

Slope Stability Assessment Using Drains: A PLAXIS 2D Analysis at MUET, Jamshoro

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KEY WORDS	ABSTRACT
Slope Stability Rainfall Numerical Modeling Factor of Safety (FOS) PLAXIS-2D Horizontal Drains	This research investigation evaluates the slope stability of the road that is adjacent to Mehra University of Engineering and Technology (MUET), Jamshoro's administration building. The region's steep topography and unpredictable rainfall can lead to slope failure and damage infrastructure. To evaluate the road slope's performance, PLAXIS-2D (finite element modelling software for geotechnical analysis) was used for precise simulations. The analysis demonstrates that even in dry weather, the slope had a relatively low Factor of Safety (FOS), i.e., 1.238, due to its steep gradient and its considerable height. The FOS further decreased to 1.002 when it was exposed to rainfall intensity of 0.06 m/day (2.5 mm/hr), which implies that it is at risk of failure. Excessive pore water pressure was found to be one of the causes of instability, and traffic load only aggravated the situation, contributing to deformation. Horizontal drains were used to stabilize road slope. Different configurations were tested, and the best results were obtained when drains were installed at 1 m spacing across the full width and depth of the road slope, starting from its base. This arrangement successfully reduced excessive pore pressure and restored stability to a safer level. However, the FOS of 1.11 was achieved, and it is only enough to solve rainfall-induced instability; it was insufficient to address other factors that cause slope instability, such as heavy traffic loading or seismic activity. Therefore, to improve further stability, the road slope should be flattened with sandy material by obtaining from riverbeds or other sources. This approach involves removing existing riprap, adding fresh materials to level the slope while maintaining quality control, and then reconstructing the riprap. Additionally, combining these precautions with horizontal drains has the potential to raise the factor of safety above 2, offering further protection against slope failure under many different situations.

1. Introduction

Slopes may be either natural or artificial. Slope stability issues have arisen throughout history whenever internal or external pressures interfered with a slope's natural equilibrium. Internal forces, such as severe rainfall that causes erosion and landslides, are a prime example of disruptive forces. Human initiatives like drilling and slope levelling are examples of external factors that might result in landslides. In the past, there were many places with excellent soil available, so troublesome sites were frequently disregarded. However, individuals are feeling more and more pressure to use these difficult places due to the current trends of increased urbanization and industrialization. The expansive nature of clay is seen to dominate in the Jamshoro region near the ground surface, where the soil profile

is subjected to seasonal and environmental changes. These soils of expansive nature are usually unsaturated, meaning that as they absorb water, their volume increases, and when the soil dries out and moisture is lost, their volume decreases and moisture is lost, their volume decreases [1]. The behavior of expanding soil was modelled using a custom-designed swelling rock simulation in PLAXIS-2D. Laboratory and field tests verified that the soil in the research region is expansive shale, categorized as A-7-5 per AASHTO (American Association of State Highway and Transportation Officials) and as CH according to USCS. Furthermore, it was noted that swelling intensified with elevated water levels and diminished under applied load, whereas suction exerted a negligible influence on the swelling phenomenon [2].

Around the world, slope failure due to rainfall is a relatively common issue. Engineering geologists and geotechnical engineers are striving to subdue the impacts of this natural hazard at the global level. With appropriate evaluation, investigation, plan, and development, slope vulnerability issues can be reduced [3]. In recent decades, the finite element method has seen a significant rise in its application for slope stability analysis. The finite element approach presents a significant advantage over traditional limit equilibrium methods by removing the necessity to make prior assumptions regarding the shape and location of the failure surface, as well as the slice side forces and their directions. This adaptability facilitates the analysis of complicated slope patterns and soil deposits in two or three dimensions, enabling the modelling of a wide variety of responses. In addition to this, the approach offers the application of various general soil materials models, such as the Mohr-Coulomb model, among others. It is observed that the finite element method provides very accurate results since the equilibrium stresses, strains, and shear strengths within the soil mass are adequately predicted [4].

Early remedial strategies, particularly those aimed at groundwater regulation, have been shown to play a vital role in mitigating such failures. One of the studies identifies excess pore water pressure as a key factor governing slope instability and demonstrates that early-stage remedial measures can effectively mitigate landslide movement. Drainage-focused interventions and slope unloading were shown to reduce deformation by improving subsurface stress conditions. The findings highlight pore water pressure control as a critical first-line stabilization approach for rainfall-sensitive slopes [5]. The use of horizontal drains to stabilize the slope—a financially viable means of preventing its failure—was one of the mitigation strategies that academics have been studying continuously up to this point. One study demonstrates that horizontal drains significantly improve slope stability by lowering groundwater levels and dissipating excess pore water pressures. The effectiveness of the technique was shown to depend on soil permeability, drain configuration, and spacing, with notable increases in the factor of safety. The findings confirm pore water pressure control as a highly effective mitigation measure for rainfall-induced instability [6]. All of these studies highlight the significance of drainage-based stabilization methods as viable and low-cost measures to deal with rainfall sensitive slopes. In a similar manner, another study was carried out on the application of horizontal drains on landslide-prone slopes in Slovakia. The authors showed that correctly installed drains can

greatly decrease the pore-water pressure and increase slope stability, thus making them a useful tool in controlling shallow landslides.[7]

Another study evaluated landslides that were caused by water infiltration on the Sindhuli Road, Nepal and evaluated the effectiveness of horizontal drainage as a mitigation method. Horizontal drainage systems were effectively installed to reduce the elevation of the groundwater table and pore water pressure, and, consequently, the slope stability was increased, and the deformation of the road surface was minimized. These observations support the usefulness of horizontal drains in stabilizing landslide susceptible slopes in mountainous landscapes [8]. Recent experimental studies also support the basic correlation of slope stability and horizontal drains. Based on numerical studies that incorporated coupled transient seepage and stability models, the factor of safety of the slope was enhanced by up to 11.5% when the drains were placed horizontally, which is a moderate improvement in the stability of cracked and weak soils when subjected to high and constant intensive rainfall [9].

The 2022 Pakistan floods, driven by unprecedented monsoon rainfall, caused widespread geological hazards and severe damage to infrastructure, demonstrating the impact of extreme rainfall events in mountainous regions [10]. Despite this, the vulnerability of slopes to rainfall-induced failures remains under-researched in Pakistan, highlighting the need to investigate mitigation measures such as horizontal drains for slope stabilization.

2. Materials and methods

2.1 Site selection in MUET, Jamshoro

This project was initiated by first identifying a viable area of inquiry that would be consistent with our research objectives. The location selected is the Admin Block of MUET in Jamshoro. The location had a road on an embankment with a steeper slope, as shown in Figures 2.1 and 2.2.



Fig. 2.1 Admin Block, MUET (Coordinates)



Fig. 2.2 Site under investigation.

2.2 Geometric calculation of road slope

The geometry of the road slope is also important to understand because the stability depends largely on its geometry. First of all, theodolite surveying was used to measure the angle in order to have exact data. The road slope was determined to be 66.319° or $66^\circ 19'10''$. In order to assure precise distance measurements, the length of the inclined surface— $51' 2''$ or 15.6 m —was then determined using a measuring tape. Using these two essential variables, we implemented the Trigonometric Theorem to determine the road slope's horizontal distance and vertical height. Upon calculating the geometric data, the road slope's geometry was determined using PLAXIS-2D software, as illustrated in Figure 2.3.

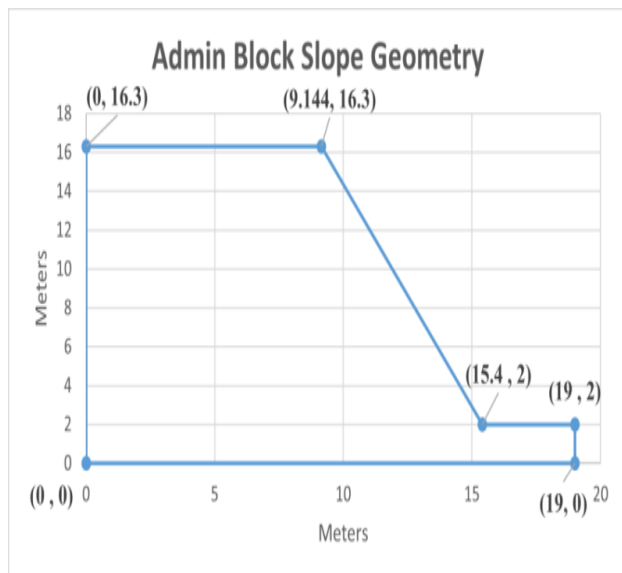


Fig. 2.3 Admin Block Road slope Geometry

The fundamental information required for further stability assessments and simulations is provided by these geometric simulations.

2.3 Sample collection:

The Sample was collected by the Pit Method, as shown in Figure 2.4.



Fig. 2.4 Collection of samples

2.4 Estimation of soil parameters:

After the collection of soil samples, the preliminary tests were conducted that were needed to incorporate into the PLAXIS-2D software for assigning the soil, as shown in the table.



Fig. 2.5 Different tests involved for calculating soil parameters.

Table 1

PLAXIS-2D Simulation Parameters

1	Angle of friction (ϕ)	29.46°
2	Cohesion (c)	0.439 kg/cm^2 (43.051 kPa)
3	Young's Modulus of Elasticity (E) [2]	25000 kN/m^2
4	Poisson's Ratio [2]	0.2
5	Optimum Moisture Content (O.M.C)	16
6	M.D.D (γ_d)	18 kN/m^3
7	Saturated density (γ_{sat})	20.9 kN/m^3
8	Soil type (AASHTO Classification)	Clay (A-7-6)

9	Liquid Limit (Casagrande Method)	47 %
10	Plastic Limit (Thread Method)	18.65 %
11	Plasticity Index (P.I)	28.35 %
12	Specific Gravity (G) (Pycnometer Method)	2.7

2.5 Use of PLAXIS-2D:

The stability of the road slope at MUET Jamshoro has been analyzed comprehensively with the help of PLAXIS 2D, which is a potent finite element software designed specifically to be applied in geotechnical applications. In order to gain a complete insight into road slope stability, simulation and experimentation of various models were conducted in order to identify the most significant parameters.

2.6 Method of Analysis: Mohr-Coulomb model.

The Mohr-Coulomb model gives a simple and practical description of soil behavior and needs a small number of parameters. It estimates soil response as elastic-perfectly plastic, and the stress-strain behavior is linear within the elastic behavior, which is measured by the Young modulus (E) and Poisson ratio (ν). The friction angle (ϕ) and the cohesion (C) regulate soil failure, and a non-associated flow rule applies to irreversible volumetric fluctuations as a result of shearing.

3. Results and Discussion

3.1 Analysis of Road Slope

3.1.1 Dry Model:

The performances of the road slope in dry conditions were successfully modelled to examine the performance prior to the occurrence of any precipitation. This simulation establishes a baseline for evaluating the fundamental stability of the road slope in the absence of rainwater infiltration. The examination of the road slope in its dry state yields significant insights into its performance under typical loading circumstances, as seen in Figure 3.4.

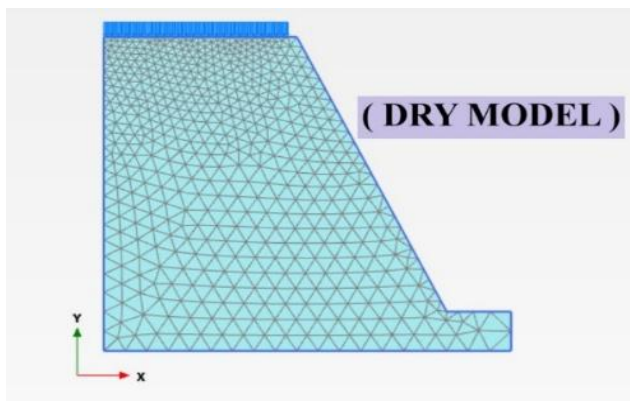


Fig. 3.4. Dry Model

i) Factor of safety:

As seen in fig. 3.5, the factor of safety in the dry model was estimated to be 1.238.

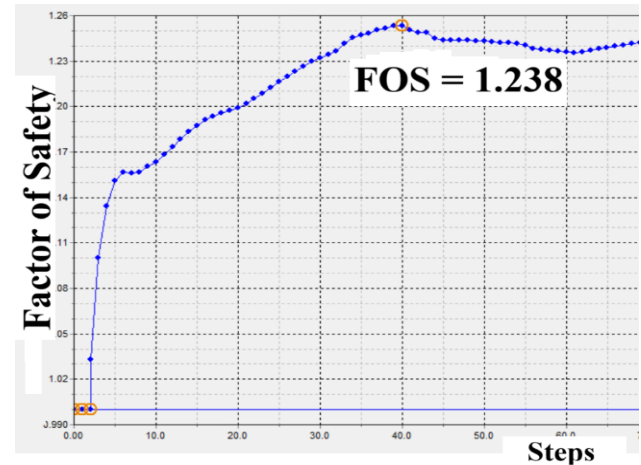


Fig. 3.5. Factor of Safety in Dry Model

Extensive calculations indicate that the road slope possesses an FOS of 1.238 in its dry form, implying that it is in a critical condition under these circumstances [9,11]. This Factor of Safety indicates that the road slope is sufficiently stable to withstand typical environmental and operational loads. However, slope failure might be triggered in the long term by any unforeseen occurrence, such as high precipitation or seismic activity.

ii) Pore pressure:

The pore pressure of the road slope in its dry state was estimated to be 0.46 kPa, as shown in Figure 3.6.

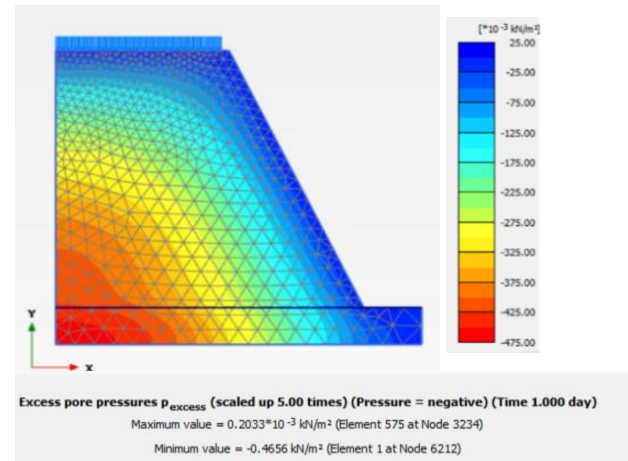


Fig. 3.6. Dry Model, pore pressure contour simulation

It simulated the pore pressure and found out that it was 0.46 kPa, which is near negligible. Such low-pore-pressure soil cannot be in an unstable condition since the water pressure exerted by the soil pores is low.

iii) Total deformation

The findings of the simulation indicate that the total deformation of the road slope was estimated to be in the order of 0.054 meters, as indicated in Figure 3.7.

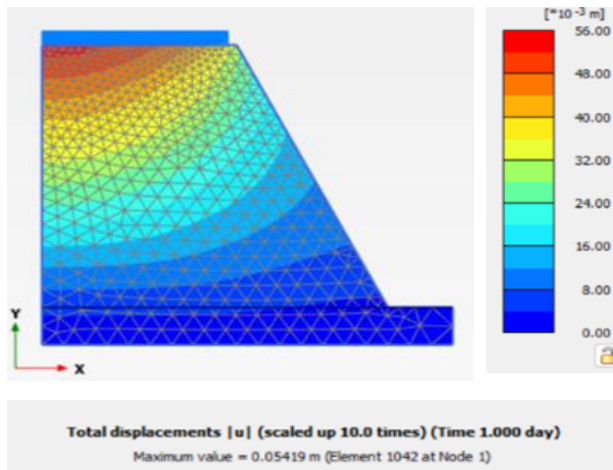


Fig. 3.7 Dry Model: total deformation contour simulation

The PLAXIS-2D response indicates that when the road slope is kept dry, and it is subjected to a maximum load of 100 kPa, it deforms only slightly. It has low total deformation, which indicates that the road slope is resilient and structurally stable at these loading conditions.

3.1.2 Wet Model:

The research on climatic changes in Pakistan in 2022 indicates that the Jamshoro region experienced significant environmental variations. The amount of rainfall that was recorded in this area was quite large, and the highest value of 0.06 meters per day was recorded, which showed the high nature of the weather in this area as extreme[12]. The high rainfall was also a challenge in the sense that to the slopes, which might be unstable in the region when combined with other contributing factors. An assessment of the impact of vehicular live load on slope stability was conducted simultaneously. The calculated corrective live load for the vehicle approached up to 100 kPa [13], [14], a pressure that increases stress on the slopes, which are already prone to failure. Consequently, the investigation was performed to identify the primary reason for the slope failures.

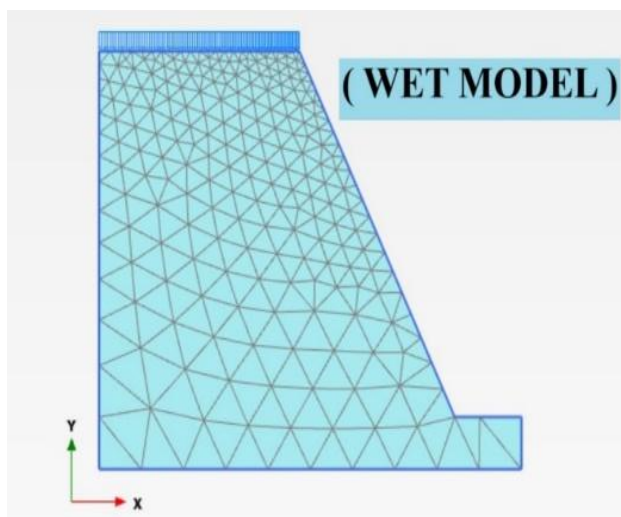


Fig. 3.8. Wet Model: Pore Pressure Contour simulation

i) Factor of safety

Findings reveal that the FOS has reduced to a critical value of 1.002 due to the effect of recent rainfall, as illustrated in Figure 3.9.

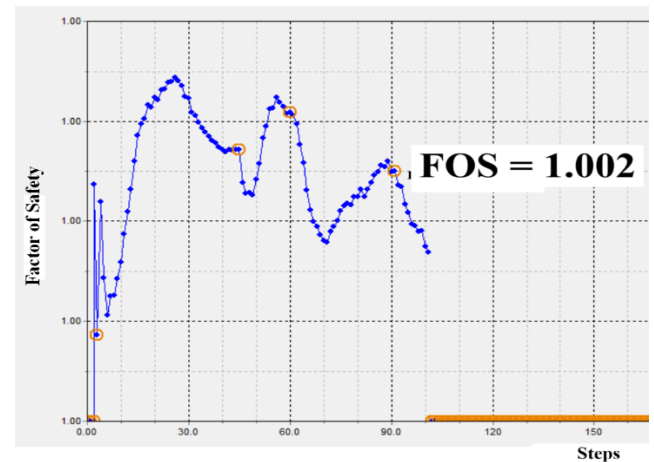


Fig. 3.9. Factor of safety in wet model

This drop suggests that the road slope is getting near its failure value [9]. This reduction indicates that it is near its failure criteria. Excessive rainfall has significantly saturated the road slope, undermined its structural integrity, and indicated that further load or further water infiltration could trigger an accident or structural failure.

ii) Pore pressure:

In the wet model, the rainfall effect was imposed, and it was discovered that the pore pressure rose to 92 kPa (wet state) compared with 0 kPa (dry state), as illustrated in Figure 3.10.

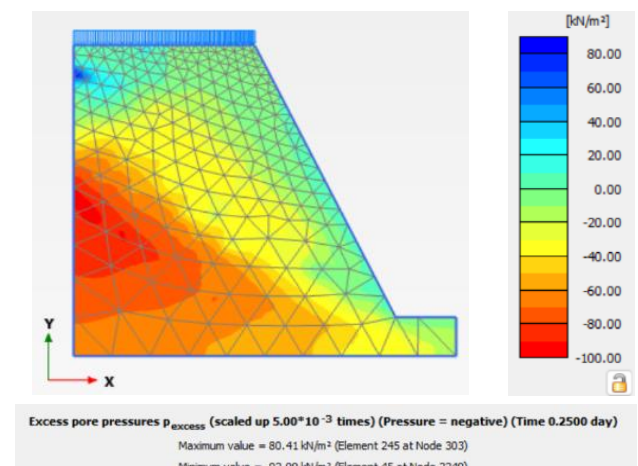


Fig. 3.10. Wet Model: Pore Pressure Contour simulation

This study demonstrated that pore water pressure had tremendously increased in the road slope. The rise of the pore pressure and the increase of the effective stress due to loaded forces lowered the shear strength of the soil, therefore, decreasing the resistance of the road slope to the external forces.[15] The reduced shear strength significantly diminished the safety factor of the slope, rendering it susceptible to instability from a relatively minor vehicular live load

that would typically pose no concern under normal conditions.

iii) Total deformation

The overall deformation was modelled in a wet model, and it was determined that it has increased by 1.199 m through the effect of rainfall and traffic live load.

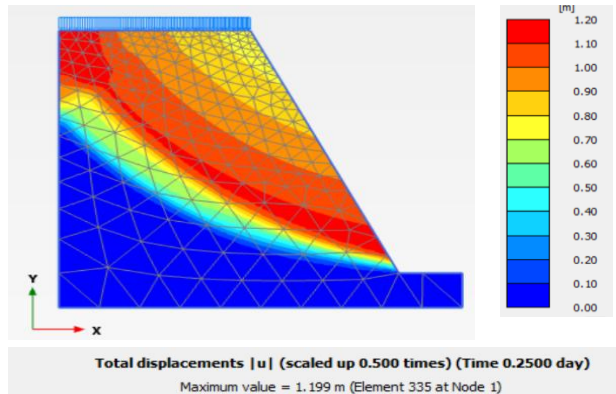


Fig. 3.11. Wet Model: total deformation contour simulation

Preliminary assessments of road slope deformation revealed minimal displacement, evidenced by a 0.0058 m shift, suggesting a generally stable situation. Conversely, the road slope exhibited quick destabilization, evidenced by a 1.199 m deformation rise during precipitation. In addition to indicating an immediate risk of the slope's catastrophic failure, the steep increase in deformation and the slope's already extremely unstable condition imply that the road slope will fail if nothing is done before then.

3.2 Use of Drains in Road Slope in Plaxis-2d:

3.2.1 Model- 3 (provision of drains at 1 m spacing)

The drains were installed in this arrangement as a precautionary measure. In an effort to assess the performance of the horizontal drains, they were laid at 1 m spacing throughout the entire depth and width of the road slope, as shown in Figure 3.12. Simulation was used to produce the Factor of Safety, pore pressure, and total deformation to determine the capabilities of drains in slope failure prevention.

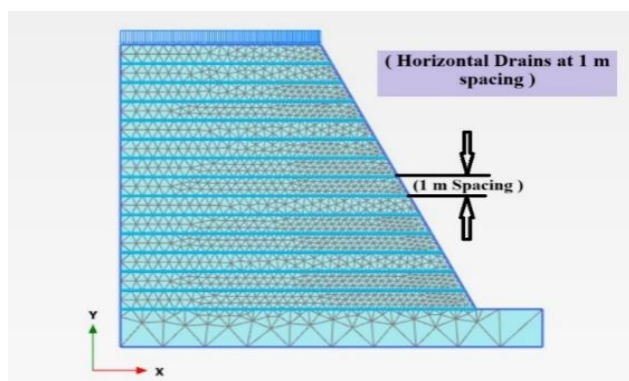


Fig. 3.12. Horizontal Drains at 1 m Spacing

i) Factor of safety

The FOS was estimated, and it was calculated as 1.111, as shown in Figure 3.13.

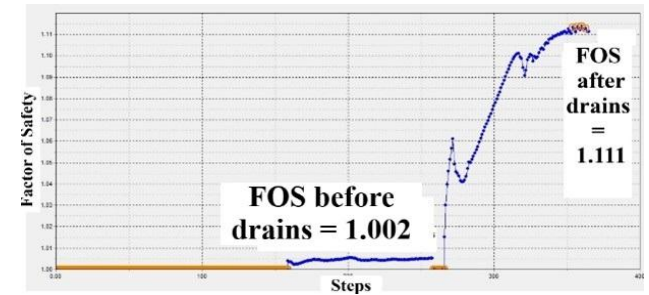


Fig. 3.13. Factor of Safety in Model 3: Provision of Drains at 1 m Spacing

The factor of safety was initially set at 1.0, representing the threshold of marginal stability. However, after horizontal drains were installed with 1 m spacing, the safety factor went up to 1.11, which is almost the same as its original value. This enhancement is important for slope stability, as it shows a point where the road slope is now better able to handle possible failure. Thus, even in the most difficult situations, safety is enhanced.

ii) Pore pressure:

The excess pore pressure was estimated as 17.86 kPa, as shown in Figure 3.14.

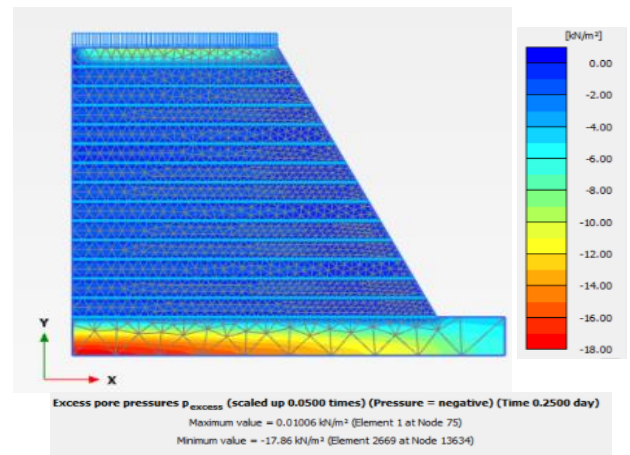


Fig. 3.14 Provision of Drains at 1 m Spacing: Pore Pressure Contour Simulation

The laying of horizontal drains at 1-meter spacing has drastically lowered pore water pressure within the road slope. Measurements demonstrate an important reduction in pore pressure, from 92 kPa to merely 17.86 kPa, due to the installation of these drains. These drains help in the preservation or improvement of the shear strength of the soil by lowering the moisture content of the soil, thereby maintaining the resistance of the slope to the destabilizing influence of rainfall infiltration. This increase in shear strengthening improves the ability of soil to sustain loads and lateral stresses that are imposed upon it, thus reducing the chances of failure [6].

iii) Total Deformations

For this model, adding drains at 1-meter spacing significantly reduced total deformation to only 0.056 meters, as shown in the figure. 3.15.

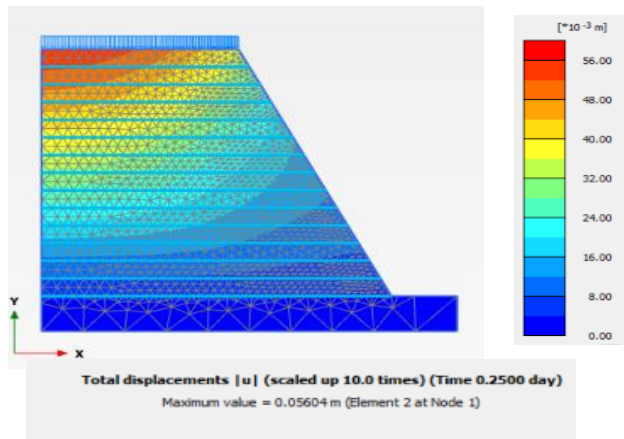


Fig. 3.15. Provision of Drains at 1 m Spacing, Total Deformation Contour Simulation

This reduction in total deformation is mainly due to the introduction of horizontal drains, which relieved the moisture of the soil and reduced the chances of slope failure. The horizontal drains maintained the shear strength of soils, which enabled the road slope to resist the external forces such as traffic loads and precipitation without critical displacement and failure.

3.2.2 Model- 4 (provision of drains at 2 m spacing)

This model implemented the drains as a preventive measure. Their placement was at 2 m intervals across the entire depth and width of the road slope, as seen in Figure 3.16, to evaluate the efficacy of horizontal drains. The factors such as FOS, Pore pressure and total deformation were simulated to assess the extent to which horizontal drains can mitigate slope instability.

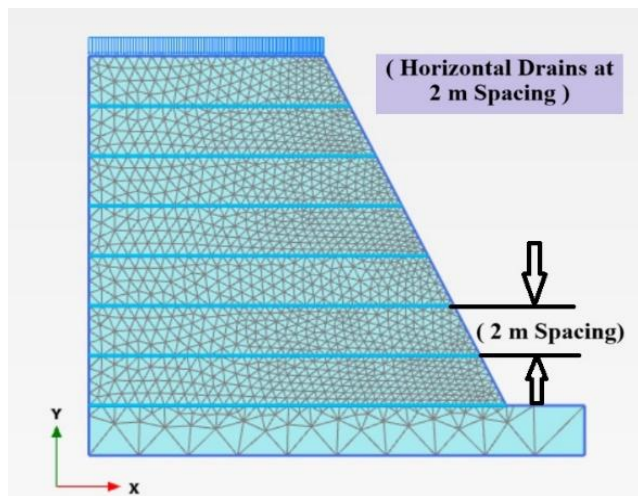


Fig. 3.16. Horizontal Drains at 2 m Spacing

i) Factor of safety:

As seen in Figure 3.17, the factor of safety was raised from 1.002 to 1.105.

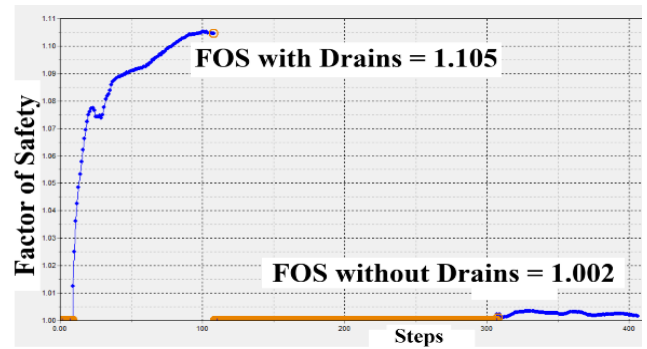


Fig. 3.17. Factor of Safety in Model 4: Provision of Drains at 2 m Spacing

This enhanced factor of safety indicates not only increased structural integrity but also an improved capacity to withstand variations in load and environmental conditions. The road slope possesses a FOS of 1.10, making it less susceptible to minor variations in moisture or additional weight, since it maintains adequate resilience to prevent becoming excessively steady in response to minor variations.

ii) Pore pressure

The excess pore pressure was estimated as 28.53 kPa, as shown in Figure 3.18.

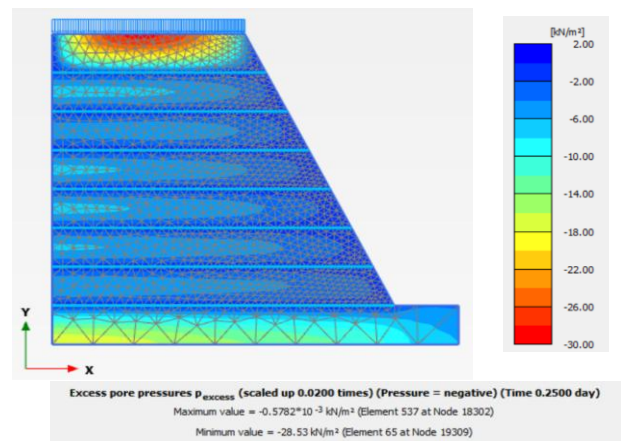


Fig. 3.18. Provision of Drains at 2 m Spacing: Pore Pressure Contour Simulation

The stability of the slope was also significantly enhanced by fully reducing the pressure of excess water in the soil through the installation of 2-meter-spacing drains. Reduction of pore pressure to 28.53 kPa increased the friction on soil particles greatly, and as such, increased the strength of the road slope considerably. This improves the movement of water to reduce the accumulation of pore pressure, which is a major contributor to slope failure, particularly when there is heavy rainfall or when the groundwater level is higher. The decrease in the pore pressure consequently led to an increase in the soil strength against the lateral and vertical loads [3]. The improvement is essential in ensuring stability in changing conditions by avoiding unnecessary soil settlement and eliminating the risks of landslides.

(iii) Total Deformations

The overall road slope deformation at a 2m interval was calculated as 0.055 m, as illustrated in Figure 3.19.

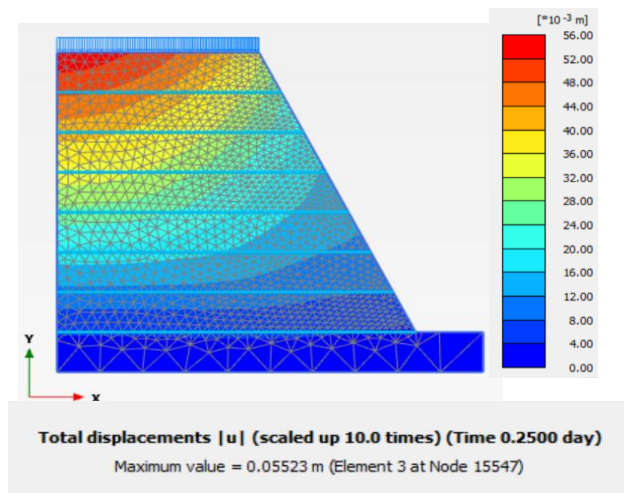


Fig. 3.19. Provision of Drains at 2 m Spacing, Total Deformation Contour Simulation

The total road slope deformation also reduced drastically to 0.055 meters, which shows the effectiveness of reducing the pore water pressure in stabilizing the region. Drains at 2 m apart improve the shear strength of the road slope, thus having a significant contribution to the stability of the slope and the ability to resist the external forces without dramatic displacement and settlement [3]. Such an increased resilience is crucial, as the road slope can currently sustain an extra load due to the constant traffic and rainfall actions.

3.2.3 Model- 5 (Provision of Drains at 3 m Spacing)

Drains at 3 m were used in this model to determine the effectiveness of horizontal drains as a preventive measure, as demonstrated in Figure 3.20. The parameters, including FOS, excessive pore pressure, and total deformation, were simulated to assess the performance of horizontal drains.

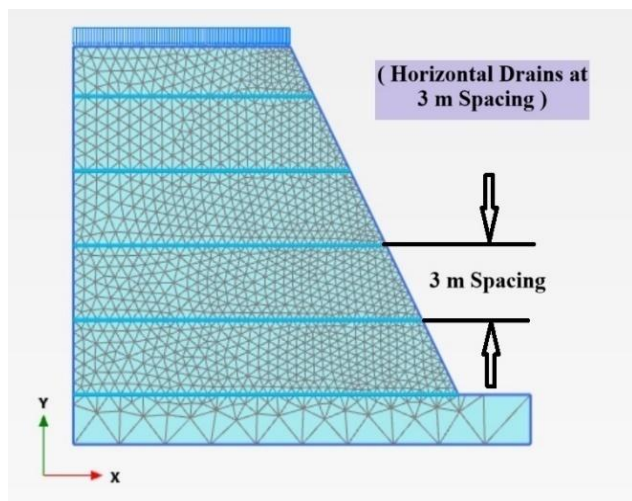


Fig. 3.20. Horizontal Drains at 3 m Spacing

i) Factor of safety:

The factor of safety was increased from 1.002 to 1.090, as shown in Figure 3.21.

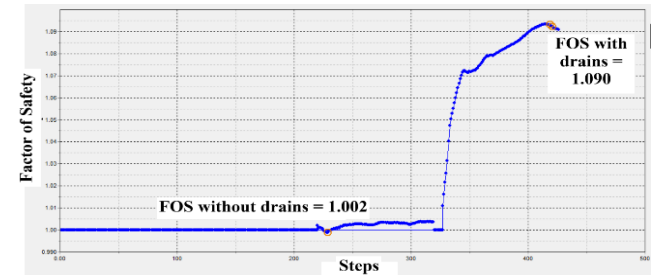


Fig. 3.21. Factor of Safety in Model 5: Provision of Drains at 3 m Spacing

The increase in the FOS was small when the drains were placed at 3 m spacing. This implies that the spacing would not give significant improvements in stability. The FOS has demonstrated a bit of success in reaching the necessary threshold of 1, but it is rather close to the same base value, which proves that the stability of the slope in the present conditions is improved somewhat, but is hardly desirable.

ii) Pore pressure

The excessive pore pressure was reduced to 28.20 kPa, as shown in Figure 3.22.

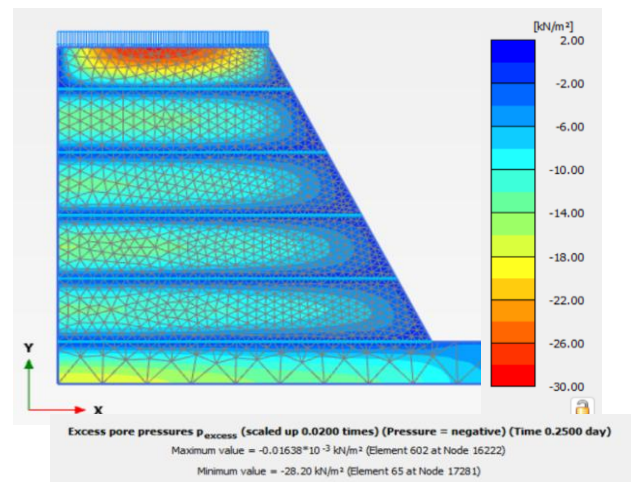


Fig. 3.22. Provision of Drains at 3 m Spacing Pore Pressure Contour simulation

The drains, although not sufficient in increasing the factor of safety, are successfully cancelling one of the main causes of instability, i.e., excess pore pressure. Reduction of pore pressure every 3-meter distance is also a critical attribute in the stability of the entire structure. Hence, the drains, despite this interval, substantially reduce the risks associated with increased pore pressure, which increases the overall stability of the infrastructure.

v) Total deformations

The Total deformation was decreased to 0.055 m, as shown in Figure 3.23.

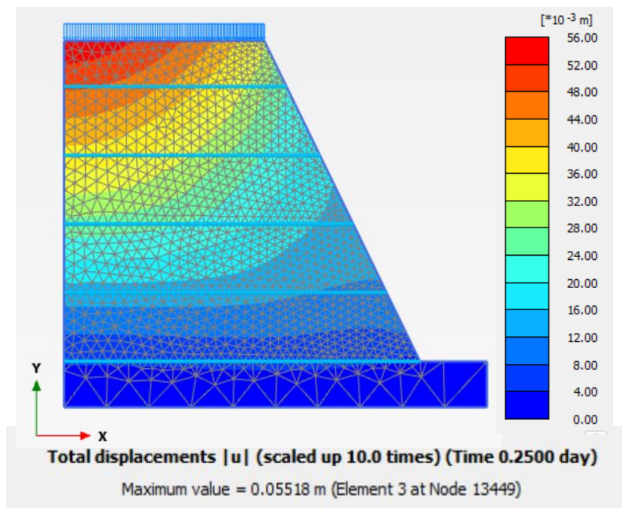


Fig. 3.23. Provision of drains at 3 m spacing: total deformation contour simulation

The FOS was not as high as anticipated; the application of the horizontal drains much decreased the total deformation by an order of magnitude. The general stability of this slope relates primarily to the reduction of the deformation, which reduces the susceptibility of the road slope to extreme weight of traffic and rainfall situations, compared to the state of the road slope without the intervention of drains.

3.2.4 Model- 6 (Provision of Drains at 4 m Spacing)

Figure 3.24, in this model, indicated the installation of the horizontal drains at 4 meters to identify their appropriateness as a measure to prevent slope stability. The effects of the drainage system were measured through the simulation of numerous crucial factors, including the FOS, high pore water pressure, and overall deformation. These simulations were to be conducted to extensively explore the impacts of the drains on the behavior of the road slope under the influence of varied traffic loads and rainfall influence.

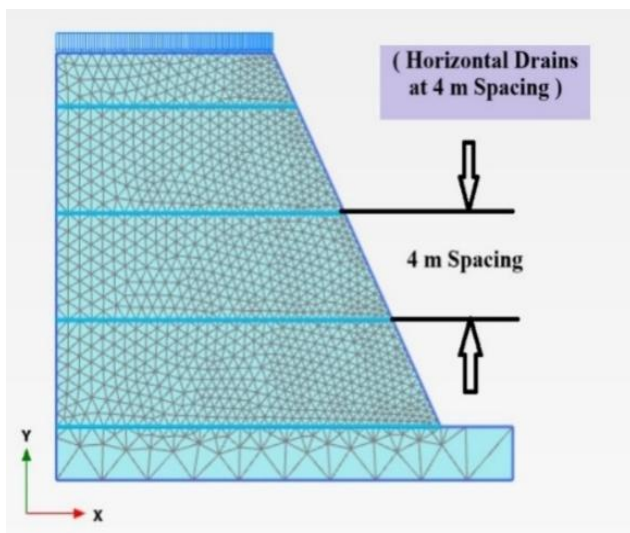


Fig. 3.24. Horizontal Drains at 4 m Spacing

i) Factor of safety

The FOS was increased from 1.002 to 1.061, as shown in Figure 3.25.

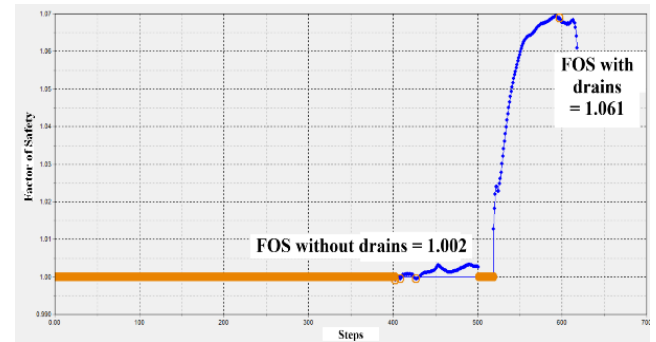


Fig. 3.25. Factor of safety in dry model 6: provision of drains at 4 m spacing

The factor of safety that is nearly on the threshold of 1 represents the fact that the horizontal 4-meter-apart drains do not offer major stability to the slope. There may be, however, certain regions which are vulnerable to the disturbing effects of over-precipitation or to overload. Although the drains reduce the pore pressure, they fail to reinforce the soil structure in a proper manner to provide the necessary stability during the course of time to be safe.

ii) Pore Pressure

The pore pressure was reduced to 31.08 kPa, as shown in Figure 3.26.

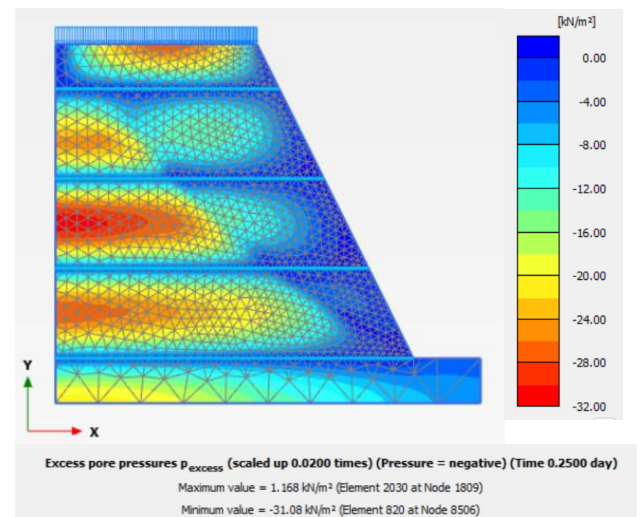


Fig. 3.26. Provision of Drains at 4 m Spacing: Pore Pressure Contour Simulation

It reduced the pore pressure, and this showed that despite the 4 meters interval, the horizontal drains are successfully taking away the excessive pore pressure and giving the necessary shear strength to withstand heavy loads and unfavorable weather conditions during rains.

v) Total Deformations

The total deformation was estimated as 0.058 m, as shown in Figure 3.27.

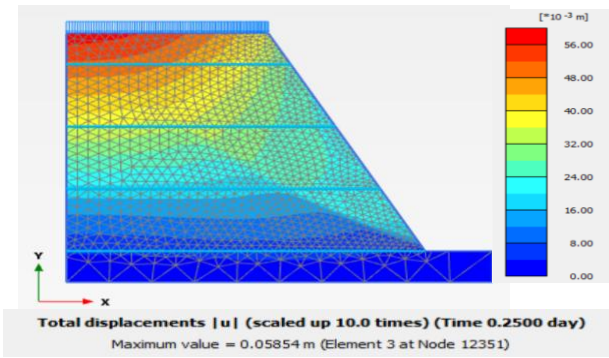


Fig 3.27. Provision of Drains at 4 m Spacing: Total Deformation Contour Simulation

The total deformation diminished, showing that the soil shear strength was maintained by the drainage system, resulting in negligible displacements. The drains were allowed to extract water through a strategically configuration of spacing, minimizing excessive accumulation that could harm the slope's stability under severe load.

4. Comparison Of Various Drains Provisions with Wet Conditions

i) Factor of safety

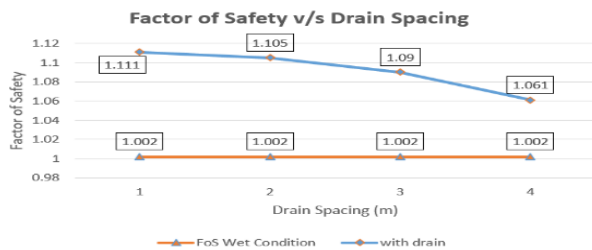


Fig.4.1. Factor of Safety v/s Drains Spacing.

The given graph shows the comparison of the FOS of all the models, with the focus on how different drain spacing would influence slope stability under the conditions of rainfall and traffic live loading. The first FOS measurements represent that slope stability is reduced with continuous traffic live load and precipitation. But upon the installation of horizontal drains at various intervals, there was a considerable increase in the Factor of Safety, the most successful stabilization being an installation at 1-meter intervals. These observations are confirmed by the graph, which demonstrates the trend of increasing FOS as the distance between drains is reduced, where the 1-meter configuration has the greatest stabilizing value.

ii) Pore pressure

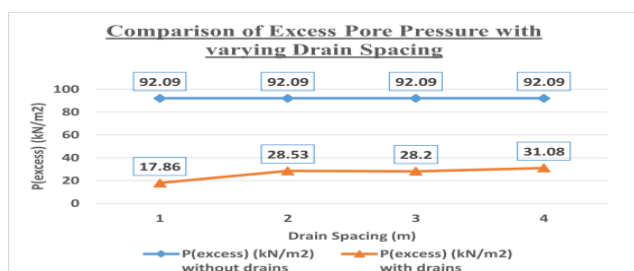


Fig. 4.2. Pore Pressure v/s Drains Spacing.

The pore pressure comparison described in the graph illustrates that drains installed at 1-meter intervals throughout the entire depth and width of the road slope extracted more water from the soil, thereby enhancing shear strength as compared to the rest of the models with varying drain spacing. The enhanced shear strength is crucial, as it allows the road slope to more effectively withstand destabilizing factors, such as precipitation and vehicular loads, which could otherwise cause slope failure [8].

iii) Total deformation

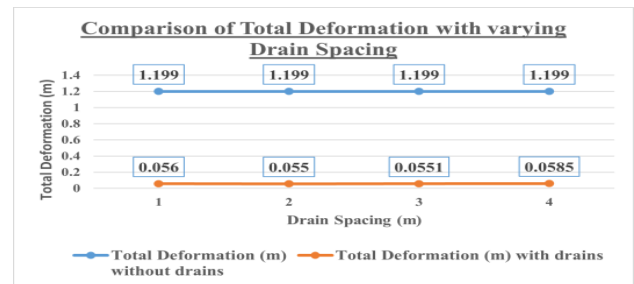


Fig. 4.3. Total Deformation v/s Drains Spacing.

The comparative graph describes the idea that the variation of drain spacing was performed in creating variations in the total deformation. It was proven that the total deformation decreased with variations in the drain spacing across various configurations. That horizontal drain can effectively overcome the influence of rain and the live load of traffic regardless of spacing, thereby indicating that closer spacing can be desirable when under high risk to provide as much resilience as possible. The data also indicates that horizontal drains at 1 m were more effective in achieving such a high degree of decrease in deformation, hence indicating that closer spacing can be preferred under high-risk conditions.

5. Conclusions

The following conclusions can be obtained from the above analysis:

1. At present, the road slope is in an unstable situation, with a FOS of 1.23 under dry conditions. It further diminishes to 1.002 due to the impact of live loads up to 100Kpa, and rainfall precipitation of 0.06 m/day (2.5 mm/hr) was applied.
2. The numerical investigation using PLAXIS-2D concludes that vertical spacing of horizontal drains of 1 m is ideal and at that separation the installation of Horizontal drains are up to the entire width and depth of road slope which will fluctuate between the top level of the road slope to the bottom level to remove water of soil as well as provide adequate shear strength and diminish total deformation to mitigate failure during rainfall.

3. Based on slope stability calculations and various models, the installation of horizontal drains at 1 m was identified as highly effective in removing the primary cause, i.e., excess rainwater from soil. It reduces pore water pressure from 92 kpa to 17.86 Kpa and reduces total deformation to 0.056 meters, thereby enhancing soil shear strength, making it suitable for use during rainfall circumstances.
4. Horizontal drains have been implemented to diminish pore water pressure and enhance slope stability; however, they have only improved the FOS to 1.11, rendering it resilient merely against precipitation. Moreover, slope failure can be caused by a variety of factors besides rainfall. External factors and unavoidable events, such as earthquakes in the Jamshoro region and increased vehicular traffic, might further lead to slope failure. Hence, based on the results of this study, road slopes can be flattened to lower slope angles through the use of sandy material obtaining from the riverbed or another location in order to raise FOS. In order to achieve this, the following actions can be implemented:
 - i) To remove the present riprap (the layer of rocks which prevents the movement of soil).
 - ii) Fresh materials will be added to the current road slope to flatten it, and the riprap must then be reconstructed. Along with the horizontal drains, to increase the factor of safety to greater than 2.

6. Future Recommendations

This research was done in the two-dimensional finite element modelling software, i.e., PLAXIS-2D. The slope stability analysis was conducted specifically to evaluate the slope stability during infiltration induced by rainfall only. The results, therefore, present the slope response in the context of two-dimensional numerical modelling under the conditions of rainfall induced instability. Hence, the following are the future recommendations:

- i) An adequate investigation should be done to stabilize the road slope against different agents, like seismic effects in PLAXIS-2D.

- ii) The same site provision of a case study of a retaining wall should be done in order to have an enhanced fundamental factor of safety of up to 2.
- iii) A three-dimensional numerical modelling based on the use of PLAXIS-3D should be adopted to describe three-dimensional failure mechanisms, redistribution of transverse stresses, and discrete drain interaction effects.

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