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Investigation and Analysis of Stabilization of Potential Landslides Based on Structural Elements

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ABSTRACT:
The purpose of this study is to investigate and analyze the stabilization of potential landslides based on structural elements. Initially, a simple model without the presence of pillars was examined. To this end, the potential landslide was created in the 2D software Plexus. The results showed that the presence of small pillars caused the stabilization of the potential landslide and increased the coefficient of confidence to 1.17, which does not provide acceptable results in terms of the coefficient of confidence, as the coefficient of confidence obtained is below the minimum value of 1.5 that is recommended in the Department of Building and Safety of Los Angeles (1.5> coefficient of confidence >1.3) for static analysis. The warning of stabilization of this potential in the dynamic state is significant. Considering the region's soil conditions, the best element for stabilization is the pillar or a combination of elements for stabilizing the region.

Keywords: Potential Landslide, Structural Elements, Stabilization, Static Analysis

INTRODUCTION:

Landslides and rock falls are examples of mass movements of the earth, and a general term for the downward movement of rock, soil, and sedimentary units under the influence of gravity. This process acts on sloping lands and can cause the destruction of houses and facilities, blocking the path of roads and rivers, and in some cases, the formation of lakes when the volume of operation is enormous. Unlike the creep phenomenon in landslides, there is one or more separate fracture surfaces. The speed of landslides is typically around one meter per day, and in special cases, such as landslides caused by trapped air and earthquakes, it can reach up to 300 kl/h.

The factors that cause the creation and activation of this phenomenon include severe erosion along rivers and waterways, steep slopes of sedimentary and rock units, and lack of strong connection between the units and the bedrock, heavy rainfall, and increased pore water in alluvial sediments, etc. Human activities such as excavation and road construction, loading due to construction on sloping and susceptible lands, cutting down trees and vegetation, and the entry of water from sewage wells, pools, and lawn irrigation can also activate and accelerate this phenomenon. Sharp (1938) in his work entitled "Landslides and Related Phenomena" defines landslides as "the perceptible sliding or falling of a relatively dry mass of earth, rock, or a mixture of both down a slope." Terzaghi (1950) defines the term landslide as "the rapid movement of a mass of rock, soil, or accumulated debris down a slope." [1]

The speed of the masses in a sample landslide increases more or less from zero to at least one foot per hour. Varnes (1958-1972) defines a landslide as "the gravitational downward and outward movement of slope-forming materials composed of natural rock, soils, artificial fills, or a combination of these materials." Natural surface creep is excluded from this definition. In this definition, most movements caused by freezing and thawing, as well as avalanches that are usually accompanied by ice and snow, will not be considered [2].

Varnes in 1976, based on the main characteristics of landslides, namely the type of movement and the type of materials moved, presented a classification of landslides that is used as the simplest and most common landslide classification. The main feature of this classification is the use of characteristics that are preserved even after the occurrence of the landslide and are less subject to change over time, and this feature can be used to classify old landslides as well. [3] According to Mathewson (1981), in this classification, slope movements are divided into 5 categories based on the shape and speed of the movement of materials: fall, toppling, sliding, lateral spreading, and flow. In Varnes' classification, the materials involved in the movement are divided into two categories: bedrock and engineering soils. These materials are classified according to the definition of the International Association of Engineering Geology. According to this definition, engineering soils are divided into two categories: debris and soil, where soil refers to fine-grained materials in which at least 50% of the particles are in the size of sand, silt, or clay. [4] Typically, there is failure along the bedding planes, joints, and fault zones. The detachment and collapse of rocks are usually caused by processes such as weathering, ice pressure in the joints, temperature changes, slope undercutting, and seismic shaking. Worldwide, earthquakes-related landslides have claimed many human lives and destroyed numerous buildings [6]. One of the methods of slope stabilization is to increase the factor of safety so that after stabilization, the resulting factor of safety is higher than the allowable limit [7]. Janbu et al. (1965) presented a method for determining the factor of safety of slopes, in which the slip surface is non-circular, and it is assumed that the shear forces between the segments are zero. [8]

The present research examines a potential landslide. For this purpose, geotechnical information from a credible article was used for modeling, and the modeling was performed in the Plaxis 2D software. Therefore, the aim of the present research is to investigate and analyze the stabilization of the potential landslide based on the structural elements.

METHODOLOGY

The geotechnical properties of the materials and soils used for the models developed in this research were extracted from a paper titled "Some experience in numerical modelling of unsaturated slope instabilities" written by Joseph Jozefowicz and Stanislaw Lenart, and presented in Table 1. It is worth noting that the modeling using the Mohr-Coulomb method is performed in Plaxis-2D to determine the maximum displacement and obtain the safety factor.

Table 1. Geotechnical characteristics of the soil of the studied area

Properties	γ (KN/m^3)	φ(degree)	C(Kpa)	ʋ	E(Kpa)
Sandy-clay	20.14	23	12	0.32	10000

Table 2. Hydraulic specifications

Properties	$K_{sat}(m/s)$	θ_s	θ_r	φ	n
Sandy-clay	1E-6	10.45	1.1	0.355	4.17

Specifications and Introduction of Materials Used

The materials used in this study include reinforced concrete, piles, and silty soil. Due to the inability to define separate properties for the pile cap and pile concrete in the Plaxis software, and based on the research conducted by Shangji Shu in 2005, a general modulus of elasticity of 30,000,000 KN/m^2 is considered for the pile.

The soil considered in this research is a silty clay soil. The Mohr-Coulomb criterion and drained soil are modeled. The assumed properties for the modeled soils are provided in Table (3).

Table 3. Soil characteristics in modeling

Mechanical specifications	(KN/m^3)ɣ	E (Pa)	Ʋ	Φ˚	C	Ψ ˚
silty clay	16	10000000	0.35	22	5	0

The Mohr-Coulomb model with five parameters is well-known among geotechnical engineers and these parameters are obtained through primary testing of soil samples. These five parameters are:

1. Young's modulus (E) - This is the main stiffness parameter used in elastic and Mohr-Coulomb models. Stiffness is related to the stress state. Determining the value of stiffness requires special attention, as some materials exhibit nonlinear behavior from the beginning of loading. In soil mechanics, the initial stiffness is denoted by E_0 and the stiffness at 50% of the resistance is denoted by E_{50}. For materials with high elasticity, it is reasonable to use E_0, but for soil loading, E_{50} is generally used.

2. Poisson's ratio (v) - In standard triaxial drained tests, a significant reduction in volume may occur at the beginning of loading. Therefore, the initial value of Poisson's ratio may not be obtained. For some cases, such as specific loading conditions, it is reasonable to use lower values. However, when using the Mohr-Coulomb model, a higher value is generally recommended. Choosing the value of Poisson's ratio for an elastic or Mohr-Coulomb model used for gravity loading is straightforward. In some cases, this value is taken between 0.3 and 0.4. Generally, such values can be used for non-unidirectional loading conditions as well. Although typically, values between 0.15 and 0.25 are used for loading.

Cohesion (C)

Cohesive strength has the same unit as stress. Considering the possibility of errors in the calculations performed in the Plaxis software, the value of C for sandy soils is considered as 0.02 instead of zero, and for the silty clay soil used for modeling in this thesis, the value of 5 kN/m2 is considered.

Friction Angle (Φ)

The unit of the friction angle is degrees. A high friction angle, which is usually considered for dense sands, consequently leads to an increase in the calculations of the plastic state. The calculation time increases or decreases exponentially with the friction angle. The friction angle plays an important role in determining the shear strength through the Mohr's stress circles. In this study, the friction angle for the clay soil is considered as 22 degrees.

Dilation Angle (ψ)

The unit of the dilation angle is degrees. Except for the overconsolidated layers, clay soils tend to have a low dilation angle. The dilation angle of sand depends on both the density and the friction angle. For quartz sands, this angle is obtained from the relationship ψ = 30 - Φ. Although for Φ values less than 30 degrees, the dilation angle is usually considered as zero. Negative values of ψ are only valid for loose sands.

Pile Characteristics

Detailed explanations about the piles were provided in Chapter 2. Table (4) shows the characteristics considered for the piles in the modeling. The pile behavior is also assumed to be linearly elastic.

Table 4. Specifications of the pile

Pile diameter	mm 350
modulus of elasticity of the pile	30000000 (KN/m^2)
Poisson ratio of the pile	0.2
Micro density of the pile	(KN/m^2) 24

Model Construction Steps

Modeling in the Plaxis 3D Foundation software is divided into different phases. At the beginning of the program, the "New Project" option is selected. Then a page opens where the project name and description are entered. The first step in any analysis is setting the initial parameters of the limited element model, which is done in the "General Settings" window. In the "General" box, the value of G is set to 1 for the vertical Y value. In this study, the default value of 8/9 is chosen for Earth Gravity, and the value of 10 is selected for γ_water.

Pile Definition

Next is the placement of piles in the foundation. We enter the pile definition page. In this page, for the pile under "Type Of Pile," the option "Massive Circular Pile" is selected, and then the desired diameter is entered. The "Outside Interface" option is chosen to ensure that the pile has a point of intersection along the outer perimeter. The angle of each section of the pile, defaulting to 60 degrees, is left unchanged. After making the settings and clicking OK, the pile indicator appears, and based on the coordinates of the piles, their location on the foundation is determined.

Entering Soil Material Specifications

After clicking on the icon, the page for specifying soil material properties opens. In the "Set Type" dropdown menu, the option "Soil And Interfaces" is selected. Then, the "New" option is chosen, and the specifications for the silty soil are entered. The specifications are entered in 3 sections: Interfaces, Parameters, and General.

The third part is defining Interfaces. In the modeling, there is a very thin layer between the soil and the pile, which is neither soil nor pile material. This interaction layer between the soil and the structure is defined by the software developers in Plaxis. The suggested values for this coefficient by the software developers are provided in Figure (1).

Suggestions for R_{inter}:

- Interaction sand/steel = R_{inter} ˜ 0.6 – 0.7
- Interaction clay/steel = R_{inter} ˜ 0.5
- Interaction sand/concrete = R_{inter} ˜ 1.0 – 0.8
- Interaction clay/concrete = R_{inter} ˜ 1.0 – 0.7
- Interaction soil/geogrid = R_{inter} ˜ 1.0
  (interface may not be required)
- Interaction soil/geotextile = R_{inter} ˜ 0.9 – 0.5
  (foil, textile)

Figure 1. Soil-structure interaction figures suggested by Plaxis software developers

In this modeling, in the Interfaces section, first the Manual option is selected, and then the value of 0.66 is chosen for the silty sand soil for this coefficient.

Entering Pile Material Specifications

To define the pile materials, a new section called Pile is created. In the General menu, the pile behavior is entered as linearly elastic, and its density is considered as 24 KN/m^3. The other information related to the pile is entered in the Parameters menu.

Meshing

By selecting the Mesh option and its degree, the model is meshed, and the meshes will be more precise at the critical points.

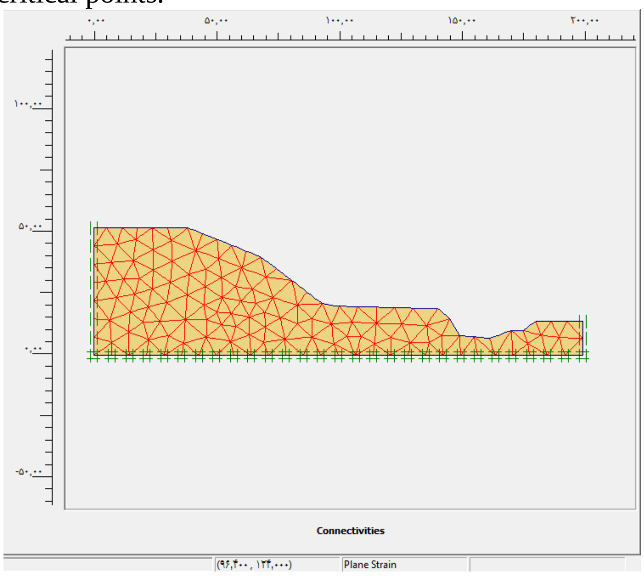

Figure 2. Meshing

After updating the mesh, the following definition is made, which is according to Figure (2).

Model Phasing

To perform calculations in the Plaxis 3D Foundation software, the model must be phased. The models developed in this research consist of 4 phases. When defining each project, the first phase is the Initial Phase, whose task is to automatically calculate the initial stress in the soil when defining the excavation. It should be noted that the settlement of the model after this phase will be zero.

In this modeling, the second phase is related to the implementation of the pile stages. In this phase, the settlement will also be reset to zero so that the final settlement obtained is only related to the fourth phase (excavation) and the settlement changes are more tangible. This stage is related to the definition of the loading surface (foundation) and the loading on it. (In this stage, the settlement will also be zero for the same reason mentioned.)

The final phase is related to the excavation.

Loading

The Plaxis software starts the load from zero and brings it to the final load applied by the user. Plaxis makes the load in M-Stage form and applies it to the system from 0 to 1.

The loading of the models in this research is assumed to be a vertical distributed load of 100 KN/m^2. After selecting the type of loading and applying it to the foundation, by clicking on the page where the load is applied, we can define the load value.

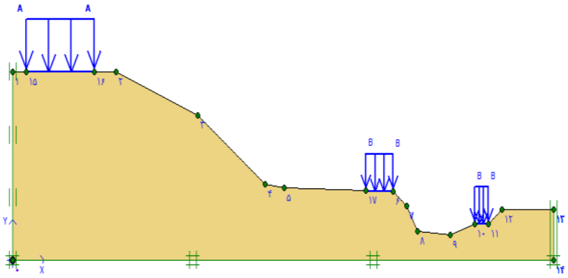

Figure 3. Model loading

Performing Calculations

After modeling, we enter the calculation phase. The calculation program starts from the Initial Phase and continues to the end.

Obtaining Output

After completing the model analysis, using the Output program, the desired outputs can be viewed. In this section, various data such as different types of stresses, strains, and displacements can be observed in different directions.

FINDINGS

Landslide Potential Model with Pile Structural Element

To stabilize the mentioned potential, the pile structural element was used, and in the following models, the maximum horizontal and vertical displacements along with the changes in stress are shown.

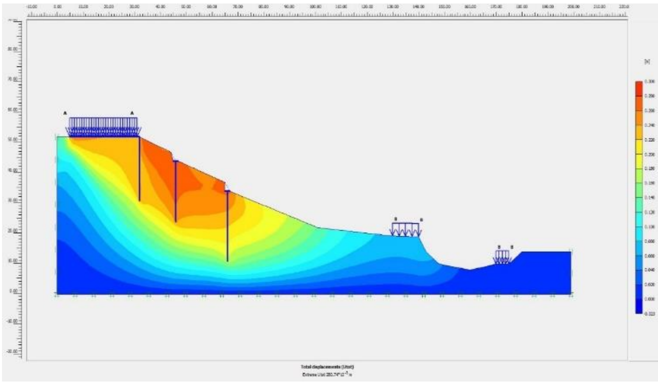

Figure 4. Total displacement in the dry state with the presence of a pile

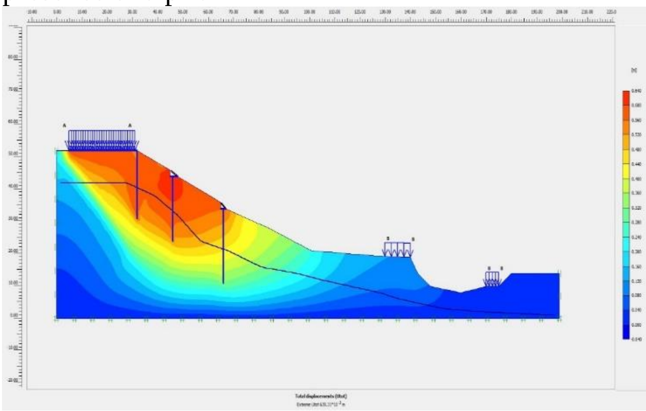

Figure 5. Total displacement in the presence of water with the presence of a pile

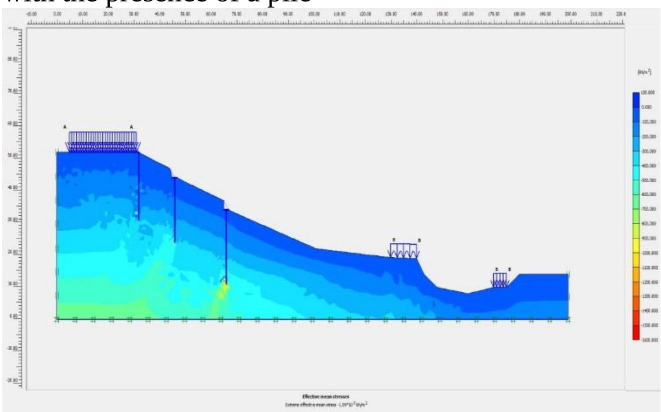

Figure 6. Dry state effective stress with pile presence

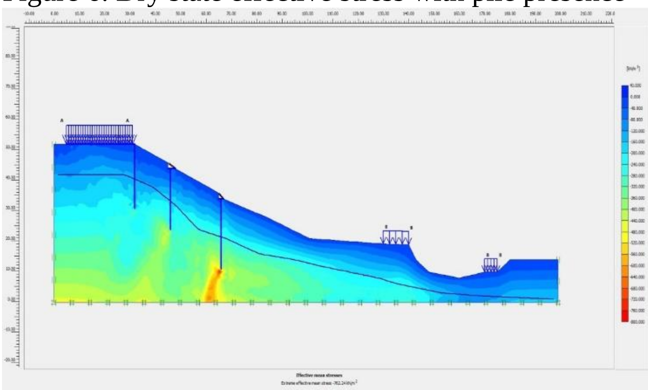

Figure 7. Effective stress in the presence of water and pile

By examining the stress tensors, displacements, and also the minimum safety factor, as seen in Figure (8), in the saturated state, the safety factor obtained from the landslide potential is approximately 1.7, indicating the stabilization of the mentioned potential.

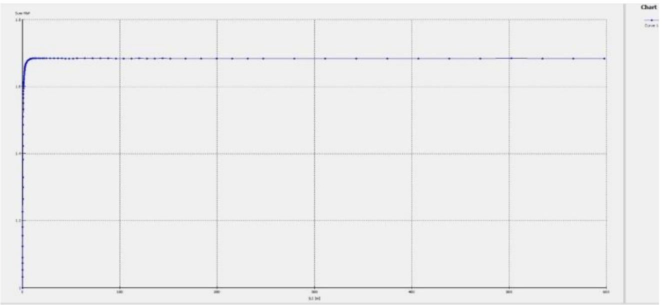

Figure 8. Reliability coefficient in the case of water seepage and the presence of piles

It is worth noting that due to the critical state of water seepage, the safety factor obtained under these conditions indicates the stability of the landslide potential.

Landslide Potential Model with Nail Structural Element

The second structural element used to stabilize the landslide potential is the nail element, and the following models show the maximum horizontal and vertical displacements along with the changes in stress.

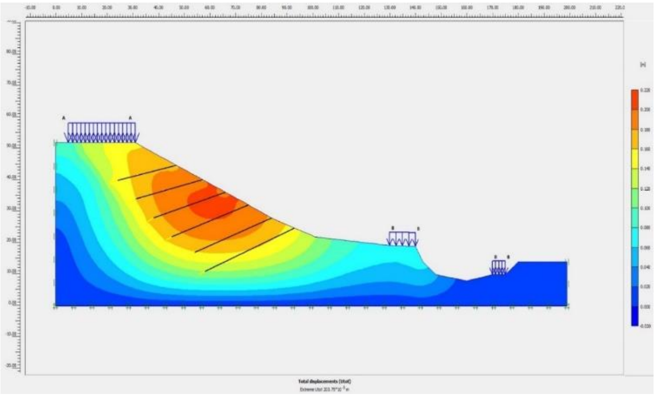

Figure 9. Total displacement in the dry state in the presence of Nile

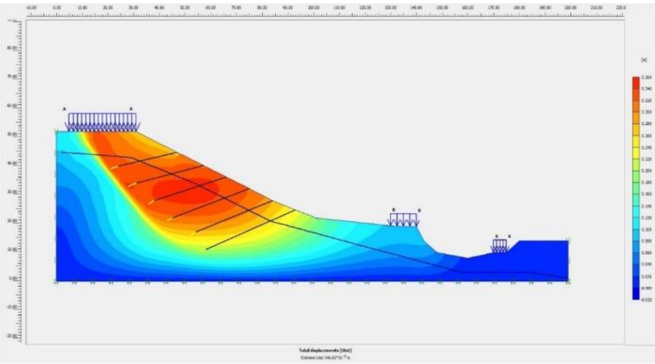

Figure 10. Total displacement in seepage mode in the presence of Nile

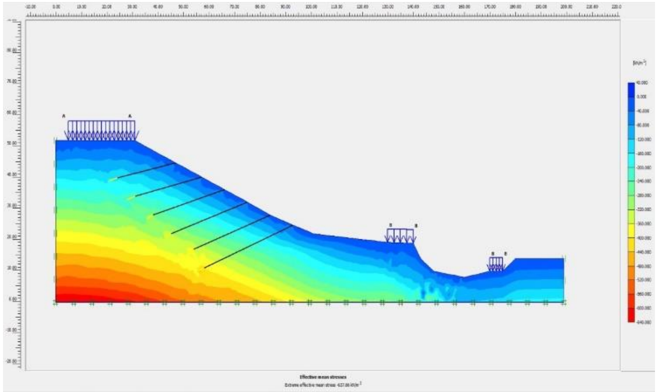

Figure 11. Effective stress in the dry state with the presence of Nile

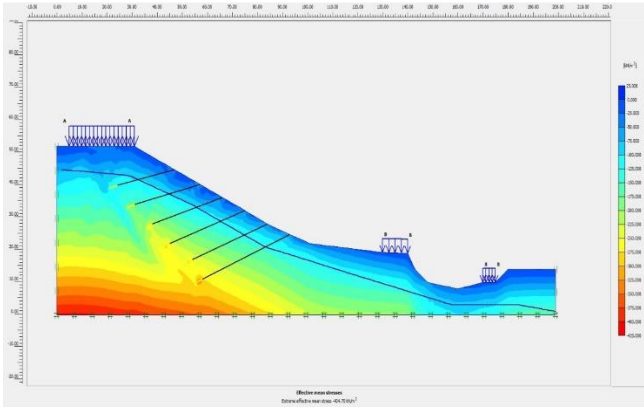

Figure 12. Effective stress in seepage mode with the presence of Nile

By examining stress tensors, displacements, and also the minimum safety factor, it was found that in the saturated state, the safety factor obtained from the landslide potential is approximately 1.61, indicating the stabilization of the mentioned potential.

Landslide Potential Model with Micro-Pile Structural Element

The third structural element used for stabilizing the landslide potential is the micro-pile element, which shows the maximum horizontal and vertical displacements along with changes in stress in the following models.

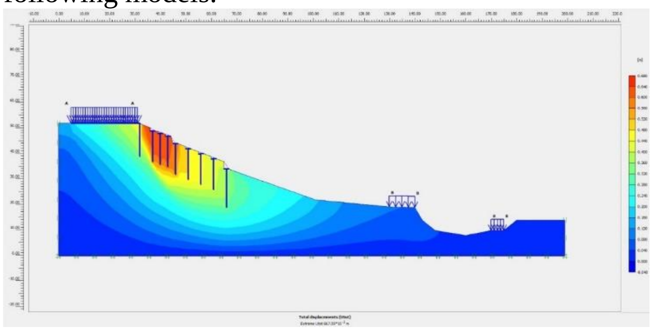

Figure 13. Total displacement in the dry state with the presence of a micropile

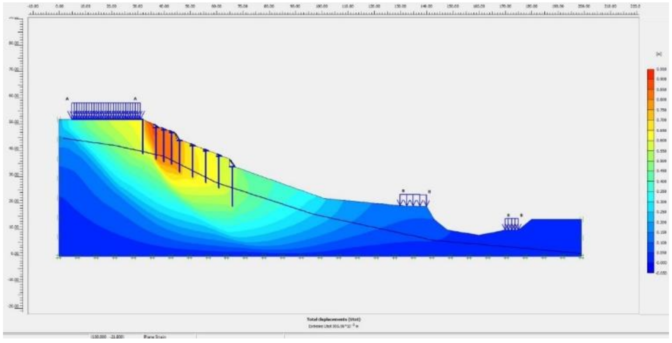

Figure 14. Total displacement in seepage mode with the presence of micropile

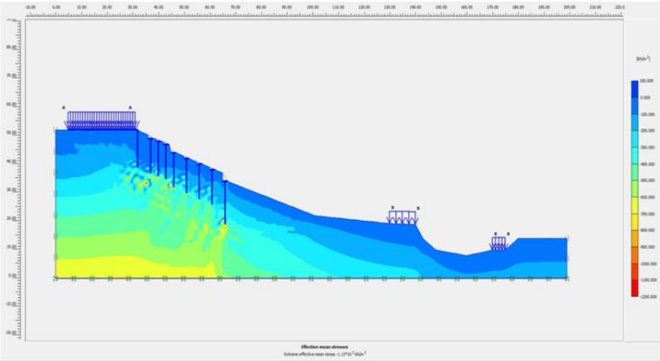

Figure 15. Effective stress in the dry state with the presence of a micropile

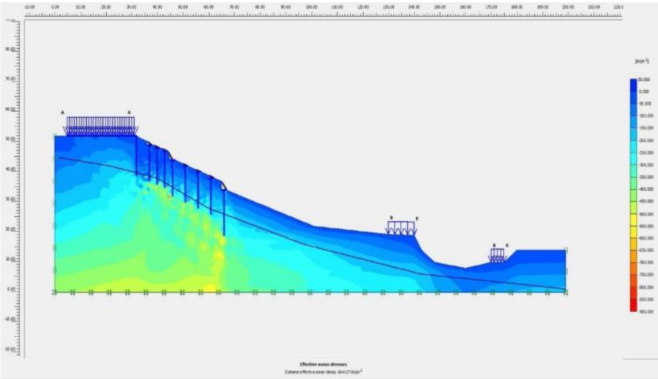

Figure 16. Effective stress in seepage mode with the presence of micropile

By examining the stress tensors, displacements, and also the minimum safety factor in the presence of the micro-pile structural element, as observed in Figure (17), in the saturated state, the safety factor obtained from the landslide potential is around 1.17, indicating the stabilization of the mentioned potential. However, this value is less than the minimum value of 1.25 specified in the FHWA code.

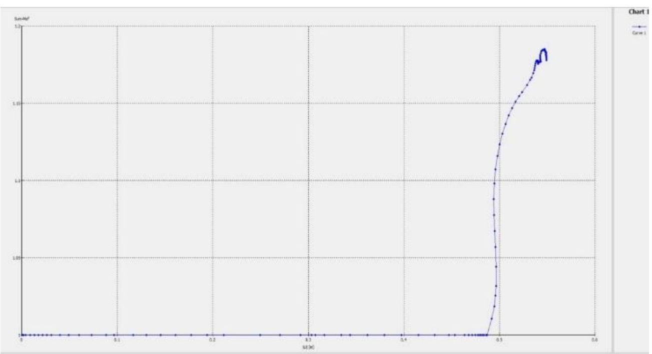

Figure (17). displacement as well as the minimum reliability factor with the presence of a small structural element of the pile

CONCLUSION

The presence of the micro-pile element has stabilized the landslide potential and increased the safety factor to 1.17, which does not provide acceptable results in terms of the safety factor, as the obtained safety factor is lower than the minimum value of 1.3-1.5 recommended in the Department of Building and Safety of Los Angeles for static analysis. This is a warning for the stabilization of this potential in the dynamic state. Considering the soil conditions of the region, the best element for stabilization is the pile element or a combination of the above elements to stabilize the region.

It is recommended to model the excavations using the Flac 3D and Flac 2D software and compare the results with the findings of this research. Investigating the effect of using drainage to keep the water level low, as well as comparing it with other structural elements and determining the most economical case, and obtaining the safety factors for landslide stability using finite difference software and the trend of their changes are also recommended.

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