Analysis and Evaluation of Landslide Failure and Using Different Techniques to the Mitigation

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Abstract. One of the most common natural catastrophic in the world is Landslides causing large casualties and large economic losses. In 1994, a landslide disaster struck a part of Nepal country along the Illam road. This landslide caused devastation in the country at that time. In this paper, an evaluation of this landslide was conducted and deep study to mitigate the danger of these kinds of incidences. Preventing landslides is permanently significant to ensure a streamlined flow of traffic when there are roads on the area with a potential landslide incidence. The slope stability degree of the mass of landslide area is evaluated before and after preventing landslide to occur. Many slope stability methods are used such as ordinary sliced method, Bishop simplified method, Janbu simplified method, Spencer method, method of Corps of engineers and gle Morgenstern price method. The factor of safety calculated by these methods is varied by around 9 percent. The calculated factor of safety was less than one at the time of landslide incidence. In order to increase the factor of safety, various technique were suggested to mitigate Landslide such as lowering the water table, using high berm at the toe of the slope and using grouted tiebacks to support the soil mass. Lowering the water table only was not adequate to increase the factor of safety to 1.5 neither using high berm. The most active technique to increase the factor of safety was grouting tiebacks to support the soil mass at the landslide area. This technique contributed in increasing the factors of safety more than 2 for static state and more than 1.1 for dynamic state. The software program, Rockscience slide 6.0, is used to verify the calculations and analyses from excel sheet for the ordinary and Bishop simplified method.

Keywords: Static, dynamic, prevention, Slope stability, factor of safety.

1. Introduction.
The general definition of the landslide is the movement of soil mass downward due the gravity effect with presence of water or not [1]. It is considered one of the most destructive disasters. It is mainly significant to
prevent landslides to save the infrastructures and roads that locate in the area of the potential landslide. In each country, the studies focus on analyzing and preventing landslides [2]. Many researchers picked up the motion of landslide around the worlds. [3] used light detection and ranging data to visually map landslides, headscarps, and denuded slopes in Seattle, Washington and he concluded that human activity is responsible for causing about 80% of historical Seattle landslides.

In Europe, Landslide activity has been highly considerable since 1950 at many sites. A continuous activity is noticed in some areas since the starting of the monitoring. Before 1950, the records are incomplete and probably indicate a lack of data rather than a lack of landslide activity. The interrelationship between the three elements landslides, climate change, and time in europe has been investigates by [4] . The main conclusion of this study is that there is no certain relationship between the climate and landslide activity. Therefore, climate signals that introduces from some landslides could not be stated for all test sites with high confidence.

[5] carried out a study to reveal the influence of slope length and shape and soil depth on slope stability analysis. Moreover, the study introduced a comparison between infinite slope analysis with circular failure analysis for grid by grid analysis in prediction of GIS-based landslide hazard. The factor of safety calculated based on infinite slope analysis is larger than that of circular failure analysis. The factor of safety depends on the shape of slope which is composed of two continuous slopes.

[6] conducted a study by large-scale field test in which an artificial landslide was induced by the application of a load to a natural slope. The measured displacement in landslide was represented numerically by use of finite element model analysis with a two-dimensional elasto-viscoplastic model. Their analysis proposed that the sliding surface strength decreased as the landslide mass moved. The method included back-calculation parameters of shear strength through reproduction of observed landslide displacements and determining the ratio (stability index) of driving force to resisting force acting on the sliding surface. They concluded that the results indicate that the stability index may be applicable to the assessment of slope stability.

There are many ways that can be applied as landslide mitigation as use horizontal drains and chemical stabilization. [7] selected bio engineering technique and they concluded the potential of landslides can be reduced using the combination methods of filter barrier to prevent landslides and scouring of the bank, immediate protective cover for the bank, and reduce toe erosion.

The slope stability of soil mass can be done using different methods, for instance ordinary sliced method, Bishop simplified method, Janbu simplified method, Janbu corrected method and Spencer method…etc. [8] clarifies the use of the appropriate method for the specific situation

Landslides in Nepal is considered a serious danger and threat for the country infrastructures and lives. The old landslides in some areas are reactivated with time. Many villages are close by unstable landslides [9]. Due to the history of eastern Nepal and three landslides were happened in the years 1984, 1992, and 1994. So the scope of this paper is to conduct study using the available date about this active area. A serious prevention of landslide was needed due to the significance of that road in the area of landslide. The factor of safety against landslide is the main point of this study which is represents the stability of the slopes. The target of the designs and analyses is to raise this factor of safety above 1 and 1.5 for dynamic and static analyses respectively.
2. Geological Investigation and Profile Coordinates.

In region of the landslide two exploration borings are investigated along the landslide line to examine the composition of the soil in region. The soil profile for the two borings explained the change of soil composition with depth to end of boring at 30 m as shown in figure 1. For the boring 1 which is at the upper half of the landslide reveals a sand soil with gravel up to depth 10.5 m and then it consists gravel up the 20 m depth. The bedrock weathered starts to reveal after depth 20 m. on the other hand, for boring 2, the weathered bedrock revealed at a depth of 12 m and the top layers consists of sand soil and gravel.

![Figure 1. Soil profile generated from the exploration data](image)

The topographic map has been used to obtain the coordinates of ground surface along the cross section by Auto CAD. In this map the sliding surface and the water table have been drawn. Figure 2 shows the topographic map for this area.

The cross-section profile of the landslide block is shown in figure 3, which shows the ground surface, water table and the sliding interface with corresponding horizontal line of station and the height of slope.
The geotechnical calculations to estimate the friction angle of the certain soil was conducted by excel worksheet trial and error. The Ordinary Method of Slice and Bishop Method were depended to carry out the analysis and a friction angle of 34 degrees was determined to obtain a static factor of safety of 1.0. Using the calculated friction angle and dynamic coefficient k=0.2, the slope stability analysis resulted a factor of safety equal to 0.77.

3. Scope and Analysis Methods.
To understanding the most cost effective landslide repair, the analysis of slope must to be conducted. The proper design of the slope which is can resist the horizontal loading with a design factor of safety of 1.1, and the static factor of safety of 1.5. The general methods of slices formulation in two-dimensions were...
used to perform the analysis. The most commonly used methods in this study are; Ordinary Method of Slice, Bishop Method, Janbu simplified, Janbu corrected, Corps of engineers #1 as well Gle/Morgenstern-price software. In each numerical model the profile coordinates included ground surface, sliding surface, water table and material properties which are defined primarily into the software. The results of numerical model were compared with the theoretical values. The scope of this paper is to present the results of the listed above methods and show how each of them is a special case of the general formulation.

Table 1 shows the results of analysis using variant software difference and Excel worksheet for static and cases. It was seen that there are shallow differences in the values of the results with respect the factor of safety, that may attributed to formulating the numerical models and method of calculating the factor of safety in these software.

Generally, the similarities and differences in these methods have been obscure, largely because of the lack of uniformity in formulating the factor of safety equations, the ambiguity concerning inter slice forces and the unknown limitation imposed by non- circular failure surfaces [10].

| Friction Angle = 34 degrees | F.O.S (Static) | F.O.S (Dynamic) |
|----------------------------|----------------|-----------------|
| METHOD                     | SLIDE 6.0      | THEORETICAL     | SLIDE 6.0 | THEORETICAL |
| ORDINARY                   | 1.081          | 1.015           | 0.636     | 0.772 |
| BISHOP SIMPLIFIED          | 0.996          | 1.015           | 0.582     |      |
| JANBU SIMPLIFIED           | 0.989          |                 | 0.571     |      |
| JANBU CORRECTED            | 0.992          |                 | 0.580     |      |
| SPENCER                    | 0.984          |                 |           |      |
| CORPS OF ENGINEERS #1      | 0.988          |                 | 0.573     |      |
| GLE/MORGENSTERN-PRICE      | 0.982          |                 | 0.573     |      |

4. Technique of Landslide mitigation.

Among the most common methods of mitigation techniques, the subsurface drainage of landslide slopes is the most suitable by using horizontal drainage borehole. Therefore, the study of lowering the water table on the factor of safety was investigated. The lowering of water table was analyzed in three depth measured from top surface 1, 2 and 3m.

4.1 Lowering the water table only.

In case of decreasing the water table to 1m from top surface of slope, the factor of safety for the static state increased by approximately 10% for all software models, as shown in table 2.
Table 2. Slide 6.0 software vs excel worksheet analysis with water level lowered by 1m

| METHOD               | SLIDE 6.0 | % Increase | THEORETICAL | % Increase |
|----------------------|-----------|------------|-------------|------------|
| ORDINARY             | 1.168     | 8%         | 1.120       | 10%        |
| BISHOP SIMPLIFIED    | 1.096     | 10%        | 1.120       | 10%        |
| JANBU SIMPLIFIED     | 1.078     | 10%        |             |            |
| JANBU CORRECTED      | 1.094     | 10%        |             |            |
| SPENCER              | 1.084     | 10%        |             |            |
| CORPS OF ENGINEERS #1| 1.089     | 10%        |             |            |
| GLE/MORGENSTERN-PRICE| 1.082     | 10%        |             |            |

The second analysis is when the water table is lowered to 2m and 3m as shown in figure 4. The results showed that the factor of safety (Static) was increased by approximately 20% and 30% respectively for all software models as shown in table 3. It was seen that lowering the water table technique by more than 1m is not enough to increase the factor of safety more than 1.5 and it still less which is not recommended.

Figure 4. Slide 6.0 software analysis with water table lowered by (a) 2 and (b) 3m
**Table 3.** Slide 6.0 software vs excel worksheet analysis with water table lowered by 2 and 3m

| Friction Angle = 34 degrees | Lowering the water table by 2m | F.O.S | F.O.S |
|----------------------------|--------------------------------|-------|-------|
| METHOD                     | SLIDE 6.0                      | % Increase | THEORETICAL | % Increase |
| ORDINARY                   | 1.250                          | 15%     | 1.226     | 21%     |
| BISHOP SIMPLIFIED          | 1.195                          | 20%     | 1.223     | 20%     |
| JANBU SIMPLIFIED           | 1.173                          | 20%     |           |         |
| JANBU CORRECTED            | 1.192                          | 20%     |           |         |
| SPENCER                    | 1.184                          | 20%     |           |         |
| CORPS OF ENGINEERS #1      | 1.185                          | 20%     |           |         |
| GLE/MORGENSTERN-PRICE      | 1.179                          | 20%     |           |         |

| Friction Angle = 34 degrees | Lowering the water table by 3m | F.O.S | F.O.S |
|----------------------------|--------------------------------|-------|-------|
| METHOD                     | SLIDE 6.0                      | % Increase | THEORETICAL | % Increase |
| ORDINARY                   | 1.329                          | 23%     | 1.331     | 31%     |
| BISHOP SIMPLIFIED          | 1.290                          | 30%     | 1.328     | 31%     |
| JANBU SIMPLIFIED           | 1.265                          | 29%     |           |         |
| JANBU CORRECTED            | 1.285                          | 29%     |           |         |
| SPENCER                    | 1.277                          | 30%     |           |         |
| CORPS OF ENGINEERS #1      | 1.278                          | 29%     |           |         |
| GLE/MORGENSTERN-PRICE      | 1.271                          | 29%     |           |         |

4.2 Lowering the water table with 12m high berm.

The second technique in addition to lowering the water table is by adding 12m high berm in the toe of the slope so as to obtain a higher factor of safety. For this process, Rocscience software is used for the analysis. Firstly, a 12m high berm is added at the toe of the slope after lowering the water table by 1m. The distributed load applied to the software model is calculated as follows:

\[
\text{Distributed Load} = \text{Height of Berm} \times \text{Density of Soil} \\
\text{Distributed Load} = 12m \times 19.16 \text{kN/m}^3 = 230 \text{kN/m}^2
\]

Figure 4 shows slide 6.0 software analyses with water table lowered by 1 m plus Berm vertical load. From the results of the analysis, the factor of safety increased by approximately 17% as shown in table 4.
Figure 5. Slide 6.0 software analysis with water table lowered by 1 m plus Berm vertical load

Table 4. Slide 6.0 Software analysis with 12m berm and water table lowered by 1m

|                  | Lowering the water table by 1m and 12m Berm | Friction Angle = 34 degrees | F.O.S  |
|------------------|---------------------------------------------|-----------------------------|--------|
| METHOD           | Static                                      | Dynamic                     |        |
| ORDINARY         | 1.228                                       | 0.746                       |        |
| BISHOP SIMPLIFIED| 1.169                                       | 0.716                       |        |
| JANBU SIMPLIFIED | 1.140                                       | 0.691                       |        |
| JANBU CORRECTED  | 1.158                                       | 0.702                       |        |
| SPENCER          | 1.154                                       | 0.706                       |        |
| CORPS OF ENGINEERS #1 | 1.156 | 0.704 |        |
| GLE/MORGENSTERN-PRICE | 1.147 | 0.695 |        |

Therefore, from the obtained results using the above technique it was seen no way could to increase the factor of safety as required. To increase the static factor of safety over 1.5 and the dynamic factor of safety over 1.1, soil supports are performed in addition to lowering the water table and this may be using soil nails or grouted tiebacks. This technique can be applied with grouted tiebacks, which may be increases the factors of safety to required values. The tieback was used in the analysis with minimum tensile capacity of 200kN for each and bond strength of 100kN/m. The tiebacks were distributed in grid with spacing of 1m x 1m and 25m long at angle of 20 degrees from the horizontal axis. The treated distance using tiebacks of the slope was 140 m long from the berm position. The analysis was achieved in model including lowering water table to 1m, a 12m berm at the toe of the slope and grouted tiebacks for 140m up the slope as shown in figure 6. From all analysis methods, the results showed that the factors of safety increased significantly more than 2 for static state and more than 1.1 for dynamic state as shown in table 5.
Figure 6. Lowering the water table by 1m and using berm at the toe of the landslide with grouted tiebacks using Rockscience slide 6.0.

Table 5. Slide 6.0 results of 1m lower, a 12m berm at the toe of the slope and grouted tiebacks for 140m up the slope.

| Lowering the water table by 1m and 12m Berm and Support | Friction Angle = 34 degrees | F.O.S          |
|-------------------------------------------------------|----------------------------|---------------|
| METHOD                                                 | Static                     | Dynamic       |
| ORDINARY                                               | 2.293                      | 1.195         |
| BISHOP SIMPLIFIED                                      | 2.323                      | 1.199         |
| JANBU SIMPLIFIED                                       | 2.124                      | 1.112         |
| JANBU CORRECTED                                        | 2.158                      | 1.130         |
| SPENCER                                                | 2.169                      | 1.133         |
| CORPS OF ENGINEERS #1                                  | 2.175                      | 1.134         |
| GLE/MORGENSTERN-PRICE                                  | 2.146                      | 1.122         |

5. Conclusion.
A landslide in Nepal was studies to evaluate and mitigate it using different methods. A static and analysis was conducted using ordinary sliced method, Bishop simplified method, Janbu simplified method, Spencer method, method of Corps of engineers, and gle Morgenstern price method. Some points can be drawn as following:

1- There are shallow differences in the values of the results with respect the factor of safety using the above analysis methods, that may attributed to formulating the numerical models and method of calculating the factor of safety in these software.

2- The analyses revealed the avoiding the landslide needs to increase the slope stability and decrease the landslide potential.
3- The soil mass could move significantly under the effect of earthquake acceleration of 0.2 g if the area of landslide is not improved.

4- Using separate technique as lowering the water level or adding berm at the toe of the landslide area or grouted tiebacks could not increase the factor of safety as required.

5- Applying the three different landslide techniques of lowering the water level, using a berm at the toe of the landslide area and grouted tiebacks as ways of landslide mitigation methods contributed in increasing the factor of safety. Using these methods together raised the factor of safety up to more than 1.5 and 1 for static and dynamic analyses respectively.

6. References

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