Geoenvironmental Disasters

RESEARCH

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Use of RCC pile, anchor bolt and geogrid for building construction on the unstable slope

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Abstract

Rapid construction of buildings in urban area is creating lack of space available for new construction. This problem enforced to construct building on slope in hilly regions. However, the engineers and designers are concerned with the stability analysis of structures built on soil slopes, as it is difficult to achieve a uniform structural level on mountainous terrain. Also, it cannot be reduced to the same level of structural forms and part of base member may not be bound by an identical horizontal plane. The fundamental stability of the structure built on hill slope depends upon on its slope stability. Slope failure has been identified as one of the frequent devastating natural disasters that have claimed huge loss of property and lives. Therefore, in this research, "Phase 2 (2002)", a Rocscience Finite Element (FE) program and "Slide", a Rocscience limit equilibrium program were used to simulate and analyze a complex multi-staged model with RCC pile, Anchor Bolt and Geogrid for the stability analysis of slope. Bishop's method was used to evaluate and analyze the factor of safety. Analysis of the two section (Section 1-1 and 2-2) of slope was taken into consideration for slope stability analysis. As per the analysis using the limit equilibrium approach, the factor of safety for existing slope at Section 1-1 and Section 1-1 was found to be 0.579 and 0.70 respectively. Moreover, it was found that the factor of safety of slope was increased significantly from 0.579 to 1.593 in Sections 1-1 and 0.70 to 1.319 in Section 2-2. In addition, the factor of safety of slope with strength reduction method is 1.408 and 1.05 for Sections 1 and 2 respectively after slope stabilization work in seismic condition. This shows that, the construction of buildings in slope terrain is possible, but it needs specialized excavation and slope protection work. RCC pile with anchor bolt and geogrid is one of the sustainable solutions for construction of structure in slope area.

Keywords Slope stability, Strength reduction method, Limit equilibrium method, Factor of safety, RCC pile, Anchor bolt, Geogrid

Introduction

Considering the increased urbanization and hilly terrain of Nepal, there is a need to use modified methods in the field of engineering and use them to counter the growing problem of settlement. In context of Nepal this problem of settlement demands the use of slope terrain where we can construct safe structures after proper design and structural analysis. The buildings on mountainous slopes cannot have same structural foundation and base as that of plain areas. Although the topography and structure of the building in slope are distinctive, it is crucial to adapt to the mountainous terrain that is paramount. While accompanied by irregularities in vertical and horizontal planes, adjustment is tough. Thus, this emphasizes the intricate nature of seismic design and the uniqueness of the seismic response of such structures.

Few research work are carried out in the field of building's seismic design in slope land area due to the limitation to comprehend the investigation parameters and

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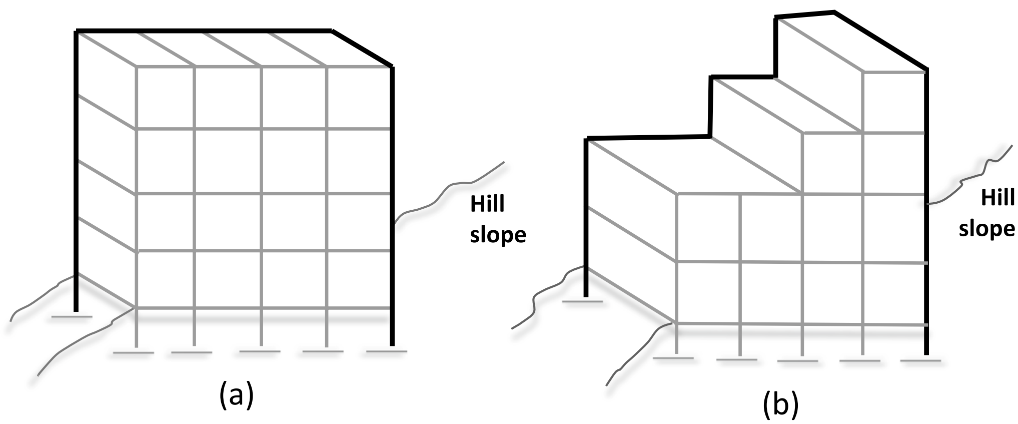

Fig. 1 Building on flat ground (modified after Paul and Kumar 1997)

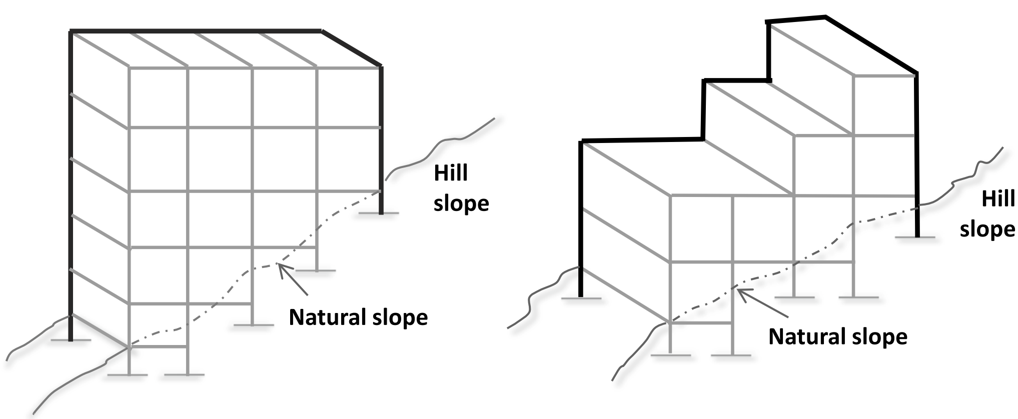

Fig. 2 Building on slope ground (modified after Paul and Kumar 1997)

earthquake damage assessment of such structures. There is a lack of organized or proper mechanism for conducting fundamental research on structural design and unique issues with structures in mountain areas (Gör et al. 2022, Parkash 2019). Even though there are no specific codes which helps an engineer design a structure on slope land, it provides great value once completed. Lack of specific codes has led to various research works that addresses different methods for slope stability which can be adopted for the safe and sound construction of structures, executed with proper design/ analysis and use of advancements engineering has achieved over this time (Kumar et al. 2021).

The stability of the slope is the main factor that determines the safety of the building constructed in slope area. In unstable slope even structurally sound buildings can collapse. Therefore, it is imperative to do stability analysis of the slope with surcharge loads under both static and seismic condition in order to determine the suitability of various construction configurations. Stability analysis was conducted to calculate the factor of safety against sliding failure, several building configurations on flat terrain and sloped ground are used (Paul and Kumar 1997); that are listed below:

(i) Building on a flat ground e.g. regular framed buildings, setback framed buildings as shown in Fig. 1
(ii) Building on sloping ground e.g. stepback framed buildings, stepback and setback framed buildings as shown in Fig. 2

Most building structures constructed in mountain areas require retaining structures (Wang et al. 2021). A specific cognitive process is required to comprehend the relationship between the retaining structure and the building structure.

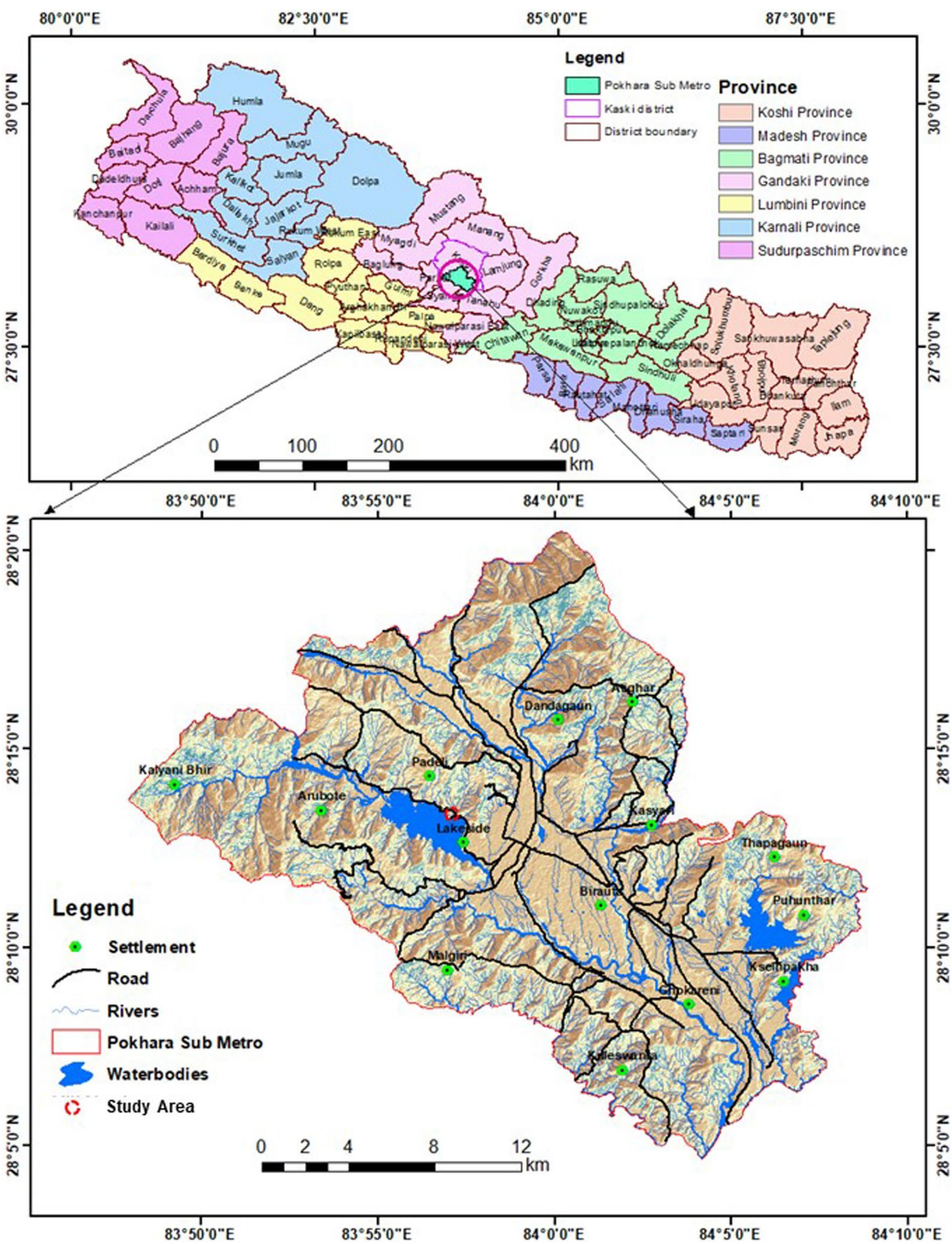

Fig. 3 Location map of the study area

Slope failure is one of the most common natural disasters that can cause significant property loss and human casualties. Several external factors, such as geological forces, weathering and erosion mechanisms, and exacerbated anthropogenic activities contribute to slope failure. The construction of road networks in hills/slope land areas, human settlement, and other development initiatives has greatly contributed to an increase in slope failures in the mountain regions over time. Stabilization of a slope may depend on a number of factors such as; its geometry, surface and groundwater condition, strength of materials and the reason for stabilization. A number of techniques have been developed to stabilize slopes considering different above mentioned factors (Abramson et al. 2001). Pile have been used successfully in many situations to stabilize slopes (ANAGOSTOPOULOS et al. 1992; Chen and Poulos 1997; Ito and Matsui 1975; Popescu 1991; Poulos 1995; Won et al. 2005). Pile and anchor rods are considered to be effective solution for slopes as they are easy to build, quick, require fewer projects (Seyhan 2009). They are usually applied during protection works for landslides and other geo hazards (Zhang et al. 2016). Similarly, geogrids are also widely used for soil reinforcement in slopes and embankments. (Mesut et al.). Therefore, the main objective of this research is the slope stabilization using reinforced pile, anchor rod and geogrid and construction of building in that stabilized slope. The study is focused on the construction of building on a steep slope with three steps of cutting. This type of research can give a useful suggestion for construction on slopes in seismic zone like Nepal.

Study area

The study area is located in the Seti watershed of the Pokhara valley. The area has a longitude of 83°57′18.30″E to 83°57′19.8″ E and latitude of 28°13′28.99″ N to 28°13′26.81″N and an elevation of 857–842 m. The watershed lies in the Pokhara Municipality, Kaski district of Gandaki Province, Nepal (Fig. 3). The area is surrounded by High mountains in the north and middle-range mountains in the south (Rimal et al. 2015).

Geology

The Pokhara valley is a famous intermontane basin of Nepal [Bhandari et al. 2021]. Diversely oriented terraces, deep and narrow gorges with disappearing white rivers, immense cliffs, and blue lakes are the main constituents of the basin landscape. The Pokhara valley lies in the core of Pokhara-Gorkha- Trishuli anticline. It has soft lacustrine sediment in its central part surrounded by hard rock geology. The central part of the

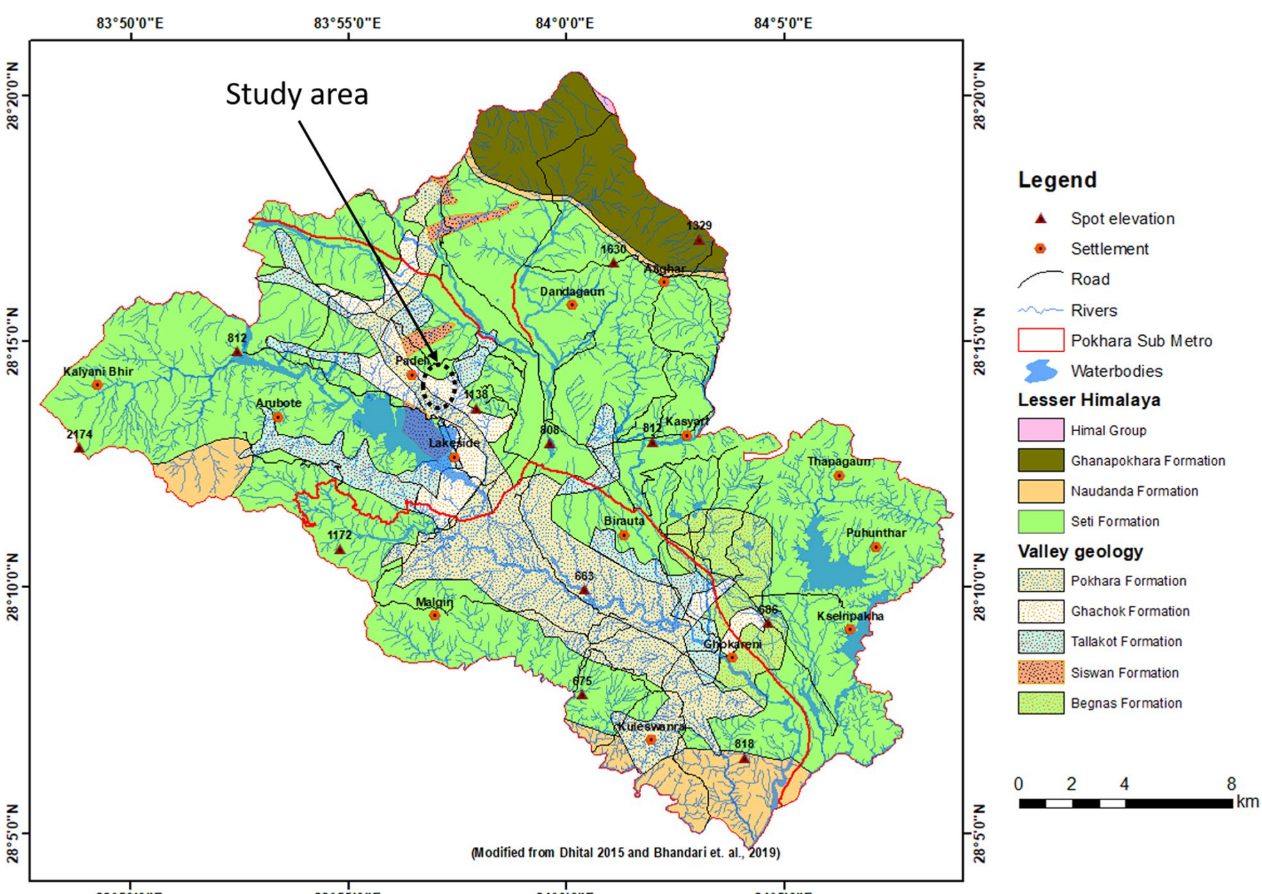

Fig. 4 Geology of Pokhara valley (modified from Dhital 2015 and Bhandari et al. 2021)

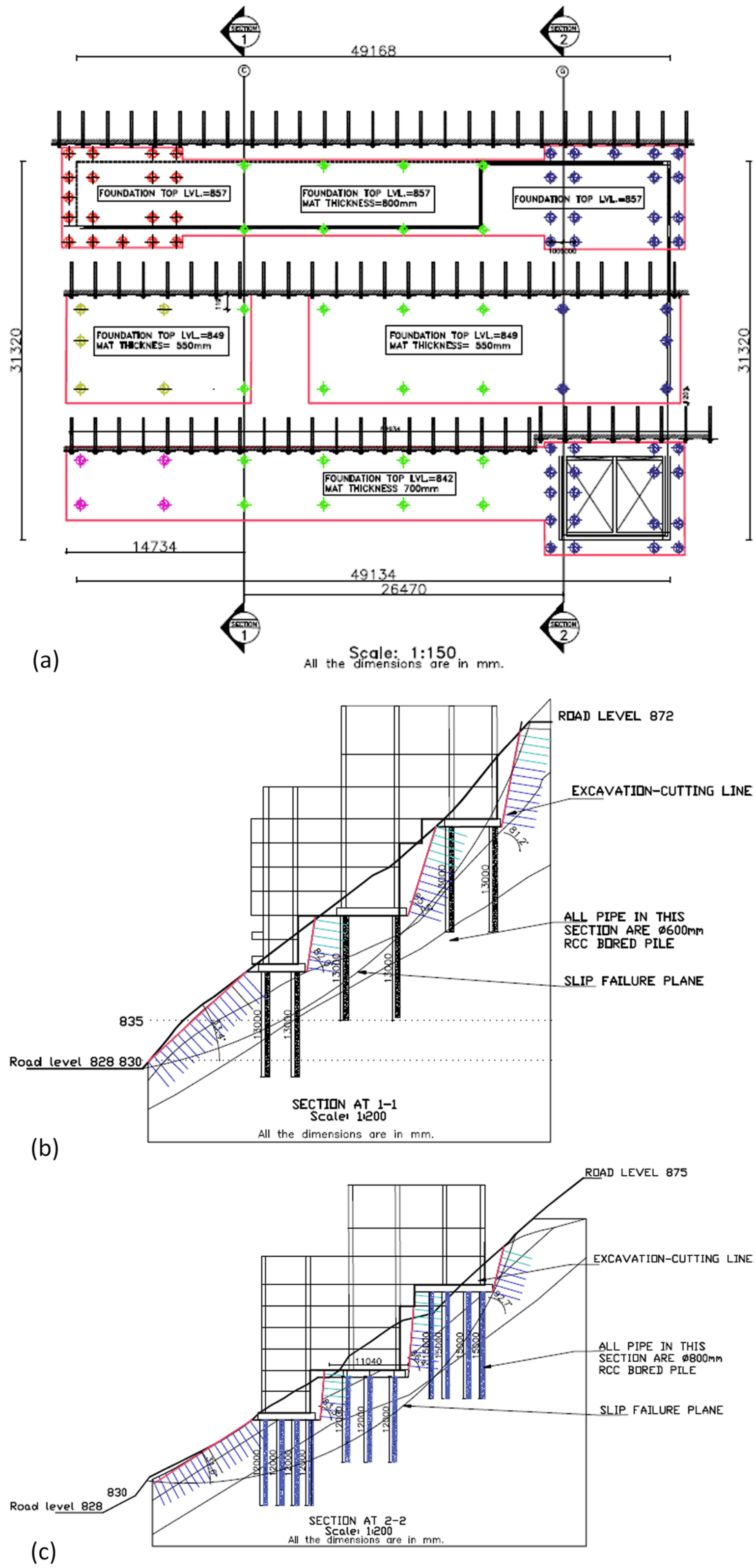

Fig. 5 **a** Foundation plan (Sectional view of block building). **b** Construction at Section 1-1. **c** Construction at Section 1-1

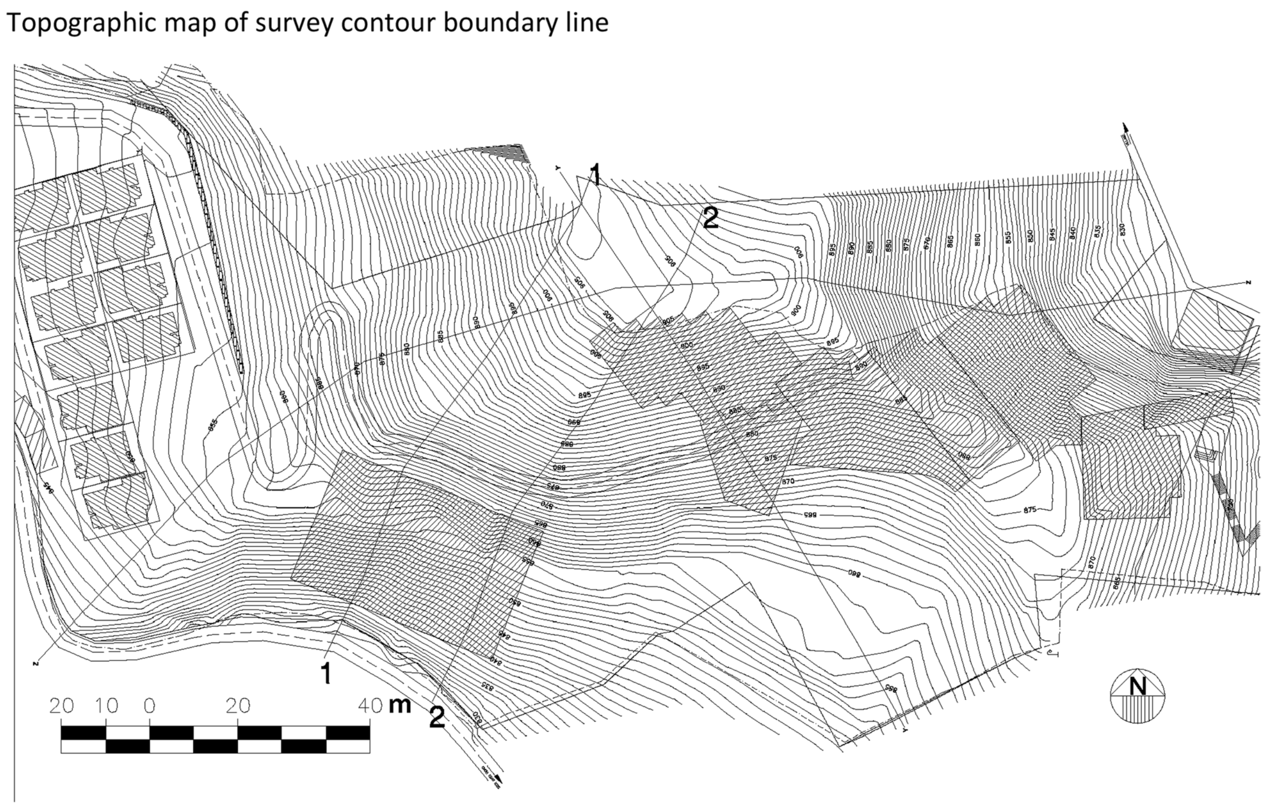

Fig. 6 Topographic map of survey contour boundary line

Table 1 Soil parameters for analysis of slope stability

Soil type	Depth	Soil unit weight (KN/m2)	Cohesion, c (kPa)	Angle of internal friction, ϕ (degree)
Red soil with phylite gravel mix	3.0	18.25	0.43	36
Phylite rock	6.0	19.5	0.00	45
Brown fracture phylite rock	> 6.5	19.00	Infinite strength	

valley has a lacustrine deposit of huge 'paleo-pokhara lake' and several lakes deposit containing peat, sand, carbonaceous clay, sand gravel and boulders (Hagen 1969). The Pokhara basin is divided into nine groups: Alluvial Deposit, Colluvial Pokhara Formation, Phewa Formation, Ghachok Formation, Indi Khola Formation, Tallakot Formation, Kuncha Formation (Koirala et al. 1996) Yamanaka et al. (1982) as shown in the figure. The Pleistocene deposits of Pokhara valley overlie the phyllites, meta sandstones, quartzites, and slates.

The area of interest in this research belongs to the Kuncha Formation in the hill range (Fig. 4). Kuncha Formation bedrock is covered with a residual and/or colluvial deposit. The Kuncha Formation basement rock is highly to moderately weathered phyllites varying from from few millimeters to several centimeters and medium to thickly bedded gritty quartzites varying from 5 cm to about 1 m. The direction of bedrock dips southwest facing slopes as in Kaon hill and the bedrock is covered by around 1–3 m thick blanket (Koirala and Rimal 1996).

Site characteristics

The specific site research area is a construction site of Hotel Barahi in Pokhara valley. The site has a Casino block building of Barahi Hotel with Mat Foundation. The study site is located on a steep slope with surrounding hills. The sectional view of the building is shown in Fig. 5.

Materials and methods

Topographic mapping, field survey and geotechnical investigation of soil sample of the project area was done for this research work. The sample were then tested in laboratory and according to lab test report and site topography, slope stability analysis was performed by Rocscience software (Phase 2 and Slide).

The topographical map prepared based on field survey is shown in Fig. 6.

The laboratory tested geotechnical properties of both soil and rock sample for slope stability analysis are tabulated in Table 1.

Using the field and laboratory test data, slope stability analysis is done. Limit Equilibrium method using Slide software and Finite Element Method using Phase 2 software are used for the analysis of stability of the area. First the numerical analysis of slope without any stability measures and then with stability measures of anchor bolt, RCC bore pile and geogrid was performed. In this research, "Phase 2 (2002)", a Rocscience Finite Element program and "Slide", a Rocscience Limit Equilibrium programs were used to understand and simulate multistaged model for stability analysis of slope of the study site.

A direct way for determining a stress reduction factor (SRF) or factor of safety that drives a slope to the point of absolute failure is the shear strength reduction (SSR) methodology of the Finite Element (FE) method for stability analysis of slope. The SSR methodology ensures that the slope's materials have Mohr–Coulomb strength. The most commonly used failure criterion in geotechnical engineering is the Mohr–Coulomb strength envelope. This linear failure model differs from others in that it can be represented directly and concisely in both principal (s1-s3) and shear-normal (t-sn) stress spaces. The Mohr–Coulomb criterion's popularity can be attributed to its simplicity, explicit representation in both main and shear-normal stress space, appropriate description of strength behavior for a variety of materials, and simple to get parameters. The

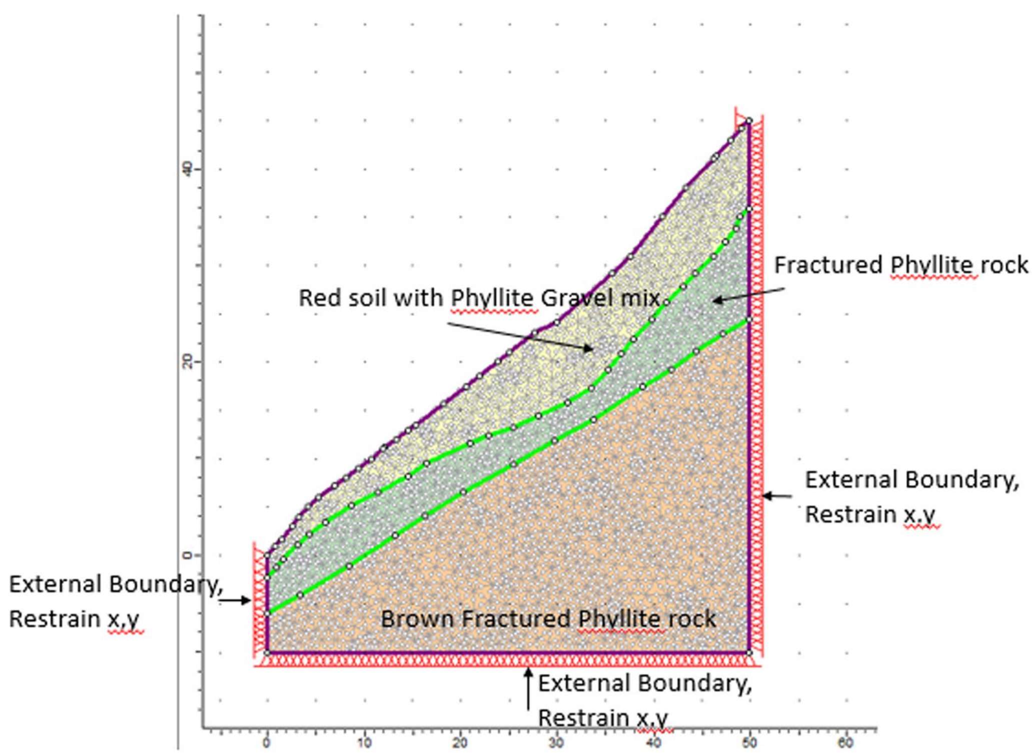

Fig. 7 Schematic diagram of Slope for FEM based simulation

equation below can be used to calculate the factored or decreased shear strength for Mohr–Coulomb material:

$$\frac{t}{F} = \frac{c'}{F} + \frac{\tan f'}{F} \quad (1)$$

It can also be written as:

$$\frac{t}{F} = c* + tanf* \quad (2)$$

where F = factor of safety; c' = effective parameter of cohesion; t' = effective shear strength; f = effective internal frictional angle $c* = \frac{c'}{F}$ and $f* = \text{arc } tan\left(\frac{\tan f'}{F}\right)$.

The following steps can be used to methodically seek for critical safety value F that pushes a once stable slope (F ≥ 1) to the brink of failure:

Step 1: Developing an FE model of a slope, using the appropriate materials deformation and strength properties. Computing the model and recording overall deformation at maximum.
Step 2: Increasing the value of F (or SRF) and calculating factored Mohr Coulomb material parameters as described above. The slope model is updated after the new strength properties are entered. The overall deformation at maximum is being noted.
Step 3: Continuously reducing strength of the material until slope collapses by repeating step 2 with precise F increases until the Finite element model that does not really yield to a conclusion. The factor of safety of slope will be the critical F value just past which failure occurs.

The process is same for a slope with less than 1 factor of safety value, with an exception that fractional F values will be gradually dropped (resulting in increases in the factored strength parameters) until the slope stabilizes.

The main benefit of SSR methodology is that it works with any FE analysis program currently available because it uses factored strength values as data into models (Fig. 7). Calculating the factored Mohr Coulomb strength parameters is all that is necessary for the approach to be used in a slope analysis.

The simplified Bishop technique (Bishop 1955) is recognized as an outstanding limit equilibrium approach for computing the factors of safety of circular slip surfaces and has been applied extensively in slope stability analysis. In this method, the inter-slice forces are assumed to be horizontal, or vertical inter-slice forces are neglected, the vertical force equilibrium and the moment equilibrium about the center of the circular slip surfaces are satisfied, but the horizontal force equilibrium is not considered.

Table 2 Material properties for anchor bolt

Material	Fe525/575
Tensile strength, Mpa	525
Shear strength, Mpa	210
Diameter of Anchor, mm	25
Cross section area, mm2	490.874
Tensile force, KN	257.709

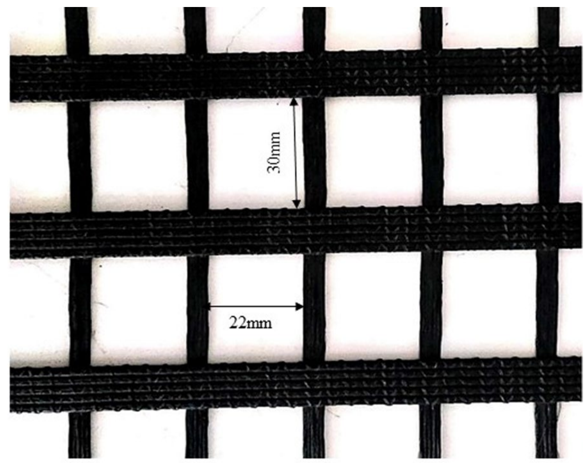

Fig. 8 Uniaxial geogrid used in construction

The simplified analysis is as follows:

$$\tau = \frac{1}{F}\left(c' + \sigma' \tan\phi'\right) \quad (3)$$

To find σ' resolve forces on a vertical axis to obtain:

$$W - \frac{1}{F}\left(c' + \sigma' \tan\phi'\right)\Delta X \tan\alpha - \left(\sigma' + u\right)\Delta X = 0 \quad (4)$$

$$\therefore \sigma' = \frac{W - u\Delta X - \frac{1}{F}c'\Delta X \tan\alpha}{\Delta X(1 + (\tan\phi' \tan\alpha)/F)} \quad (5)$$

Now, F = sum (maximum resisting forces around arc)/sum (moving forces around arc)

$$= \frac{\sum(c' + \sigma' \tan\phi')\Delta X \sec\alpha}{\sum W \sin\alpha} \quad (6)$$

$$= \frac{\sum\left\{\left[c'\Delta X + (W - u\Delta X)\tan\phi'\right]\frac{1}{M_\alpha}\right\}}{\sum W \sin\alpha} \quad (7)$$

Table 3 Properties of geogrid material

Property	Units	Value
Raw material		Polypropylene
Initial strength (ISO 10319) MD	KN/m	200
Initial Strength (ISO 10319) CD	KN/m	50
Initial strength at 5% strain (ISO 10319) MD	KN/m	100
Strain at initial strength MD	%	10

where, $M_{\alpha} = \cos\alpha + \frac{\sin\alpha tan\phi'}{F}$.$\tau$ = shear strength, σ' = normal stress, ϕ' = angle of friction, W = Weight of slice, ΔX = width of slice and u = pore pressure

To facilitate the analysis of slope stability for a large number of potential failure surfaces and a variety of conditions, computer programs are used. When compared to the results of an ordinary method of slices, the Bishop Method produces more realistic safety factors. The Bishop Method is a simplified approach that produces results for factor of safety that are near to the correct solution, according to analysis using a more sophisticated approach that takes into account the forces acting on slices' sides.

Bishop (1955), suggested that for the calculation of slope's factor of safety, whole slope is divided into vertical slices and each of them is individually analyzed using circular failure analysis to get the individual slice safety factor and summarized for overall factor of safety of slope.

Stability measures

RCC Pile

The RCC bored pile is used for its load carrying capacity in terms of lateral as well as axial load for heavy structure on unstable slope. The bored pile has medium to large diameter and it may be easy or difficult to transport. For installation, high skilled manpower and sophisticated machine grade of concrete M25 and slump 150–180 mm (IS 2911 Part1/Sec 1) and Reinforcement as per (IS1786:2008) is required. The cage reinforcement was done on the drilled hole and trimmer method was used for concreting.

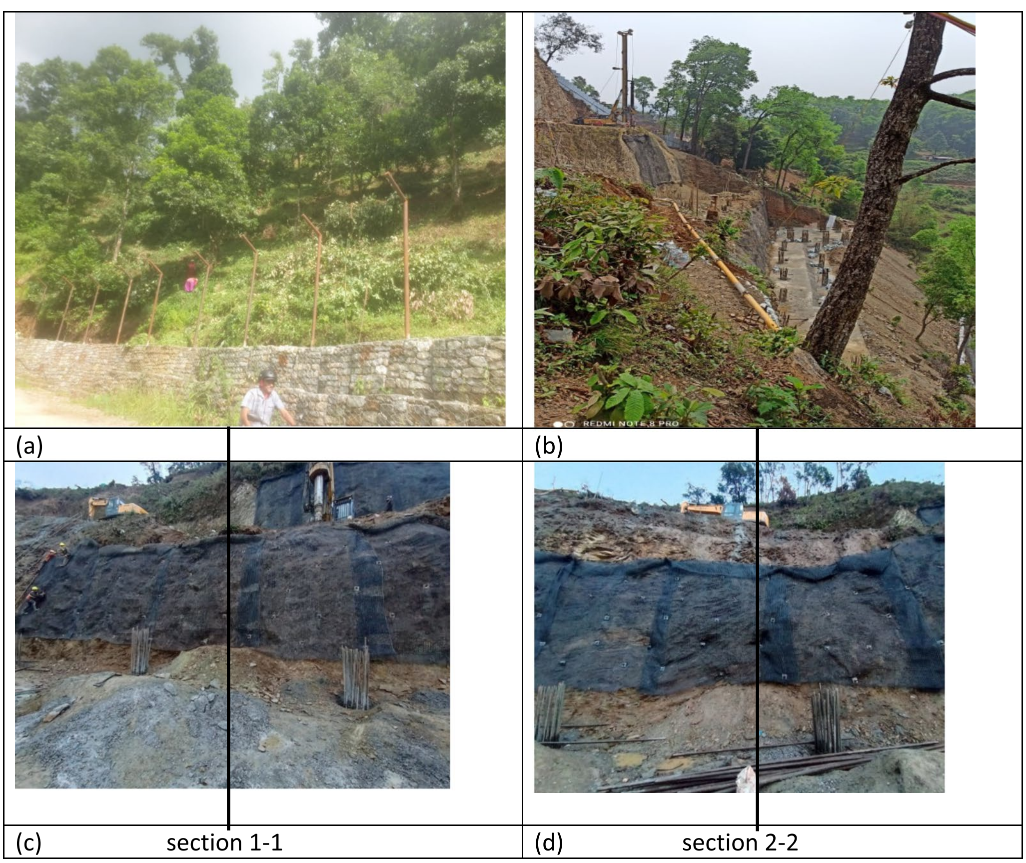

Fig. 9 **a** Steep slope of construction Site, **b** Study area after cutting, **c** Ongoing construction on site, **d** Another view of ongoing construction of site

Table 4 Material properties for modelling

Modeling Parameters	Red soil with phylite gravel mix
Elastic modulus	50000 Kpa
Poisson"s ratio	0.4
Tensile strength	4 Kpa
Friction angle	36
Cohesion	0.43
Constitutive model	Mohr coulomb failure criterion

Anchor bolt

Anchor bolt is a device to transfer forces in given direction from structure to rock – medium. By anchoring, a compression force is delivered directly to the crucial joint within the rock mass. The anchorage increases the inherent strength of the rock mass and helps in its ability to maintain itself against sliding by generating a compressive stress.

Landslides, slips and rock-falls are some of the modes of movement of rocks beneath the gravitational influence. The movement, sometimes can be extremely damaging or can even be disastrous. In highways, hydraulic engineering structures and foundations that rest on rock, it is imperative to assess the degree of stability of natural slopes and also manmade slopes. Properties of Anchor bolt used in this project is below in Table 2.

Geogrid

Geogrid are engineered materials suitable for soil reinforcement for erosion control. Geogrid are manufactured from polymer such as PET, Polyester Yarns (as per ASTM D2455, ASTM 4603 and ASTM D1248). There are different apertures of various size and have strength in the transverse and longitudinal direction. PET, HDPE and polyester geogrid maintain minimum UV resistance as per ASTM D4355. The tensile and physical characteristics of the geogrid are improved by stretching in either one, two or three directions. In this study, the uniaxial geogrid is used for surface protection with the properties as below in Fig. 8 and Table 3.

Sequence of construction method

The construction methods with reinforced soil using cast in situ bored RCC pile are well explained by Kocherzhenko and Suleymanova (2021) Zolotuchin et al. (2018). Similarly, Kaewjuea et al. (2022) and Kocherzhenko et al. (2021), has explained how RCC pile are tested and work on sloppy ground, increase the bearing capacity of reinforced concrete piles by friction forces. Khodair and Abdel-Mohti (2014), explained how RCC pile react and axial and lateral load interaction with soil. Seyhan (2009), has explained about the method and process of RCC bore piling technique.

In this study, like any other civil engineering work, at first the site was made accessible and was cleared, necessary cutting of the natural slope was done as per design to meet construction needs. Then, the work was commenced from the section one (as seen in Fig. 5a), where concrete piles of varying depth and diameter from 600 to 800 mm and 12 m to 20 m depth were bored into the ground. In total 52 nos of concrete piles were bored along the Section 1 & 2 as seen in Fig. 5 with different lengths from 12 to 20 m depth. The cut slope was stabilized using rock anchor bolts of varying depth of 3 m to 4 m and surface dressing was done using high strength geogrid of 200/50 KNm. After that, the stabilization of Section 2 was completed in the same way. The construction work was commenced starting from bottom to top and similar work procedure was followed in Section 1 at 872 m and Section 2 at 857 m as shown in Fig. 5b and c. The sequence of the state of construction site work in shown in Fig. 9. The intact steep slope of project site can be seen in Fig. 9a. According to design, the slope was cut in desired slope shown in Fig. 9b. And ongoing construction work with rcc pile, anchor bolt and geogrid was shown in Fig. 9c and d.

Analysis

The geotechnical properties of both soil and rock for slope stability analysis are taken from the laboratory test data which is tabulated in Table 4. From the topographical survey data, 2 critical sections are considered for the modeling of the slope.

The material properties of model are shown in Table 4. For vertical boundary, $u_x = 0$ and u_y is free and for horizontal boundary; $u_x = u_y = 0$. Mohr–Coulomb failure criterion is used to simulate the model. The shear strength reduction (SSR) methodology of Finite Element (FE) and the simplified Bishop method were used to analyze the slope stability problem to gain insight into soil mass behavior, progressive failures and explicit modelling of discontinuities. In both approaches, the stability of current natural slope conditions was first assessed by analysis and then, for cut slopes.

We have numerically modelled the project site using FEM in static condition considering it as a continuum by SSR approach. By determining the safety factor of natural slope (which demonstrated failure), post-disaster analysis is carried out. While, by using FEM methodology, stress developed in the slope is determined to focus on probable

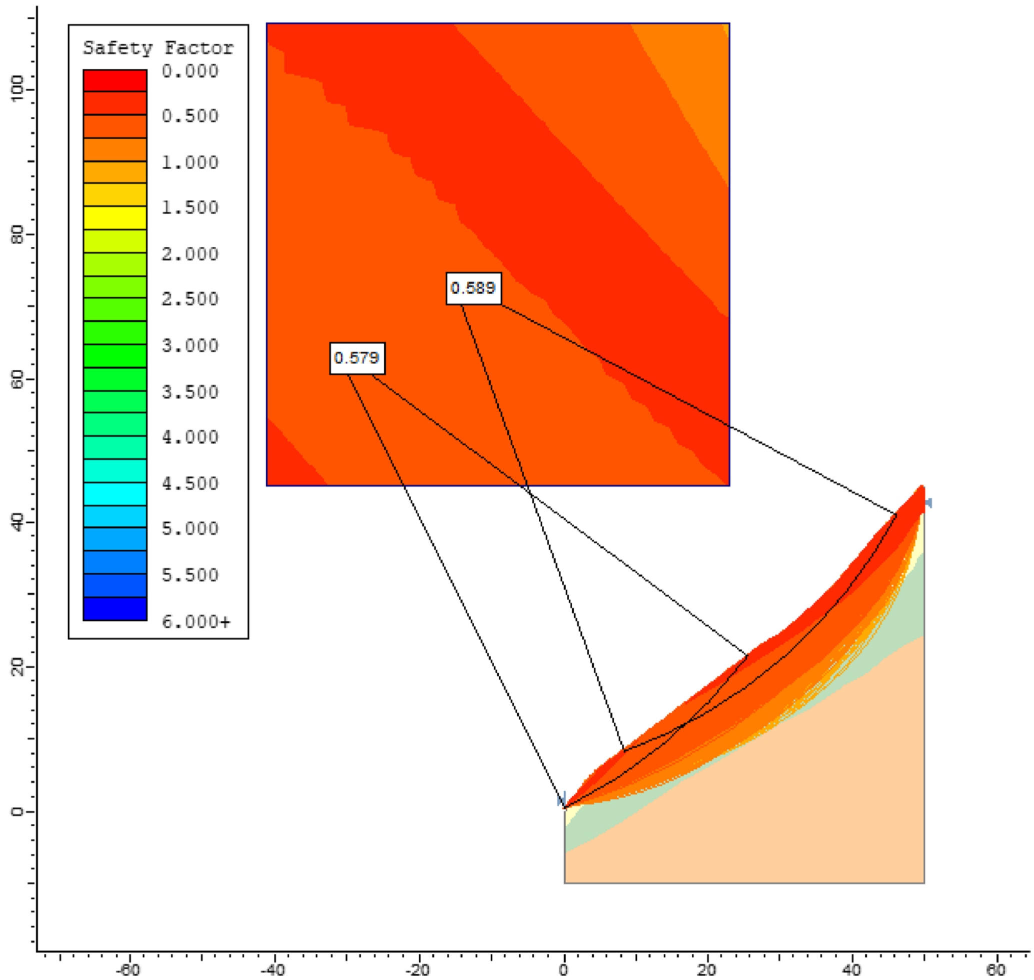

Fig. 10 Factor of safety of natural slope obtained from Bishops method for Section 1-1

failure. The Phase 2 analytical program was used to complete the task. FEM, a commonly used technique for numerical modeling of slopes, operates on the tenet of discretizing the entire design into a predetermined number of components, allowing for continuous modification in material properties. The slope design has been discretized using three triangle shaped plane strain elements in two dimensions. It has been decided to use the SSR technique using non-failure criteria. It is considered that the failure mechanism of the slope is closely linked to the growth of shear strain since the rupture surface and the failure zone's maximum shear strain coincide.

Results and discussion

The slope was evaluated for a factor of safety, analyzed as per Bishop's method, as mentioned in earlier sections. The safety factor of 0.579 and 0.70 for existing slope at Section 1-1 and Section 2-2 were obtained respectively (as shown in Figs. 10 and 11). Then, the cut slope was analyzed in which safety factor value was less than 1. After cutting slope, factor of safety of Section 1-1 and 2-2 is 0.539 and 0.799 (as shown in Figs. 12 and 13). Since Bishop's method showed safety factor value less than 1, the slope was prone to failure which was visible in the site. The existing soil was strengthened using a combination of RCC pile, Anchor Bolt, and geogrid to increase the factor of safety and improve slope stability. Further, after protection work with RCC pile, anchor bolt and geogrid were applied and stability was checked.

It was found that the slope's safety factor was increased from 0.579 to 1.593 in Section 1-1 and 0.70 to 1.319 in Section 2-2 obtained from limit equilibrium method (Figs. 14 and 15). In addition, safety factor with strength

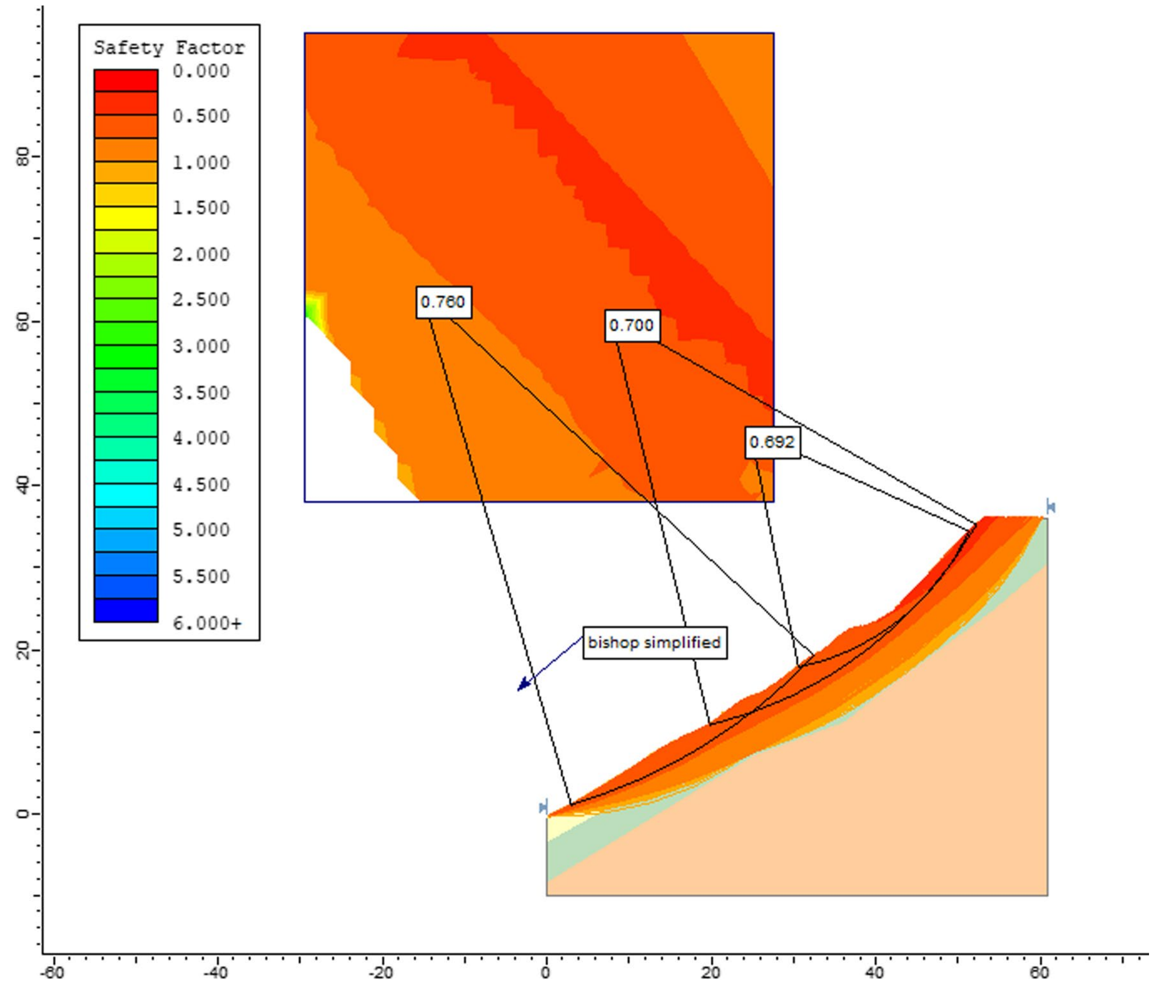

Fig. 11 Factor of safety of natural slope obtained from Bishops method for Section 2-2

reduction method is 1.408 and 1.05 for Sections 1-1 and 2-2 respectively, after slope stabilization work (Fig. 16 and 17). All these results are shown in tabular form in Table 5.

The slope was analyzed with the combination of RCC pile, anchor bolt and geogrid and it was observed that the factor of safety was improved and obtained to be greater than 1.

Failure of mass movements often result in significant loss of human lives and property. It is recognized that maintaining the stability of both natural and artificial slopes continues to be a basic problem in geotechnical engineering. There is no universally accepted method for the prevention or correction of slope failures. Each failure is unique and should be considered based on unique inherent characteristics. Stabilization of slope may depend on the number of factors such as; its geometry, surface and ground water conditions, strength of materials and reasons for stabilization. Therefore, number of techniques are developed so far to stabilize slopes.

In this research; the existing slope are known to have the safety factor below the value 1 from Bishops method. Also, after maintaining slope, factor of slope was still less than 1 from all methods. And after structure load and slope protection work with rcc pile, anchor bolt and geogrid, safety factor was greater than 1 from both SSR method in Phase and Bishops Method in Slide.

There are various methods for slope protection for building construction in slope ground. In recent years, RCC pile combined with anchor bolt and geogrid are being used in various projects of structure construction in slope ground. RCC piles are foundation

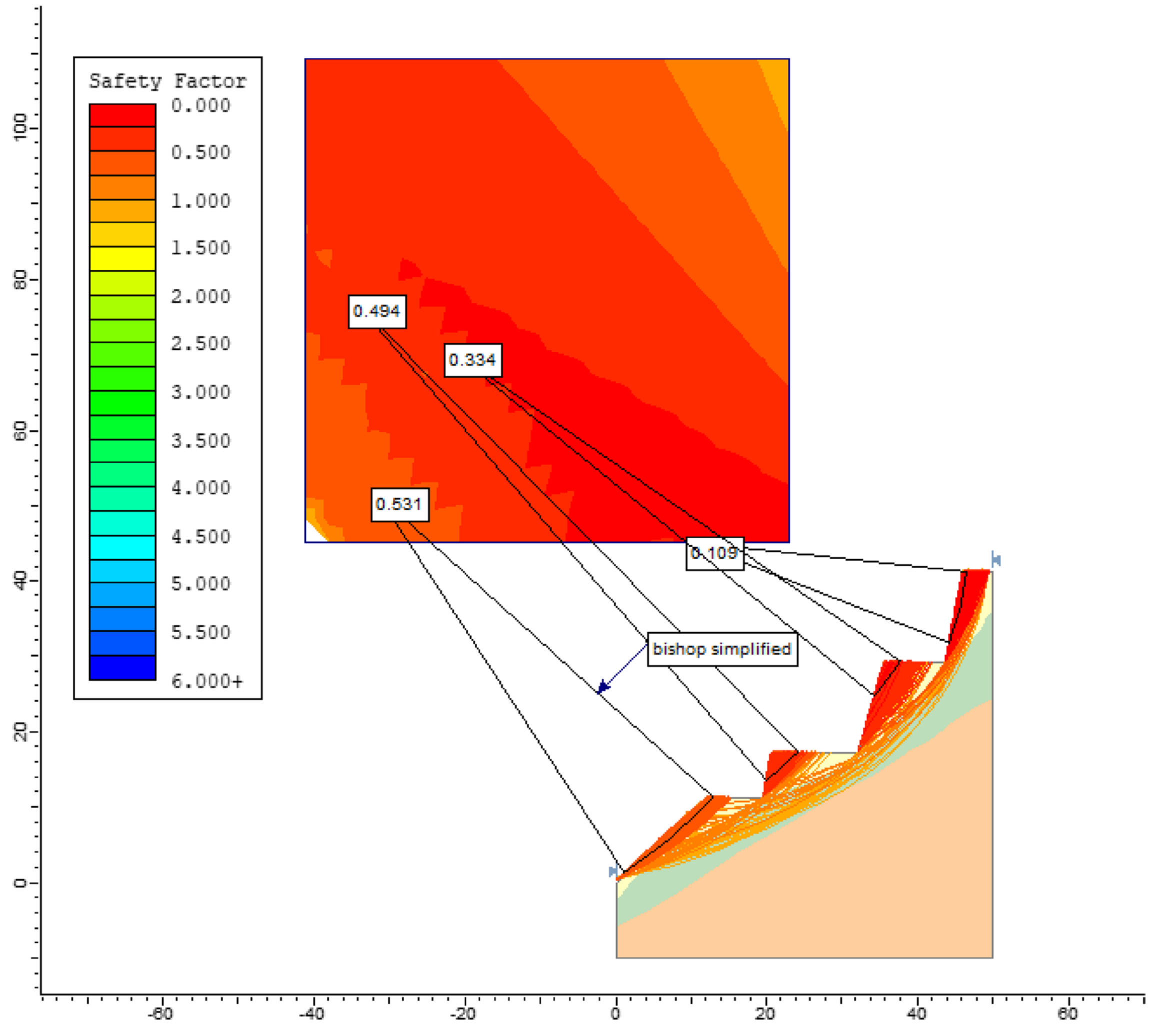

Fig. 12 Factor of safety of cutting plane obtained from Bishops method for Section 1-1

pile used for the building construction in mountainous areas. And for slope protection, anchor bolt and geogrid are widely used. In this research, concrete piles of varying depth and diameter from 600 to 800 mm and 12 m to 20 m depth were driven into the ground. In total, 52 concrete piles were driven with different lengths from 12 to 20 m depth. The cut slope was stabilized using anchor bolts of varying depth of 3 m to 4 m and surface dressing was done using high strength geogrid of 200/50 kNm. The construction work was commenced starting from bottom to top. This research has attempted to validate the solution for construction of building in slope ground.

Table 5 Factor of safety by the limit equilibrium method and by the finite element analysis

Factor of safety	Section 1-1	Section 2-2
Bishop of existing slope	0.579	0.70
Bishop of cutting Slope	0.531	0.799
Bishop of after slope stabilization	1.539	1.319
SSR of after slope stabilization	1.408	1.05

This research finding suggest that RCC pile with anchor bolt and geogrid shows good results in construction of building in slope ground as well as slope stabilization work. RCC pile was used to take lateral

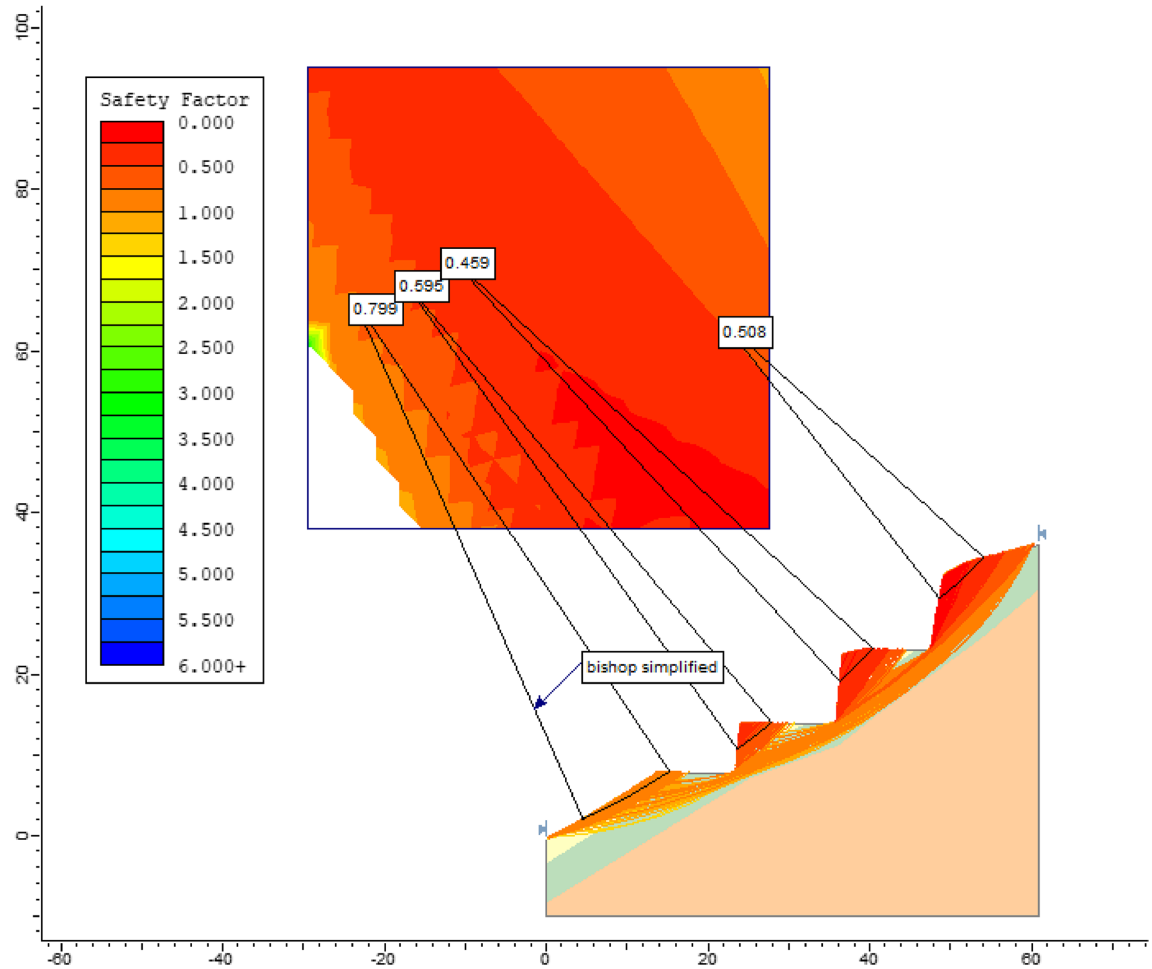

Fig. 13 Factor of safety of cutting pane obtained from Bishops method for Section 2-2

and shear force of structure, anchor bolt and geogrid was used for retaining structure as well as to increase soil strength for shear. According to soil investigation work performed in site, water table was not found, hence there are limitation in this study as in analysis was not considered but for drainage system, semi perforated HDP pile of 6inch diameter was laid in 1:2 gradient over coarse aggregates and then pile was wrapped with geotextile and sand was filled over it in each cut slope.

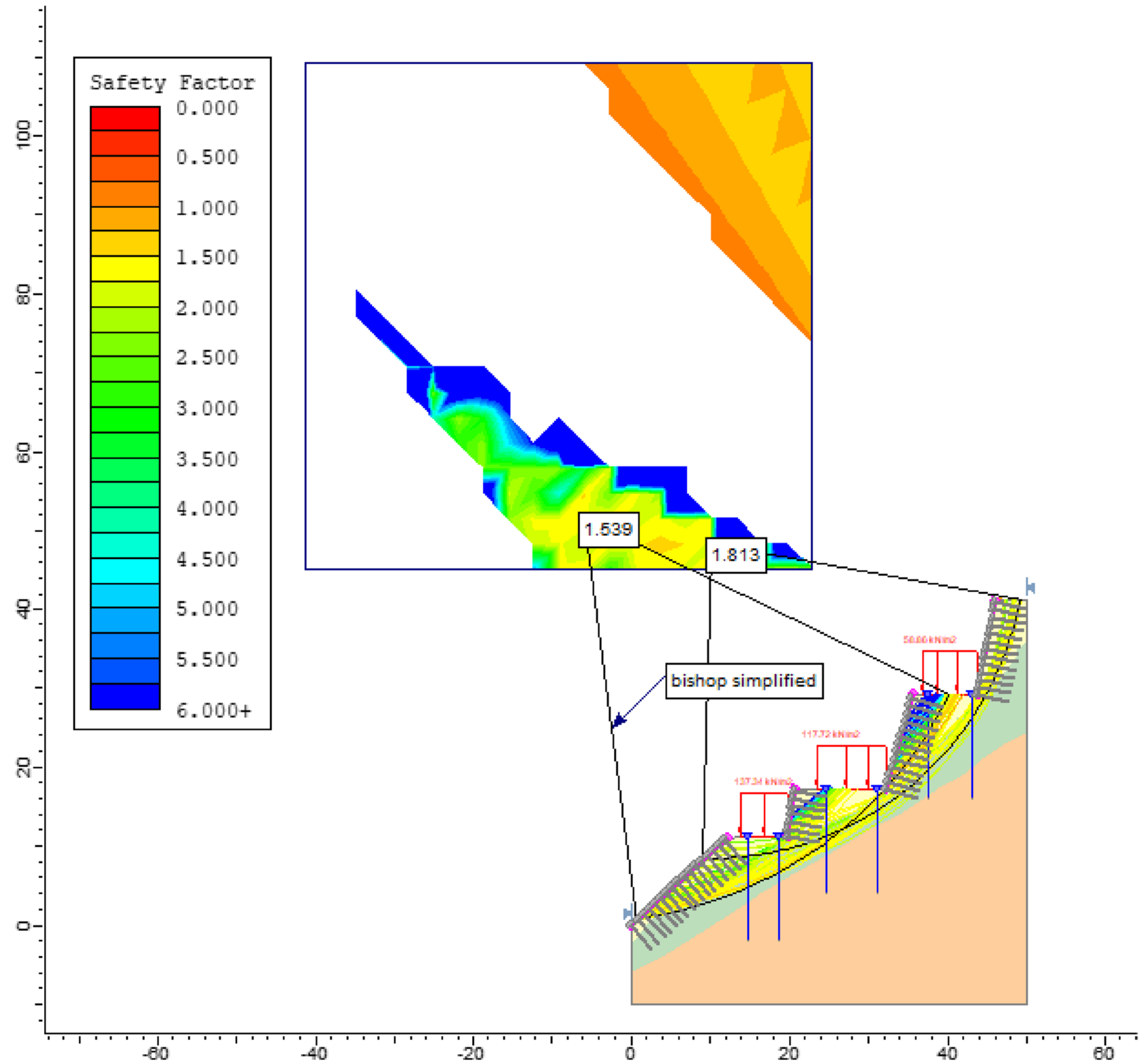

Fig. 14 Factor of safety after slope stabilization work Section 1-1

Conclusion

Even though building a structure on a slope land has its own challenges and difficulties, it is possible to execute a project with safe design/ analysis and slope stability measures. The project one completed adds a great value to the owner considering the terrain, especially in the context of Nepal. The owner will appreciate the scenery, the geomorphology and landscapes, natural lighting,

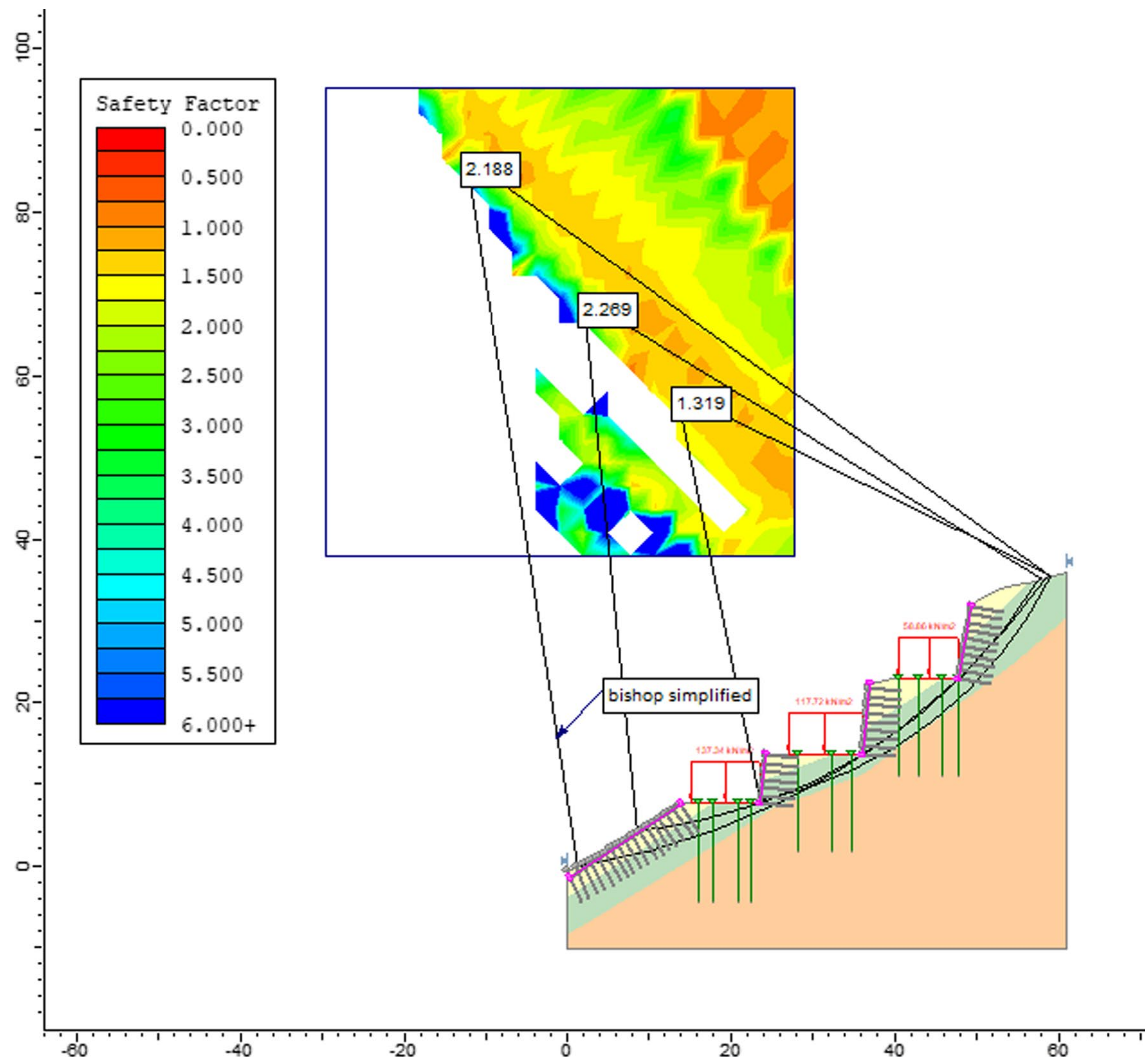

Fig. 15 Factor of safety after slope stabilization work Section 2-2

privacy, and space. This illustrates why so many of the world's most desirable residences are constructed on slopes. However, it necessitates complicated foundation systems, which add to the cost and length of the construction process. The cost is often more than that of an entire house on flat ground. It requires more concrete, deeper excavation by specialized excavation process to ensure that the building is in accordance to code and safe to inhabit.

The limit equilibrium method of analysis was widely used due to its clear physical meaning and simple calculation. At present, with development in the finite element method, the strength reduction method is

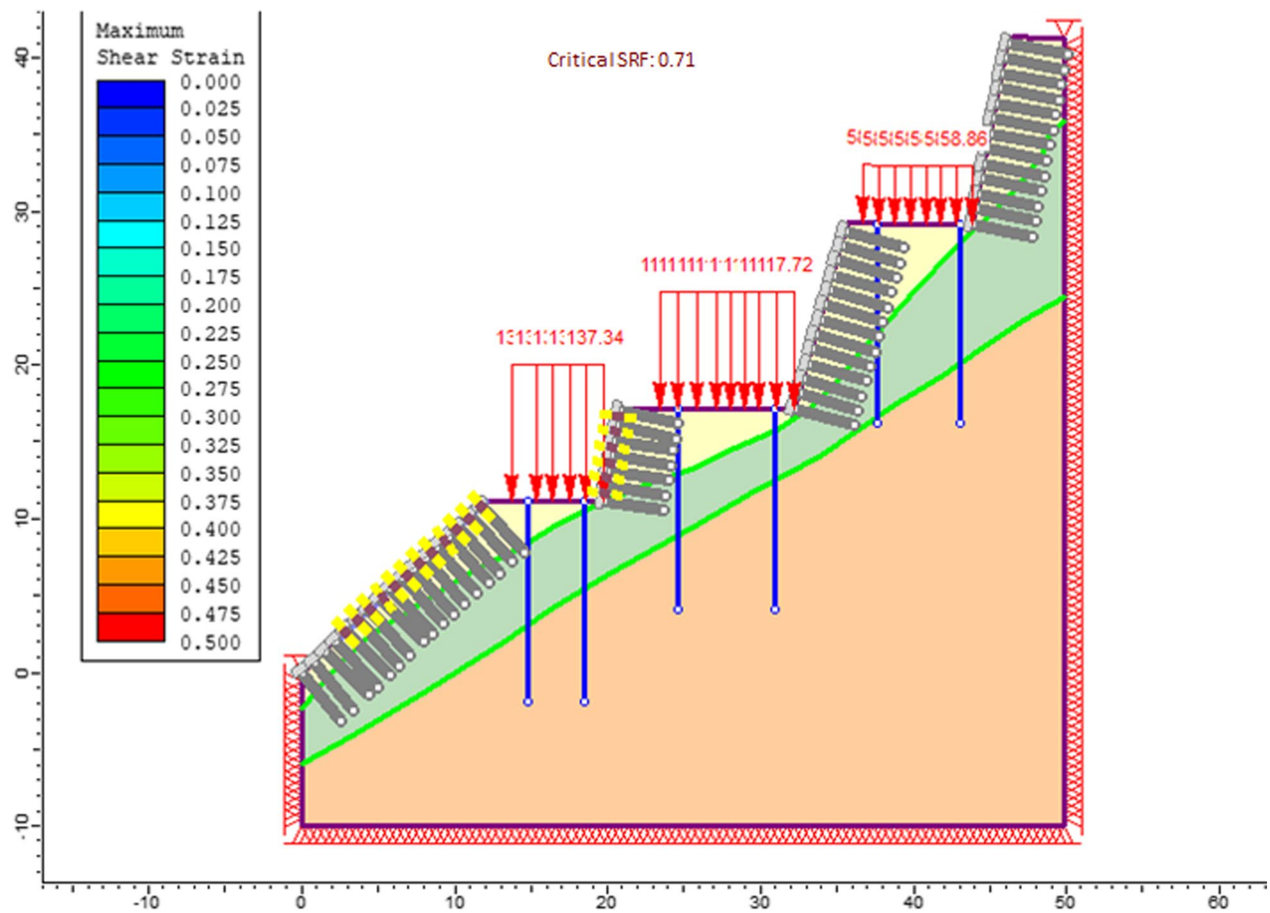

Fig. 16 Verification with Shear strength reduction (SSR) method Section 1-1

gradually recognized to assess the safety factor of slope. In this paper, the safety factor of the slope is firstly calculated by Bishop's method, which is then compared with the safety factor obtained from the strength reduction method by FEM. Thus, from LEM and FEM, factor of safety were found to be greater than 1.

The construction of building in slope ground is possible, but it needs specialized excavation and slope protection work; RCC pile with anchor bolt and geogrid can be one of the sustainable solutions among others to address the issue. Following, the safety factor is increased using RCC pile, anchor pile and geogrid as reinforcement. For construction of structure in mountainous area like Nepal, a combination of RCC pile, anchor bolt and geogrid can be an effective solution; are the concluding remarks can be drawn from this work.

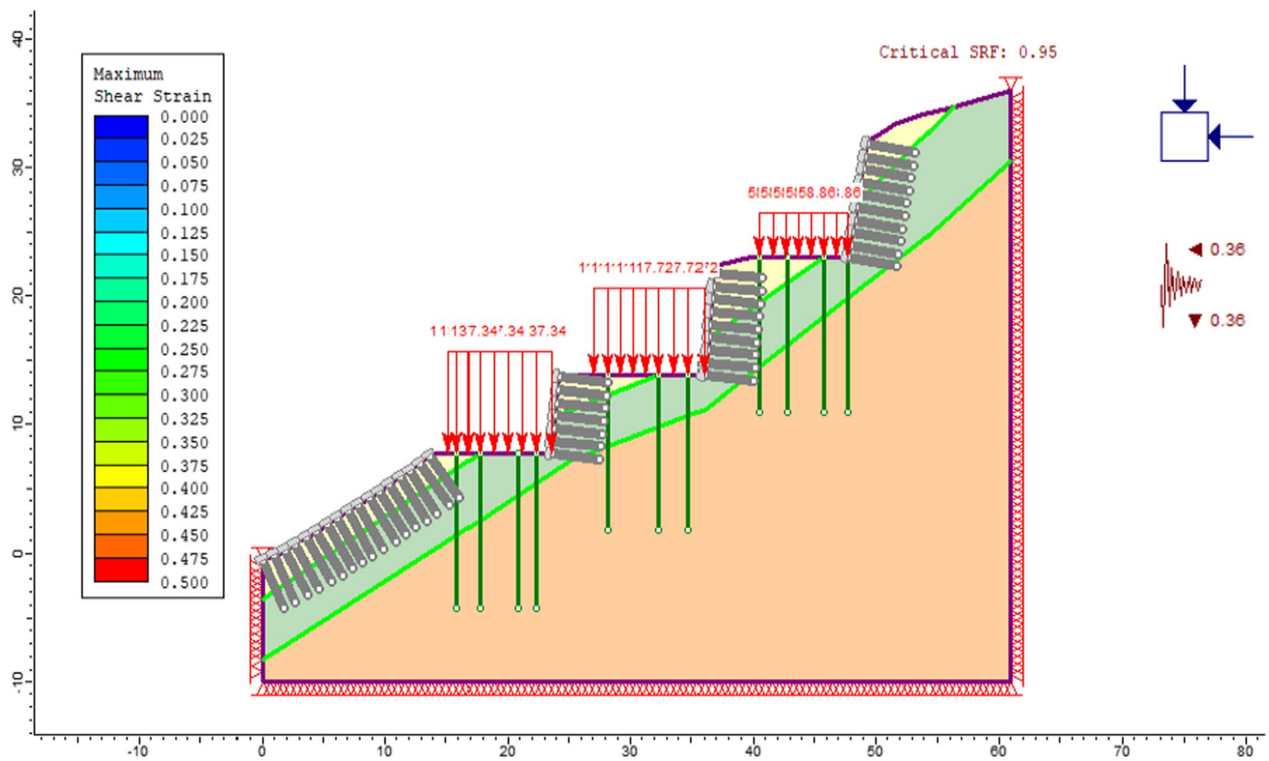

Fig. 17 Verification with Shear strength reduction (SSR) method Section 2-2

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Author contributions
SKJ was involved in the data collection in field, data analysis, simulations and writing the manuscript. And all other author contributed in data analysis, simulations and writing the paper. All authors read and approved by the final manuscript.

Availability of data and materials
The most of the data is collected from field work and simulations. The published studies that are referenced in the manuscript use some of the data that were created or examined throughout this research.

Declarations

Competing interests
The authors declare no competing interests.

Competing interest
The authors claim to have no conflicts of interest.

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