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Comparison of Displacement and Effective Stress of Landslide Potential in Dry and Seepage Conditions

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ABSTRACT:
The current study aims to compare the displacement and effective stress of the landslide potential in dry and seepage conditions. First, we examine the simple model without the presence of piles. For this purpose, the mentioned landslide potential was created in the 2D Plexis software. The results showed that in the saturated state, the safety factor obtained from the landslide potential is about 0.95, which is numerically unstable and warns of the instability of the landslide potential in the saturated state. Therefore, structural elements are used to stabilize it. In the dry state without the presence of structural elements, the mentioned potential is stable, but the maximum displacement is 0.572 meters, which decreases to 0.281 meters with the addition of the pile structural element and to 0.203 meters with the nail structural element, and increases to 0.667 meters with the micro-pile element. In the seepage state without the presence of structural elements, the mentioned potential is unstable, which decreases to 0.639 meters with the addition of the pile structural element and to 0.346 meters with the nail structural element, and increases to 0.906 meters with the micro-pile element. With the addition of the pile structural element, it reaches 762.2 kN/m^2, the nail element reaches 404.7 kN/m^2, and the micro-pile element reaches 864 kN/m^2.

Keywords: Landslide Potential; Effective Displacement, Effective Stress, Dry Condition, Seepage

INTRODUCTION:

The phenomenon of landslides causes economic damage to roads, railways, power transmission lines and communications, irrigation and water supply canals, mining facilities, oil and gas extraction and refining facilities, vital urban arteries, factories and industrial centers, dams and artificial and natural lakes, forests and rangelands and natural resources, farms and residential areas and villages every year in most provinces of the country or threatens them.

Investigating the potential for landslides is one of the most important current concerns in civil engineering. The reason for this importance is the displacement of a huge volume of soil and materials, which leads to the destruction of roads and damage to infrastructure, as well as financial losses. Also, in dams, the entry of this huge mass into the reservoir creates waves behind the dam, which can damage the body and also the possibility of instability or destruction of the dam body and related facilities and equipment.

Landslides are a category of mass movements that involve the displacement of rock or soil materials on the slope under the influence of gravity. This movement occurs on a specific failure surface and is divided into different types based on criteria such as the failure surface, sliding materials, sliding factors, etc. The identification of active landslides is easy. Usually, the trees inside the active landslide area are not vertical, the buildings are damaged, and the presence of tensile cracks in the landslide area is visible. The scarp at the top of the active landslide is steep and devoid of any vegetation, and open cracks are often observed. Landslides that have been stabilized naturally or by stabilization measures and have a low probability of further movement are called stable landslides. Landslides mainly occur in rock blocks and, according to Varnes' classification, are rarely seen in soils and debris. Areas that are affected by forest and bush fires are less resistant to settlement and may cause landslides.

In all landslide potentials, with the rise of the water table and the reduction of effective stress between the grains, changes will occur in the adjacent areas of the landslide potential, the most important of which is the instability of the slopes in the elevations overlooking the downstream of the sliding surface. Depending on the topographic conditions of the site (slope and elevation), the type of formations, and tectonic activities, the instabilities can occur in different forms such as landslides and rock falls. The instabilities mentioned, depending on their location, will have different degrees of importance, so that the potential instabilities near residential areas and ancillary structures, due to the possibility of irreparable hazards and damages, are of great importance. Accordingly, the study of various instabilities in residential areas or strategic locations such as roads, as well as the study of the consequences of these, is an essential necessity to ensure the necessary confidence in the stability and potential instabilities, in order to be able to take timely measures for providing stabilization solutions and necessary preventions. Accordingly, the present study aims to compare the displacement and effective stress of the landslide potential in dry and seepage conditions.

METHOD:

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)	ʋ̀	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

The materials used in this study include reinforced concrete, piles, and silty clay 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 properties	(KN/m^3)ɣ	E (Pa)	U	° Φ	C	Ψ °
silty clay	16	10000000	0.35	22	5	0

The Mohr-Coulomb Model with Five Parameters is recognized by geotechnical engineers, and these parameters are obtained through primary tests on soil samples. These five parameters are:

1. Young's Modulus (E)

Young's modulus is used as the primary stiffness coefficient in Mohr-Coulomb and Cam-Clay models. The stiffness coefficient is stress-dependent. Determining the stiffness value requires special attention in calculations because some materials exhibit nonlinear behavior from the beginning of loading. In soil mechanics, the initial slope is represented by E_0, and the slope at 50% of the strength is represented by E_50. For materials with high stiffness, it is linearly reasonable to use E_0, but for soil loading, E_50 is generally used.

In soils, the values of the preloading modulus E_ur and the initial loading modulus E_50 tend to increase with increasing confining pressure. Therefore, deep soil layers have higher stiffness compared to shallow layers. Additionally, observed stiffness depends on the stress path. The stiffness for preloading and loading is much higher than for initial loading. It has also been observed that soil stiffness in terms of Young's modulus may be less for compression (consolidated) than for shear. Therefore, when a constant stiffness coefficient is used to represent soil behavior, it is better for its value to be compatible with stress levels and their increase.

2. Poisson's Ratio (ν)

In triaxial drained tests, a significant volume reduction rate may occur at the beginning of axial loading. As a result, the initial Poisson's ratio value may be low. For some cases, such as specific loading issues, it is realistic to use lower initial values. However, in general, when using the Mohr-Coulomb model, a higher value is recommended. Choosing the Poisson's ratio value for the Cam-Clay or Mohr-Coulomb model used for gravitational loading is simple. In some cases, this value is considered between 0.3 and 0.4. Generally, values between 0.15 and 0.25 are used for loading.

3. Cohesion (C)

The cohesion resistance is stress-dependent. Due to 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 in this thesis, a value of 5 kN/m^2 is considered.

4. Friction Angle (Φ)

The unit of the friction angle is degrees. A high friction angle, usually considered for dense sands, can also increase the calculation of the viscous state. The calculation time exponentially increases or decreases with the friction angle. The friction angle plays an important role in determining the shear resistance through Mohr circles. In this study, a friction angle of 22 degrees is considered for silty clay soil.

5. Dilatancy Angle (ψ)

The unit of the dilatancy angle is degrees. Except for over-consolidated layers, silty soils tend to have a low dilatancy angle. The sand dilatancy angle depends on both compaction and the friction angle. For quartz sands, the dilatancy angle is obtained from the relationship 30 - Φ = ψ. Although for values of Φ less than 30 degrees, the dilatancy angle is usually considered zero. A negative value of ψ is only valid for loose sands.

Specifications of Piles

Detailed explanations about piles are provided in Chapter Two. Table (4) shows the specifications considered for the piles in the modeling. Additionally, linear elastic behavior of the piles is assumed.

Table 4. Specifications of the pile

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

Model Construction Steps

Modeling in the Plaxis 3D Foundation software is divided into various 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 model components, 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 selected in the "Earth Gravity" box, and the value of 10 is chosen in the "ɣ_water" box. The "Dimension" header is then selected, where the dimensions of the soil environment and general units used for length, load, and time are defined.

Pile Definition

Now it's time to place the piles in the foundation. We will enter the pile definition page. In this page, for the pile under the "Type Of Pile" section, the "Massive Circular Pile" option is selected, and then the desired diameter is entered. The "Outside Interface" option is chosen to ensure that the pile has an intersection point along the outer perimeter. The angle of each section of the pile, which is by default 60 degrees, is left unchanged. After making the settings and clicking OK, the indicator appears in the form of a pile, 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" drop-down menu, the "Soil and Interfaces" option is selected. Then, the "New" option is chosen, and the specifications for silty clay soil are entered. The specifications are entered in 3 sections: Interfaces, Parameters, and General.

The third part is the definition of Interfaces. In modeling, there is a very thin layer between the soil and the pile, which is neither soil nor pile material. This interface is defined by the software developers in Plaxis to accurately model the interaction between soil and structure. The suggested numbers 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 (interface may not be required) = R_{inter} ˜ 1.0
- Interaction soil/geotextile (foil, textile) = R_{inter} ˜ 0.9 – 0.5

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 66/0 is chosen for the silty clay soil for this coefficient.

Entering Pile Material Specifications

To define the pile materials, a new section named "Pile" is created. In the "General" menu, the behavior of the pile is set as linear elastic, and its density is considered as 24 KN/m^3. Other information related to the pile is entered in the "Parameters" menu.

Meshing

By selecting the "Mesh" option and adjusting its degree, the model is meshed, and critical points in the mesh will be more accurately defined.

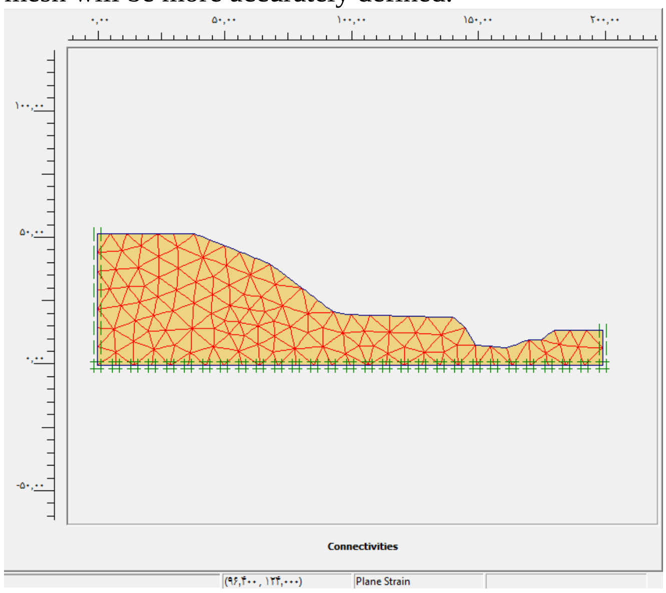

Figure 2. Meshing

After updating the mesh, the definition is made 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 applies the load in M-Stage form from 0 to 1 on the system. 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.

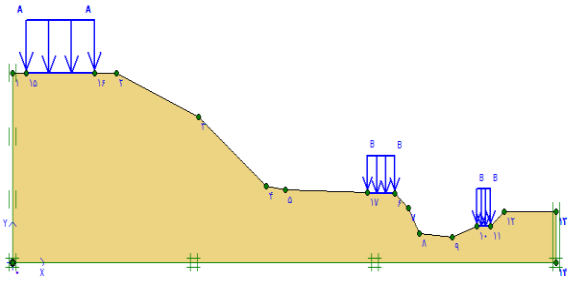

Figure 3. Model loading

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.

<u>FINDINGS</u>:
Initial Modeling in Dry Condition
First, we examine the simple model without the presence of piles. For this purpose, the mentioned landslide potential is created in the 2D Plaxis software as shown in Figure (4).

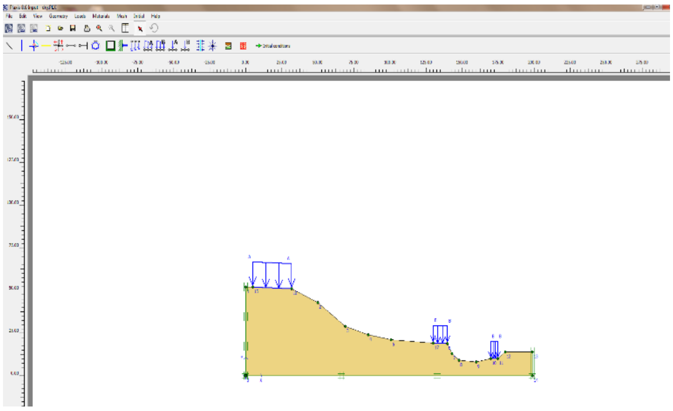

Figure 4. Initial modeling

By reviewing the software outputs, the maximum displacement in the x-direction and the displacement of the structures placed on the sliding potential are as shown in Figures 5 to 9.
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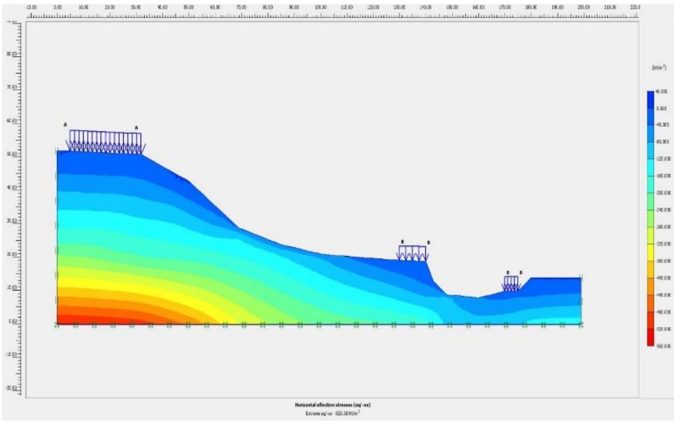

Figure 5. Horizontal effective stress in dry state without structural element

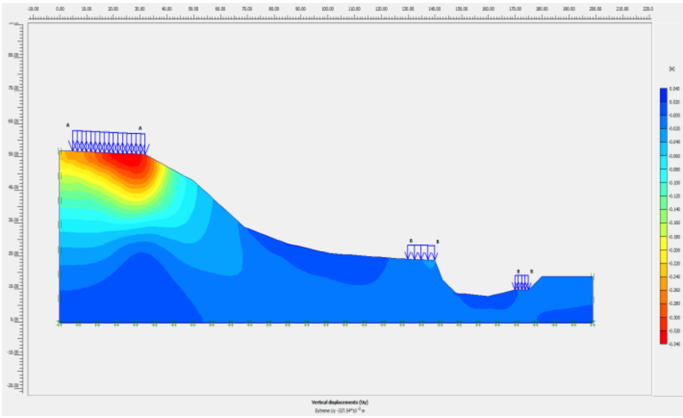

Figure 6. Horizontal displacement in dry state without structural element

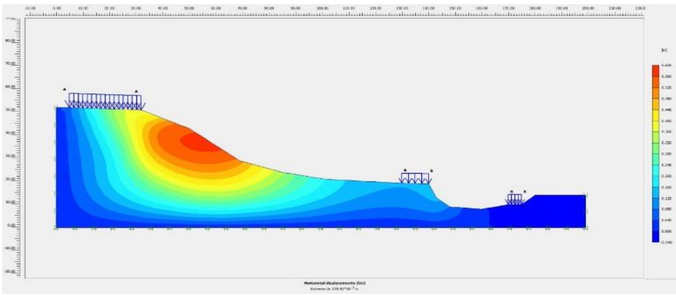

Figure 7. Vertical displacement in dry state without structural element

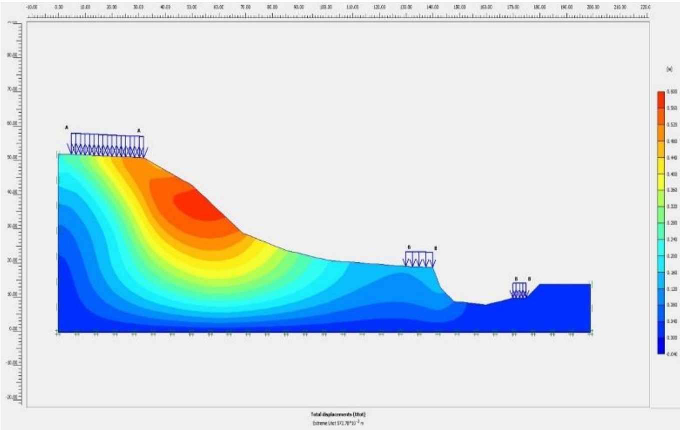

Figure 8. Total displacement in dry state without structural element

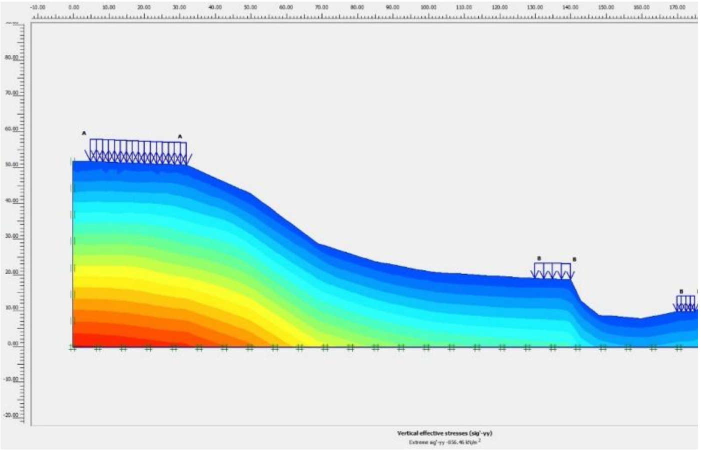

Figure 9. Vertical stress in dry state without structural element

In the dry state, the safety factor (FOS) obtained from the landslide potential is around 1.1, which indicates relative numerical stability, but by reviewing the FHWA code, the minimum safety factor for static conditions (minimum safety factor) is 1.25, indicating the possibility of future sliding under unstable weather or seismic conditions in the region.

Modeling in the Case of Rising Water Table

Considering the regional rainfall and the rise in the water table in the mentioned area, the mentioned potential was modeled in the presence of water to observe its effect on the horizontal and vertical stresses and displacements. Figure (10) shows the initial model in the presence of water.

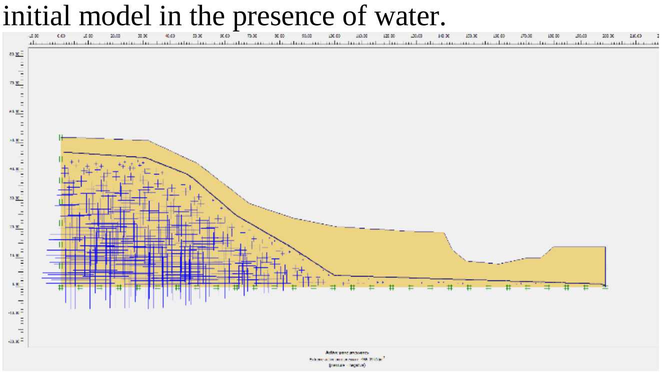

Figure 10. The initial model with the presence of water

Figure (11) shows the changed state of the environment due to the presence of water.

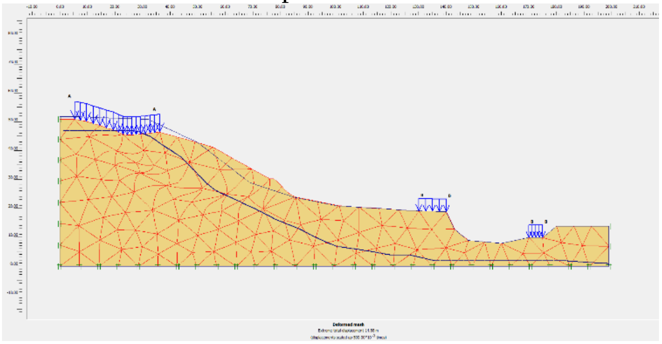

Figure 11. Deformation of the environment due to the presence of water

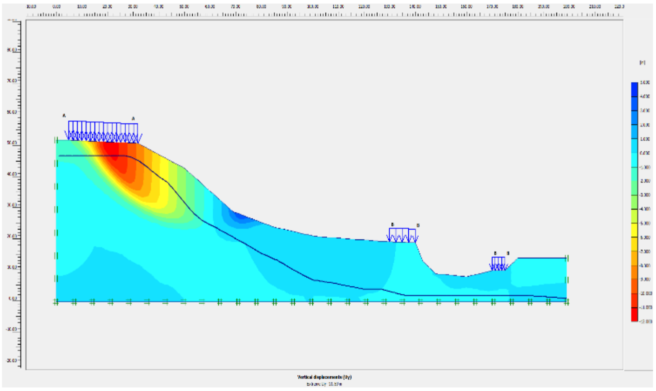

Figure 12. Vertical displacement in case of water seepage

In the saturated state, the safety factor obtained from the landslide potential is approximately 0.95, which is numerically unstable and indicates the potential instability of the landslide in saturated conditions. Therefore, structural elements are used for stabilization.

By examining all available conditions and analyzing Figure (13), it is observed that in the dry state without the presence of structural elements, the mentioned potential was stable, but the maximum displacement was 0.572 meters. With the addition of pile structural elements, it decreased to 0.281 meters, with the addition of Nile structural elements to 0.203 meters, and with the addition of fine pile elements, it increased to 0.667 meters.

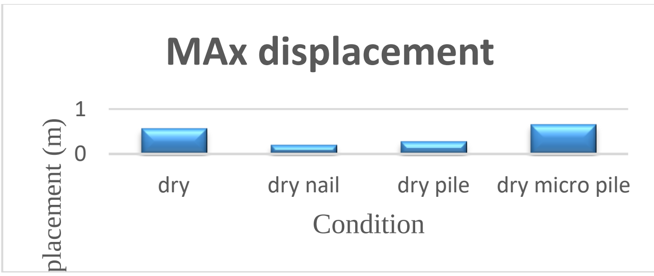

Figure 13. Comparative total displacement in dry state

By evaluating the contours, displacement and shape (Figure 14) show that in the seepage condition without the presence of structural elements, the mentioned potential was unstable, which decreased to 0.639 meters with the addition of pile structural elements, decreased to 0.346 meters with the addition of Nile structural elements, and increased to 0.906 meters with the addition of fine pile elements.

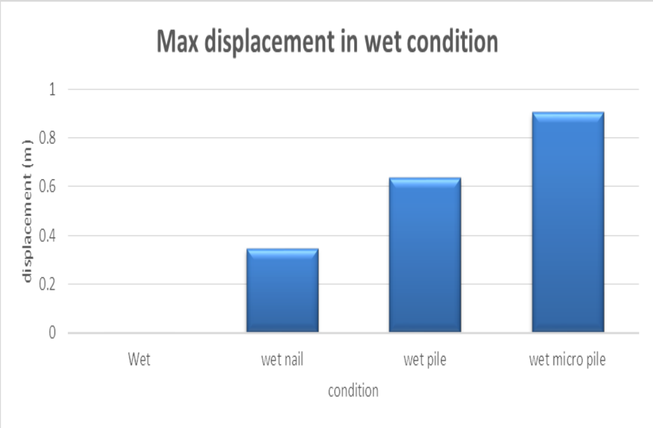

Figure 14. Comparative total displacement in seepage mode

The changes in maximum effective stress, which significantly impact the determination of the desired structural element, were 399.86 kiloNewtons per square meter in the dry state without structural elements. With the addition of pile structural elements, it increased to 1590 kiloNewtons per square meter, with the addition of Nile structural elements to 637.66 kiloNewtons per square meter, and with the addition of fine pile elements to 1130 kiloNewtons per square meter, as visible in Figure (15).

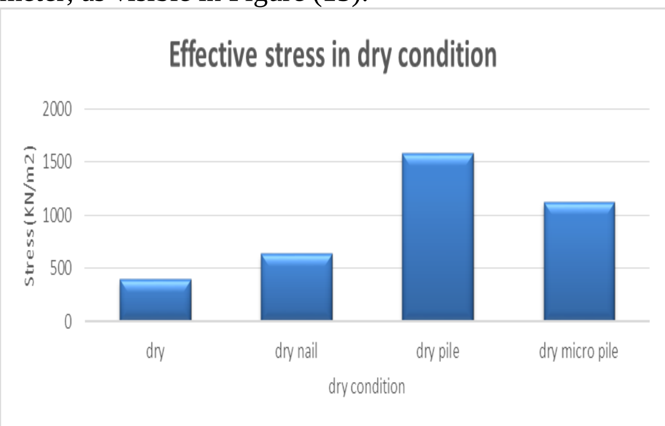

Diagram 15. Comparative effective stress in dry state

The maximum effective stress changes in the seepage condition without structural elements were 395 kiloNewtons per square meter. With the addition of pile structural elements, it increased to 762.2 kiloNewtons per square meter, with the addition of Nile structural elements to 404.7 kiloNewtons per square meter, and with the addition of fine pile elements to 864 kiloNewtons per square meter.

CONCLUSION:

The presence of the pile element has stabilized the landslide potential and increased the safety factor to 1.7, which provides acceptable results in terms of the safety factor, as the obtained safety factor is higher than the minimum value of 1.3-1.5 recommended in the Department of Building and Safety of Los Angeles for static analysis. The presence of the Nile element has stabilized the landslide potential and increased the safety factor to 1.6, which provides acceptable results in terms of the safety factor, as the obtained safety factor is higher than the minimum value of 1.3-1.5 recommended in the Department of Building and Safety of Los Angeles for static analysis.

It is recommended to conduct initial geotechnical studies in the area to increase the accuracy of calculations, investigate the dynamic condition and apply the earthquake force to the created model, and examine the conditions in this case, as well as perform quasi-static modeling and analysis, which can be among the future recommendations for this topic.

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