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Reduction of Slope Failure Hazards: An Analysis of the Khosr River Slope in Mosul, Iraq, Utilizing Geo-Studio Programs.

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A B S T R A C T

In this study, the stability of the slope close to the Khosr River in Mosul, Iraq, is examined. Three different layers make up the slope: sandstone at the bottom, highly malleable clay (CH) in the middle, and gravel, sand, and clay at the top. Concerns regarding possible failure, which may cause large material and human losses, have been raised by the growing construction of multi-story buildings at the top of the slope. The SLOPE/W, SIGMA/W, and SEEP/W modules of the Geo-Studio 2012 program were used to perform a two-dimensional (2D) numerical analysis. The stability of the slope was investigated under a number of circumstances, such as increasing groundwater levels (4 to 10 m), rainfall (10 and 30 mm/day for up to 60 days), and external loads (250, 350, 450, and 500 kPa). The slope's initial factor of safety (FOS) ranges from 3.935 to 4.03, making it stable under typical circumstances. But when exposed to external stresses, more rainfall, and higher groundwater levels, the FOS dramatically drops. When a 500 kPa external load was applied, for example, the FOS decreased by up to 71.9%, and when a 100 kPa load and a 4 m water table were combined, the FOS decreased by more than 70%. The study assessed the efficacy of three reinforcement treatments—anchors, micropiles, and a retaining wall—to reduce the chance of failure. The outcomes demonstrated how well these actions improve stability. When positioned at a 25-degree angle, anchors raised the FOS by 24.1% to 196.8%. Three meters below the surface, micro-piles increased the FOS by 37.4% to 164.2%. The most successful option was a retaining wall, which increased the FOS by 178.5% and restored stability in critical conditions. It was 10 meters high and 6.5 meters wide at the foundation. The results show how important it is to have adequate drainage systems and slope reinforcement in order to protect the growing residential area.

1. Introduction

Slope stability is a crucial consideration when evaluating the stability of both existing slopes and newly constructed hillsides or excavations [1]. Landslides are among the most hazardous natural disasters that can happen in mountainous areas, and because of the potentially disastrous social and economic repercussions, they have received increased attention in geotechnical and geologic engineering studies [2-3]. Slopes, whether natural or man-made, can become unstable [4]. Slope stability refers to the ability of slopes to withstand or undergo movement [5].

Water channels, erosion activity and Groundwater, together with climatic factors, are the primary causes of slope deformations. Rainfall frequency and intensity, together with the frequent floods in our area, are all associated with rapid erosion processes that can lead to soil landslides. Wet slopes now have a higher risk of landslides. Floods are caused by different shear strength parameter values [6-7]. There are two types of slope stability analysis: static and dynamic [8-9]. An assessment of slope stability using numerical methods to understand the causes of slope collapse or the factors causing slope displacement. The answer is found in stability analysis when both force and moment equilibrium are needed. Slope stability is the safety factor, which is the shear strength divided by the shear stress [10].
Long-term and short-term stability, failure type (circular or non-circular interface; toppling; flow), seepage + pore-water pressure transit, discontinuity occurrence and inclination, soil layering, and numerical calculation methods should all be considered [11-12].

Traditional approaches with slope stability analysis that have shown success but are typically resource- and time-intensive include limit equilibrium methods and numerical modeling [13-14]. The groundwater level has a major impact on slope stability and landslide development [15-16].
Landslides can occur in almost any circumstance, either gradually or suddenly, and with or without warning. The slope safety effect must therefore be ascertained through a slope stability analysis [17].Although the current study focuses on a particular slope along the Khosr River near Mosul, Iraq, the chosen approach and analytical framework can be applied to other areas with comparable geotechnical and environmental characteristics, even if the current study concentrates on a particular slope along the Khosr River near Mosul, Iraq. For slopes made of layered soils with similar mechanical characteristics, the numerical modeling technique utilizing the Geo-Studio suite (SLOPE/W, SEEP/W, and SIGMA/W) in conjunction with the assessment of external loads, groundwater variations, and rainfall effects is suitable. However, differences in the local geology, climate, building techniques, and groundwater regimes may restrict the direct generalization of the quantitative results. Therefore, when implementing the suggested analysis and reinforcing procedures to other areas, site-specific soil characteristics, hydrological conditions, and loading scenarios should be carefully taken into account.

In this research, a numerical method will be used to process a real failure slope to increase the value of the safety factor and make it more stable by using the GeoStudio program and its sub-programs.

2. Study Area

The case study's slope is situated 8 kilometers from the heart of Mosul, Iraq. A little seasonal river that flows through the center of this hill is the Khosr River, whose water level rises in the winter and spring. The construction of multi-story structures extremely near the slope's edge has started to exploit the region near the top of the slope. Because of this, it is crucial to investigate the slope's stability in order to avoid failure, which could result in material and human losses. The slope consists of three layers, as shown in Figure (1). The slope is composed of the following layers:
1- The top layer: is made up of a mixture of gravel, sand, and some clay (sub-base material). The peak of the hill is two meters below this layer.
2- The intermediate: layer is made of highly plastic clay (CH). Seven meters are covered by this layer from the slope's summit.
3- The last layer: sandstone. Six meters separate this layer from the slope's summit.

Fig. 1. Case study slope shape.

3. Method and Parameters

The study's objectives are shown below. In order to investigate and accomplish all of the objectives, 2D geometry modeling was created. The Geo-Studio (2012) tool was used to model and analyze slope stability. The software can effectively assess both simple and complex slope problems, such as:

1- Slope shape.
2- Boundary conditions.
3- Properties of slope layers.
4- External load condition.
4- Treatments like:
a- Anchors.
b- Retaining wall.
c- Micro-piles.

The program Geostudio 2012, developed by Geoslope International, is used for numerical analysis by earth scientists and geo-engineers. Geostudio offers the following applications: QUAKE/W, TEMP/W, SEEP/W, Sigma/W, AIR/W, CTRAN/W, and SLOPE/W [18].
SLOPE/W is a program that uses the limit equilibrium method to determine the factor of safety for rock and earth slopes [19]. The slicing and numerical approaches are frequently used for slope stability analysis, and they mainly rely on the limit of equilibrium and elastic-plastic theory, respectively.

Two-dimensional (2D) slope stability modeling will be used for the analysis. FEM, or the large deformation elastic-plastic finite element method, will be applied [20]. The more established and traditional of the two methods for the slope stability investigation is the limit equilibrium approach. The techniques that make up this majority include the slide wedge, the Janhu technique, the Bishop, the Fellenius, the Spencer, and others [21]. Site-specific data from the real slope close to Mosul was used to create the Geo-Studio model. Soil samples were taken from the slope's various layers, and the slope was visually examined and photographed. The mechanical and physical characteristics of these materials were assessed in the lab and used as input parameters in the SLOPE/W, SEEP/W, and SIGMA/W modules. The credibility of the model's factor of safety values is ensured by the combination of laboratory data and field observations, which guarantees that the numerical predictions closely mirror the real slope behavior.

SEEP/W software analyzes problems with excessive pore water pressure dissipation and groundwater seepage in porous materials, such as rock and soil, using finite elements [22]. A finite element program called SIGMA/W is used to examine earth works for deformation and tension [23]. For the SIGMA/W module of the Geostudio 2012 program, a typical section for the model's building and configuration had to be defined as part of the finite element method's (FEM) simplification of the numerical analysis. The existence of the soil layers and the theory that the regions with the most deformation are likely to experience made this feasible [24]. Several loads were applied to the slope 250, 350, 450 and 500 kPa until failure was reached.

4. Slope Properties and Boundary Conditions

The slope's height is 15m, its upper edge is 16m, its bottom edge is 25m, and its slope angle is 83°, as shown in Figure (2).

The slope's boundary criteria include keeping the sides from moving horizontally (x = 0) and keeping the lower edge from moving both horizontally and vertically (x = y = 0). Two meters from the slope's edge, Figure (3) shows the external load applied to the slope as well as its boundary conditions.

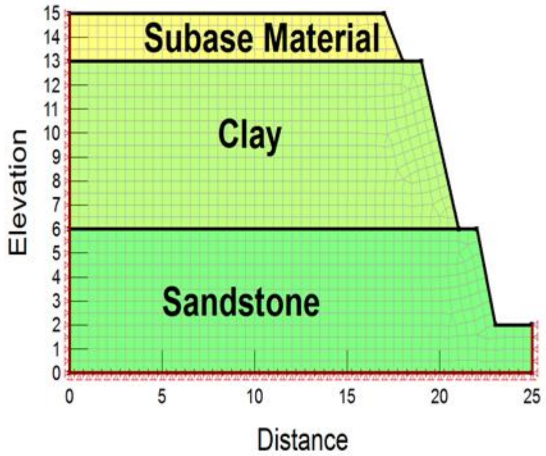


Fig. 2. Slope shape with its boundary conditions by Geo-studio 2012.

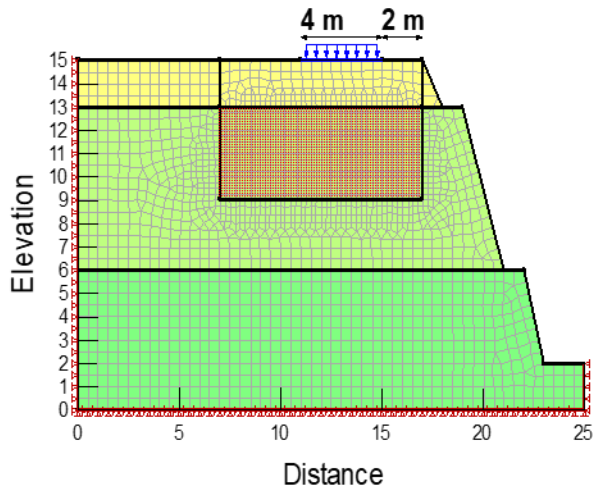


Fig. 3. External load with analysis network in Geo-studio 2012.

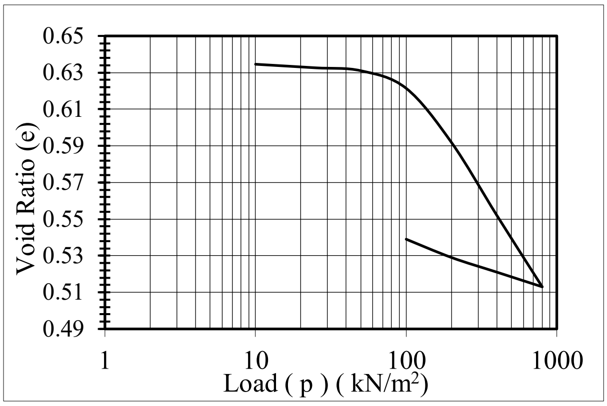


Fig. 4. particle size distribution curve for slope soil.

5. Properties of Slope Layers

The slope's mechanical and physical properties are listed in Table (1), and Figure (4) shows the slope soil's particle size distribution curve. Figure (5) shows the slope's clay soil layer consolidation curve, where the initial void ratio (e=0.6), compression index (Cc=0.136), and swelling index (Cs=0.0197). are calculated. Through extensive laboratory testing on the slope's soil, including Atterberg limits, dry density, compaction, direct shear tests, and soil classification, a useful method of sensitivity evaluation was included into this study. Because the Geo-Studio model used the measured soil qualities from these experiments as input parameters, the study was able to represent actual variations in soil behavior. These laboratory-based observations give confidence in the factor of safety results, even if a formal parametric sensitivity analysis was not carried out. This study should be expanded upon in future research by performing a thorough sensitivity analysis to methodically assess the impact of changes in groundwater levels, external loads, and soil characteristics on slope stability.

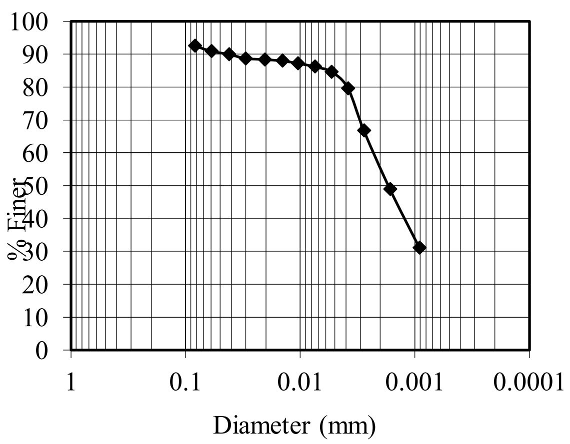


Fig. 5. Consolidation curve for slope soil.

Table 1. Soil properties.

Layers / Testes	Subase materals	Clay (CH)	Sand stone
Liquid limit %		70%	
Plastic limit %		38%	
Shrinkage limit %		19.75	
Plasticity index (P.I)		32%	
Specific gravity (G.S)		2.81	
Friction angle (φ)	42°	14°	47°
Cohesion (C) (kPa)	2	90	29,000
Void ratio (e)		0.6	
Permeability coefficient (K) (m/s)		1.7×10^{-7}	
Dry density (kN/m³)	21.5	17.9	19.5
Modulus of elasticity (E) (kPa)	90,000	11,000	20×10^{6}
Poisson's ratio	0.3	0.37	0.36
Clay percentage %		52%	
Soil classification system	Unified Classification System		

6. Result and Discussion

6.1. Slope stability methods

The SLOPE/W and SIGMA/W software's numerical results for the factor of safety (F.O.S.) in the absence of an external force on the slope are displayed in Table (2).

The safety factor is represented by these numbers using the finite element (FEM) and limit equilibrium (LEM) methods. The slope is subjected to multiple external loads of 250, 350, and 450 kPa until the critical load of 500 kPa is achieved. These loads are analyzed using Slope/W and SIGMA/W in tandem to determine the safety factor values, which are then compared to the safety factor values for the slope that is free of external loads.

According to Table (3), the slope is completely stable when analyzed in the normal state (without load), where the safety factor value ranged between 3.935 and 4.023 for the limit equilibrium methods and 4.03 for the finite element method. However, when applying external loads, the safety factor value ranged between 1.592 and 1.132, decreasing by a percentage ranging between 61.45-71.9%.

Table 2. F.O.S. values for slope (without external loads) using the LEM and FEM methods.

Type of analysis	F.O.S
Morgenstern-Price	3.962
Ordinary	3.935
Bishop	4.023
Janbu	3.961
Finite Element (FEM)	4.03

Table 3. F.O.S. values for slope (with external loads) using FEM methods.

Loads	F.O.S
0	4.03
250	1.592
350	1.459
450	1.284
500	1.132

6.2. Rainfall and water table

Slopes that occur naturally are typically unsaturated or somewhat saturated. When groundwater levels rise due to seasonal variations or when exposed to prolonged periods of strong rainfall, slope failure may result. The amount of rainfall and its duration in relation to the level of soil saturation is one of the variables under investigation. The rainfall intensity was 10, and 30 mm/day for 10, 20, 30, 40, 50, and 60 days. Because it is difficult to determine the precise levels of slope saturation at the location when rainfall occurs at varying intensities, multiple saturation levels were imposed. To make the numerical modeling easier, fixed groundwater levels and rainfall were assumed in this work. Although this method gives a clear picture of how the slope behaves under controlled circumstances, it does not fully account for the variability of changes in the natural environment. The accuracy of the estimated factor of safety may be marginally impacted by these assumptions, especially in situations that are harsh or changing quickly. In order to more thoroughly evaluate the slope stability under dynamic climatic conditions, future studies could expand the analysis by taking into account varied rainfall intensities, durations, and fluctuating groundwater levels.

Groundwater levels and rainfall intensity are naturally time-dependent. Fixed rainfall and groundwater conditions were used in this study to simplify the numerical analysis and to assess each factor's impact on slope stability. Although a fully transient analysis would offer a more accurate depiction of field conditions, it requires continuous hydrological data, which were unavailable for the research area. While the use of fixed values may marginally affect the accuracy of the factor of safety, it nevertheless captures critical stability conditions and provides reliable insight into potential failure processes. Time-dependent analyses may be incorporated in future research to further improve model accuracy. Figure (6) illustrates the rainfall model for slope analysis by SEEP/W, SIGMA/W, and SLOPE/W. Various saturation levels of 55, 75, and 85% were utilized with a constant external load of 250 kPa.

The association between the safety factor at various saturation levels 55, 75, and 85% and rainfall intensity (equivalent to 10, and 30 mm/day) and rainfall length (between 10 and 60 days) is depicted in Figure (7). The safety factor value drops by a percentage between 35.75 and 50.7%, as can be seen from the figure (7-a). As illustrated in figure (7-b), the safety factor values drop by 38% to 52.3% when the daily rainfall intensity is 30 mm.

As soil moisture content rises, infiltration reduces matric suction, which enhances pore water pressure and reduces the soil's shear strength. Consequently, compromised soil cohesion may lead to slope failures. This drop in shear strength increases the likelihood of slope failures, especially during times of prolonged wetness or severe precipitation [25].

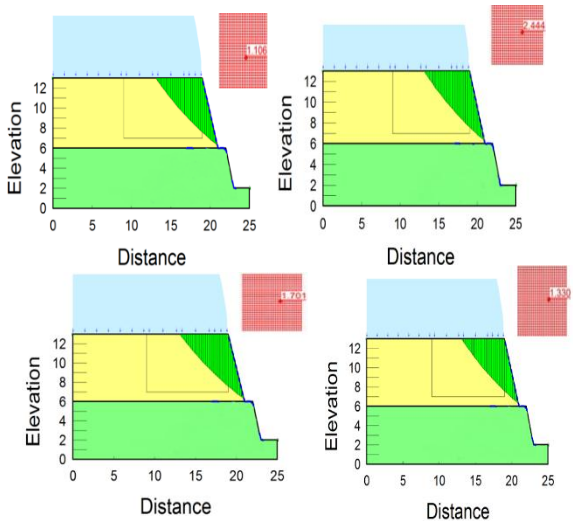
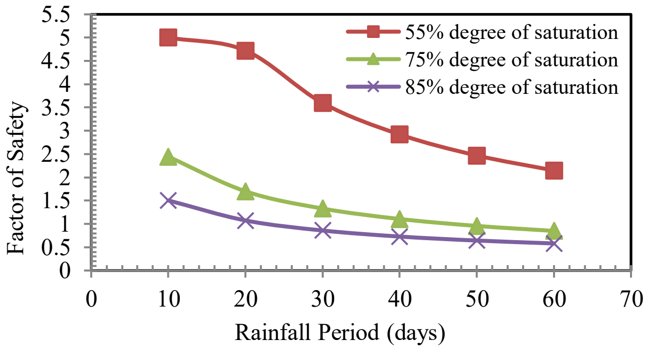
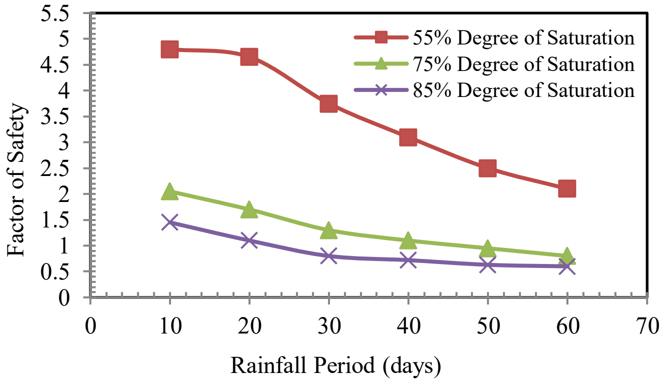


Fig. 6. Slope with rainfall and external load.



(a)



(b)

Fig. 7. Relationship between safety factor and rainfall duration for a slope with intense rainfall at varying saturation levels: (a) 10 mm/days, and 30 mm/days.

If the slope is near a water source, it is frequently vulnerable to water leakage due to seepage from rainwater, snowmelt, the presence of civil water drainage tanks due to exploitation, turning it into a residential area, and the absence of a drainage system that complies with international standards. This causes the water level inside the slope to rise and fall in accordance with the season, whether it is summer or winter.

The slope's water level (4, 6, 8, and 10 m) was measured from the bottom, and it was subjected to 100, 200, 300, 400, and 500 kPa of stresses. Figure (8) shows the water table inside the slope represented by the GeoStudio program, the safety factor value (4.799) dropped by 70.5% at water level and with an external load of 4m and 100 kPa, respectively, while it dropped by 67.2% at the same height but with a load of 500 kPa (2.276) when the water level reached 10 m. The Table (4), shows that when the external load increases from 100 to 500 kPa and the water reaches a height of 5 m, the safety factor value decreases by 52.6%. However, when the water rises to a level of 10 m and the load increases by the same values as previously mentioned, the percentage decrease in the safety factor value may reach 47.2%.

According to these resulting, the determinants of safety decline sharply as water table levels get closer to a critical depth and decline as water table levels increase. The slope needs to be reinforced in order to maintain stability at high water table levels. If not, collapse or landslides are likely to happen [26]. Applying an external force (such buildings, traffic, or seismic stresses) makes a slope with a high water table much more unstable. The increased shear stress from the external load and the decreased shear strength from the elevated pore water pressure drastically reduce the Factor of Safety (FOS) and increase the failure risk [27].

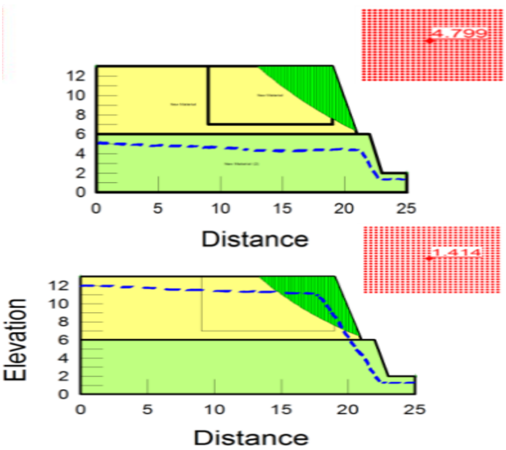


Fig. 8. Shows the water table inside the slope represented by the GeoStudio program.

Table 4. Factor of safety value with different water tables and external loads.

Factor of safety					
Loads (kPa)	100	200	300	400	500
Water levels					
4	4.799	3.613	2.914	2.452	2.276
6	3.515	2.65	2.144	1.811	1.614
8	2.569	1.958	1.596	1.358	1.267
10	1.414	1.11	0.916	0.794	0.746

6.3. Treatments

6.3.1. Anchors' treatment

Deep reinforcements, such as anchor and micro-pile reinforcement, were employed because of the high risk of slope failure. The study that followed looked at these two systems; numerical techniques were used to analyze the displacement of a slope and optimize the parameters. to ensure that the slope's safety factor meets all applicable requirements [28].

At 500 kPa of external force, the slope has reached the critical condition, or failure stage. In order to prevent this, anchors were utilized in accordance with the guidelines listed in Table (5) below. As shown in Figure (9), the anchors reinforce the mass's resistance to shear and exert a force on the mass that is most likely to slide.

Table 5. Anchor specifications [29].

External diameter (mm)	Ultimate strength (N/mm2)	Ultimate Load (kN)	Yeild load (kN)
37.8	1028	1050	865

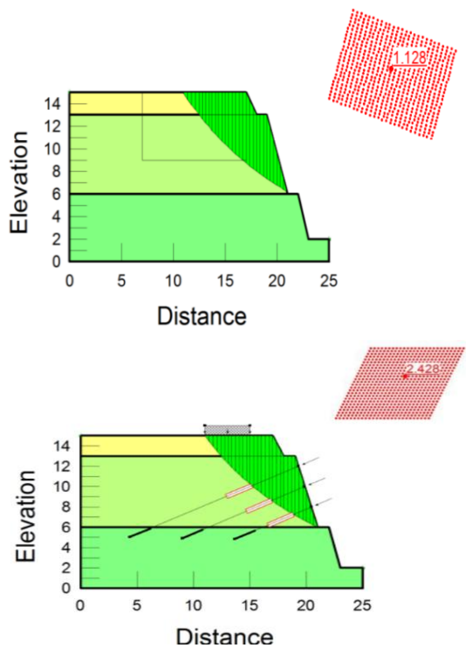


Fig. 9. SIGMA/W and SLOPE/W models (with and without anchors).

The anchor rods were positioned in Figure (10) at depths of 3 meters from the slope surface and at an angle of 25 degrees to the horizon. The displacement rises as the anchor gets closer to the slope surface, indicating that the load at the top of the anchor is greater than the load at the bottom. When the same row of anchors is nearer the middle of the slope, more displacement takes place. This suggests that the stress at the center of the slope is higher than that at other locations and that the anchor rods are subjected to a greater load force [30]. This angle was chosen to allow the anchor rods to penetrate the rock layer; anchoring angles of 20 to 25 degrees work best and shouldn't be higher than 45 degrees [31].

Anchors rod spacing varied from 1 to 4 meters. Understanding the significance of each distance in terms of the quantity of rods and any safety elements that designers may need is crucial. Anchor rods placed 3m below the slope surface increase the safety factor value by a percentage ranging from 24.1% to 196.8%. Figure (11) illustrates the simulation and evaluation of a slope with a water level of 12 meters and an external load of 250 using the three programs SEEP/W, SIGMA/W, and SLOPE/W. The safety factor value increased by a percentage between 40.9% and 122.1% when slope anchors were placed at a depth of 3 meters and with a distance of 1-3 meters between bars.

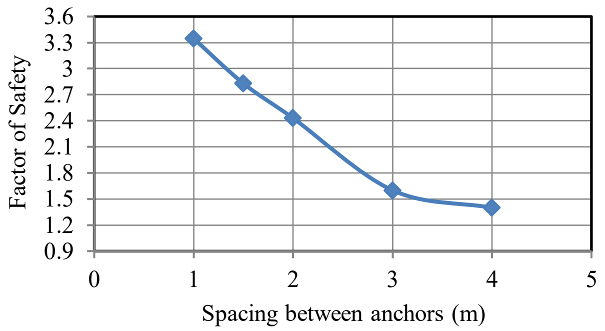


Fig.10. The relationship between the distance of the anchor bars and the safety factor.

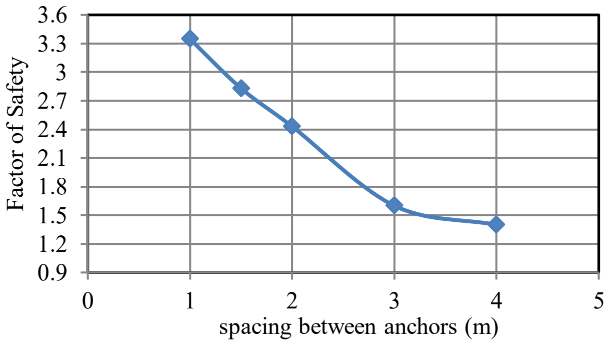


Fig. 11. The relationship between the distance of the anchor rods and the safety factor.

6.3.2. Micro-piles' treatment

The stability of slopes reinforced with anchors and micro-piles is frequently predicted using methods based on displacement or pressure [32]. After determining the quantity of anti-slide micro-piles, the distance between them is another crucial factor to take into account. Too much or too little space between anti-slip piles will not contribute to the strengthening effect [33].

For a slope with an external load of 500, the safety factor values are displayed in Table (6). Analysis revealed that 1.128 was the safety factor value. Since this safety factor value is regarded as critical or near failure, precision piles were employed in accordance with the guidelines provided in Table (7).

Table 6. Number and distance between micro-piles and the safety factor.

Number of micro-piles	1	2	3	4
Spacing between micro-piles				
1m	1.55	2.32	2.78	2.99
2m	1.55	1.87	2.55	-
3m	1.55	1.77	-	-

Table 7. Micro-piles specifications [34].

Outside diameter (mm)	140.2
Inside diameter (mm)	120.62
Thickness (mm)	11.55
Weight (kg/m)	24.66
Moment of inertia (cm^4)	22.7

The micro-piles were placed three meters below the slope surface in accordance with the Sigma and Slope program, as seen in Figure (12). According to the previously mentioned Table (5), the safety factor values rose by percentages ranging from 37.4% to 164.2% when micro-piles were positioned in numbers (1 to 4), with an approximate distance of 1 m between each micro-pile. It also rose by 50.5% when two pillars were positioned with a 3 m gap between each unit.

The force required to raise the safety factor can be determined thanks to the stability of slopes reinforced by micropiles. how the position, diameter, and inclination of the piles affect the slope's stability and where the piles should be placed on the slope. Piles are frequently employed to increase or stabilize slope stability, and 2D numerical analysis demonstrates how position affects the safety factor [35-37].

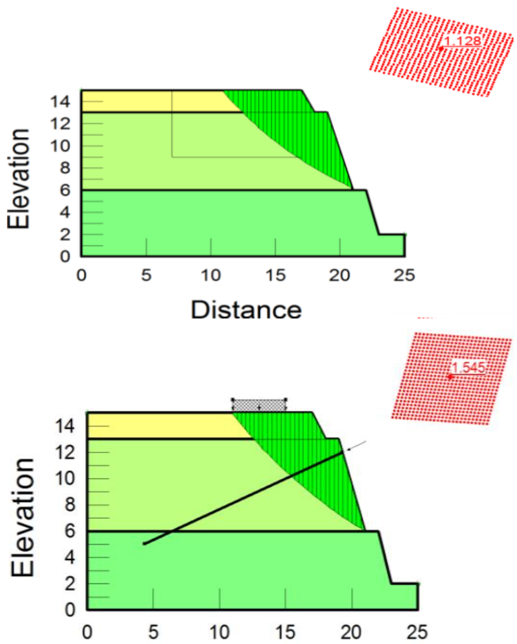


Fig. 12. SIGMA/W and SLOPE/W programs with micro-piles 3m below the slope surfac

6.3.3. Retaining treatment

Slopes, embankments, and other earthworks are supported and strengthened by retaining walls [38]. A retaining structure's function is to support soil [39]. Water table effects, lateral soil loads, seismic loads, and the self-weight of the wall are some of the several types of retaining wall loads [40-41].
In order to address the critical slope condition, the retaining wall is designed as shown in Figure (13), which also illustrates the wall's measurements.
Designed to stabilize the critical slope, the retaining wall is a 9-meter-height reinforced concrete structure with an initial factor of safety (FOS) of 1.128. Its design explicity accounts for overturning, rotation, sliding, and shear failure, ensuring stability under lateral soil pressure, ground water effects, surcharge loads, and the wall′s self-weight. Numerical analysis using SLOPE/W, SEEP/W, and SIGMA/W confirmed that the wall substantially improves slope stability, raising the FOS to over 3 (Table 8), representing a 178.5% enhancement in safety. Extreme circumstances, such as excessive rainfall and groundwater rise, were considered through conservative assumptions. Future research may include long-term field monitoring to further verify the wall′s performance under practical conditions.

Even though the technical effectiveness of the proposed reinforcement techniques is the main focus of this study, economic viability is an important consideration. Anchors are generally the most affordable option, micropiles are more expensive but provide robust reinforcement,and retaining walls require the largest investment while delivering the greatest safety improvement. A detailed cost-benefit analysis could be included in future research to guide practical implementation.

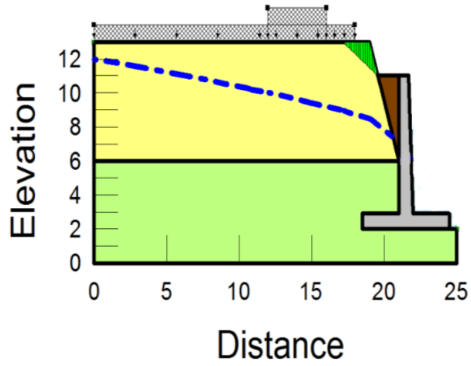


Fig. 13. Models of retaining walls by SEEP/W, SIGMA/W, and SLOPE/W.

The slope that requires a retaining wall has a safety factor of 1.128, which is considered critical or near failure. The wall was built as previously mentioned to prevent the slope from failing or collapsing, given an external load of 250 and a groundwater level 12 meters above the slope's base.

The dimensions of the wall are as follows: 10m for height, 0.8m for width,1m for thickness, and 6.5m for foundation width. A safety factor increase of 178.5% was found when the slope with its retaining wall was analyzed. Using the limit equilibrium method after treatment, Table (8) displays the safety factor values.

Table 8. Factor of safety for slope with retaining wall by LEM methods.

Method of analysis	F.O.S
Morgenstern-Price	3.157
Ordnary	3.138
Bishop	3.144
Janbu	3.106

The potential environmental impacts of the proposed slope reinforcement methods were carefully considered. Anchors and micropiles generally represent localized interventions that cause minimal disturbance to the soil, thereby limiting their impact on the surrounding ecosystem. Retaining walls, while effective in stabilizing slopes, may slightly alter local groundwater flow and surface runoff patterns; however, these effects can be mitigated through thoughtful design and implementation of proper drainage systems. To ensure that slope stabilization remains both effective and environmentally responsible, future studies could investigate the real-world ecological consequences of these reinforcement techniques under field conditions.

The importance of validating the numerical model against real-world conditions is clearly acknowledged, although this study predominantly relies on numerical modeling to evaluate slope stability and the effectiveness of reinforcement strategies. Site-specific data obtained from field observations and laboratory testing were used. To ensure that the input parameters accurately represent actual slope behavior. Future studies could incorporate systematic long-term slope monitoring, including measurements of groundwater levels, displacement, and pore water pressure over time, to enhance model validation. Such as continuous field monitoring would provide essential data to verify the accuracy of the numerical predictions and to update the model as necessary, ensuring that the proposed stabilization techniques perform effectively under practical conditions.

7. Future research and Recommendations

Future research could focus on continuous field monitoring of slope behavior, including groundwater levels, displacements, and pore water pressures, to enhance the validation of numerical models. Time-dependent analyses that account for variable rainfall, groundwater fluctuations, and seismic loads would further improve predictive accuracy. Additionally, advanced technologies such as smart sensors for real-time monitoring, drone-based topographical surveys, and sustainable or innovative soil reinforcement materials could be explored to optimize slope stability assessment and design.

8. Conclusions

1- Without any outside loads, the slope is naturally stable. A high degree of stability was indicated by the factor of safety (F.O.S.) values for the untreated slope, which varied from 3.935 to 4.03.
2- The stability of the slope is greatly diminished by the development of multi-story buildings at the summit, which is symbolized by rising external loads. The slope had a critical failure condition when the external load hit 500 kPa, and the F.O.S. fell to about 1.128. This indicates a 61.45% to 71.9% decrease in stability.
3- To increase the stability of the slope, three distinct reinforcing techniques were examined:
a- Anchoring was a very successful strategy. With gains ranging from 24.1% to 196.8%, the safety factor was significantly increased by positioning anchor rods at different spacings 3 meters below the slope surface.
b- Micropiles turned out to be a workable solution as well. Their placement three meters below the slope surface resulted in a percentage rise in the F.O.S. that ranged from 37.4% to 164.2%.
c- Retaining Wall is the most successful solution, which increased stability the most, was a retaining wall. With values exceeding 3.1 employing a variety of limit equilibrium techniques, the research demonstrated a 178.5% increase in the safety factor.
4- The study effectively employed the Geo-Studio 2012 software suite, including SLOPE/W, SEEP/W, and SIGMA/W, to simulate and examine the behavior of the slope.

The accuracy of the factor of safety and the efficacy of the several stabilization methods were evaluated using the Limit Equilibrium Method (LEM) and the Finite Element Method (FEM). Under extreme external load circumstances, the numerical findings show that all three treatments retaining walls, micropiles, and anchors can successfully maintain the slope and avoid failure.

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