The effect of the pile on the stability of slope using numerical analysis

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ABSTRACT

The stability of a slope may be made vulnerable due to many reasons like an earthquake, mining, liquefaction, seepage, excess load on the slope, rainfall, excess pore water pressure, etc. Slope stability can be attained by deploying different techniques. The factor of safety of a slope reinforced with piles is analyzed numerically in this paper. A 3D model was created using the finite element software PLAXIS. Pile parameters which affect the factor of safety of slope like the spacing of the pile, pile head conditions were studied. The optimal position and location of the pile are verified from the study. It shows that the factor of safety increases when the pile spacing is reduced.

Keywords— *factor of safety, numerical analysis, pile, PLAXIS, slope stability,*

1.INTRODUCTION

Slopes may be manmade or natural. Both the slopes may fail due to various reasons. The different types of slope failure are wedge failure, circular failure, noncircular failure, and translational failure. Slope failure occurs when the shear stress developed exceeds the shear strength of the slope. Thus, it requires stabilization.

Slopes can be stabilized using various elements like geotextiles, micro piles, nails, and piles. Achieving slope stability by reinforcing slope with piles is a regularly used technique. There are a variety of numerical methods method to analyze slope stability. Numerical models are computer programs that show us the mechanical behavior of the structure. They solve complex problems which are not possible using conventional methods. Here, the finite element method of numerical analysis has been used. The response of slope and the stability of slope are considered simultaneously. This is known as the coupled approach[1]. The coupled analysis is executed using 3D finite element method in the current study to analyze the stability of slope reinforced with piles of various parameters. Finite element method is considered to be the most accurate method in providing solutions to more complicated engineering problems.

A 3D finite element model is developed and analyzed in the following sections. Various parametric studies like the effect of the spacing of the pile [2], the pile head condition on the slope stability are studied in terms of the factor of safety. The behavior of the slope such as slip surface, displacement of soil, deflection and bending moment of the pile are also found [3]. Optimal condition is chosen from the result for engineering works [4].

2.FINITE ELEMENT MODEL

PLAXIS 3D is a three-dimensional finite element computer program used to analyze different types of geotechnical problems. PLAXIS 3D is used to create a 3D numerical model of the slope and various pile parameters and analyze it.

The entire process in PLAXIS 3D can be divided into two stages:

Input - The input program is used to define problem geometry, material properties, to generate a mesh, to define various phases and to calculate the phases.

Output - The output phase is used to view the calculated result in various forms such as graphs, tables, and three-dimensional diagrams.

2.1.The geometry of the model

The model slope is of 10m height and 15m width with an inclination of 1:1.5. The thickness of the ground is 10m and the ground is 35m wide. Steel piles were used in the analysis.

2.2.Properties of the soil and pile

Table 1

Soil properties	
Unit weight (KN/m^3)	16.5
Saturated unit weight (KN/m^3)	20
Cohesion (KPa)	10
Friction angle (^{0})	20
Elastic modulus (KPa)	200e6
Poisson's ratio	0.25
Pile properties	
Diameter (m)	0.8
Unit weight (KN/m^3)	78.5
Young's modulus (KPa)	200e3

2.3.Finite element model verification

Plaxis 3D was used to develop the three-dimensional finite element model. Plaxis 3D is a 3D finite element computer program used to analyze various types of deformations and stability in geotechnical engineering problems and rock mechanics.

2.4.Soil layers and structures

Boreholes are created as shown in Fig.1 and the soil layers are defined. After the construction of the soil layer, structures mode is opened and the slope is constructed using coordinates. Fig.2 shows the construction of the slope. Various structural elements are built in this stage and material properties are defined.

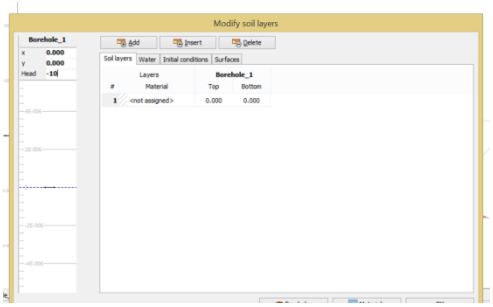

Figure 1: Creation of borehole in the soil layers

The slope is designed as a slice and the piles are defined as embedded piles whose head conditions are assumed as free and rigid and are perpendicular to the surface. Fig.3 shows the creation of embedded pile in the structures mode.

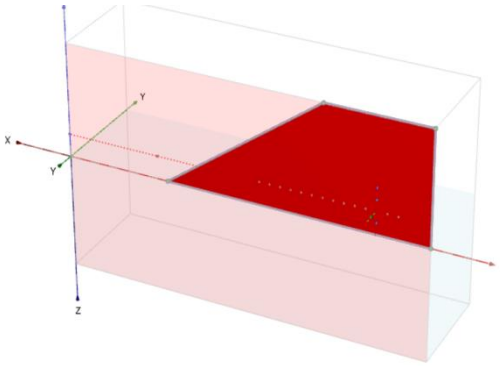

Figure 2: Construction of slope.

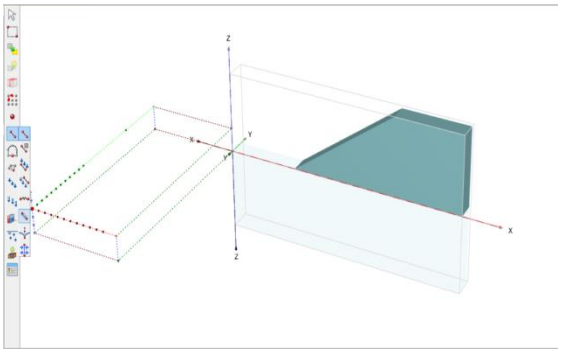

Figure 3: Defining embedded pile in the structures mode.

2.5.Generation of mesh

Once the model is created, a mesh is generated for the created surface [5]. Fig.4 shows the mesh generated using PLAXIS 3D. Mesh divides the entire model into small elements. The medium sized mesh was chosen. Generation of fine mesh takes much more time than a medium mesh and that is why medium mesh was selected.

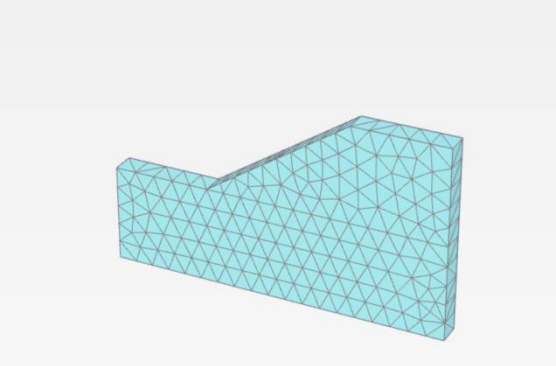

Figure 4: Mesh generated after the creation of the model slope.

2.6.Analysis

Staged construction mode is opened where three phases are generated. Soil layer is activated in the initial phase. The first phase is given as plastic and the embedded pile is activated. The nodes are then chosen. The second phase is given as a safety phase. Finally, the results are calculated by choosing the calculate option as shown in Fig.5. Various results of the analysis like the bending moment of the pile, soil displacement, pile displacement, factor of safety and slip surface can be viewed in the results window and the optimum conditions can be interpreted.

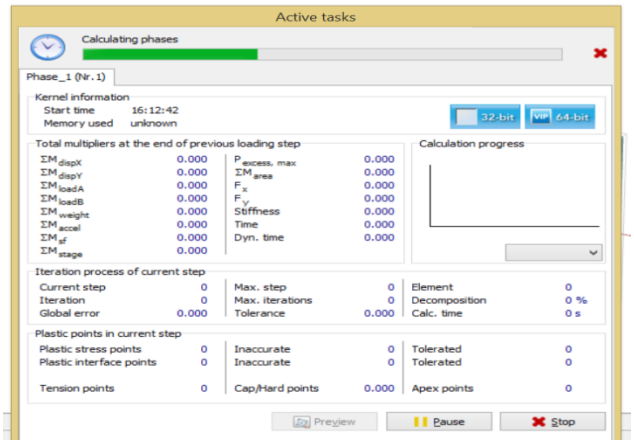

Figure 5: Calculation of phases using the given data.

3.RESULTS OF SLOPE STABILISATION

The effect on the factor of safety due to the change in pile parameters like the spacing of the pile (S) and the pile head conditions are presented. First, the factor of safety of the slope was found without reinforcing the slope with piles and then the piles were inserted. The piles are inserted vertically. The length of the pile is taken as 15m and the diameter of the pile (D) is taken as 0.8m. The optimum parameter is used for engineering works. Piles of different head conditions were analyzed. Free head piles and rigid head piles were analyzed to find the optimum conditions. Free head piles are one in which the deflection at the head is not constrained by using a pile cap whereas, in rigid head piles, the deflection and rotation at the pile head are restricted by using a pile cap.

3.1.Stability of the slope without reinforcing the slope with the piles

The slope was constructed and the factor of safety of the slope was tested by analyzing the slope. The slope had a factor of safety of 1.18 which shows that the slope is not stable. When an excessive load is applied or when any other unfavourable conditions occur, the slope will fail and cause damage. It shows the need to reinforce the slope to improve stability.

3.2.The spacing of the piles

The most optimum spacing of the pile is the one which gives the maximum factor of safety. The diameter of the pile (D) was taken as 0.8m. The spacing of the pile (S) was varied as S = 2D, 5D and 8D. It was seen that the factor of safety of the slope increased as the spacing between the piles decreased. The soil displacement and pile displacement was also reduced as the spacing between the piles was reduced.

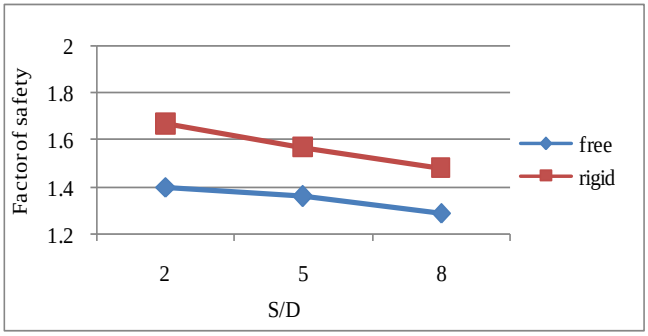

Figure 6: Effect of pile spacing on the factor of safety.

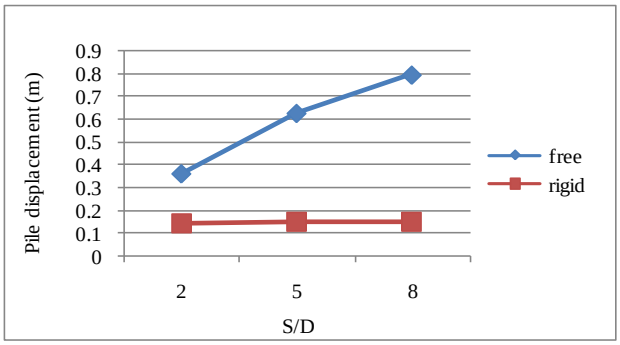

Figure 7: Effect of pile spacing on pile displacement.

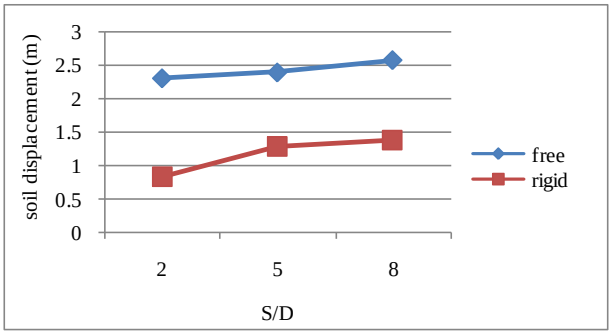

Figure 8: Effect of pile spacing on soil displacement.

The pile is placed at the centre of the slope along the width of the slope. Fig.6 shows the factor of safety of the slope for varying spacing of the piles. The factor of safety increased with decreasing S/D ratio. It can be observed from the Fig.6 that the best spacing of the pile according to the factor of safety is when the S/D ratio is 2. The factor of safety is more for the rigid head piles than the free head piles.

Fig.7 shows the displacement of the pile used for reinforcing the slope with reference to the spacing. It can be seen that the pile displacement has minimal changes in the rigid head condition of the pile for various spacing of the piles. For the free head condition of the pile, the displacement of the pile is more than that of the rigid head condition of the pile. The pile displacement increases a lot as the spacing increases in free head condition. This shows that the favorable condition with reference to the displacement of the pile is when the S/D ratio is 2 and the head condition of the pile is rigid.

The effect of spacing of the piles on the displacement of the soil can be seen from the Fig.8. The soil displacement keeps increasing as the spacing between the piles increase. The soil displacement is less in the rigid head condition of the pile than the free head condition for all the pile spacing. The minimum soil displacement occurs when the S/D ratio is 2 and the pile head is rigid.

4.CONCLUSION

From the above discussions, the following conclusions can be arrived.

The factor of safety increases when the spacing between the piles decreases. The maximum factor of safety is achieved when the S/D ratio is taken as 2. The spacing between the piles is the major factor influencing the factor of safety of the slope. Piles with free head have a lower factor of safety than the piles with a rigid head. The displacement of the pile is minimum when the S/D ratio is 2 and the pile is of a rigid head condition. The soil displacement decreases as the spacing between the piles are reduced and the head of the pile is rigid. S/D ratio of 2 gives the optimum result.

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