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Slope Stability Analysis and Preventive Actions for a Landslide Location along NH-05 in Himachal Pradesh, India

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Abstract

The Himalayan mountain range is susceptible to slope instability in numerous areas due to its complicated topography, because of the existing natural conditions and human influence and intervenes. National Highway-05 is considered in this work. The area under investigation located in Rampur, district Shimla, Himachal Pradesh is evaluated for slope stability. The primary purpose of this work is to maintain the slope's stability in order to protect NH-05 and the neighboring three-sided residential structures. Following the site visit, the geotechnical investigations in the form of bore holes and laboratory tests are conducted. Analysis of slope stability is commenced after interpreting the geotechnical study report. For an analytic slope stability, the studied area is divided into three sections, labelled A1-A1', B1-B1', and C1-C1'. Taking into account the geotechnical aspects of the specified research region, the mitigation design parameters for the area and the circular slip failure are calculated using the numerical modeling techniques. The software computes the safety factor for both the static and dynamic situations. As a result, preventative measures and a few improvements are suggested.

1. Introduction

The geotechnical engineers have always had a strong interest in determining the stability of slopes. There is a lot of debate over what methodologies to use in applications and how to pick the right soil parameters to analyse. Since the soil behavior affects the slope stability analysis accuracy, the soil characteristics are critical inputs for numerical models. The soil properties must be accurately measured for an appropriate slope stability study. The easiest way to accomplish this is to conduct a few site investigations. A method (e.g.- finite difference method, limit equilibrium method, finite element approach,) that has various materials and soil models in which soil behavior and stresses (e.g.- static or dynamic) can be modelled realistically is also required [1-3].

The use of two-dimensional finite element modelling in slope stability analysis has been a trend in the recent years, and the geotechnical researchers have taken advantage of this. Furthermore, as computing power improves, the finite element method's use in geotechnical investigations is becoming more widespread. A number of advantages include the ability to accurately depict slopes (i.e., complicated geometry, variable loading conditions, and the inclusion of material as reinforcement) and to better illustrate soil deformations [4 & 5]. Another benefit is that no assumptions about the position or geometry of the failure surface need to be made in advance. When the soil's shear strength is unable to withstand the imposed forces, the failure occurs naturally. However, it is essential for the designers to understand the results of the analysis because of the many variables. Several case studies are included in this section to show how well the finite element method works.

Each variable that contributes to slope stability was examined using the strength reduction approach- including pile support, slope curvature, and local loading of the slope by structures [6-8]. According to the author, the concave slopes are

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more stable than the straight ones. Compared to a straight slope, smooth concave curvatures raised the safety factor values by 5-10% and acute concave curvatures by 15-25%. A near safety factor was achieved by piles with radial, circular, and rectangular cross sections. Pile row placement was generally agreed upon to be between the middle of the slope and the centre of the critical shear surface, but most often close to the middle of the slope without any surcharge. However, the pile row had to move uphill toward the load to make sure the slope was stable both globally and locally when there was local loading at the top of the slope because the shear strains were mobilized by the surcharge [9 &10].

A number of numerical analyses were carried out in order to better understand the effects of pile spacing and location on the strength of a slope reinforced with a single row of piles. Slope stability was shown to be greatly affected by soil-pile interaction; as such, the failure mechanism of the piled slope varied depending on whether piles were situated at the top, middle, or bottom of the slope. To maximise safety, it was recommended that the piles be placed in the middle to upper half of the slope [11-13].

They used numerical analysis to analyse the performance of the piles in order to discover the cause of a slope's failure. In order to make the system more stable, the free-head pile worked less well than the fixed-head pile. Because of this, the failure surface of the whole system was said to have been changed by the pile head conditions [14 & 15].

As seen in the preceding literature review, there are numerous aspects that influence the safety factor of a slope that has been fortified with piles and other remedies. In this work, both the static and dynamic conditions were used to figure out how well the slope stability would work from a safety viewpoint, taking into account the diameter, length, and spacing of the piles and anchors.

2. Studied area

In this work, National Highway 05 is considered- The area under investigation is located in Rampur, district Shimla Himachal Pradesh at latitude 25°54'53.50"N and longitude 82°5'25.50"E (Figure 1). The research area measures 30 m wide by 25 m long. The southern side of the land is 989 m above the sea level, while the northern side is around 1000 m above the sea level. On the east, north, and west sides of the site are buildings; NH-05 is on the south.

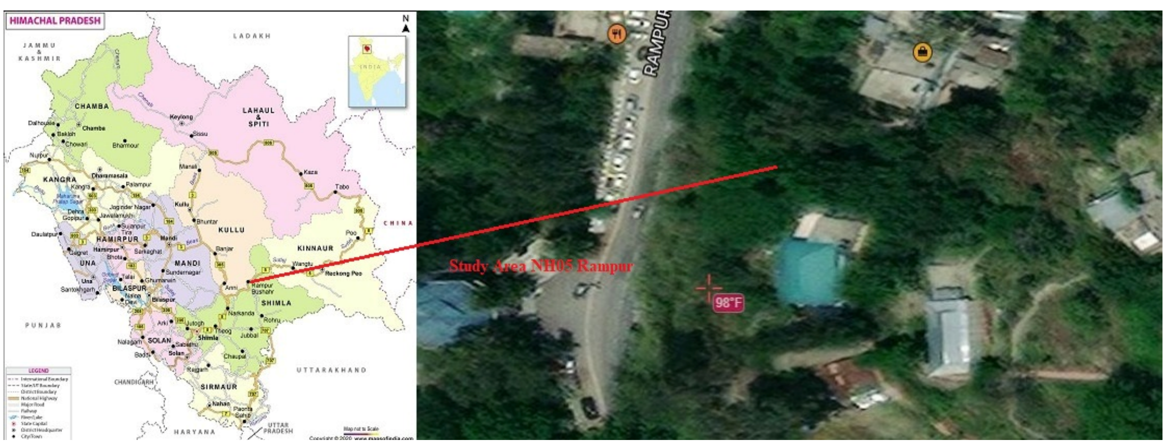

Figure 1. Location on map of studied area in Rampur Himachal Pradesh, India.

On three of the plot's four sides, the research area is cut off by around 10 m. In addition, on three sides, the studied area is bordered by residential development. It is barely 2m from the plot's boundary on the left and right, but it is around 6m from the boundary on the backside.

This involves ensuring that the maximum amount of space can be used for stability through the preventive measures.

3. Methodology

The main objective of this work was to keep the slope stable so as to safeguard the NH-05 and also the residential buildings surrounding it in three directions.

The first step is a reconnaissance survey, which includes a site evaluation of the planned site. There are houses on all three sides of the site, with the land sloping from mid-to-high, as discovered during the site tour. The geotechnical investigations were carried out at the site following the visit, in the form of bore holes and laboratory testing. The slope stability analyses were following the interpretation of the geotechnical investigation report. The stability analysis and design of a cut slope are shown in the following section (Figure 2).

3.1. Geotechnical properties of studied area

The design of the cut slope is based on the analysis results. Listed in the table are the engineering properties that were used in the analysis (Table 1).

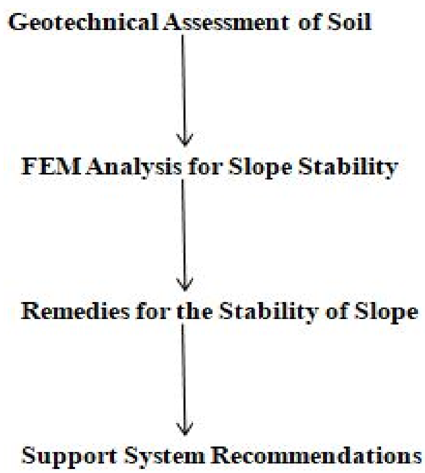

Figure 2. Flowchart showing approach and methodology involved in this work.

Table 1. Soil properties of studied area used in analysis.

Property	Unit	Soil
Unit Weight, ϒ	kN/m^3	19
Poisson's ratio	Unitless	0.25
Deformation modulus, E	MPa	16
Cohesion, c	MPa	0.023
Friction angle,	°	30°

3.1.1. Loads

1. Earthquake load

According to IS 1893-part 1, the research area is located in Zone 4. The seismic coefficients can be obtained by doing the following calculations [16].

$$\text{Horizontal Seismic Coefficient (Ah)} = \frac{ZISa}{2R} \quad (1)$$

where, Z = Zone factor, based on location = 0.24 for Zone IV

I = Importance Factor, for Important Structures = 1.5

Sa/g = Design acceleration coefficient for different type of soil and rock = 2.5

R = Response Reduction Factor = 3

Calculated Horizontal Seismic Coefficient (A_h) = 0.15

Vertical Seismic Coefficient (A_v) = 0.10 (2/3 of Ah)

2. Building Loads

The northern edge of the studied area is bordered by the G+1 buildings. In these buildings, the axial stress created is 0.4, 0.4, and 0.4 MPa. In ETABS, the finite element mathematical model of the building was looked at in light of the loads that the G+1 structure put on the foundations.

3.2. Assumptions for slope stability analysis

The following assumptions were adopted in the analysis:

1. The site observations and laboratory tests are used to estimate all of the soil mass characteristics.
2. The Mohr-Coulomb failure criterion is used in the study, which is based on the idea that the soil mass is homogeneous.
3. In addition to the forces exerted by the body, the effect of gravity is also taken into account. Other structures, including buildings, are also included in the design.
4. The analysis ignores temperature and creep stress.
5. The impact of grouting was not taken into account during the study.

According to the IS code 14243 (Part 2), if the FOS value is higher than the minimum, the structure is safe under the current loading and support conditions. The structure will be redesigned if FOS falls below the required level (Table 2)[17].

Table 2. Minimum FOS required.

Case	Required minimum FOS
Static case	≥1.5
Dynamic case	≥1.2-1.5

With the help of the Geo5 software, stability check and preventive measures were performed.

3.3. Section for analysis

Three different sections were divided from the studied area, namely A_1-A_1', B_1-B_1'and C_1-C_1' so as to analyse the slope stability as shown (Figure 3).

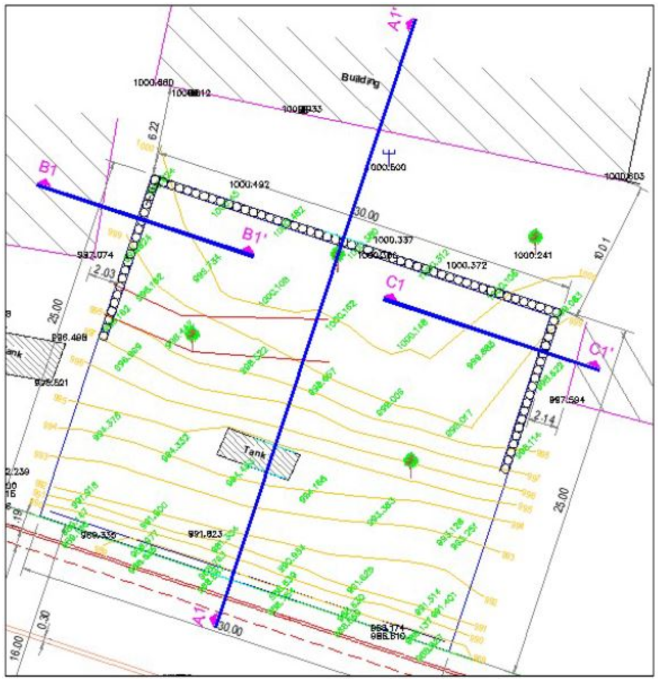

Figure 3. Section adopted for analysis.

3.4. Description of numerical model

A two-dimensional finite element method was used throughout the study to evaluate the slope's safety factor under both the static and dynamic loads. The Mohr-Coulomb model was used in this study's numerical analysis to represent the soil's behaviour.

Finite element models' accuracy and complexity are directly related to mesh density in the finite element method, which is a key issue. Because of its importance, choosing the right element size for a finite element model is the most pressing issue when it comes to getting reliable findings from finite element analysis [18]. As a result of these factors, a series of numerical computations were conducted in order to find the optimal mesh density. Five alternative mesh densities, ranging from the coarsest to the finest, were evaluated in the numerical analyses. As a result, the mesh density was increased from medium to very fine without significantly altering the findings. Therefore, the finite element meshes were scaled down to medium-to-fine sizes. In order to reduce the computation time and computer memory requirements, it was made possible by adopting a medium to fine mesh density. For the finite element model, a number of elements and nodes were used to construct a mesh that ranged from medium to fine in size. Also- structural parts like piles and anchors got better because of the changes to the mesh [19].

Table 3. Specification of FEM models for each part.

S.No.	Section	Edge length	No. of nodes	No. of element
1.	Section A_1-A_1' (Natural condition)	1m	24587	12730
2.	Section A_1-A_1' (Stable condition)	1m	20457	10489
3.	Section B_1-B_1' (Natural condition)	1m	20896	10881
4.	Section B_1-B_1' (Stable condition)	1m	18245	8547
5.	Section C_1-C_1' (Natural condition)	1m	13204	6925
6.	Section C_1-C_1' (Stable condition)	1m	11548	5214

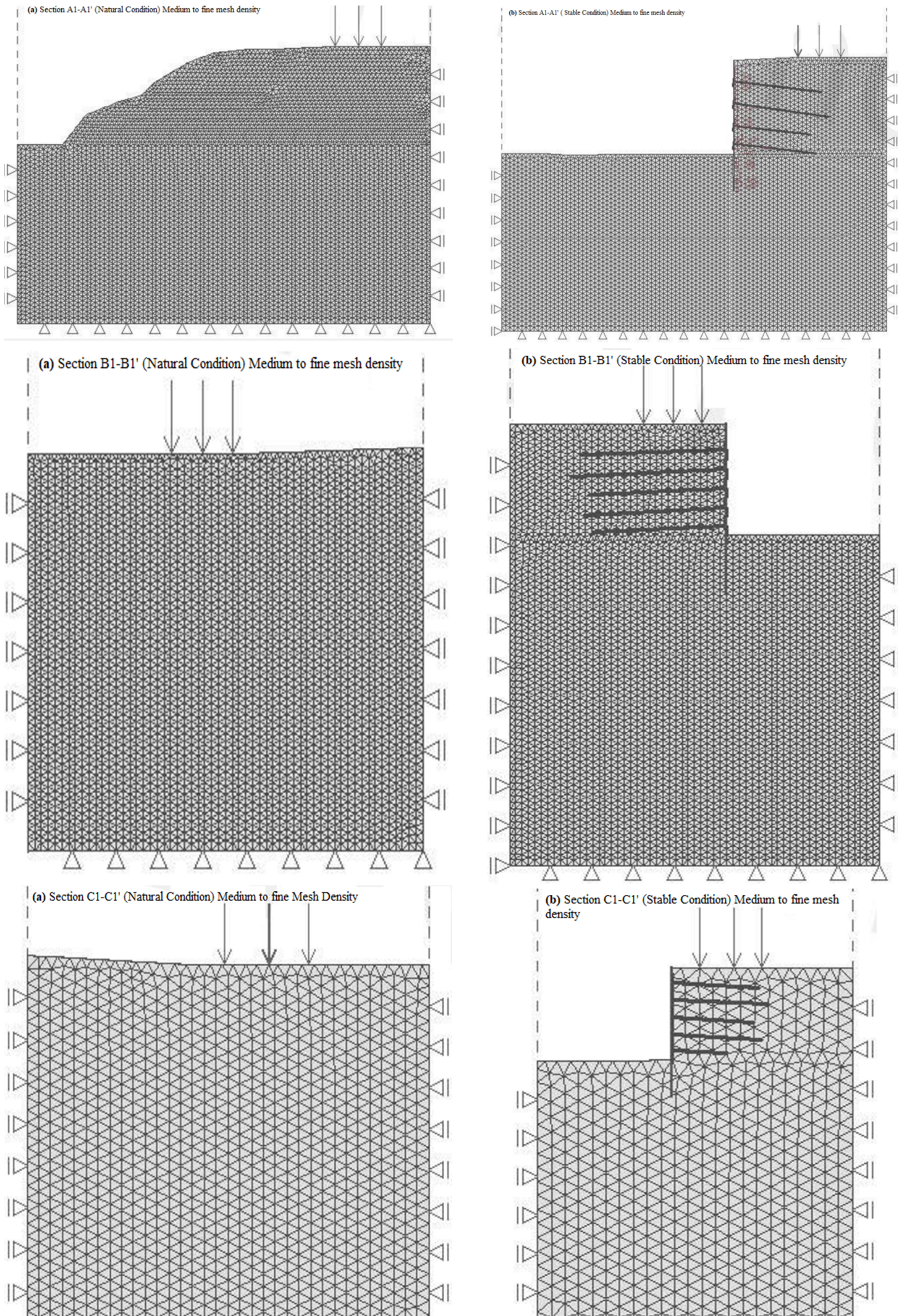

Figure 4. Finite element model for all sections from medium to fine mesh density.

4. Results and Discussion

It is common practice to evaluate slopes in terms of their ability to resist sliding. With a wide range of topography and materials, the NH-05's slope conditions are quite varied. The material's shear strength is affected by variations in moisture content and physical–chemical characteristics. Because of the wide variety of materials and their varying physical qualities, greater attention is being drawn to the need for an accurate model for mitigating the various types and dimensions of landslides that have been exposed or that are projected to occur in the future. Stability in the portions of NH-05 was found to be caused by an inherent physical property of the slope forming material like shear strength capacity, asymmetrical slope geometry, and structural features that significantly diminish effective shear strength. In addition, human actions have altered the slope geometry, causing instability on the NH-05. Taking into consideration the geotechnical considerations of the selected studied area, the mitigation design parameters of the area and circular slip failure were carried out by using the software Geo5.

4.1. Stability analysis results

For both the static and dynamic scenarios, the software calculates the Factor of Safety (FOS) and displays (Table 3). The figures show the FOS output files that were generated. Each of the examined portions has the minimum necessary FOS and relevant support.

For the stability check, consider sections A_1-A_1' (Figure 4).

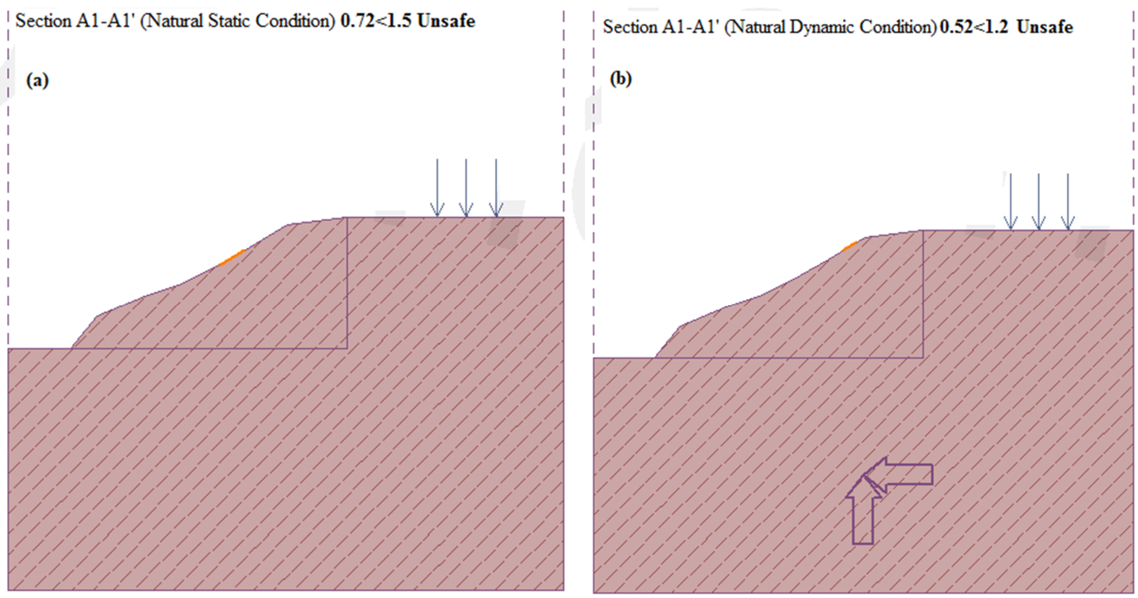

Figure 5. Section A_1-A_1' FOS at (a) static and (b) dynamic condition.

Table 4. Forces and moments acting on section A1-A1' before remedies under static and dynamic conditions.

Sections	Active forces (kN/m)	Passive forces (kN/m)	Sliding moment kNm/m	Resisting moment kNm/m	FOS	Remark
A_1-A_1' (Static)	0.13	0.09	1.10	0.79	0.72 < 1.5	Unsafe
A_1-A_1' (Dynamic)	0.14	0.07	13.17	6.81	0.52 < 1.2	Unsafe

Section A_1-A_1' is clearly unstable under the surcharge as shown in the table. Anchors and piles are put in place to ensure the system's stability. For both the static and dynamic situations, FOS must be met.

Following are the five stages of the stability analysis.

1. Installation of piles depth 10m and diameter 0.5m.
2. Excavation upto 4m depth and installation of anchor at 2m from top (length = 10m, slope = 10° from horizontal, diameter = 32ϕ).
3. Excavation upto 6m depth and installation of

anchor at 4m from top (length = 10m, slope = 10° from horizontal, diameter = 32ϕ).

4. Excavation upto 8m depth and installation of anchor at 6m from top (length = 10m, slope = 10° from horizontal, diameter = 32ϕ).

5. Excavation upto 10m depth and installation of anchor at 8m from top (length = 10m, slope = 10° from horizontal, diameter = 32ϕ) (Figure 5 and 6) (Table 4).

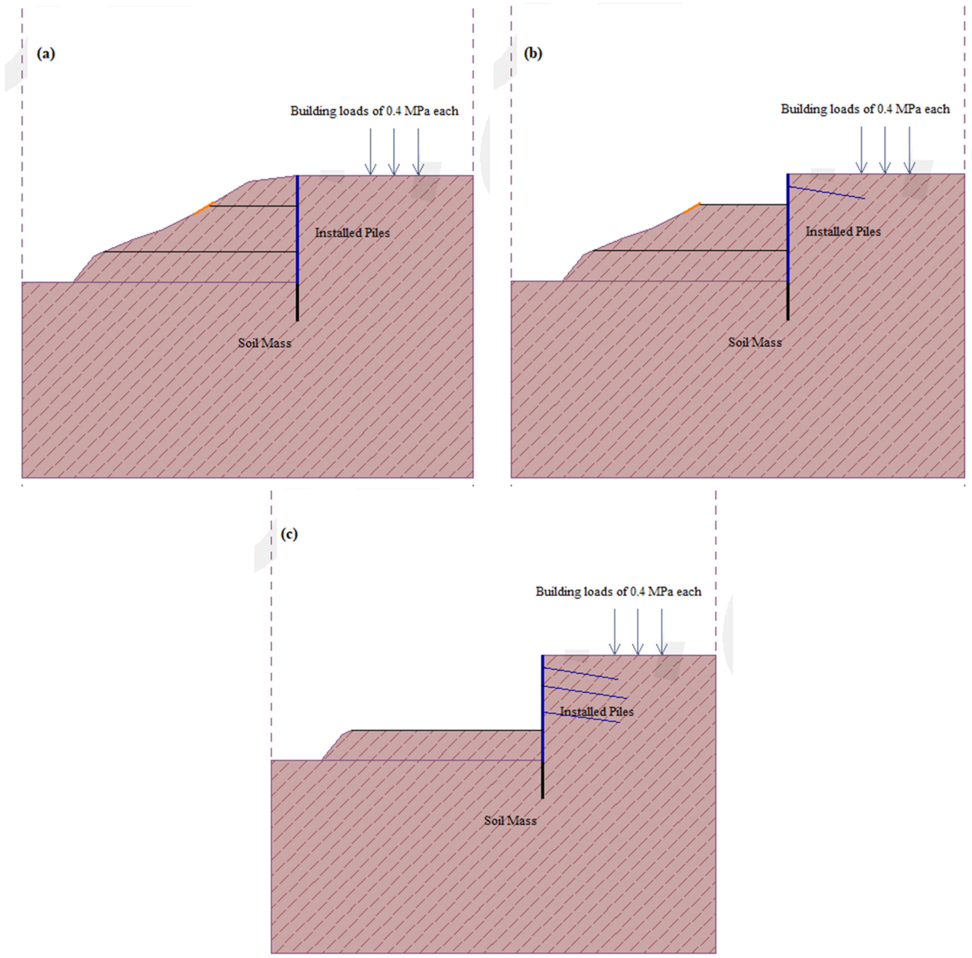

Figure 6. Steps involved in section A1-A1', (a) installation of pile, (b) and (c) installation of anchors

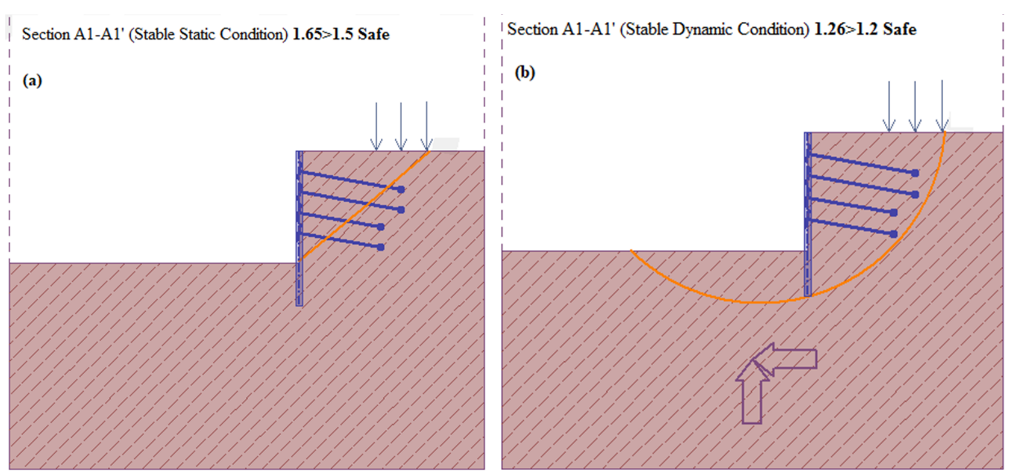

Figure 7. Stability check after remedies (a) stable static condition, (b) stable dynamic condition.

Table 5. Forces and moments acting on section A_1-A_1' after remedies under static and dynamic conditions.

Sections	Active forces (kN/m)	Passive forces (kN/m)	Sliding moment kNm/m	Resisting moment kNm/m	FOS	Remark
A_1-A_1' (Static)	1185.36	1958.68	527980.98	872437.14	1.65 > 1.5	Safe
A_1-A_1' (Dynamic)	1767.57	2233.92	30048.72	37976.67	1.26 > 1.2	Safe

Similarly considering the sections B_1-B_1' and C_1-C_1',(figure 7) (Table 5).

Following are the four stages of the stability analysis.

1. Installation of piles depth 10m and diameter 0.5m.
2. Excavation upto 4m depth and installation of anchor at 2m from top (length = 12m, slope = 10° from horizontal, diameter = 32ϕ).
3. Excavation upto 8m depth and installation of two anchors at interval of 2m in each anchors from top (length = 12 and 10m, slope = 10° from horizontal, diameter = 32ϕ).
4. Excavation upto 12m depth and installation of two anchors at interval of 2m in each anchors from top (length = 10m of each anchor, slope = 10° from horizontal, diameter = 32ϕ) (Figure 8 and 9) (Table 6).

Table 6. Forces and moments acting on sections B_1-B_1 and C_1-C_1' before remedies under static and dynamic conditions.

Sections	Active forces (kN/m)	Passive forces (kN/m)	Sliding moment kNm/m	Resisting moment kNm/m	FOS	Remark
B_1-B_1' (Static)	364.92	272.01	795.52	592.99	0.75 < 1.5	Unsafe
B_1-B_1' (Dynamic)	353.24	213.15	692.35	417.78	0.6 < 1.2	Unsafe
C_1-C_1' (Static)	293.41	203.87	619.1	430.16	0.69 < 1.5	Unsafe
C_1-C_1' (Dynamic)	285.44	166.94	685.05	400.65	0.58 < 1.2	Unsafe

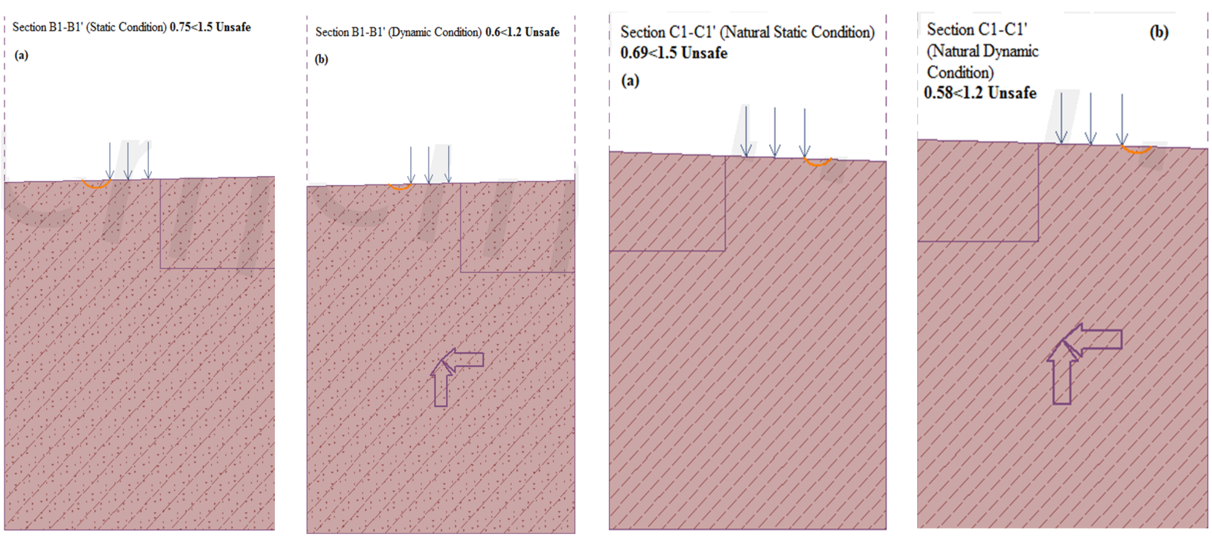

Figure 8. Section B_1-B_1' and C_1-C_1', FOS at (a) static and (b) dynamic condition.

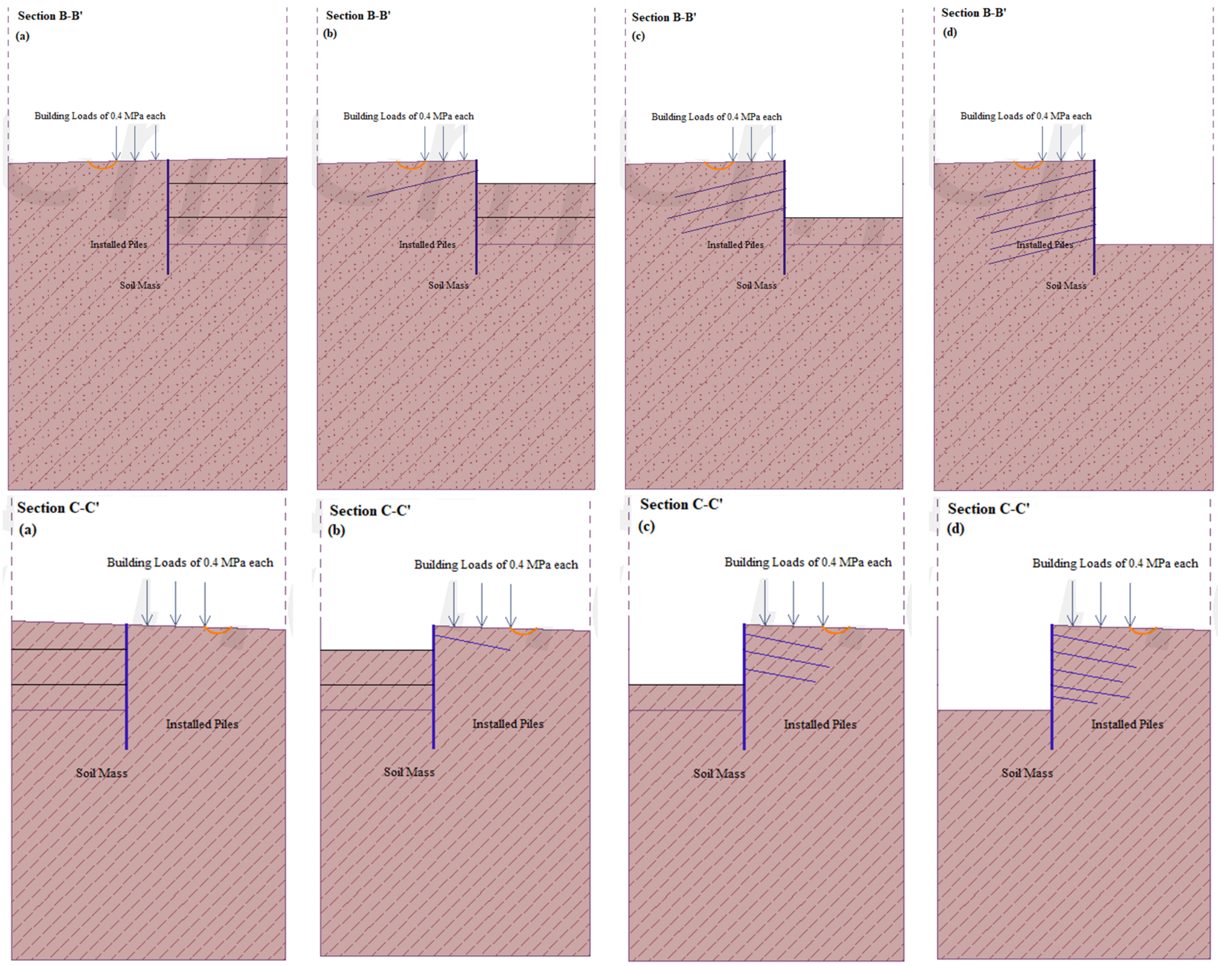

Figure 9. Steps involved in sections B_1-B_1' and C_1-C_1'- (a) installation of pile, (b), (c), and (d) installation of anchors.

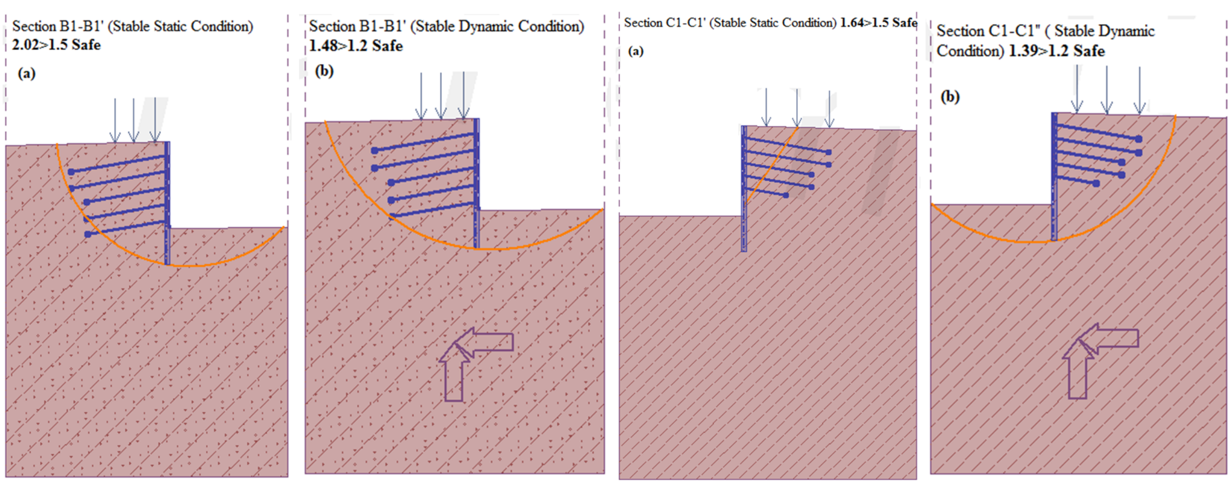

Figure 10. Stability check after remedies (a) stable static condition, (b) stable dynamic condition.

Table 7. Forces and moments acting on section B_1-B_1 and C_1-C_1' after remedies under static and dynamic conditions

Sections	Active forces (kN/m)	Passive forces (kN/m)	Sliding moment kNm/m	Resisting moment kNm/m	FOS	Remark
B_1-B_1' (Static)	1206.67	2439.43	19511.93	39445.6	2.02 > 1.5	Safe
B_1-B_1' (Dynamic)	1578.08	2340.43	31151.26	46200.02	1.48 > 1.2	Safe
C_1-C_1' (Static)	836.30	1370.46	242433.79	397281.72	1.64 > 1.5	Safe
C_1-C_1' (Dynamic)	1404.39	1947.31	23776.22	32967.99	1.39 > 1.2	Safe

5. Conclusions

The studied area was situated on land with a slope of about 35°, and was bounded on three sides by residential buildings, with a distance from the plot border of 2 to 6 m. A 20m thick overburden of slope wash material with a top layer of fill material was discovered through geotechnical study and assessment. Using the Geo5 software, the optimal option was found for stabilizing the slope involved without compromising the stability of nearby buildings. A1-A1’, B1-B1’, and C1-C1’ are the three sections of the research area. At the beginning, all the sections were evaluated in all aspects, and appeared to be unstable.

1. Considering Section A-A', the FOSs were 0.72 and 0.52 under natural static and dynamic conditions, which were less than the minimum FOS. The active forces kN/m were 0.13 and the passive forces kN/m were 0.09. Similarly, the sliding moment kNm/m was 1.10 and the resisting moment kNm/m was 0.79. After taking the preventive measures in the section, the active forces were 1185.36 kN/m and the passive forces were 1958.68 kN/m. The sliding moment was 527980.98 kNm/m and the resisting moment was 872437.14 kNm/m. Now, the FOS of the sections were 1.65 and 1.26, which were greater than the minimum FOS.
2. In Section B-B', under the natural static and dynamic conditions, the FOSs were 0.75 and 0.60, which were less than the minimum FOS. The active forces were 364.92 kN/m and the passive forces were 272.01 kN/m. The sliding moment was 795.52 kNm/m and the resisting moment was 592.99 kNm/m. After taking the preventive measures in the section, the active forces were 1206.67 kN/m and the passive forces were 2439.43 kN/m. The sliding moment was 19511.93 kNm/m and the resisting moment was 39445.6 kNm/m. The FOSs of the sections were 2.02 and 1.48, which were greater than the minimum FOS.
3. In Section C-C', the natural static and dynamic FOS were 0.69 and 0.58, which were lower than the minimum FOS. The active forces kN/m were 293.41 and the passive forces kN/m were 203.87. Similarly, the sliding moment kNm/m was 619.1 and the resisting moment kNm/m was 430.16. After taking the preventive measures in the section, the active forces were 836.30 kN/m and the passive forces were 1370.46 kN/m. The sliding moment was 242433.79 kNm/m and the resisting moment was 397281.72 kNm/m. Now, the section's FOS were 1.64 and 1.39, which were both higher than the minimum FOS.

According to the preceding, the resisting moment is less than the sliding moment since the passive forces are less than the active forces. The passive forces have a greater value than the active forces, and the resisting moment has a greater value than the sliding moment under both the static and dynamic conditions, as a result of the preventative measures implemented in all sections. The value of the factor of safety in every section exceeds the minimal factor of safety. These locations required preventative precautions because of the economic and physical devastation. As a result, the preventative measures were advised, along with a few modifications. Using the research area's criteria, the engineers can determine the most effective slope stabilization methods.

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Conflict of Interest

The authors have no conflict of interest with any one, and are related to the material presented in the paper.

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آنالیز پایداری شیب و اقدامات پیشگیرانه برای مکان لغزش در بزرگراه NH-05 در هیماچال پرادش، هند

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چکیده:

رشته‌کوه هیمالیا به‌دلیل توپوگرافی پیچیده‌ای که دارد، به دلیل شرایط طبیعی موجود و تأثیرات انسانی، مستعد ناپایداری شیب‌ها در مناطق متعددی است. بزرگراه ملی-۰۵ در این پژوهش در نظر گرفته شده است. منطقه تحت بررسی واقع در رامپور، ناحیه شیملا، هیماچال پرادش از نظر پایداری شیب ارزیابی می شود. هدف اصلی این کار حفظ پایداری شیب به منظور محافظت از NH-05 و سازه های مسکونی سه طرفه همسایه است. پس از بازدید از محل، بررسی‌های ژئوتکنیکی در قالب حفره‌ها و آزمایش‌های آزمایشگاهی انجام می‌شود. آنالیز پایداری شیب پس از تفسیر گزارش مطالعات ژئوتکنیکی آغاز شد. برای پایداری شیب تحلیلی، منطقه مورد مطالعه به سه بخش با برچسب های'A1-A1، 'B1-B1 و 'C1-C1 تقسیم شد. با در نظر گرفتن جنبه‌های ژئوتکنیکی منطقه تحقیقاتی مشخص شده، پارامترهای طراحی کاهش برای منطقه و شکست لغزش دایره‌ای با استفاده از تکنیک‌های مدل‌سازی عددی محاسبه می‌شوند. این نرم افزار ضریب ایمنی را برای هر دو وضعیت استاتیک و پویا محاسبه می کند. در نتیجه اقدامات پیشگیرانه و مواردی بهسازی پیشنهاد می‌شود.

کلمات کلیدی: ایمنی، خطرات، معادن، سنگ ساختمانی، آنالیز حالت و اثرات شکست