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Slope Stability Assessment using 2D-Model: A case study of Kathmandu-Nijghad Fast Track

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Abstract
This paper deals with the analysis of slope in bridge section of Kathmandu Nijghad fast track using the limit equilibrium method. The topic of slope stability is numerically simulated in this paper utilizing computer-based geotechnical software called slide 2D. The numerical model discussed in this study is based on the outcomes of laboratory tests and borehole data collected from several samples to ascertain the physical and mechanical characteristics of rock and soil. Through a number of examples, such as altering the GSI and UCS values, it was determined how cohesion and internal frictional angle affected the factor of safety. Factor of safety for the slope was determined for different anticipated conditions. The result suggests that the safety factor improves as the cohesion and internal frictional angle of the rock and soil layer increase.

Keywords
Slope stability-Factor of safety (FOS)-Cohesion-Internal friction angle-Geological strength index (GSI)-Intact uniaxial compressive strength (UCS), Strength reduction factor

1. Introduction

The ability of a slope or a mass of soil, rock, or other geological materials to withstand destabilizing forces and maintain its equilibrium is known as slope stability. To assess the probability of a slope failing or landslide, numerous aspects, such as soil or rock characteristics, slope geometry, groundwater conditions, and external loads, must be analyzed [1]. Slope stability refers to the ability of a slope or embankment to resist the downward movement of soil or rock under the influence of gravity. It is a critical factor in various engineering and geotechnical applications, including highway construction, building foundations, and mining operations. The analysis of slope stability involves assessing factors such as soil properties, groundwater conditions, and external forces that could potentially trigger slope failure [2].The ability of an inclined surface to resist sliding or collapsing may also be referred to as slope stability. The primary objective of slope stability is to find the term known as Factor of Safety. The FOS must be greater than one for any slope to be stable since it evaluates the ratio of the driving force to the resisting force of the slope [3].

1.1 Study area

The proposed investigation area is located along the fast track between Kathmandu and Nijghad for an approximate length ranging from 57+536 to 57+576 kilometers. The study area is located in the Makawanpur district's Shreepur Chhatiwan via Hetauda-Phaparbari Road. Figure following shows depicts where the study area is located[4].

1.1.1 Lithology of the study area

Nepal's geology is separated into five zones: the Terai, the Siwalik zone, the Lesser Himalaya zone, the higher Himalaya zone, and the Tibetan Tethys zone [5]. The study area is located at the Siwalik region of Nepal. The Siwalik region of Nepal has been divided once again into 5 sections: Upper Siwaliks, Siwalik Mudstone, Lower Middle Siwaliks, Upper Middle Siwaliks, and Lower Siwaliks. Lower parts of the Middle Siwalik are dominated by thin to thick bedded, fine to medium grained, salt and pepper textured coarse grained sandstone. The sandstones have a texture that is primarily salt and pepper. The bedrock is made of coarse-grained sandstone, which contains shards of pebble. In the most northern sections of the central Siwalik, coarse-grained sandstone is interbedded with shale partings. Rock-beds slope slightly to the northeast.

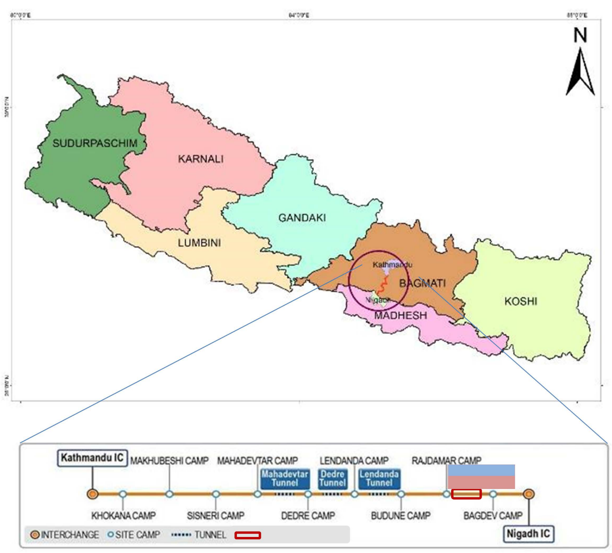

Figure 1: Study area with Ktft Project

Figure 2: Alignment of Kathmandu-Nijgad fast track and study area

1.2 Objective of study

The main objective of the study is to use slide 2d software to analyze the slope stability of the Kathmandu-Nijghad fast track in the chainage extend between 57+536 and 57+576 kilometers in the Makawanpur District.

However, the study's specific objectives include are as follows:

- To evaluate the impact of a slope's geological study with modification in the GIS parameter.
- To evaluate the impact of a slope's geological study with modification in the UCS parameter.
- To locate the critical failure surface and understand its shape of failure Patten.
- To evaluate the slope under different natural conditions, such as dry condition, saturation condition, as well as seismic loading condition.

1.3 Literature review

When the resisting force of a slope is larger than the driving force of a slope, such a slope is considered to be stable. [3]The primary factors that need to be taken into consideration while performing slope stability are the geology and geomorphological factors, slope geometry, seismic activity, regional rainfall, external force, internal shear strength parameter of rock and soils, and variation of groundwater along the slope. There are several slope stability methods in use nowadays, however for the purposes of this paper, only limit equilibrium and finite element methods are utilized.

1.3.1 Limit Equilibrium Method(LEM)

Limit equilibrium studies take into consideration a mass of soil above the possible failure surface's force and/or moment equilibrium [6]. In geotechnical engineering, the Limit Equilibrium Method is a commonly used method for assessing the stability of slopes. It involves evaluating the equilibrium conditions for each of the individual slices or blocks created by the slope's division. By comparing the resistive forces to the driving forces within each slice, the approach aids in calculating the factor of safety against slope failure [7]. The Limit Equilibrium Method, a traditional geotechnical approach, analyzes whether the forces that resist sliding (resisting forces) along potential failure surfaces are equal or greater than the amount of forces that encourage sliding (driving forces) in order to determine the stability of slopes[8]. The Cullman approach can be used to study slopes that fail by translation on a planar failure surface, such as a bedding plane, a rock joint, or a seam of weak materials, with relative ease[9].Analysis using wedge methods is possible for slopes when collapse is anticipated to happen on two or three planes [10, 11]. Methods like the common approach of slices are typically used to analyze slopes on relatively close, homogeneous surfaces [12] or assume circular failure surfaces while using Bishop's modified technique. Non-circular failure surfaces are more likely to occur when subsurface conditions are not homogeneous. Methods like Spencer, Janbu those of could be applied in these circumstances [13, 14, 15]. The Limit Equilibrium Method has a wide range of variants and software applications. In contrast, we exclusively apply the Bishop's approach and the Janbu Simplified approach in this study.

1.3.2 Bishop' Method

Bishop's method, named after the British geotechnical engineer Dr. A. W. Bishop, is a widely used slope stability analysis technique in geotechnical engineering. It is used to assess the stability of slopes subjected to various loading and boundary conditions. Bishop's method provides a simplified approach to calculate the factor of safety for slope stability by considering the mobilized shear strength along potential slip surfaces. The factor of safety is a measure of how close a slope is to failing under specified conditions [16].

Factor of Safety: The factor of safety (FS) is defined as the ratio of the resisting forces to the driving forces. It is calculated by comparing the shear strength resisting sliding along the failure plane to the shear stress promoting sliding:

$$\mathrm{FS} = \frac{\text{Sum of Resisting Forces}}{\text{Sum of Driving Forces}}$$

The resisting forces include the soil cohesion and friction along the failure plane, while the driving forces include the weight of the slice and any externally applied loads.

1.3.3 Janbu Method

The Janbu Simplified Method is a widely used technique in geotechnical engineering for analyzing the stability of slopes. Named after Norwegian engineer Olav Janbu, this method is a simplified variation of Bishop's method and is particularly useful for assessing the stability of slopes subjected to circular or nearcircular failure surfaces. The Janbu Simplified Method is an improvement over the original Bishop's method by introducing a linear relationship between the factor of safety and the vertical effective stress along the slip surface [15].

Factor of Safety vs. Depth: In the Janbu Simplified Method, the factor of safety (FS) is related to the depth from the ground surface along the potential slip surface. A linear relationship is established between the factor of safety and the vertical effective stress. The equation typically takes the form:

$$\mathrm{FS} = \mathrm{FS}_{\min} + (\mathrm{FS}_{\max} - \mathrm{FS}_{\min}) \times (Z/H)$$

Where:

- FS_{min} and FS_{min} are the minimum and maximum factors of safety considered for the analysis
- Z is the depth from the ground surface to the midpoint of the slice
- H is the total height of the slope.

1.3.4 Finite Element Method(FEM)

The Finite Element Method (FEM) is a numerical technique used in geotechnical engineering to analyze and assess the stability of slopes, embankments, and other geotechnical structures. It is particularly useful for modeling complex geometries, material properties, and boundary conditions. While FEM can be applied to various geotechnical problems, including slope stability, it is often used in conjunction with other methods for more comprehensive analyses [17]. The shear stress for the analysis is determined using a finite element method, taking into consideration the soil's linear and non-linear stress-strain behavior. Zones that are insufficient to stand up to the shear loads applied induce the slope failure in a finite element method. As a result, the results of the analysis are considered as being more accurate than the limit equilibrium technique [18]. Traditionally, the Strength Reduction Method (SRM) is used to carry out the slope stability analysis using a finite element approach. When using this method, the slope must reach the failure mode by dividing the original shear strength parameters by the factor safety[18]. To determine the SRF value that will simply cause the slope to fail, a systematic estimation is necessary. The SRF value that causes a slope to fail is referred to as the factor of safety [6]. However, there are a few limitations to this method, including the need to carefully choose the constitutive model and geological parameters, as well as the need to specify boundary limits and a failure condition.

2. Research Methodology

2.1 Desk study

The desk study provided some preliminary information about the research work as well as it provides the general idea to carry out the field work and laboratory The study includes a collection of numerous research publications, books, journals, research works about regional geology, and site response analysis, methodology and different approaches in Nepal and abroad, both published and unpublished. Around the research region, a number of lithological logs from bore holes were gathered and examined.

2.2 Borehole data

The NX-double tube, NMLC core barrel, and HX (0-7.5) m, NX casing were used to drill the borehole to a depth of 43 meters. The 1.6m-thick overburden is made up of angular to subrounded, coarse-grained, and grey to light brown mudstone gravels. At a depth of 1.6 meters, bedrock is found, which is composed of a significant layer of brown, moderately weathered (W3), soft (H6), low to very low strength mudstone, and is highly to completely weathered (W5-W4), moderately soft to very soft (H5-H7), low to extremely low strength interbedded siltstone/sandstone. At the borehole the surface of the ground water is seen to be overflowing. The overall core recovery ranges from 28- 95, while the RQD is between 0 and 83.

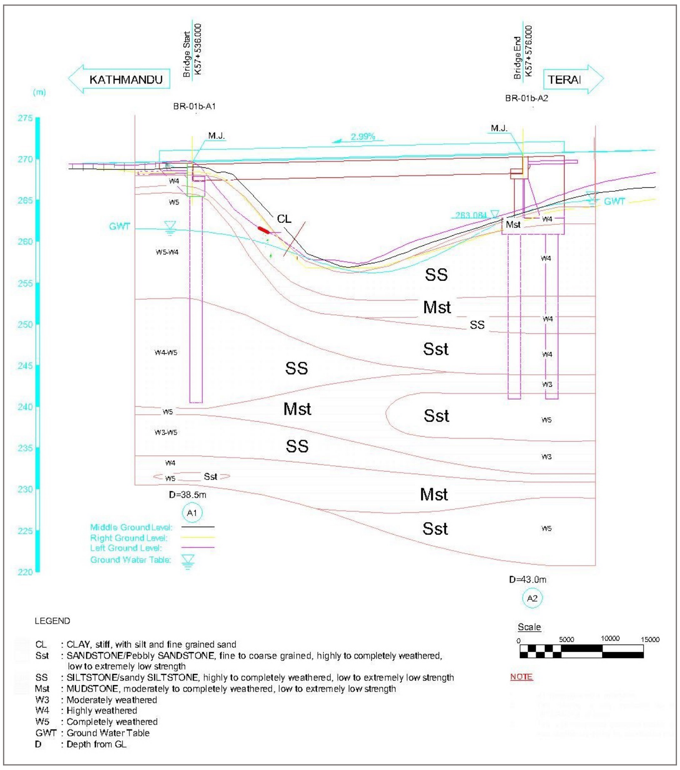

Figure 3: Figure showing different types of soil and rock layer

2.3 Laboratory report

The findings of the rock's laboratory test indicate that its average water absorption, density, and porosity are 12.45, 2030 kg/m3, and 25.32, respectively. Slake durability values range from (43.1-47.3).The rock's strength, as determined by an unconfined compression test, ranges from 0.63 MPa to 2.96 MPa. Modulus of Elasticity and Poisson's Ratio values fall between (23.99 GPa and 28.96 GPa) and (0.18 and 0.20), respectively. Direct shear tests yielded cohesion and friction angles that ranged from 0 MPa to 1.91 MPa and 4.19° to 24.9°, respectively. Similar results were achieved for cohesiveness and friction angle, which ranged from (1.39 MPa-2.58 MPa) and (16.66°-30.63°), respectively, in triaxial tests.

2.4 Define layer

The drill hole log of the field can be used to determine the many layer that are present here. Additionally, the record include the joint's depth and a list of various type of rocks The model depicts the actual field with the rock layer as follows Figure 2 with the aid of the information provided.

2.5 Model preparation

The model of the multiple rock layer in Slide 2D software is used to analysis. the shear strength parameters of various types of rock and soil computed by Roclab are also taken into account by this model.The model makes it easier to identify the rock's failure pattern. The model has also been built to account for the following list of various natural conditions that might exist in the field.

- Seismic condition
- Wet condition (rainy condition)
- Dry condition

The following factors can be managed by smart investment, which may change the way slope stability failure patterns.

- Geological strength index (GSI)
- Intact uniaxial compressive strength (UCS)

2.6 Calculation

Dates used for the calculation of the shear strength parameter based on field and laboratory test results are listed in table 1.

Table 1: Calculated parameter for Design of slope

Layer	Siltstone	Mudstone	SandStone	Siltstone / Sandstone
Intact Uniaxial Compressive Strength, Mpa	1.7	2.2	2.4	2
SURFACE CONDITION OF DISCONTINUITIES	Poor to Fair	Poor to Fair	Fair	Fair
Geological Strength Index, GSI	30	30	35	30
mi	7	7	17	10
Disturbance Factor, D	0.7	0.7	0.7	0.7
Unit Weight, KN/m3	23	22	23	23
Slope Height, m	11	11	11	11
c, Kpa	17	18	32	21
phi, °	18	20	30	22

3. Results and Discussion

Below is a list of the numerous sorts of output that the model produces under various natural conditions.

3.1 Seismic condition

The factor of safety of the model under the seismic loading i.e. 0.2 condition is 0.873 and 0.840 under the Bishop simplified and janbu Simplified respectively. The change factors for rock parameter, such as GSI and Value of UCS, are presented in the following chat along with a safety factor. And also the factor of safety is 0.84 by using Strength reduction factor in finite element method.

3.2 Wet condition

The factor of safety of the model under the under natural condition i.e. full wet condition is 0.937 and 0.896 under the Bishop simplified and Janbu Simplified respectively. The change factors for rock parameter, such as GSI and Value of UCS, are presented in the following chat along with a safety factor. And also the factor of safety is 0.92 by using Strength reduction factor in finite element method.

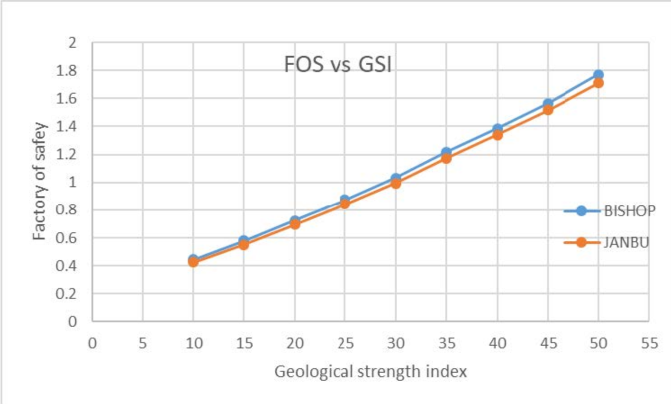

Figure 4: Variation of Factor of safety with variation of Geological strength index under seismic condition

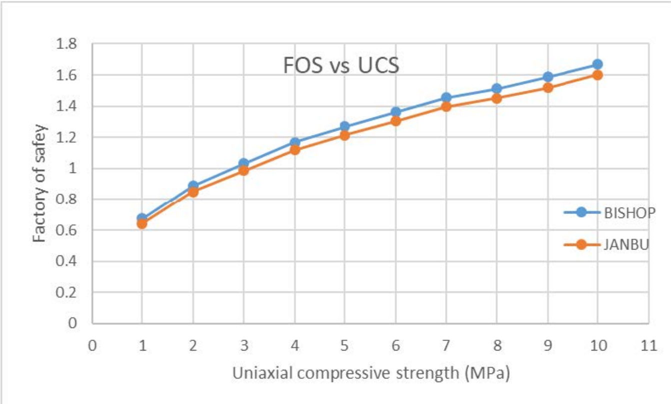

Figure 5: Variation of Factor of safety with variation of Intact uniaxial compressive strength under seismic condition

3.3 Dry condition

The factor of safety of the model under the under natural condition i.e. full dry condition is 1.259 and 1.125 under the Bishop simplified and Janbu Simplified respectively. The change factors for rock parameter, such as GSI and Value of UCS, are presented in the following chat along with a safety factor. And also the factor of safety is 1.26 by using Strength reduction factor in finite element method.

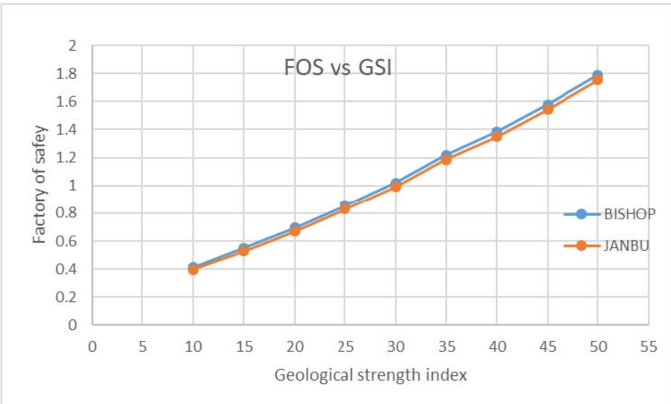

Figure 6: Variation of Factor of safety with variation of Geological strength index under wet condition

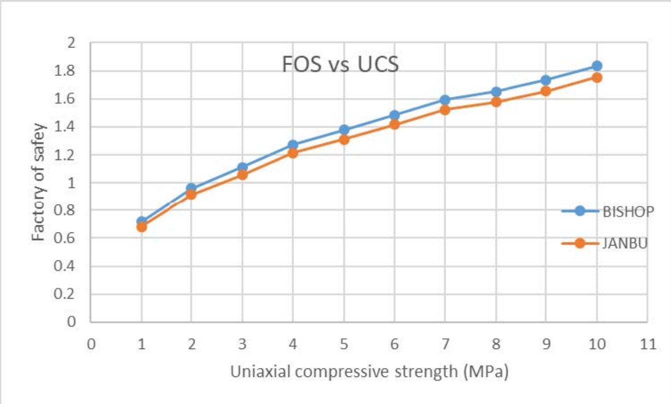

Figure 7: Variation of Factor of safety with variation of Intact uniaxial compressive strength under wet condition

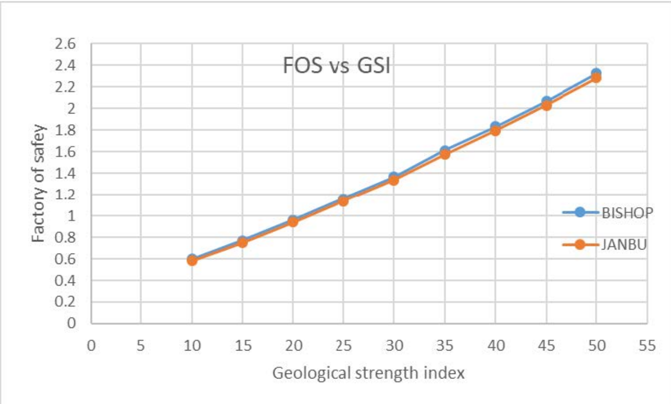

Figure 8: Variation of Factor of safety with variation of Geological strength index under dry condition

4. Conclusion

The data above indicate that the worst case scenario for slope stability is when seismic loading is applied to a slope when ground water is present in its natural state.

The aforementioned result also demonstrates that rocks have a Factor of Safety of 1 when their GSI value is 29 and their UCS is approaching seismic state at 2.77 MPa. The factor of safety is Figure 9: Variation of Factor of safety with variation of Intact uniaxial compressive strength under dry condition reached when the GSI is 30, 21, and the UCS is 2 .26, 1 .06 MPa, respectively, much like in other wet and dry circumstances. Additionally, there is almost no difference between the strength reduction factor value acquired using the finite element approach and the level of safety derived using the limit equilibrium method.

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