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Improvement Stability of Slopes Using Anti-Slide Piles

Moamen E. Abd El Raouf

Lecture, Civil Engineering Department, Faculty of Engineering, Al- Azhar University, Egypt

Abstract. Anti-slide piles are vertical members from reinforced concrete used to resist the landslide and improve the slope stability**.** Recently, the anti-slide piles are widely used because it's characterized by high slide resistance, good retaining effect, small masonry compared with the anti-slide retaining wall**.** The goal of this paper is studying the parameters effect on the factors of safety for slopes and the performance of the pile-stabilized slopes. These factors include the pile diameter, pile spacing, the length of the pile embedded in the stable zone (under slip surface), and the most suitable location of the piles within the slope. The finite element program GEO5 was used in this analysis to study the stability of slopes using the anti-slide pile. The results of the finite element program indicated that using the anti-slide piles is an effective method to increase the factor of safety for the slopes. As the piles spacing increase, the factor of safety decreases. The optimum pile spacing occurred when S= D. The critical embedded length of pile occurs when the depth of the unstable zone above the slip surface is equal to the embedded length of piles. The optimum position of the piles is in the middle of the slope.

Keywords: Slope stability, soil–pile interaction, anti-slide piles, factor of safety.

1.Introduction

There are many methods can be used to improve the stability of the slope. Anti-slide piles are a common and effective method used to resist the landslide and improve the stability of slopes. Driven or bored piles are installed to resist the slope failure. The shape of the piles may be circular or square and have a large cross-section. The anti-slide piles are subject to horizontal forces resulting from horizontal movement of the surrounding soil. So, the piles used in slope stabilization must be buried in the stable layer of soil to transmit the horizontal forces to a deep stable soil. The piles in the upper unstable zone are counted as passive piles and the piles in the lower stable zone are active piles. Figures (1&2) show the horizontal force resulting from the sliding soil mass above the sliding surface.

Recently, the anti-slide piles are widely used because it's characterized by high slide resistance, good retaining effect, small masonry compared with the anti-slide retaining wall and small disturbance to the landslide and slopes. The piles may be constructed in a single row or multiples rows. Also, the anti-slide piles may be free piles or anchored piles. Many methods were developed to describe and design the anti-slide piles [2,3,4,5,6,7,8,9,10,11,12,13].

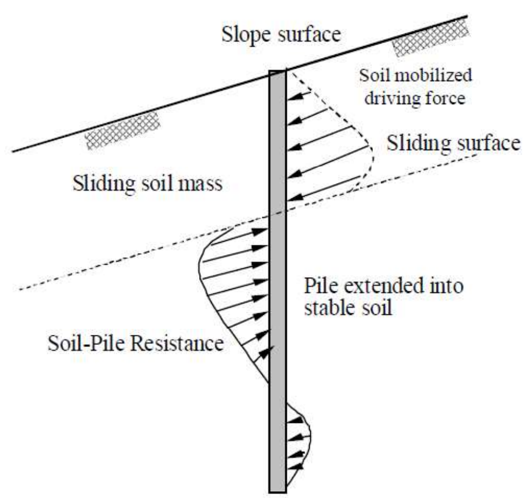

Figure 1. Horizontal force resulting from the sliding soil mass above the sliding surface (after Hamed Ardalan and Mohamed Ashour,2013)

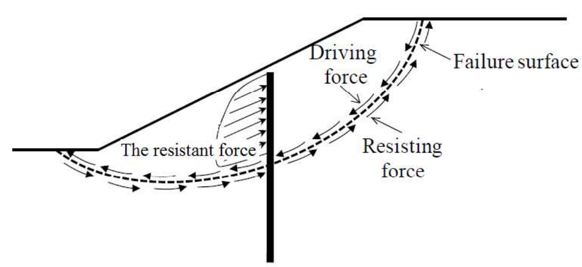

Figure2. Forces acting in anti-slide piles (after Hamed Ardalan and Mohamed Ashour,2013)

The analytical methods can be divided into two types depending on pressure or displacement. [14,15,16,17]. The modulus of subgrade reaction (k_h) below the sliding surface in the stable zone consider as a very important parameter when analyzing and studying the anti-slide piles because this parameter controlled in piles deformation. Various numerical methods have been developed by researchers to study and analysis the soil-pile interaction in the anti-slide pile [18,19,20,21]. Cai and Ugai [10] used a finite element method to analyses the effect of stabilized piles on the stability of slopes. This paper aims to study the parameters effect on the factors of safety for slopes and the performance of the pile-stabilized slopes. These parameters include the pile diameter, pile spacing, the length of the pile embedded in the stable zone (under slip surface), and the most suitable location of the piles within the slope.

2. Case History

The anti-slide piles have been applied effectively and successfully to support the slopes such as roads and railway embankment. The pile-stabilized slopes were used to supporting a clay embankment with an 8 m height in Hildenborough, Kent, UK. In October 2000, it was noticed that a part of the embankment slope is close to being a failure. The embankment material according to site investigation is a Weald clay (Weald is a formerly wooded area of southeastern England) to depth about 25 m. Two hundred bored concrete piles with 0.6 m diameter, 10 m long and 2.4 m spacing were used to support the slope and increase the factor of safety. The piles were constructed using a continuous flight auger [22]. A small horizontal platform with 3.5m height at the toe of the embankment was constructed as shown in figure (3).

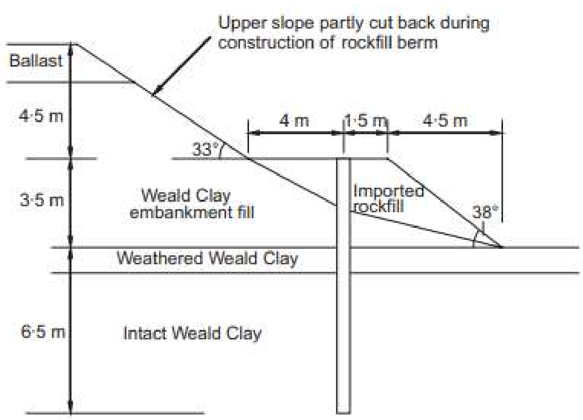

Figure 3. Embankment profile (after Smethurst, J. A. and Powrie, W., 2007)

The geotechnical parameters of the soil according to site investigation are given in table (1).

Table (1) The geotechnical parameters of the soil (after Smethurst, J. A. and Powrie, W., 2007)

Soil type	Unit weight (kN/m^3)	Friction angle	Cohesion(C) (kpa)
Weald Clay	19	25	1
Softened Weald Clay	19	19	1
Weathered Weald Clay	19	25	1
Weald Clay	20	30	5
Rockfill	19	35	0

3.Soil Pile Interaction in Anti-slide piles

The interaction between soil and pile in anti-slide piles is a very complicated process. The soil pile interaction is depending on many factors such as properties of piles, properties of soli, stiffness of pile, the embedded length of the pile in stable and unstable soil layers, and the pile spacing. In the last few years, the method of analysis and design of the anti-slide pile depends on the computation of the soil-pile pressure result from the interaction between the deflected piles and the sliding soil mass above the failure surface. The equilibrium in pile-stabilized slopes depends on the soil-pile pressure above the failure surface and the lateral resistance below the slip surface from stable soil.

4.Soil Arching between the Piles

The behaviour of piles in slope and arching effects was studied by many researchers. Wang and Yen [23] proved that for cohesive and cohesionless soil there is a critical pile spacing, if the pile spacing less than the critical pile spacing almost no arching develops. Soil arching between the Piles results from the stress transfer from soil to piles through the mobilization of shear strength.

5.Finite element modeling of anti-slid pile

The finite element program GEO5 was used in this paper to study the stability of slopes using the anti-slide pile. The stability analysis of the anti-slide piles in this paper can be divided into two parts. First, study the stability of the slope without using anti-slide piles. The second step is studying the stability of the slope improved by using anti-slide piles. This can be achieved by determining the factor of safety for the slope with and without piles.

5.1The global stability of slopes without piles

The global stability of slopes was analyzed using the program a GEO5 slope stability. In this analysis, the main model is 7.5 m height and 25m crest width as shown in figure (4). The surcharge from the traffic equal to 20 kN/m^2.

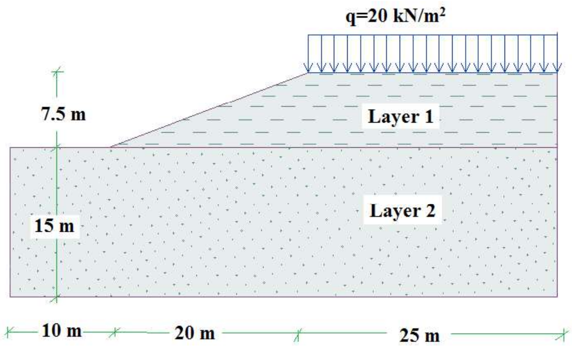

Figure 4. Geometry of the model

The geotechnical parameters of the soil are as follow:

Layer 1 - unstable zone (H_u): clay with a unit weight = 19 kN/m^3, cohesion (c) = 10 kpa, and friction angle (ϕ) = 0.

Layer 2 - stable zone (L_e): sand with a unit weight = 20 kN/m^3, cohesion (c) = 0, and the angle of internal friction (ϕ) = 35 degree.

The modulus of subsoil reaction is calculated according to Schmitt [24].

5.2 The global stability of slopes reinforced with piles

Constructing a retaining structure such as a row of anti-slid piles can be improved slope stability. In this analysis, the slope is reinforced using anti- slide piles. In this section, the effect of changing pile properties (diameter, embedded length, spacing and location) on the factor of safety of slopes is studied. The piles used in this analysis are a circular bored pile. The properties of the piles are shown in table (2).

Table.2 The properties of the piles used in the analysis

Cylinder compressive strength(f_{ck})	25.0 Mpa
Tensil strength (f_{cm})	2.56 Mpa
Elasticity modulus(E)	31475.81 Mpa
Shear modulus (G)	13114.92 Mpa

6. Results and discussion

The results can be summarized as follow:

6.1Effect of pile embedment

The embedded length of piles under the slip surface (L_e) and the ratio between the length of piles in the stable zone under the slip surface and the unstable zone above slip surface has been studied. In this analysis, the slope is improved using piles with various pile length (10,11,12,13and 14 m). The diameter of the piles (D)is equal1.2 m, and the pile spacing (S)= D.

From figure (4) and the results of GEO5 program, the following results can be obtained.

-When the embedded length of piles is less than the depth of the unstable zone above the slip surface (L_e<H_u) the factor of safety increases as the embedded length increases.

-When the embedded length of piles is equal or more than the depth of the unstable zone above the slip surface ($L_e \geq H_u$) the factor of safety stays almost constant as the pile length increases.

Figure (5) shows the effect of the embedded length of piles on the factor of safety.

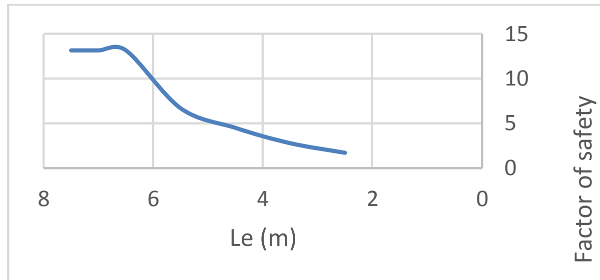

Figure 5. The relation between the factor of safety and the embedded length of piles

6.2Effect of the pile spacing

In this analysis, the pile spacing is varied as follow: 1,1.2,1.4.1.5,1.75,2,2.25,2.5, and 3 m. For each spacing, the pile diameter is taken So that the value of S=D, the pile length = 12 m and the piles are located at the top of the slope. The relation between the factor of safety and the pile spacing derived from finite element analysis is shown in figure (6).

Based on the results from the finite element model, the factor of safety decreases, as the pile spacing increases. When the spacing between the piles decreases the piles become like a continuous pile wall. So, it's preferable to take the value of pile spacing to not more than 2 D (S≤2 D). If S >2 D each pile will behave as a single pile and no soil arching between the piles will be developed, in this case, the soil can flow between the piles.

Moreover, when the spacing between the piles are relatively small a group action between the adjacent piles below and above the slip surface will be generated. According to the results obtained from the finite element model, the optimum spacing occurred when S/D=1.

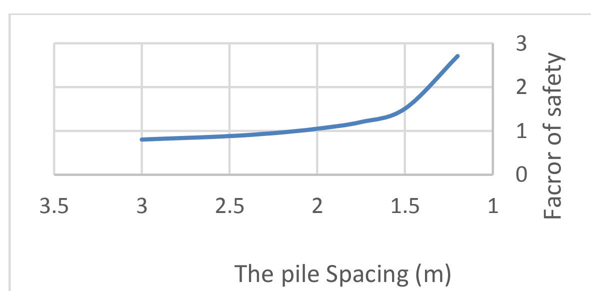

Figure 6. The relation between the factor of safety and the pile spacing

6.3 Effect of pile diameter

In this analysis, the pile diameter (D) is varied as follow: 0.8,0.9 and 1 m. For each spacing, the pile diameter is taken So that the value of S=D, the pile length is taken

9,9.5 and10m. The piles are located at the top of the slope. According to the results obtained from the finite element model, the factor of safety increases, as piles diameter increases as shown in figure (7).

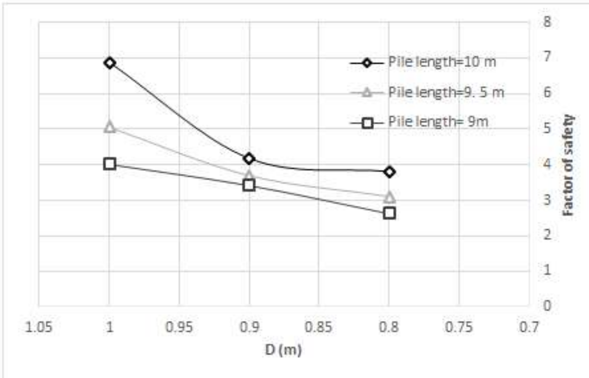

Figure 7. Effect of changing the pile diameter on the factor of safety

Also, increasing the diameter of the piles resulting improved the lateral bearing capacity of piles.

6.4Effect of piles location

Three locations for piles is modelling in this analysis. First position, at the toe of the slope. The second position, in the middle of the slope. The third position, at the top of the slope as shown in figure (8). The diameter (D) is varied from 1.2 to 2 m, the ratio S/D=1, and the pile is vertical with length equal 12 m.

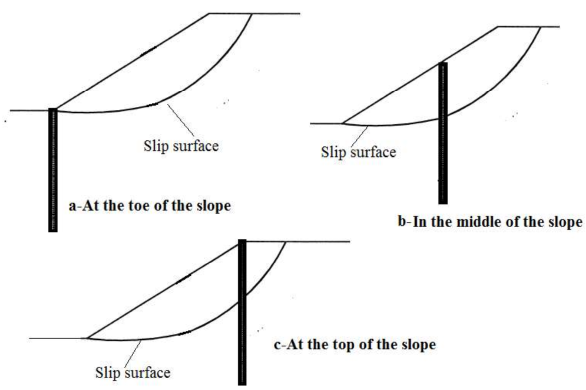

Figure 8. The location of the anti-slide piles

As shown in figure (9) construction the piles in the middle of the slope result in increasing the factor of safety. When the piles located at the toe of the slope, there isn't any effect for piles on the factor of safety. In this case, there are not any intersection between the piles and slip surface. When the pile's location be at the top of slopes the piles intersect with slip surface at the top of the slope. According to that the optimum location of the anti-slide piles is in the middle of the slope.

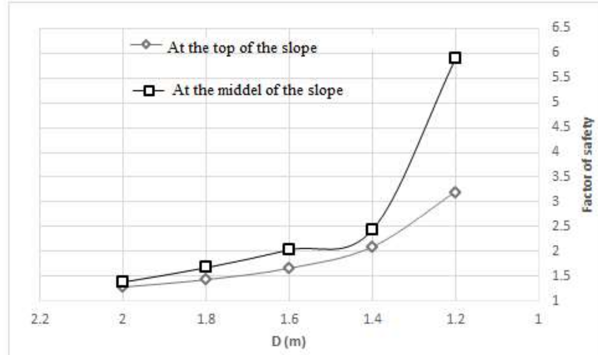

Figure 9. The effect of the pile's location within the slope on the factor of safety

7.Conclusion and Recommendations

In this research, the anti-slide piles were studied. Depending on this study, the following conclusion and recommendations can be given.

1- Using the anti-slide piles is an effective method to increase the factor of safety for the slopes. In the present analysis the factor of safety for the slope increase from 0.54(unsafe) to 2.71(safe) by using piles with diameter =1.2, pile length=12, and S=D. The use of the anti-slide piles has resulted in the conversion of the slope from the unsafe situation to a safe situation (considering that the factor of safety=1.5).

2-The factor of safety for the slopes is changing with different the spacing between the piles. As the piles spacing increases, the factor of safety decreases. For the purpose of increasing the factor of safety for the slopes, the optimum pile spacing is taken as S= D. But due to economic reasons, the spacing between piles can be increased to S=2D. In general, it's recommended the spacing between the anti- slide piles not exceed 2 (S≤2 D).

3-The critical embedded length of piles occurs when the depth of the unstable zone above the slip surface is equal to the embedded length of piles ($L_e \geq H_u$). When the embedded length of piles is equal to the critical embedded length of piles, the factor of safety stays almost constant.

4- The optimum position of the anti-slide piles is in the middle of the slope. When the piles located at the toe of the slope, there isn't any effect for piles on the factor of safety.

5- The factor of safety increases, as piles diameter increases.

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