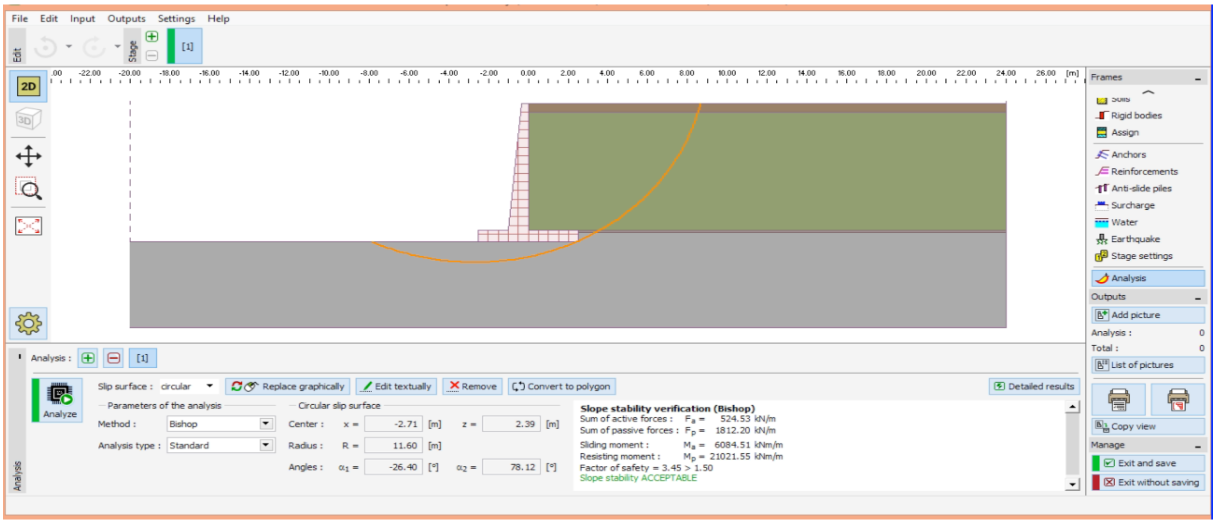


Figure 40 Factor of safety by Bishop method

6.7.3 Spencer Method

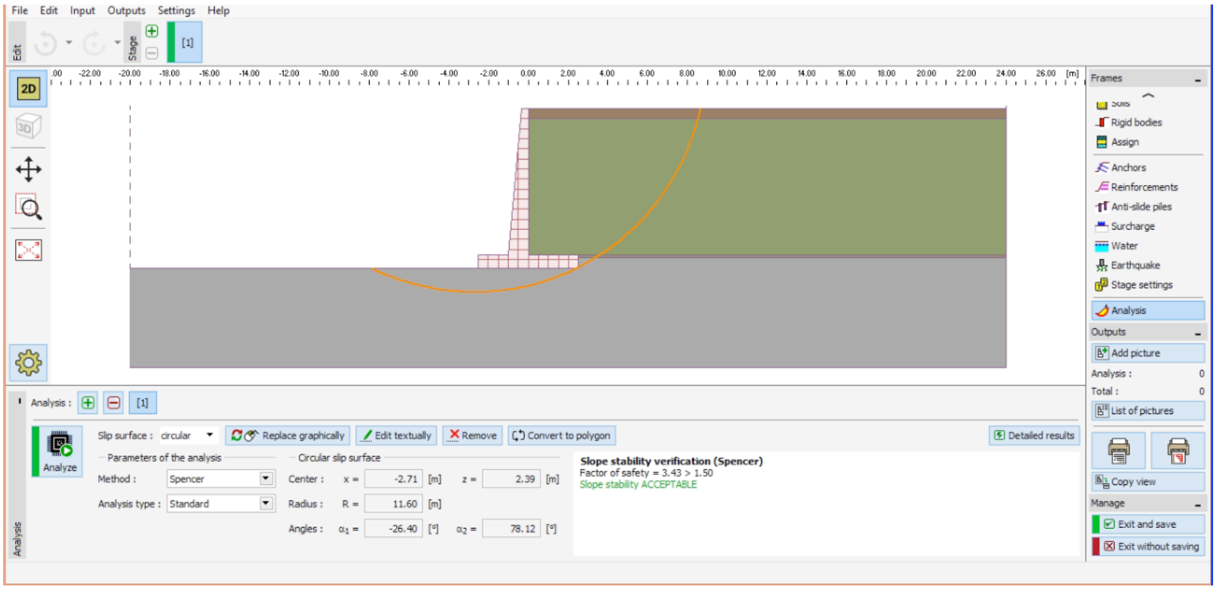


Figure 41 Factor of safety by Spencer method

6.7.4 Factor of safety by Janbu Method

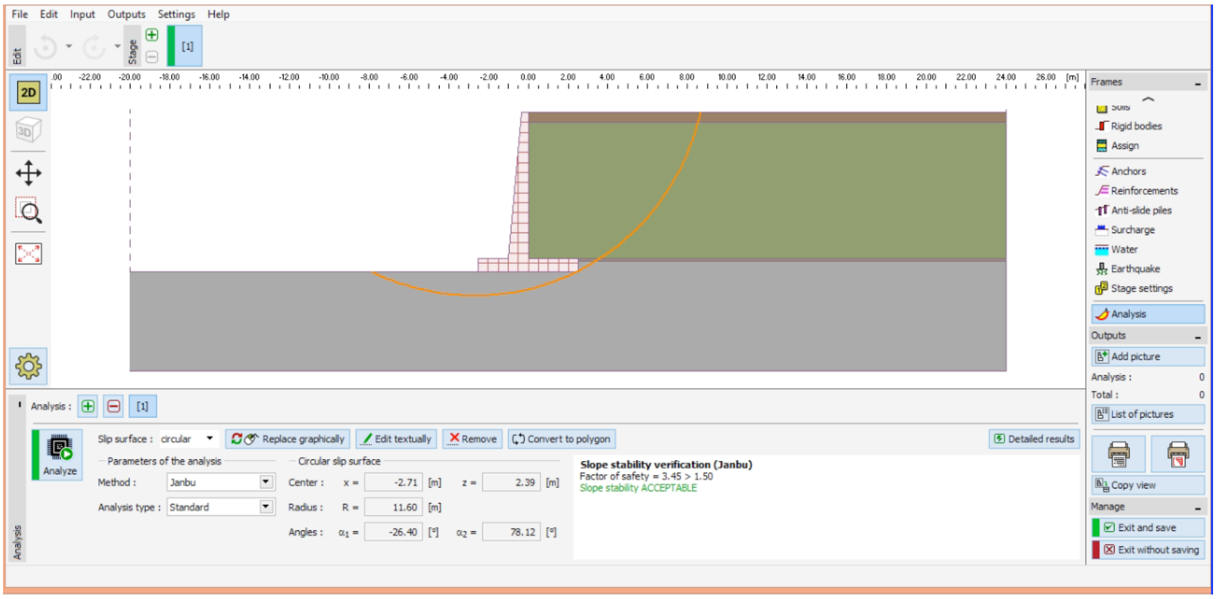


Figure 42 Factor of safety by Janbu method

6.7.5 Morgenstern Price

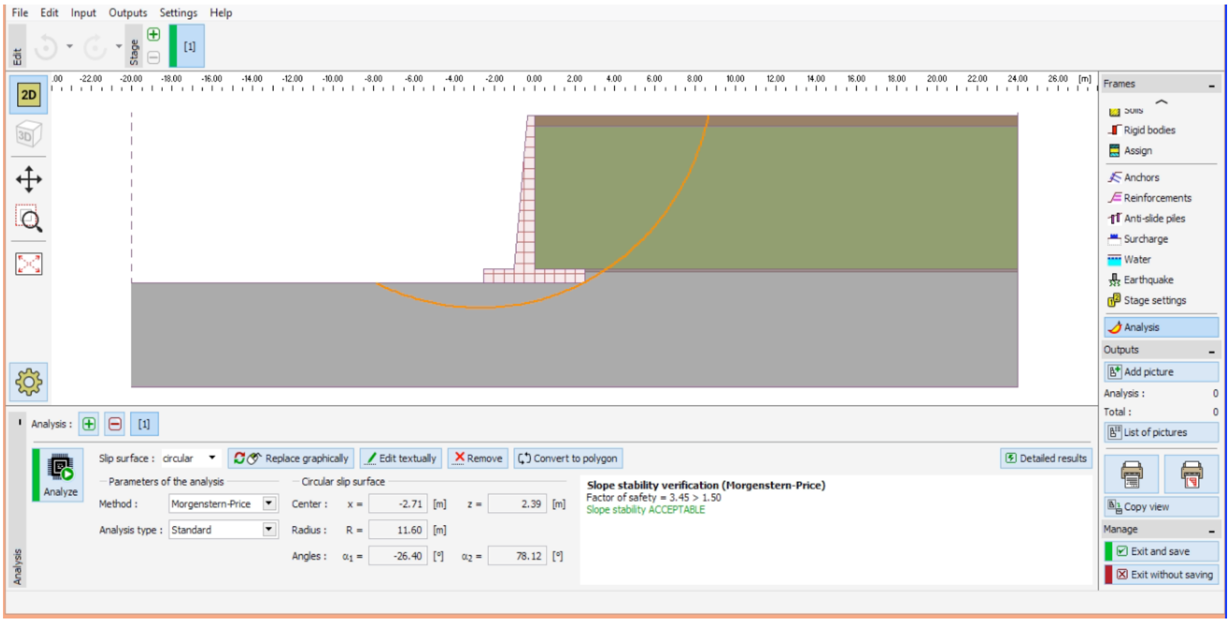


Figure 43 Factor of safety by Morgenstern Price method

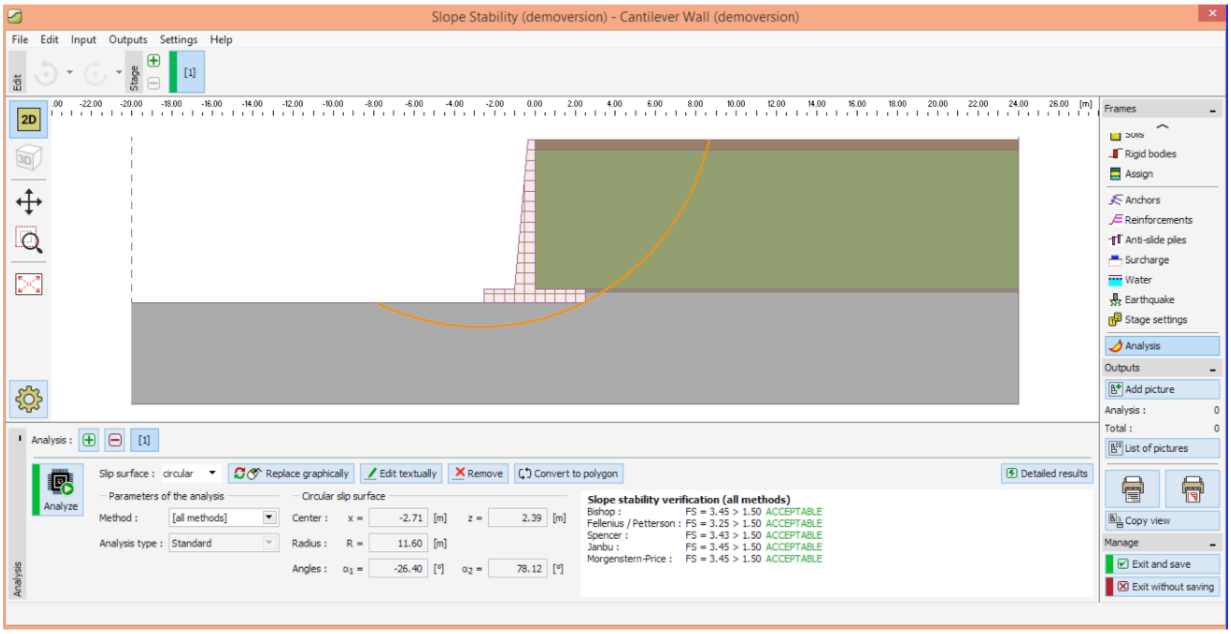


Figure 44 Factor of safety from all methods.

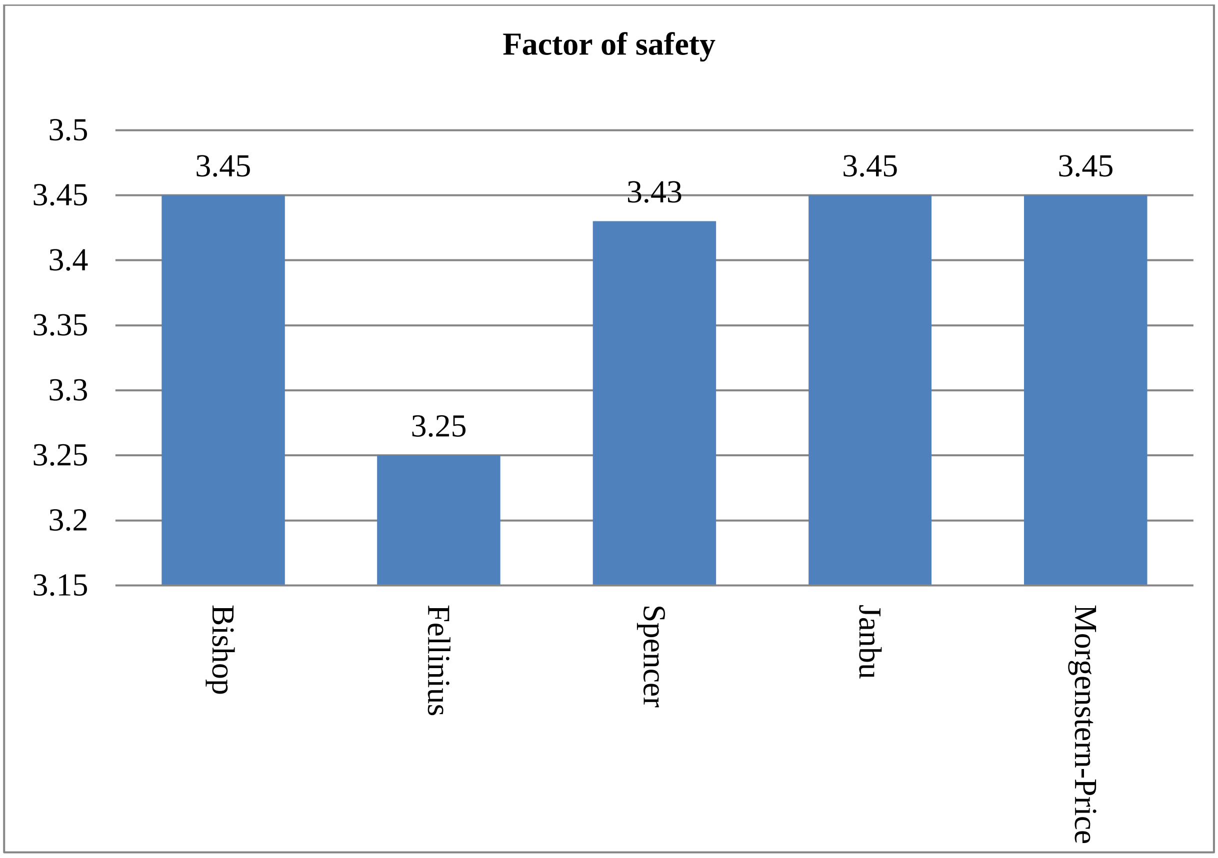


Figure 45 Factor of safety after giving retaining wall

The graph given above shows the analysis of factor of safety after giving retaining wall where the slope came out to be stable under all conditions.

CHAPTER 7

CONCLUSION

7.1 General

This chapter focuses on the conclusions that can be drawn from the results obtained.

7.2 Conclusion

From the results the following conclusions can be made:

The soil present is majority of phyllite with only colluvium upto a height of 10 m.

Angle of internal friction (ϕ) = 37.4 ^{0} and Cohesion of soil (C) = 0

Slope Angle (θ) =

The soil samples of the Reldri landslide consists of more than 50 percent by weight consists of particles of sand and silt. Thus, soil particles can be classified as mudflow.

The slope has been expanding since 2004 so the slope in Reldri can be classified as Infinite Slope.

The slope was analysed for its stability and upon analysis it was concluded that the slope was unstable. Thus, for stability of the slope, a cantilever retaining wall was selected as it’s remedy because it is not only economical but also very convenient to construct.

The slope with the designed cantilever wall fulfilled the three aspects of failure, i.e., it is safe against overturning, against failure of under soil and also safe against sliding. From these three aspects it can be concluded that the cantilever retaning wall is a good option for stabilising the slope but also from all the limit equilibrium methods, the value of factor of safety came out to be greater than 1.5.

7.3 Limitations

There were some limitations that was faced during the completion of the project report and following are some of the limitations.

1. **Sample collection:** Due to the pandemic situation and the slope location under a lockdown, actual experimental testing of the sample and the sample collection could not be done.
2. **Rainfall data:** The rainfall data needed could be collected only from the Department of Hdyro met services of Phuentsholing. And the data available with them is a daily rainfall reading which dwindled the accuraccy of the information.

7.4 Recommendation

Since this research paper suffered some limitations which directly impacted the final output of this paper, following are some recommendations that can be considered for obtaining more accurate results.

1. Experimentally performing all the tests to determine the soil properties.
2. Collect the samples from all the soil layers encountered throughout the potential depth of the slope.
3. Get accurate rainfall data from reliable sources.

REFERENCES

[1] Sazzad, Md., Mahmud and Hie, A. & Hossain, Md. (2016), Stability analysis of reinforcement using FEM, International Journal of Advances in Structural and Geotechnical Engineering, 5 (83), 88.

[2] Azzmi, Milal., Noor, Mohd., Jamaludin. (2011). Geotechnical approaches for Slope Stabilization in Residential Area, Procedia Engineering, 20 (474 - 482).

[3] Tempa K., Chettri N., Komal R.A., Gautam D. (2021) Geohazard vulnerability and condition assessment of the Asian highway AH-48 in Bhutan. Geomatics, Natural Hazards and Risk 12:1, 2904-2930.

[4] Kumar, T., Kiran., Kumar, E., Kishan. (2019). A Critical Review on Stability of Earth Retaining Structures, IJSDR. 4 (3) 44

[5] Dini, B., Daout., Simon and Manconi, Andrea and Loew., Simon. (2019). Classification of slope processes based on multitemporal DInSAR analyses in the Himalaya of NW Bhutan, Remote Sensing of Environment. ISSN. 0034-4257

[6] Dikshit, A., and Sarkar, R., Pradhan, B., Acharya, S., Abdullah, M.A. (2020)., Spatial Landslide Risk Assessment at Phuentsholing, Bhutan, Geosciences (Switzerland). 10 (4), 131-140.

[7] Salunkhe, D.P., Chvan, G., Bartakke, R.N., Kothavale, P.R., (2017). An Overview on Methods for Slope Stability Analysis. International Journal of Engineering Research, 6(3), 528-535.

[8] Tan Y. C. and Gue, S.S. (2006), Landslide: Case Histories, Lessons Learned and Mitigation Measures, IEM/JKR Geotechnical Engineering Conference 2006, Ipoh, Perak, 6 - 7 March 2006.

[9] Griffoths, D. V. and Lane, P.A. (1999), Slope stability analysis by Finite Elements., Geotechnique, 49(3), 387-403.

[10] Abramson, L. W., Lee, T. S., Sharma, S., and Boyce, G. M. (2002). Slope Stabilization and Stabilization Methods. In Slope Stability Concepts, John Willey and Sons,Inc. (329-461).

[11] Aryal, K. P. (2006). Slope Stability Evaluations by Limit Equilibrium and Finite Element Methods. Trondheim.

[12] UNDP in Bhutan. (2015, October 5). UNDP helps stabilizing landslide prone areas in Phuentsholing, Retrieved, May12, 2016.

[13] Goh, A. (1993). "Behavior of Cantilever Retaining Walls". Journal of Geotechnical Engineering, 119(11), 1751-1770.

[14] Bhoyar, P. (2019). "Review Paper on Static Analysis and Design of Retaining Wall

with and without Shelve using Software". International Journal for Research in

Applied Science and Engineering Technology, 7(5), 837-841.

[15] Al Atik, L., and Sitar, N. (2010). "Seismic Earth Pressures on Cantilever Retaining

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