Shahrood University of Technology

Journal of Mining and Environment (JME)

Journal homepage: www.jme.shahroodut.ac.ir

Iranian Society of Mining Engineering (IRSME)

Assessment of Slope Stability and Its Remedies in Palampur, Himachal Pradesh

Alankrit Walia* and Amrit Kumar Roy

Department of Civil Engineering, National Institute of Technology Hamirpur, India

Article Info

Received 16 August 2022
Received in Revised form 10 September 2022
Accepted 14 September 2022
Published online 14 September 2022

DOI:10.22044/jme.2022.12215.2217

Keywords

Slope stability
Numerical modeling
Circular slip failure
Numerical modelling
Highway

Abstract

The complex geography of the Himalayan mountain range, along with the natural circumstances that already exist and the ways in which people have influenced and intervened in the region- makes various regions of the range vulnerable to slope instability. The slope stability of the area that is the subject of this work is evaluated in Palampur, which is in the Kangra district of Himachal Pradesh. The primary objective of this work is to ensure that the slope remains stable so that the nearby three-sided residential structures and the highway remain protected. After the site visit, the geo-technical studies, which include testing in the form of bore holes and in the laboratory, are carried out. After evaluating the geo-technical technical report, the next step in the process is to begin the analysis of the slope's stability. In order to do an analytical analysis of the slope stability, the area has been subdivided into three portions, and labelled A-A, B-B, and C-C, respectively. Using the numerical modelling approaches, the mitigation design parameters for the area and the circular slip failure are computed. These calculations are based on the geo-technical characteristics of the studied area that have been specified. The factor of safety is calculated for both the natural and stable scenarios by the program. Because of this, some preventative steps and a few improvements are suggested.

1. Introduction

The geo-technical engineers have traditionally taken a keen interest in evaluating slope stability. There is a great deal of discussion on the use of techniques and the selection of soil characteristics for analysis. Since the soil behavior influences the precision of slope stability analysis, the soil properties are significant inputs for numerical models. The soil parameters must be precisely assessed for a suitable slope stability analysis. It is most straightforward to do this by conducting several site investigations. A technique (e.g.- finite difference method, limit equilibrium method, finite element approach) with numerous material and soil models that can accurately represent soil behavior and stresses is required.

In the recent years, the use of two-dimensional finite element modelling in slope stability analysis has become popular, and the geo-technical researchers have benefited from this [1]. In addition, as computation advances, the finite element method is being more widely used in the geo-technical studies [2] [3]. The capacity to correctly illustrate slopes (i.e.- sophisticated geometry, changeable loading conditions, and the incorporation of material as reinforcement) and to better demonstrate soil deformations are examples of the numerous advantages [4] [5]. There is also no need to make assumptions about the position or shape of the failure surface in advance. Failure happens spontaneously when the soil's shear strength is inadequate to resist the applied stresses. Due to the numerous factors, it is crucial that the engineers comprehend the conclusions of the investigation. In this part, several case studies are given to show how well the finite element approach works [6-11].

The selection for a pile row, according to many experts, is between the slope's center and the

Corresponding author: 21mce022@nith.ac.in (A. Walia).

critical shear surface's center, with many rows located towards the slope's center and no surcharge applied. The shear stresses generated by the surcharge necessitated the pile row to advance upslope toward the load to ensure global and local stability of the slope under local loading at the top of the slope [12].

A series of numerical evaluations were performed to learn how pile spacing and placement influence the stability of a slope that has been reinforced with a single row of piles. Soil-pile interaction was shown to have a significant impact on slope stability, and as a result, the failure mechanism of the piled slope changed depending on where the piles were located on the slope. Pile placement in the slope's middle to upper half was suggested for maximum safety.

The collapse of a slope was traced back to poor pile performance, which was examined using the numerical analysis. For system stability, the fixed-head pile performed better than the free-head pile. It was thought that the pile head changed the failure surface of the whole system [14 & 15].

To avoid the rising of submerged structures and to provide support for bulkhead and wharf systems, ground anchors have been frequently utilized to support retaining walls for deep excavations. New materials have been used to greatly enhance ground anchor performance, although the design processes themselves have changed little over the years. The behavior of ground anchors under tensile load has been analyzed by several authors using a non-linear connection at the ground-grout interface. A completely elastic-plastic model of tension anchor load transmission was developed. The study was broken up into two sections: one for the interface between the anchor and the earth, and another for the strand and grout. The researchers have recently used a hyperbolic load-displacement model to study how jet mixing anchor-pile support systems change shape [15-19].

As a conclusion, the authors employed the Geo5 software to conduct stability tests along predetermined segments of the slope, ultimately deciding to use self-driven anchors, pile reinforcement, and cement grout to ensure the slope's integrity. This work highlights the importance of self-driven anchors, pile reinforcements, and grouting as a method for slope stabilization in the Himalayas.

2. Studied area

The area being investigated is in Palampur, district Kangra, Himachal Pradesh. It is at 32°6′35″ N latitude and 76°32′11.91″ E longitude. The length of the research area is 80 m and its width is 45 m. The land is 1593 m above the sea level on the southern side and 1680 m above the sea level on the northern side. There is a road on the east and south sides, a building on the west side, and a forest on the north side (Figure 1).

Figure 1. Location on map of studied area and site view in Palampur, Himachal Pradesh, India.

3. Methodology

There is an initial reconnaissance survey, which comprises an examination of the proposed location. The land slopes from mid-to-high on all three sides of the property, as was shown during the site visit. After the inspection, the site underwent geo-technical investigations- including drilling holes and performing tests in the lab. Slope stability studies have commenced because of the report's interpretation. The following section demonstrates how to do a stability study and build a cut slope (Figure 2).

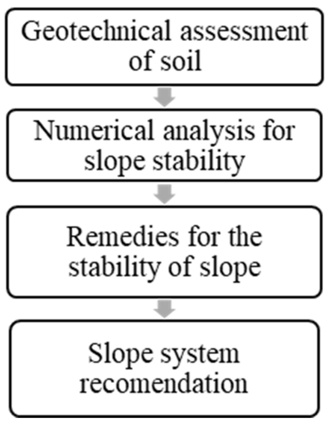

Figure2. Study's approach and methods are shown in a flowchart.

3.1. Geo-technical assessment of soil

The ground exploration program involves two 6-meter-deep boreholes in each section. The results of the soil investigation suggest that the soil is cohesionless beneath 6.0 m.

The unit weight of soil (γ) is determined using the core cutter method. This test is performed in accordance with IS-2720-Part-29 to determine the in-situ dry density of soil using the core cutter method (1975). The core cutter method is ideal for soft to moderately cohesive soils in which the cutter may be pushed. The cutter cannot be driven over hard and boulder-laden soils.

Through the triaxial test, the internal angle of friction (ϕ) and cohesion (c) are computed. The triaxial shear strength test examines the soil's mechanical characteristics. In this test, a soil sample is stressed such that the tension in one direction is different from the stress in the perpendicular direction. This test determines the material properties of the soil- such as shear resistance, cohesion, and dilatancy stress. The test is the most popular, and is applicable to all soil types.

The relative density test involves the assessment of the maximum dry density and the water content (humidity/density ratio) of cohesionless mixes (Figure 3).

According to the results of the soil analysis, the area is in the drained condition (Table 1).

Table 1. Studied area's soil characteristics used for analysis.

Properties	Values
Unit weight (γ)	20.25 kN/m^3
Internal angle of friction (ϕ)	28.85°
Cohesion (c)	17.67 kPa
Saturated unit weight (γ_s)	21 kN/m^3
Poisson's ratio	0.25

Nonetheless, a site survey revealed that the soil consists of rock pieces in a sandy soil/clay matrix that appears to have considerable cohesiveness. The properties derived from geo-technical testing have been applied to cut slope design.

Figure 3. (a) Soil sample. (b), (c), (d) and (e) triaxial testing setup. (f) and (g) relative density test.

3.2. Loads on structure

The G+1 buildings line the northern boundary of the studied area. There is an axial stress of 0.45 and 0.45 MPa in these structures. Building loads from the G+1 structure was taken into consideration when creating in ETABS software.

3.3. Slope stability analysis assumptions

Several assumptions have been made during the work:

1. The analysis relies on the bishop's method of slices and Mohr's Coulomb failure criterion, which assumes a homogeneous soil mass.
2. In addition to the forces exerted by the body, gravity is also considered. Various other

constructions- such as buildings- have been incorporated into the plan.

3. Temperature and creep stress are not considered in the analysis.
4. Structures that have FOS values greater than the minimum are safe under the present loads and support circumstances. If FOS goes below a certain threshold, the structure will be redesigned i.e. ≥ 1.5 [20].

Geo5 software has been used to conduct a stability check and implement preventative actions- (CBRI Roorkee).

3.4. Numerical modelling

In this work, the GEO5 software was used. GEO5 is a package of software that offers solutions for the bulk of geo-technical tasks. Slope stability is the basic application for stability analysis. It allows for the optimization of slip surfaces to be done automatically and for circular or polygonal surfaces to be analyzed for stability during the design process. This modelling software enables the simulation of a wide variety of phenomena- including seismic impacts, surcharges, anchors, and geo-reinforcements.

A two-dimensional finite element approach was used to determine the factor of safety (FOS). In this research work, the Mohr-Coulomb failure criterion model is used to simulate how soil behaves in the numerical analysis. The simulation of the models' boundary conditions was carried out in such a way that the bottom boundary was held constant, while a sliding surface progressed along the vertical. In order to ensure accuracy in modelling, a fixed end condition is used regardless of the presence of hard rock strata in the base plane. Because the strata are more likely to change shape in the vertical plane, a sliding surface is used.

As a major issue, mesh density in the finite element method is closely connected to the accuracy and complexity of finite element models. Getting accurate results from finite element analysis relies heavily on selecting an appropriate element size for a finite element model. With these considerations in mind, several numerical simulations were performed to determine the optimum mesh density[21]. Five alternative mesh densities, ranging from the course to the finest, were evaluated in the numerical analyses. Thus we went from a medium to a very fine mesh density, and the results held steady. As a result, the coarseness of the finite element meshes was reduced to a medium value. Adopting a medium to fine mesh density allowed us to lower the calculation time and computer memory requirements. Medium-to-fine sized meshes were created using a variety of components and nodes for the finite element model [22]. Additionally, improvements were made to structural components- including piles, anchors, and grouting- because of mesh refinements (as shown in Figure 4 and Table 2) [1] [23].

4. Results and discussion

4.1. Stability analysis

The steadiness of the slope was evaluated at three different sections: A-A, B-B, and C-C. The results of the calculations for the various forces and moments are shown in the Figure 5 and Table 3.

Table 2. Specification of FEM models for each part.

Sr.No.	Section	Edge length	No. of nodes	No. of elements
1.	A-A (Natural condition)	2m	25116	13942
2.	A-A (Stable condition)	2m	21328	12073
3.	B-B (Natural condition)	2m	24145	12519
4.	B-B (Stable condition)	2m	22924	10768
5.	C-C (Natural condition)	2m	15418	11275
6.	C-C (Stable condition)	2m	13937	10437

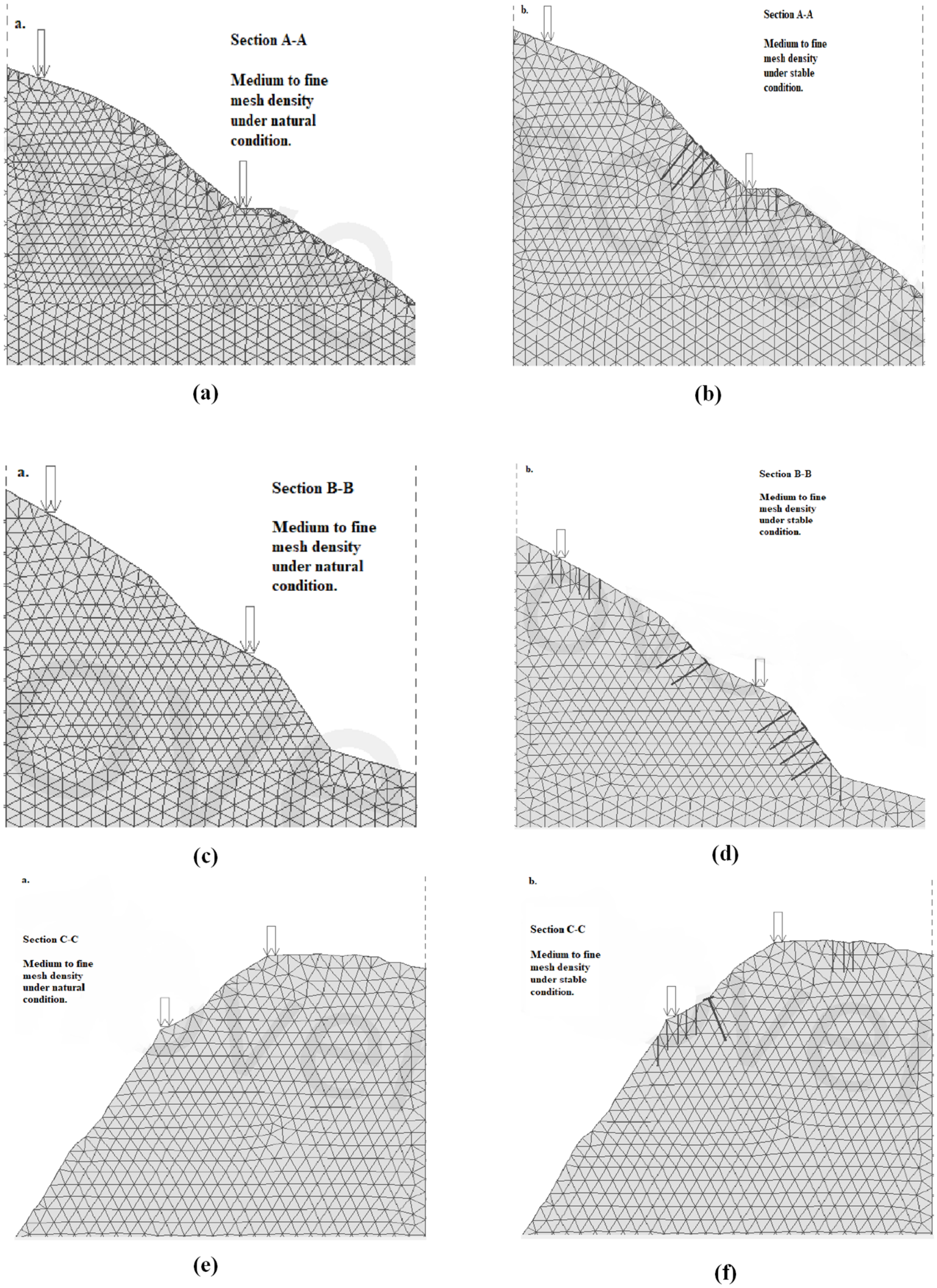

Figure 4. Finite element model for all sections from medium to fine mesh density.

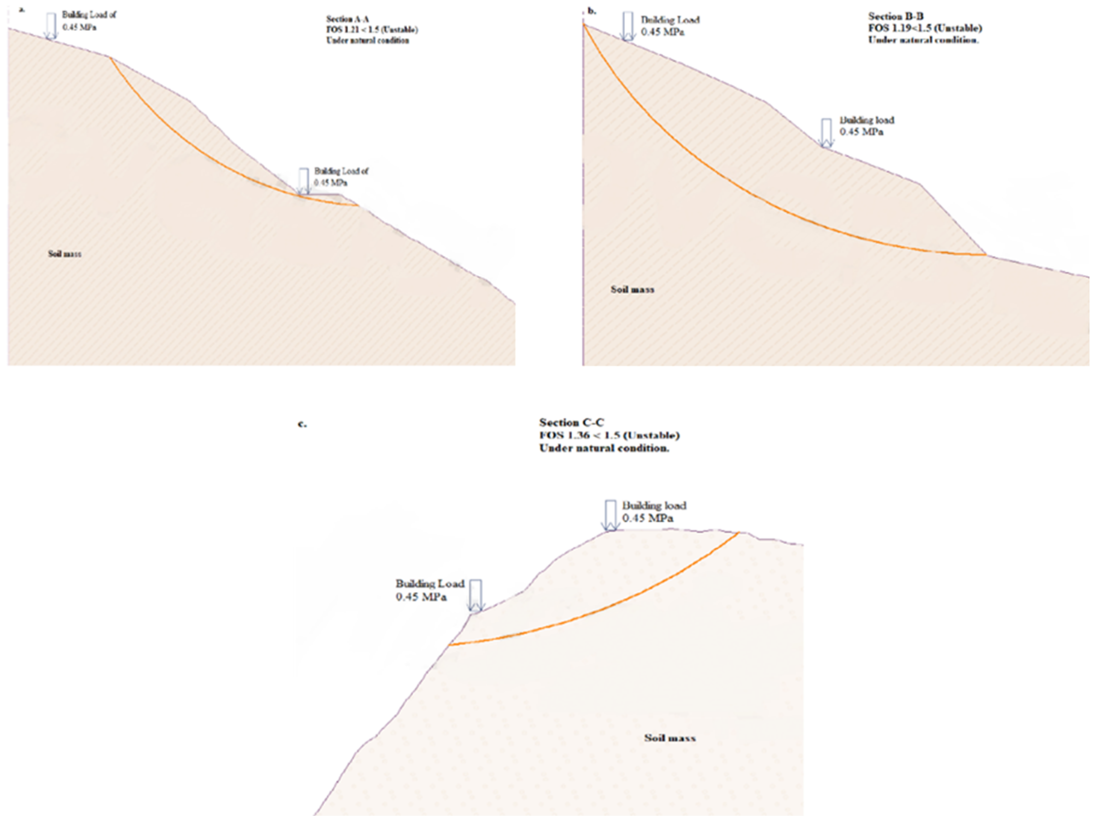

Figure 5. a) Stability check of Section A-A. b) Stability check of Section B-B. c) Stability check of Section C-C under natural condition.

Table 3. Forces and moments acting on sections A-A, B-B and C-C under natural condition.

Section	Active force (kN/m)	Passive force (kN/m)	Sliding moment kNm/m	Resisting moment kNm/m	FOS	Remark
A-A	6160.02	7466.48	713823.60	865215.65	1.21	Unsafe (<1.5)
B-B	12673.17	15029.89	3205805.68	3801961.96	1.19	Unsafe (<1.5)
C-C	10071.52	13648.41	1025783.94	1390090.77	1.36	Unsafe (<1.5)

The graphical representation of this analysis is provided in Figure 5 for the A-A, B-B, and C-C portions. To maintain the structural integrity of the sections, the passive forces and resisting moments must be greater than the active forces and sliding moments. Remedies were used to maintain the stability of the parts. After computing and analysing, the software will display FOS (Table 3). Figure 5 displays the FOS output files that were produced.

In the studied area, a combination of several types of solutions will be required- such as piles, rock bolting, anchoring, reinforcing, and nails. Based on the geotechnical features of the location, a combination of piles, anchors, and grouting appears to be the most viable approach. To protect the structure adjacent to the support system's construction, it is required to build it in phases. The stability evaluation shows that each of the evaluated components has the bare minimum of required FOS and applicable support.

4.1.1. Considering section- A-A

The following are the analysis and stability checks at each stage (Figure 6).

1. The installation of the four piles was done at a depth of 10 m, with a diameter of 0.3 m, and a bearing capacity of pile, Vu 120 kN.
2. In addition, two additional piles were installed at a depth of 7.5 m, with a diameter of 0.3 m, and a bearing capacity of pile, Vu 120 kN.
3. Another remedy was three anchors, two of which were 20 m long and one of which was 15 m long, with 1m spacing and a slope of 125° from the horizontal.
4. Following the installation of the aforementioned corrective measures, cement grouting was

carried out to a depth of 2 m down the slope. At 3, 7, and 28 days, the compressive strength of the cement grout was 59.90, 60.29, and 75.20 MPa, respectively. The cement grout properties as shown in Table 4.

Table 4. Cement grout properties

Properties	Values
Unit weight (γ)	14.4 kN/m^3
Internal angle of friction (ϕ)	36^0
Cohesion (c)	36kPa
Saturated unit weight (γ_{s})	15 kN/m^3

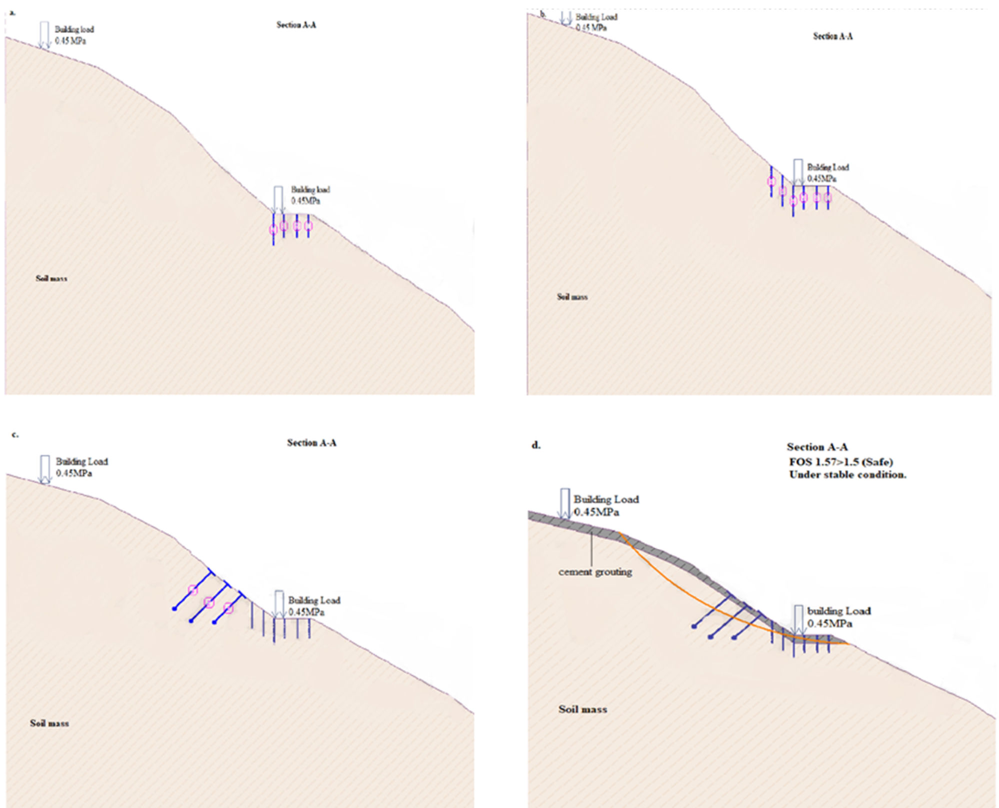

Figure 6. Steps involved in section A-A, (a) and (b) installation of piles. (c) Installation of anchors. (d) Stability checks after all remedies.

Table 5. Forces and moments acting on section A-A under stable condition.

Section	Active force (kN/m)	Passive force (kN/m)	Sliding moment kNm/m	Resisting moment kNm/m	FOS	Remark
A-A	5543.55	8708.43	642386.14	1009129.51	1.57	Safe (>1.5)

The A-A segment, after a predetermined depth, anchors were installed along with the pile in this portion. The stability checks were conducted after the installation of each stage of remedies. 5543.55 kN/m was the value of active force, which must be smaller than 8708.43 kN/m, the value of passive force. In addition, the sliding moment value was 642386.14 kNm/m, which must be smaller than the resisting moment value of 1009129.51 kNm/m. Under stable conditions, the stability of the slope depends on these two parameters. (Table 5).

4.1.2. Considering section- B-B

The following are the analysis and stability checks at each stage (Figure 7).

1. The installation of the two piles was done at a depth of 15 m, with a diameter of 0.3 m, and a bearing capacity of pile, Vu 120 kN.

2. In addition, six additional piles were installed at a depth of 15 m, with a diameter of 0.3 m, and a bearing capacity of pile, Vu 120 kN.

3. Another remedy was installing two anchors, each 20 m long, with 1 m of spacing and a slope of 125º from the horizontal.

4. In addition, four additional anchors were installed having 20 m long, with 1m spacing and a slope of 125º from the horizontal.

5. Following the installation of the aforementioned corrective measures, cement grouting was carried out to a depth of 2 m down the slope. The cement grout properties as shown in Table 4.

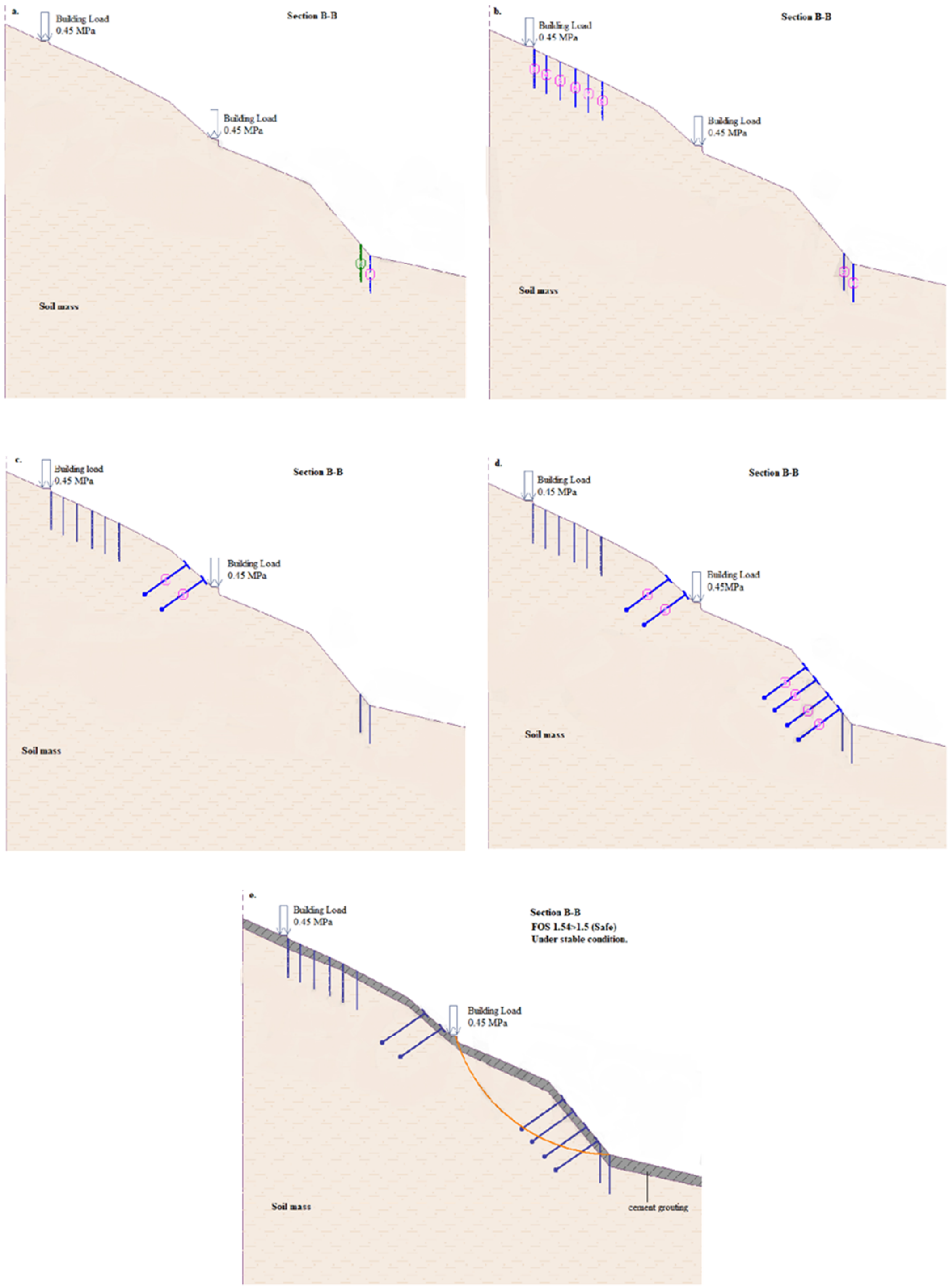

Figure 7. Steps involved in section B-B, (a) and (b) installation of piles. (c) and (d) installation of anchors. (e) stability checks after all remedies.

Table 6. Forces and moments acting on section B-B under stable conditions.

Section	Active force (kN/m)	Passive force (kN/m)	Sliding moment kNm/m	Resisting moment kNm/m	FOS	Remark
B-B	11342.58	17475.26	710952.86	1095349.44	1.54	Safe (>1.5)

Section B-B, which addresses the slope's stability in static situations. This figure must be less than the passive force value, which was 11342.58 kN/m. The active force was 17475.26 kN/m. In addition, the sliding moment value was 710952.86 kNm/m, which must be smaller than the resisting moment value of 1095349.44 kNm/m (Table 6).

4.1.3. Considering the section, C-C

The following are the analysis and stability checks at each stage (Figure 8).

1. The installation of the five piles was done at a depth of 15 m, with a diameter of 0.3 m, and a bearing capacity of pile, V_u 120 kN.
2. In addition, three additional piles were installed at a depth of 15 m, with a diameter of 0.3 m, and a bearing capacity of pile, V_u 120 kN.
3. Another remedy was installing an anchor, 20 m long, with 1 m of spacing and a slope of 125° from the horizontal.
4. Following the installation of the aforementioned corrective measures, cement grouting was carried out to a depth of 2 m down the slope. The cement grout properties as shown in Table 4.

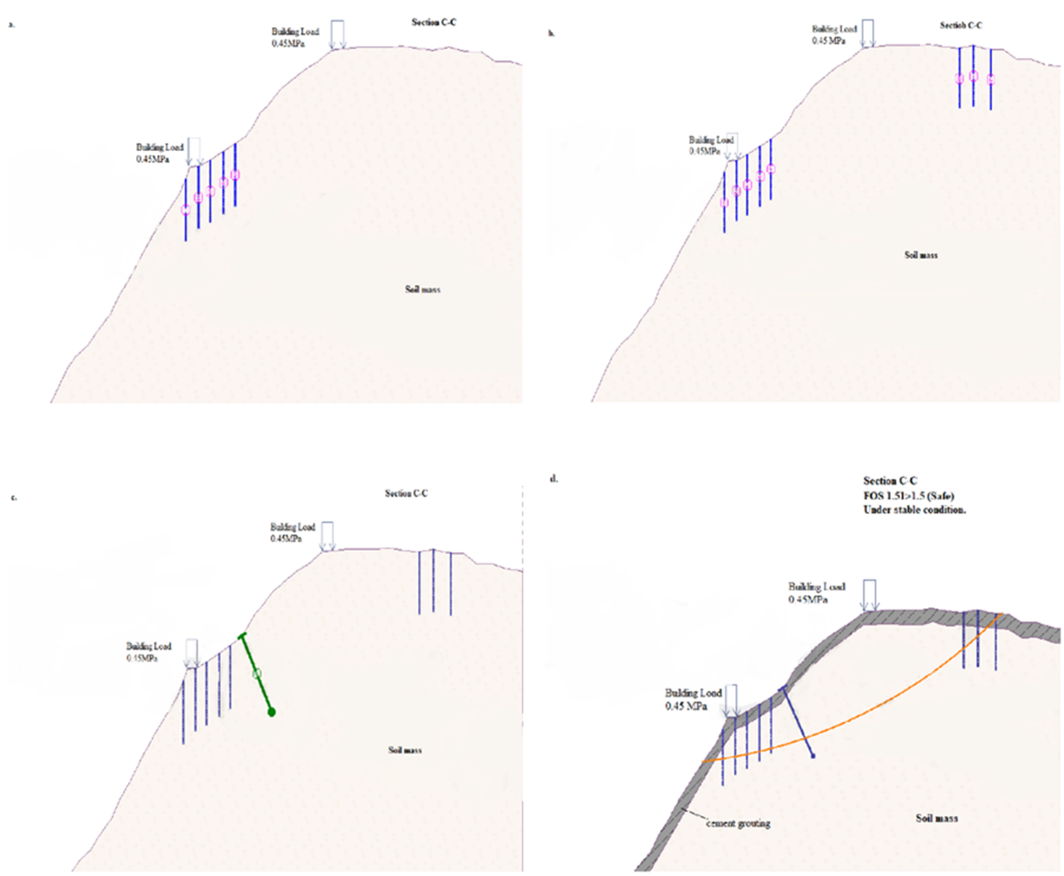

Figure 8. Steps involved in section C-C, (a) and (b) installation of piles. (c) Installation of anchors. (d) Stability check after grouting and all remedies.

Table 7. Forces and moments acting on section C-C under stable condition

Section	Active force (kN/m)	Passive force (kN/m)	Sliding moment kNm/m	Resisting moment kNm/m	FOS	Remark
C-C	9276.80	13929.87	944842.33	1418757.42	1.51	Safe (>1.5)

Section C-C, which addresses the slope's stability in static situations. This value must be less than the passive force value, which was 9276.80 kN/m. The active force was 13929.87 kN/m. In addition, the sliding moment had a value of 944842.33 kNm/m, which must be smaller than the resisting moment, which was 1418757.42 kNm/m (Table 7).

4.2. Validation

The results of the stability study that were provided by [24] were evaluated alongside the results of the present slope stability analysis. This is because both studies were conducted in the lower Himalayan region, as shown in Figure 9. The researchers- [24] employed the following soil parameters in their study: cohesiveness of 12 kPa, internal friction angle of 26.5°, unit weight of 18 kN/m^3, and Poisson's ratio of 0.35, respectively. The comparison of the factor of safety (FOS) was shown in Table 8, and it corresponded to the natural situation and the stable condition after the remedies were applied. In addition, the results of the stability analysis that were reported by [25] were compared with the findings of the current study. The region of the lower Himalayas was also the location of this case study's execution. [25] Utilized the following soil parameters in their study:- cohesiveness of 15.5 kPa, internal friction angle of 32°, unit weight 25kN/m^3, and Poisson's ratio of 0.20, respectively. The comparison of the factor of safety (FOS) was shown in the figure, and it corresponded to the natural situation and the stable condition after the treatments were implemented.

Since [24] reported the height to be 1300 m and [25] reported the elevation to be 1200 m, it's possible that the difference in results is attributable to the difference in elevation from the mean sea level (MSL).

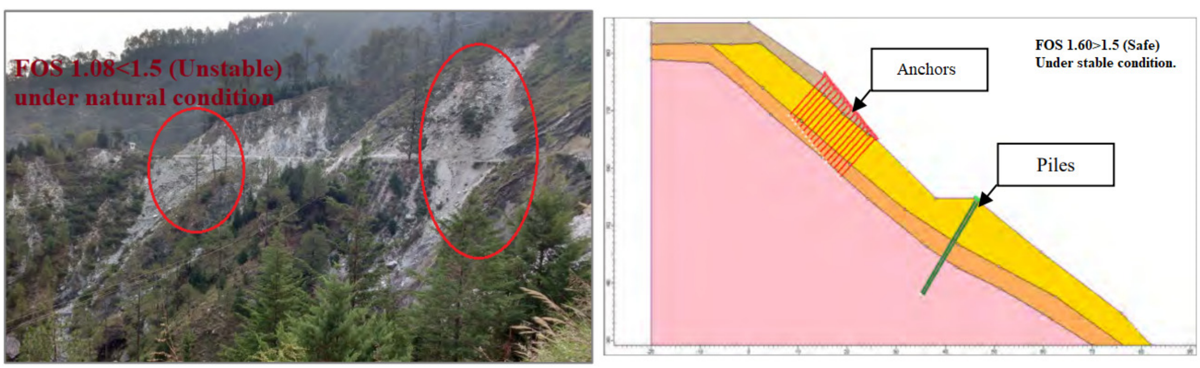

Figure 9. Natural and stable condition of studied area by [24].

Table 8. Comparison.

Studied area condition	Factor of safety (FOS)				
	Present study			Koushik Pandit *et al.*	Gaurav Tiwari *et al.*
	Section A-A	Section B-B	Section C-C		
Natural	1.21	1.19	1.36	1.08	1.01
Stable	1.57	1.54	1.51	1.6	1.52
Elevation from mean sea level (m)		1593		1300	1200

5. Conclusions

The studied area is situated on terrain with a 35-degree slope, and is surrounded on three sides by residential structures that are 2 m to 6 m from the plot edge. Using the Geo5 software, the ideal solution for stabilizing the slope without affecting the stability of neighboring structures was identified. The research area has three sections: A-A, B-B, and C-C. The results of this investigation have led to the following conclusions:

1. Using Geo5 as a stability check tool, the factor of safety (FOS) under natural conditions falls below the minimum FOS for all sections. Because the active forces and sliding moments are greater than the passive forces and resistive moments in the sections.
2. The stability of the slope section is improved largely by using the combination of piling, anchors, and grouting. By combining the remedies, the passive forces and resistive moments increase compared to the active forces and sliding moments acting on the sections.
3. The Mohr's coulomb failure criterion is applied to the sections, in order to obtain the failure envelope in the sections. Where the failure envelops exists, a combination of remedies is typically used.
4. The factor of safety for the stable slope section ranges between 1.50 and 1.58, whereas in its natural state it falls between 1.21 and 1.38.

Because of the economic and physical destruction, these areas required preventative measures to be taken. As a direct consequence of this, the preventative measures were implemented in this section of the study. The engineers are able to establish the methods of slope stabilisation that are the most effective by using the criteria that are associated with the research area.

Acknowledgement to the CSIR-CBRI Roorkee in Uttarakhand for their assistance with numerical modelling, acknowledgement is due to the writers.

Funding the author did not receive any financial reward of any type for his or her work.

A conflict of interest with the subject matter of the paper does not exist for the author.

References

[1]. Sarfaraz, H., Bahrami, A.R., and Samani, R. (2022). Numerical Modelling of Slide-Head-Toppling Failure using FEM and DEM Methods. Journal of Mining and Environment. 13 (1): 269-280.

[2]. Khosravi, M.H., Pipatpongsa, T., Takemura, J., and Amini, M. (2017). Influence of modeling material on undercut slope failure mechanism. Journal of Mining and Environment. 8 (4). 645-662.

[3]. Zebarjadi Dana, H., Khaloo Kakaie, R., Rafiee, R., and Yarahmadi Bafghi, A.R. (2018). Effects of geometrical and geomechanical properties on slope stability of open-pit mines using 2D and 3D finite difference methods. Journal of mining and Environment. 9 (4). 941-957.

[4]. Turanboy, A., Ülker, E., and Küçüksütçü, C.B. (2018). A new approach for assessing stability of rock slopes considering centroids of weak zones. Journal of Mining and Environment. 9 (1). 1-18.

[5]. Sarfaraz, H. (2020). Stability analysis of block-flexural toppling of rock blocks with round edges. Journal of Mining and Environment. 11 (4). 1217-1229.

[6]. Alikhani, A., Taheri Moghadder, M., and Mohammadi, H. (2020). Investigation of Bishop's and Janbu's Models Capabilities on Slope Stability Problems with Special Consideration to Open-Pit Mining Operations. Journal of Mining and Environment. 11 (1). 161-170.

[7]. Shah, K.S., Mohd Hashim, M.H., Ariffin, K.S., and Nordin, N.F. (2020). A Preliminary Assessment of Rock Slope Stability in Tropical Climates: A Case Study at Lafarge Quarry, Perak, Malaysia. Journal of Mining and Environment. 11 (3). 661-673.

[8]. Fattahi, H., Babanouri, N., and Varmaziyari, Z. (2018). A Monte Carlo simulation technique for assessment of earthquake-induced displacement of slopes. Journal of Mining and Environment. 9 (4). 959-966.

[9]. Shafiei Ganjeh, R., Memarian, H., Khosravi, M.H., and Mojarab, M. (2019). A comparison between effects of earthquake and blasting on stability of mine slopes: a case study of Chadormalu open-pit mine. Journal of mining and Environment. 10 (1). 223-240.

[10]. Hussain, S., Rehman, Z.U., Khan, N. M., Ahmad, I., Raza, S., Tahir, M., and Sherin, S. (2021). Proposing a Viable Stabilization Method for Slope in a Weak Rock Mass Environment using Numerical Modelling: a Case Study from Cut Slopes. Journal of Mining and Environment. 12 (4). 929-940.

[11]. Adil, M., Raza, S., and Amin, I. (2021). Rock Fall Hazard Assessment using GeoRock 2D along Swat Motorway, Pakistan. Journal of Mining and Environment. 12 (2). 351-365.

[12]. Kumar, A., Sharma, R.K., and Mehta, B.S. (2020). Slope stability analysis and mitigation measures for selected landslide sites along NH-205 in Himachal Pradesh, India. Journal of Earth System Science. 129 (1). 1-14.

[13]. Shooshpasha, I., Amirdehi, H.A., and Kharun, M. (2020, November). Factors influencing the critical piles length in reinforced slope. In Journal of Physics: Conference Series (Vol. 1687, No. 1, p. 012018). IOP Publishing.

[14]. TOLUN, M., Buse, Ü.N., EMİRLER, B., and YILDIZ, A. (2021). Stability Analyses of a Slope Reinforced with Piles Subjected to Static and Dynamic Loading Conditions. El-Cezeri. 8 (3). 1360-1371.

[15]. D. Christodoulou, P. Lokkas, A. Droudakis, X. Spiliotis, D. Kasiteropoulou, and N. Alamanis, "The Development of Practice in Permeation Grouting by using Fine-grained Cement Suspensions," Asian J. Eng. Technol., Vol. 9, No. 6, pp. 92–101, 2021, doi:

10.24203/ajet.v9i6.6846.

[16]. Ntalianis, K., Ntaliani, M., Kikili, V., Ntalianis, F., and Mastorakis, N. (2021). Inaccessible Island vs Urban Education in Greece. WSEAS Transactions on Advances in Engineering Education, 18, 1-6.

[17]. M. Kisan, S. Sangathan, J. Nehru, and S. G. Pitroda, "म ा नक," 1996.

[18]. Bryson, L.S., and Giraldo, J.R. (2020). Analysis of case study presenting ground anchor load-transfer response in shale stratum. Canadian Geotechnical Journal. 57 (1). 85-99.

[19]. B. of Indian Standards, "IS 14448 (1997): Code of practice for reinforcement of rock slopes with plane wedge failure," 1997.

[20]. IS14243-2, "Guidelines for selection and development of site for building in hill areas, Part 2: Selection and development," *Bur. Indian Stand. N.Delhi, India*, 1995.

[21]. Liu, Y., and Glass, G. (2013). Effects of Mesh Density on Finite Element Analysis 2013-01-1375.

[22]. Acharyya, R., and Dey, A. (2017). Finite element investigation of the bearing capacity of square footings resting on sloping ground. INAE Letters. 2 (3). 97-105.

[23]. Sarfaraz, H., Khosravi, M.H., and Pipatpongsa, T. (2021). Numerical Stability Analysis of Undercut Slopes Evaluated by Response Surface Methodology. Journal of Mining and Environment. 12 (1). 31-43.

[24]. Koushik, P., Shantanu, S., Manojit, S., and Mahesh, S. (2016, November). Stability analysis and design of slope reinforcement techniques for a Himalayan landslide. In Recent Advances in Rock Engineering (RARE 2016) (pp. 97-104). Atlantis Press.

[25]. Tiwari, G., and Latha, G.M. (2016). Design of rock slope reinforcement: an Himalayan case study. Rock Mechanics and Rock Engineering. 49 (6). 2075-2097.

ارزیابی پایداری شیب و درمان آن در پالامپور، هیماچال پرادش

آلانکریت ولیا* و امریت کومار روی

۱. گروه مهندسی عمران، موسسه ملی فناوری هامیرپور، هند

ارسال ۲۰۲۲/۰۸/۱۶، پذیرش ۲۰۲۲/۰۹/۱۹

* نویسنده مسئول مکاتبات: 21mce022@nith.ac.in

چکیده:

جغرافیای پیچیده رشـــته کوه هیمالیا به همراه شـــرایط طبیعی موجود و شـــیوه‌های تأثیرگذاری و مداخله مردم در منطقه، مناطق مختلف این رشـــته را در برابر ناپایداری شیب آسیب پذیر می‌کند. پایداری شیب منطقه ای که موضوع این کار است در پالامپور که در ناحیه کانگرا هیماچال پرادش است ارزیابی شده است. هدف اصلی این کار این است که اطمینان حاصل شود که شیب پایدار می‌ماند به طوری که سازه‌های مسکونی سه طرفه نزدیک و بزرگراه محافظت می‌شوند. پس از بازدید از محل، مطالعات ژئوتکنیکی که شامل آزمایش به صورت حفره چاله و آزمایشگاهی می‌باشد، انجام شد. پس از ارزیابی گزارش فنی ژئوتکنیکی، گام بعدی در فرآیند شروع به تحلیل پایداری شیب است. به منظور تجزیه و تحلیل تحلیلی پایداری شیب، منطقه به سه قسمت تقسیم شده و به ترتیب A-A، B-B و C-C برچسب گذاری شده است. با استفاده از روش‌های مدل سازی عددی، پارامترهای طراحی کاهش برای منطقه و شکست لغزش دایره‌ای محاسبه می شوند. این محاسبات بر اساس مشخصات ژئوتکنیکی منطقه مورد مطالعه مشخص شده است. ضریب ایمنی برای هر دو سناریو طبیعی و پایدار توسط برنامه محاسبه شد. به همین دلیل، برخی اقدامات پیشگیرانه و چند بهبود پیشنهاد می‌شود.

کلمات کلیدی: پایداری شیب، مدل‌سازی عددی، شکست لغزش دایره‌ای، مدل‌سازی عددی، بزرگراه.